TR-16

GUIDES FOR THE DESIGN OF WASTEWATER TREATMENT WORKS

2011 Edition

as Revised in 2016

Prepared by the

New England Interstate Water Pollution Control Commission

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Cover photos: Top, functioning Warwick, Rhode Island treatment facility (Google Earth photo); bottom, same facility flooded due to major storm in March of 2010; center, elevated pumping station in Warwick, Rhode Island, designed in part in response to new storm patterns in the Northeast.

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INTRODUCTION TO REVISED 2011 EDITION

In the Northeast and throughout the world, extreme storm events are growing in frequency and force. Hurricanes and blizzards threaten the operation of wastewater infrastructure and in some cases the infrastructure itself. Consequently existing wastewater facilities should be made more resilient though preparedness planning, design changes, and physical upgrades.

To support this important work, NEIWPCC undertook an effort beginning in 2014 at the direction of our Executive Committee to review and revise this book to reflect these resiliency and adaptation considerations. In addition to the revised technical design guidelines in this volume, NEIWPCC is releasing a supplemental guide to provide further information about mitigation measures and present programs, and plans available, in light of lessons learned from facilities that have been affected by major storm events.

New material in this volume defines critical equipment and offers guidance on backup-power requirements, determination of 100-year flood elevation, flood-elevation design considerations, and levels of protection for new equipment. Changes from the 2011 edition include new and revised design considerations in section 1.2.1.h, and expanded discussions of flooding as an emergency condition under section 1.2.13.4 and of flooding as a consideration when siting water-treatment facilities in section 4.1.2.

There are minor revisions or additions to 1.2.1.i, 1.2.12.a, 2.2.4, 3.1.3, and 3.6.2.7. The revised considerations about flooding also had implications for the discussion of plant hydraulics at 4.3.5.

A new Appendix 1 lists the individuals who helped bring this revised edition to publication.

A wastewater treatment facility must be able to operate under all conditions. Failure to operate can lead to raw sewage being discharged into rivers, oceans, and other bodies of water. The threat that hurricanes and other storms pose to wastewater treatment works is thus a direct environmental threat to communities and the public. As a result, most wastewater plants have precautions and plans in place to remain in service even under extreme conditions.

Nonetheless as storms grow more frequent and more powerful, further improved infrastructure and resiliencies are needed at wastewater plants. Wastewater facilities should prepare for flooding, power outages, equipment damage and failures, and much more.

INTRODUCTION TO 2011 EDITION

The New England states and New York State are renowned for their lakes, streams, rivers, and coastal waters. These water resources are vital to the region's economy and are precious to its citizens. Effective wastewater treatment is absolutely fundamental to protecting these invaluable assets and to protecting public health. Thus, the proper design, construction, maintenance, and operation of wastewater treatment facilities is crucial. The region is fortunate to have many dedicated professionals who are committed to this effort and have been instrumental in the great successes that have been achieved.

For many years, these professionals have turned to the New England Interstate Water Pollution Control Commission's *Guides for the Design of Wastewater Treatment Works* as a helpful resource. Commonly known as TR-16 (short for Technical Report #16), this document provides guidance of value to engineers who are responsible for designing wastewater treatment plants, state regulators who are responsible for reviewing and approving the designs, and municipalities that may need assistance with the solicitation of professional design services for a wastewater facility. TR-16 is intended for use in conjunction with other available technical manuals, such as those produced by the Water Environment Federation (WEF).

The first edition of TR-16 was developed in 1962 in an effort to standardize wastewater treatment plants and to ensure consistency of design among the facilities in New England. Rapid advances in treatment technology necessitated the publication of an updated edition in 1980, and in 1998, amid the continued technological progress, NEIWPCC published the third edition of TR-16, which was developed with the assistance of a NEIWPCC workgroup formed specifically for the task.

In 2009, NEIWPCC's Executive Committee saw a need to revise the 1998 edition to incorporate advances in technology and eliminate out-of-date material. With guidance from the Executive Committee, NEIWPCC staff formed an advisory board made up of regional wastewater experts. The advisory board identified the changes needed in existing chapters and the new concepts that needed to be incorporated, such as new technologies, energy efficiency, and climate change implications. The board drafted an outline for the revised document, then recruited volunteers from the private and public sector to create the content. For each of the thirteen chapters, a writing group was formed, with one person taking on the key role of group chair. Under the supervision of NEIWPCC's project officer, the process of writing, reviewing, editing, and graphic design began, which ultimately resulted in the publication of this, the 2011 edition of TR-16.

The immense effort involved in creating this resource is justified when you consider what is at stake. Most wastewater treatment infrastructure is owned and operated by local municipalities and directly supported by taxpayers. This infrastructure is one of the largest assets of most communities. It is essential that it be designed to operate effectively and in a cost-effective manner. To achieve this goal, it is imperative that any design guidelines be as up-to-date as possible. Advances in wastewater treatment technology and energy efficiency, new approaches based on the need for sustainability—all must be incorporated, and all have been in this new edition. Note that the absence in this guide of design criteria for any specific process does not imply that the process is unacceptable.

This 2011 edition of TR-16 is the culmination of three years of writing, reviewing, editing, formatting, and coordinating. Its purpose, however, remains the same as in 1962, 1980, and 1998—to provide guidance in the design and preparation of plans and specifications for wastewater treatment works. As a guide, it is not to be construed as superseding the requirements, regulations, policies, and standards of the appropriate state water pollution control agencies. Users of this guide should be aware of all applicable regulations, and local and state regulators should always be contacted before starting facility planning. Users should also be familiar with federal requirements that apply to the development of engineering reports, plans, and specifications.

As is noted within this document, anticipated changes in weather patterns as a result of climate change and sea level rise should be factored into design. More precise predictions about these impacts are being developed and will change as more information is available; it is important to stay abreast of the latest thinking on this critical topic. Also, while this document focuses on traditional, centralized wastewater infrastructure, there is no denying that decentralized treatment systems can be a sound alternative. The New England states and New York State have developed separate guidance for decentralized systems, as well as for green infrastructure, stormwater, and other subjects of growing importance. To the extent possible, all these materials should be considered by municipalities seeking the best solutions for a clean environment.

Lastly, let us never forget that clean water is a finite resource that needs to be protected for future generations. Successful project designs should always have one priority above all others—the long-term protection of the precious water in our lakes, rivers, and streams.

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CHAPTER 1

PROCUREMENT OF DESIGN AND CONSTRUCTION SERVICES

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REVISED IN 2016

All engineering plans, reports, and specifications must be submitted to the authority having jurisdiction for review. Engineering reports must include full citations of the pertinent section of the applicable regulations, and designs submitted for review must include a project's construction drawings and specifications. Final review copies must contain full design drawings and specifications, any required environmental and geotechnical reports, a detailed construction cost estimate, and any permit applications required for construction.

There are three major participants in the planning, financing, designing, construction, and operation of a modern water pollution control facility:

- The owner, who is in charge of the management, financing, and, ultimately, the operation of the facility.
- The designer, who is responsible for the planning, permitting, and design of the facility.
- The contractor, who is responsible for construction of the facility.

This chapter deals with the procurement of design and construction services. The design of wastewater treatment facilities requires a combination of managerial, financial, and technical skills. The designer must be familiar with the regulations and financial requirements in the jurisdiction where the facility will be built in addition to the technical requirements provided in this document. The technology in modern pollution control facilities requires expertise in biology, chemistry, geology, and many engineering disciplines including environmental, mechanical, and electrical engineering. This chapter provides guidance in the selection of a firm or team of firms that will ensure a successful design.

Many of the techniques that are delineated for selecting a designer are also applicable to the selection of a construction contractor. (In many jurisdictions, more than one prime contractor may be required.) The major difference is that the selection of a professional designer is generally based on qualifications-based standards; prime contractors are selected on the basis of the lowest bid from among a group of contractors predetermined to be qualified for the job.

The various sections of this chapter have been provided to introduce the technical requirements necessary for a successful project. For more detailed design criteria, refer to the rest of the guidelines in this document as well as peer-reviewed technical manuals and textbooks.

1.1 Procurement of Engineering Services

1.1.1 General

The procurement of planning and design services is one of the most important steps in the design or upgrade of wastewater treatment facilities. When a community lacks the engineering staff to provide the services in-house or the work is outside the scope of an entity that may be providing services to the community, feasibility and design services should be procured via a competitive process. For simplicity, the municipality or community procuring design services will be referred to in this part of the report as the owner. Several approaches should be considered during the procurement process:

Design/Bid/Build: The traditional design/bid/build (DBB) approach requires retaining an architectural/engineering (A/E) firm to plan, study, and design the project. Depending on procurement requirements, the owner then conducts a construction bidding process or hires one or more separate construction contractors to build the project. Construction services, including construction management, are performed by the A/E firm. Start-up, as-built drawings, operation manuals, and operator training services are also typically performed by the A/E firm. The DBB approach typically gives the owner the most flexibility and the most control over the end product, but it requires detailed supervision by the owner's staff over each phase of the project.

Teaming: Rather than have a single A/E provide all of the services, an owner can bring in specialty firms to perform specific tasks. The owner may elect to contract with the firms directly or the firms may serve as subcontractors to a primary A/E firm; the latter approach may be preferred as full liability would remain with the primary A/E firm. The team method is especially beneficial when an owner wishes to retain a local or small A/E that may not have the personnel capacity or technical capability to provide all of the required services.

1.1.2 Alternative Forms of Facility Planning, Design and Construction

Historically, the majority of water pollution control facilities have been constructed using the planning, design, bid, and build approach. In this approach, an independent A/E firm plans and/or designs the project, and prepares a set of contract documents that are used to generate bids from one or more independent contractors and sub-contractors. The qualified bidder with the lowest price is then selected to construct the facility. The design engineer or an independent construction management firm (owner's project manager) is generally retained to monitor construction activities and advise the owner with regard to scheduling, budgetary, and technical quality issues.

Before selecting an alternative form of procurement and/or professional services, it must be confirmed that such procurement conforms to state law. These forms of alternative project delivery are designed to promote early collaboration between the design engineer and the builder, thereby providing for more integrated project delivery and reducing constructability, schedule, and quality problems and associated change orders during the project construction phase. Forms of alternative project delivery include:

Design/Build: Design/build (DB) is a method of project delivery in which one entity forges a single contract with the project owner to design and construct a facility as a single integrated process. (Design/build is also known as design/construct and single-source responsibility.) Since the mid-1990s, use of design/build has greatly accelerated in the United States, making application of this delivery method one of the most significant trends in design and construction.

Turnkey: Similar to design/build in that a single entity designs and constructs a facility, the turnkey approach goes one step further by having the contractor initially operate the facility. The owner does not take over the facility until it has been proven to operate in accordance with performance criteria for one year. At that time, the "keys" are turned over to the owner. This method reduces the need for an owner's staff to respond to any unusual conditions during the start-up of the facility, which reduces uncontrolled costs. However, the owner's staff is still obliged to observe the start-up, so as to become familiar with the facility that the staff will ultimately be responsible for operating. As with design/build projects, the owner is advised to retain the services of a qualified representative to help with the procurement process and to oversee the work of the design/builder.

Design/Build/Operate: The design/build/operate (DBO) concept is similar to the turnkey approach except that the design/builder operates the facility for a specified period of time instead of the owner operating the facility.

Design/Build/Own/Operate: The concept of municipalities retaining an outside firm to design, build, own, operate (DBOO) or privatize a facility allows the owner to enter into a long-term contract with a single entity and to eliminate initial capital outlays. This may not reduce the total cost, but it does eliminate the need for staffing, operating, and managing a facility.

(**Note:** In all the approaches above, with the exception of DBOO, an owner's staff should attend all start-up and process training to better understand the operation of the facility and to ensure a smooth transition between the end of construction and start-up.)

Construction Management: CM is a fee-based service in which a construction manager is engaged directly by an owner to offer advice on construction-related issues during the project design phase and to subsequently serve as the general contractor during construction. (The construction manager works in conjunction with the design engineer.) Advantages often cited for the CM approach include an ability to better shape the construction process to accommodate unusual project constraints and any special needs of the owner, and to reduce project implementation time by allowing for advance purchase of large equipment or other schedule-critical project items.

Construction Management at Risk: At-risk CM is similar to the CM approach, except that the construction manager provides the owner with a guaranteed maximum price (GMP) for project construction. As with CM, the construction manager acts as a consultant to the owner in the development and design phases of a project, and as the equivalent of a general contractor during the project construction phase. The GMP is typically developed by the CM at-risk firm when the project design is approximately 60 to 80 percent complete, and is subject to review by the designer and owner prior to acceptance.

Program Management: Utilities with a small staff but several ongoing capital projects may hire a program manager. Program management is the practice of professional construction management applied to a capital improvement program of one or more projects from inception to completion. Comprehensive construction management services are used to integrate the different facets of the construction process—planning, design, procurement, construction and activation—for the purpose of providing standardized technical and management expertise on each project.

Regardless of the approach selected, a planned, documented strategy should be used when procuring a professional services consultant or firm to plan, study, and design a project. Licensed professional engineers and A/E firms may or may not have individual or company expertise in certain areas of modern wastewater treatment. Organizations with experience across multiple disciplines are generally required for projects, and frequently engineers will form teams with other firms to provide the required services.

1.1.3 Qualifications Based Selection (QBS) Procurement

Qualifications Based Selection (QBS) is a competitive procurement process in which A/E firms submit qualifications to the owner of a projected facility; the owner assesses the expertise of the competing firms, and the most qualified firm for the project is selected to negotiate the project scope, schedule, and appropriate fee. If the owner and selected firm cannot reach an agreement, the owner negotiates with the next most qualified firm. This process is widely endorsed by such entities as the American Council of Engineering Companies (ACEC), American Bar Association (ABA), American Public Works Association (APWA), Associated General Contractors (AGC), and all major A/E design trade organizations.

The services provided by design firms are the single most important factor in determining a project's overall construction and life-cycle costs. The fee for the technical skills and experience provided by a highly qualified A/E firm may amount to approximately 1 percent of the total life-cycle cost of a major project. While this can be a considerable amount, it is vital to remember that an A/E firm's services significantly impact the other 99 percent of a project's life-cycle costs as well as the quality of the completed project. Through the QBS process, an owner and A/E firm develop a relationship that allows them to develop an appropriate project scope, incorporating alternatives and innovations that minimize long-term operation and maintenance costs. With QBS, owners gain a clear understanding of a project and the related financial requirements.

Selecting a professional services consultant is an important and work-intensive process. The level of effort should be tailored to the size of the project. Professional services consultants need time to prepare responses, and the individuals doing the selecting need time to review and analyze the materials submitted by competing firms. The following, multi-step approach attempts to minimize the time and effort involved, while ensuring the selected contractor is the highest qualified and can meet the owner's budgetary criteria. The approach incorporates procurement procedures used by the federal General Services Administration, the U.S. Amy Corps of Engineers, and other federal, state, and local agencies.

1.1.4 QBS Procurement Process

The first step in the QBS procurement process is for the owner to decide if QBS is necessary at all—that is, if professional services are needed that are not available in-house or from firms the owner already utilizes. If additional services are required, the QBS process should be initiated. (Some states and other funding agencies require that an owner has used the QBS process to be grant-eligible.) Typically, the QBS process proceeds as follows:

a. An owner or independent consultant develops a general statement of work for the specific project.

b. A procurement document (request for qualification (RFQ) or request for proposal (RFP)) is developed and appropriately advertised for the size of the project.

c. Submissions are reviewed.

d. Interviews may or may not be conducted, depending on scope of project.

e. The submitting firms are ranked based on submissions and interviews (if conducted).

f. The owner invites the highest ranked firm to assist in developing a detailed scope of work, schedule, and appropriate fee.

g. An agreement covering the scope, schedule, and fee is awarded or, if no agreement is reached, the next highest ranked firm is invited to participate until an agreement is reached.

h. Firms involved in the selection process are notified once an agreement is signed; post-selection feedback should be provided if requested.

1.1.4.1 Request for Qualifications/Request for Proposals

The first key decision to be made once it is determined to procure services is whether to utilize a request for qualifications (RFQ) or a request for proposals (RFP). An RFQ focuses on the qualifications of an A/E firm or team as they relate to a project. An RFP takes that process a step further and asks firms to provide an approach to completing the project; this approach provides the basis for a preliminary scope of services to be developed in the final state of the firm selection process. The decision of whether to use an RFQ or RFP should be based on the level of complexity of the project, with more complex projects requiring an RFP. The size and complexity of the project (and any legal requirements) should also drive the choices for advertising the RFQ or RFP; options include local newspapers, regional or national journals, and local trade associations.

An RFQ or RFP should include the selection criteria, and parties that respond should be supplied with a statement of work or general project description, the location of the project, the proposal and project schedules, and any unique legal, financial, or proposal requirements such as local, small, or minority business criteria. This package of information is intended to eliminate, at the outset, those firms unable to provide the necessary services, or it allows such firms to form or join teams to meet the project's needs. It is often beneficial for an owner to hold a pre-proposal meeting within a reasonable time after the issuance of a request but well in advance of the submittal date. As described in Section 1.1.4.3, a pre-proposal meeting provides an owner with the opportunity to outline needs and present information on the selection process and project. A tour of the project site is usually included.

To allow an owner to more easily review and evaluate submissions, an RFQ or RFP should precisely specify the format to be used by submitting firms and the elements to be provided. Whenever possible, page limits should be imposed to encourage firms to focus on the specific project. The material typically requested includes the following:

- Letter of intent
- Relevant experience of firm or team
- Project organization
- Résumé of project manager
- Résumé of principal
- Résumés of other key personnel
- Table showing individuals on the project organizational chart and indicating total time available, time currently committed to other projects, and time to be devoted to the project under consideration.

An RFP requires additional materials, typically including the following:

- Project approach
- Scope of work
- Project schedule

1.1.4.2 Review

To review the submittals, an owner should select a committee of 5–7 people that includes at least one professional engineer, one representative of the public, one individual involved in facility operations, and at least one elected official.

Each committee member should record his or her evaluations on a standardized score sheet. On the score sheet, each evaluation criterion should be assigned points relating to its importance in the overall selection process, and the points should be weighted for relevance to the project. To minimize the impact of one committee member being a particularly high or low scorer, it is recommended that the high and low scores in each category be dropped and the remainder added to generate a representative score. A sample score sheet is presented in Figure 1-1.

FIgure 1-1 **Sample Score Sheet**

Name of Firm ____

Evaluator: ______________________________ Date ____________________

Evaluation Criteria	Maximum Points	Weighting Points 3 - High 2 - Medium 1 - Low 0 - None	Total Points = Maximum Factor × Weighting Factor
1. Letter of Intent	0		
2. Relevant Experience of Firm	40		
3. Project Organization	15		
4. Résumé of Project Manager	40		
5. Résumé of Project Principal	15		
6. Résumés of Other Key Personnel	25		
7. Anticipated Schedule	15		
8. Commitment Table	25		
9. SF 254	10		
10. Legal/Special Compliance	15		

Once the scores have been tabulated, it may be possible to identify a cut-off level; submissions scoring below this level would be deemed unsuitable for the project. If desired, a two-step process can be used whereby respondents to a request are initially ranked strictly on qualifications. A minimum of three firms and maximum of seven firms are then short-listed and solicited to prepare technical proposals and approaches. Prior to the process being finalized, the short-listed firms attend a mandatory pre-proposal meeting with representatives of the selection committee.

Regardless of the review approach, it is important that reviewers place emphasis on the actual personnel selected for a project and not just the history of a firm. The key individual on any project is the project manager, who is ultimately responsible for the schedule, budget, and quality of the project. Although a firm's relevant experience is important, the firm should be able to document that the personnel selected for a project have relevant experience as well. Otherwise, there is no assurance that the firm's experience will be beneficial to the project.

1.1.4.3 Pre-Proposal Meeting

A pre-proposal meeting should have a formal agenda including a presentation by the owner's representative, who will discuss the proposed project, update the status of the selection process, and describe the remaining steps and proposed schedule. All short-listed firms should be informed of the need to contact the owner in writing before a pre-determined cut-off date. The owner should be prepared to issue addenda to the RFP, if necessary, extending the due date to ensure responsive proposals.

During the pre-proposal meeting, all participants should be advised of the required proposal format, including page limits. The submission of qualifications material and standardized literature should be discouraged at this stage, although organizational charts and résumés of key personnel should be submitted. The emphasis of the meeting should be on ensuring a consensus on the technical approach to be submitted, allowing the firms to present innovative alternative technologies.

1.1.4.4 Interviews

Once the proposals are received and reviewed, the owner should schedule a day for interviews with the short-listed firms. The interviews should be scheduled at least 60 minutes apart, and the firms should be allowed time for a presentation and to answer questions from the owner. Following the interviews, the selection committee should evaluate the proposals using a second score sheet and the same selection procedure used in the initial evaluation of qualifications.

The firm ranked highest by the review committee should be invited in to finalize a scope of services, appropriate schedule, and proposed fee. If the owner and consultant agree that the scope, schedule, and fee are reasonable for the project, the contract is awarded. If no agreement can be reached, the owner invites the next highest ranked firm to enter this process, which continues until an award is made.

1.1.5 Application of U.S. Government Standard Form 330

Federal Acquisition Regulations (FARs) require federal agencies to select firms for most A/E contracts through a process that prequalifies at least three of the most highly qualified firms based upon demonstrated professional competence according to specific criteria published in an RFQ. Projects utilizing federal money require professional services to be acquired via QBS per the Brooks Act. This legislation requires that, following the prequalification step, federal agencies negotiate a contract on the basis of a fair and reasonable price, beginning with the most qualified firm.

In the selection process, local and state government agencies have the option of using a standardized form (330), prepared by the Federal General Services Administration for use by federal agencies. Most A/E firms dealing with government agencies are familiar with this form and can respond expeditiously. Once the responses have been reviewed and evaluated, the hiring agency can determine how many technical proposals should be solicited.

1.1.6 Summary of Procurement of Engineering Services

The guidance presented here can be applied to the selection of an outside firm or team of firms regardless of the chosen method of project delivery (traditional, alternative, etc.). The complexity of the selection process should of course be adjusted in accordance with the total value of the project. Selecting professional services on a qualifications basis is considered good practice, as decisions made during the project planning and design phases of a project have a disproportionate impact on the overall cost and long-term success of a project. To the extent possible, therefore, the selection of firms involved in the planning and design process should be based on qualifications rather than cost.

1.2 Engineering Report

1.2.1 General

The degree to which a project is defined and evaluated, and a recommended plan developed, is greater in the planning phase than in the preliminary design phase. Similar information is provided in both but more detail is considered and presented in the later phase. This section describes the information that should be addressed in an engineering report, but the degree of evaluation will vary depending on the phase of the project.

The engineering report serves as a basis for selecting an alternative for final design and construction. The purpose of the engineering report is to present a detailed evaluation of alternative solutions to a given problem. This would include solutions that are examined, rejected, and recommended, as well as their technical and financial feasibility and their environmental impact. The report should contain a detailed basis-of-design table covering each component of the treatment process.

The report should be written clearly, summarizing the principal information needed by the owner as well as regulatory and funding agencies. For easy reference, assumptions made and factors used in the evaluation of alternative systems should be summarized in tables and graphs when possible. Details on structural, mechanical, and electrical designs are typically excluded, except for cost estimates or when reference to such elements is necessary to appraise the functional operation of the facility.

For all sewers, pumping stations, and wastewater treatment works that pertain to the project, the engineering report should include the following:

a. Brief Description of Project

Include a detailed statement of existing facilities and future needs.

b. Location

Compare alternative sites. Describe locations of existing and proposed sewers, pumping stations, and wastewater treatment works as they relate to the proposed improvements.

c. Topography

Briefly describe topography and include contour maps of the project area and alternative sites, with specific reference to areas affected by the project.

d. Population

Include a review of past population data and the extent of the service area, along with an estimate of growth. Review zoning maps and regional planning agency projections if available. Use population projections to project future domestic wastewater loadings

e. Classifications

These include classifications of receiving waters, existing discharge permit limits, orders from state agencies, etc. Pay special attention to discharge permit limits and possible future discharge restrictions as they can impact the level of treatment required.

Request assessment of probable future permit requirements from the regulatory agency with jurisdiction over the proposed project. In cases where discharge limits are not clearly defined because of water quality limitations, give consideration to modeling of receiving stream.

f. Affected Water Supply

Closely examine public health effects of potential discharges to existing or proposed water supplies and their wellhead and recharge protection areas in the project area. Discuss potential or planned improvements that would impact such supplies.

g. Existing Wastewater System

Location: Present the location of the existing treatment plant and sewers on a suitable map or exhibit. Discuss areas of probable future expansion and show in map form.

Sewers: Determine the capacity available in existing sewers. Show sewer sizes and material type as well as manhole locations. Take into consideration the amount of inflow and infiltration.

Existing Wastewater Treatment Facilities: Provide a detailed evaluation of the wastewater treatment works, including a site layout plan and design criteria/capacity summary of each process unit. Present a process flow diagram.

h. Design Considerations

Volume and Strength of Wastewater Flow: For existing sewers, use a detailed statistical evaluation of existing data to determine the volume and strength of wastewater flow. A minimum of two years of data should be used. The statistical evaluation should identify the maximum waste loadings that correspond to the permit conditions (e.g., maximum monthly average, maximum per week). A plot of exceedence values is often helpful in defining key design conditions. These data should be obtained from actual flow measurements during wet and dry weather periods. Where data are not available, take samples for analysis. Obtain a sufficient number of data points to perform a reliable statistical analysis. If a public water supply already discharges to the sewer system, give approximate maximum, minimum, and average daily water consumption and, where appropriate, analysis of water as it might affect the character of the wastewater.

Data collection should be based on composite samples taken during the maximum significant period of sewage and industrial waste discharge. The data should cover a sufficient period of time to be representative of actual conditions. If needed, the engineer should confer with the reviewing agency for details concerning the collection and analysis of samples to supplement existing data.

Industrial and Commercial Wastes: Define waste discharges from all industrial users in terms of quantity, producing periods, and character of industrial wastes as they may affect the collection system or wastewater treatment works. Base quantity and character of wastes on flow gauging and laboratory analysis of composite samples. Discuss pretreatment requirements as they relate to existing industrial pretreatment program requirements and/or sewer ordinances.

Septage: Review projected septage volume generation rates tributary to the system. Determine the seasonal variations and regulatory requirements related to on-site systems that generate the most septage. The impact of flow and loadings on the treatment facility must be considered.

Soil Investigations and Borings: Describe the extent of investigations, including information on rock likely to be encountered. Discuss unusual foundation conditions and indicate high groundwater level. Include a summary of preliminary borings made, their depth, depth to ledge and groundwater, nature of soil encountered, and a map locating the borings.

Infiltration/Inflow: Measure the quantity of infiltration/inflow (I/I) in existing sewer systems. Compare dry weather and wet weather flows to determine the magnitude of I/I and how I/I can be most economically eliminated—i.e., by reconstruction or repair of the sewer system. When necessary, perform a preliminary I/I flow gauging program.

All systems should evaluate sewer lines that run cross country through easements located in a 100-year floodplain. The sewer manholes in these sections should be protected from I/I in flood conditions. Considerations to include water-tight manholes or manholes raised above the 100-year flood level.

Underground fuel tanks for generators should be safeguarded against buoyancy and lateral movement by floods. Extra ballast can be added above the tank as needed.

Flooding: Include a review and evaluation of existing and projected flood conditions in the project area. This review should take account of sewer-system, pump-station, and wastewater-treatment plant operations and facilities. The evaluation of flood conditions, potential impacts and warranted improvements should consider all potential impacts on flood-water elevations including ice dams, storm surge, wave action, and potential future sea-level rise. The designer should confirm the latest estimate of relevant flood elevations at the project site using the appropriate flood study, which can include documents prepared by: Federal Emergency Management Agency, (FEMA) Flood Insurance Rate Map, a FEMA Advisory Base Flood Elevation Map, a FEMA publically-released working map, and/or a preliminary FEMA Flood Insurance Rate Map), U.S. Army Corps of Engineers (ACOE). The designer should also consult local regulations and ordinances. Federal and state regulations regarding floodplain and floodway obstructions should be considered.

Existing flood studies may be based only on analysis of historical stream- and tide-gauge data and may not consider effects of climate change on future flooding. Climate change may increase currently identified flood risks due to increased precipitation, larger run-off volumes, sea-level rise, and higher storm surges. The design of wastewater conveyance and treatment facilities as well as related flood mitigation measures should reflect projections of future flooding over the planned service life of a wastewater facility.

Until such time that FEMA or ACOE flood criteria are amended to include the impact of climate change, a greater level of flood protection may be warranted. The nature and manner in which improvements are implemented to provide a greater level of protection from existing or potential flood conditions depend on a number of factors, including the configuration and site constraints of the facility and the cost of improvements.

Existing facilities are those constructed using prior editions of these Guidelines and similar documents such as “Recommended Standards for Wastewater Facilities” (10-State Standards). As a result, treatment plants and pump stations upgraded prior to issue of this document should have been designed to (1) provide for uninterrupted operation of all units during conditions of a 25-year (4% annual chance) flood and (2) be placed above or protected against the structural, process, and electrical equipment damage that might occur in a 100-year (1% annual chance) flood elevation. Treatment plants and pump stations that do not currently meet these criteria should be upgraded as soon as practical even if no other improvements are required.

Existing pump stations or treatment facilities that are planned for upgrade or expansion should be improved to the maximum extent possible to meet the flood protection criteria noted herein for new facilities. However, existing facilities may present significant challenges to implementing increased levels of protection. The possible vulnerability and the differential cost of increasing the level of protection above the 100-year flood elevations for uninterrupted operation and protection from damage, respectively, should be weighed against replacement cost in selecting the level of flood protection implemented when upgrading existing facilities.

New pump stations, new facilities within a treatment plant and new wastewater treatment plants should (1) provide for uninterrupted operation of all units during conditions of a 100-year (1% annual chance) flood and (2) be placed above, or protected against, the structural, process, and electrical equipment damage that might occur in an event that results in a water elevation above the 100-year (1% annual chance) flood. The level of protection depends on how critical a component of the facility is to operation of the facility. Specifically, critical equipment of these facilities should be protected against damage up to a water surface elevation that is 3 feet above the 100-year flood elevation. Non-critical equipment should be protected against damage up to a water surface elevation that is 2 feet above the 100-year flood elevation.

Some agencies, such as USDA Rural Development, may require that flood protection be provided up to the 500-year (0.2% chance) flood elevation. In circumstances where the level of protection noted above for new pump stations and treatment facilities (i.e., 2 or 3 feet above the 100-year flood elevation) exceeds the 500-year flood elevation, the more restrictive elevation should be used.

In addition, all SCADA system components and instrumentation used to monitor and control facility operation should be protected from flood conditions to the maximum extent practical.

Critical Equipment: Protect critical equipment, which includes conveyance and treatment system components identified for protection including, but not limited to, all electrical, mechanical, and control systems associated with pump stations and treatment facilities that are responsible for conveyance of wastewater to and through the treatment facility to maintain primary treatment and disinfection during the flood event. Other equipment that, if damaged by flood conditions, will prevent the facility from returning to pre-event operation after cessation of flood conditions is also critical equipment.

Backup Power Supply: Normal operation of the treatment processes should be maintained at all times. Furnish the backup power supply for critical equipment by using emergency power generation or an alternative power source of sufficient capacity. In addition, ensure that there is enough fuel to run under full load or peak flow for at least 48 hours, or under normal operating conditions for at least 96 hours, whichever requires the greater amount of fuel.

Flood Elevation: The one-percent annual chance of flood elevation (100-year flood plan) is the flood elevation associated with a flood event that has a one percent chance of occurring in any given year, at the treatment plant and pumping station sites. Confirm that the design is based on the latest one-percent flood elevation using the appropriate FEMA Flood Insurance Study and accompanying Flood Insurance Rate Map.

> More recent FEMA flood mapping products, including Advisory Base Flood Elevation Maps, working maps, preliminary updated Flood Insurance Rate maps or FEMA non-regulatory RiskMAPs may be available in some locations. If such maps have higher base flood elevations, those elevations should be considered. Check with your state's NFIP coordinating office, or MSC.FEMA.gov, to find out the status of FEMA flood mapping products in your project area.

Protection of New and Existing Equipment: Apply the standard of a one percent annual chance of flood elevation (100-year flood elevation) plus 2 feet for noncritical equipment and plus 3 feet for critical equipment for a new treatment plant, new facilities within a treatment plant, or new pump stations. Safeguard existing equipment that is below the level of protection from water damage or wave action and salt exposure if in tidal zones. Means of protection for existing equipment include construction of barriers, water tight enclosures, or additional methods.

i. Wastewater Treatment Alternatives

Provide a description of alternative wastewater treatment and solids handling processes screened for consideration, as well as factors considered in selecting processes. Such factors should include the following:

- Compatibility with existing facilities
- Flexibility for expansion
- Ability to meet required permit limits
- Ability to be adapted to meet potential future limits
- Suitability to handle probable variations in plant loading

- Proven effectiveness
- Land area requirements
- Labor requirements
- Construction costs
- Operational and maintenance costs
- Energy requirements
- Sustainability
- Odor potential and impact
- Sea level rise, storm surge, wave action

Provide preliminary alternative site layouts, showing the proposed overall layout and process unit orientation on the proposed treatment plant site.

Provide process schematics for each process evaluated, along with a tabular summary of process unit loading and/or sizing parameters applicable to each process unit.

j. Treatment and Disposal of Residuals

Provide a detailed discussion of current and potential future residuals handling systems, including information on sludge, biosolids, scum, screenings, and grit. Consideration should be given to ensuring flexibility in all handling systems in case of future changes in the availability of disposal options and regulations.

Provide sludge handling evaluations that include all aspects of solids processing, such as thickening, storage, dewatering, stabilization, transportation, and disposal. Odor control needs should also be considered.

Ensure that recommended residuals handling and disposal systems are capable of meeting the requirements of applicable local, state and federal regulations.

Prepare a comparative analysis of the various alternatives considered; this analysis should provide a comparison of capital and operational costs, as well as noneconomic factors, in a tabular format. Include a summary of design criteria and a process schematic for each option considered.

k. Conclusions, Recommendations, and Proposed Schedules

Clearly summarize the detailed evaluations contained in the body of the report. Provide a clear description of what is being proposed, the economic impact of the proposed project, and an implementation schedule. For ease of reference, present data in tabular format.

A table that details the basis of design by component should be included, with a separate column showing the generally accepted sizing criteria as well as the appropriate reference citing.

Summarize the economic impact of the proposed alternative based on data developed in the detailed comparison of alternatives. The study should contain the possible approaches to be taken with regard to sustainability, green architecture, and carbon footprint reduction as well. Where appropriate, calculate the estimated impact on the tax base and/or user charges. Such calculations should take into account possible outside funding sources, if available.

To provide a basis for evaluating a future course of action, develop a project implementation schedule. A typical schedule should reflect various future phases of the project, such as final design, bidding and contract award, and construction. When appropriate, implementation schedules should reflect the potential time needed for approvals from local funding sources as well as regulatory agency approvals for future phases of the project.

It is important to also provide a broad analysis of environmental/permitting issues. Since permits often drive the sequence of work and overall schedule, applicable permits should be listed and impacts should be discussed in the engineering report.

1.2.2 Water Conservation

When planning the design of any wastewater facility, the engineer should ascertain the water conservation policies of water and wastewater utilities, as well as those of local and state governments. Both the initial-year and design-year bases should take these policies into account.

1.2.2.1 Reduced Flow Plumbing

The engineer should examine the local plumbing code and actual plumbing practices when estimating initial-year and design-year wastewater flows and strengths. When the engineer believes that reducing wastewater flow through the use of low-flow plumbing fixtures or other water conservation methods is economical, the engineer should make a detailed evaluation of the proposal and recommend a low-flow fixture ordinance in the engineering report.

1.2.2.2 Water Reuse

When the wastewater utility or other governmental entity has an established plan for the reuse of treated wastewater effluent or the engineer believes there is potential for safe, economical reuse of effluent, the engineer should include an evaluation of reuse options in the engineering report.

1.2.3 Industrial Wastewater Discharges

In wastewater planning, special consideration should be given to wastewater discharges from industrial and commercial processes. The engineer should get an inventory of all industrial processes and large commercial establishments discharging wastewater into the treatment facility under consideration. The engineer should also consult with operators at the existing treatment plant, the wastewater utility manager, and state authorities to determine which of these industrial or commercial dischargers might contribute wastewaters of unusual strength or toxicity or wastewaters that are untreatable. On the basis of this examination, the engineer should decide which dischargers warrant further evaluation.

1.2.3.1 Pollution Prevention

When evaluating significant dischargers, the engineer should consider the feasibility of reducing the toxicity and quantity of pollutants. In doing so, the engineer should seek the participation of the discharger, the wastewater utility, and the state authority. If a reduction of pollutants appears possible, the engineer should document his or her findings in the engineering report, including recommendations and an outline for further study of each discharger.

1.2.3.2 Pretreatment

When evaluating significant dischargers, the engineer should review existing pretreatment facilities and the pretreatment policies of both the wastewater utility and the state. If there appear to be technical or economic reasons for instituting or improving pretreatment processes at a discharger, the engineer should document those findings and provide recommendations in the engineering report.

1.2.3.3 Landfill Leachate

The engineer must assess the strength and constituents of any landfill leachate that a facility receives. Permit limits may need to be evaluated by the state before leachate may be accepted. The engineer must also consider how the leachate arrives at the plant (i.e., by pipe or tanker) and how and where it is introduced into the processes. Leachate shares many of the same characteristics as septage and poses many of the same problems for plant processes.

1.2.3.4 Septage

When a facility receives septage, the engineer must consider provisions for the receipt, storage, and introduction of this waste into the wastewater and/or residual treatment processes. The engineer must make an accurate estimate of the septage contribution (both volume and strength) as well as the method and frequency of delivery. Seasonal variations should also be assessed. Before establishing the septage treatment scheme and accompanying facilities, the engineer must consider pretreatment, dilution, point of introduction, and wastewater processing modifications. Without pretreatment or wastewater process modifications, septage addition should not exceed 2–5 percent of actual wastewater flow on any day, and must be slowly metered into the wastewater stream during periods of the day with higher flow.

1.2.3.5 Treatability

Having assessed the pollutant constituents of all non-domestic wastewater sources, the engineer must determine the treatability of those pollutants and their potential for interference with treatment processes. The basis of design must reflect this assessment, which can influence the technical appropriateness and economics of competing treatment process alternatives. Constituents that will pass through the processes without treatment or that will inhibit plant processes need to be evaluated for pretreatment or special handling.

1.2.3.6 Capital and Operating Costs

The engineer should evaluate all non-domestic wastewater discharges that cause unusual process design or operating considerations for the facility, including their impact on capital and operating costs. If these costs are significant, the engineer should include an estimate of the capital and operating costs associated with each discharge. The engineer should make recommendations for recovering the capital costs from dischargers; these suggestions can include user fee surcharges for treatment of unusual wastewaters. (For more information, see Section 1.2.10 on system alternatives.)

1.2.4 Flow Rates

In assessing the flow rates for a particular collection and treatment system, include the following data, both existing and proposed, in the engineering report:

- Design period.
- Residential areas, including population density per acre.
- Area served in acres.
- Per capita wastewater average distribution. Calculate these flow rates using existing state data, information from technical journals, and/or actual water use rates.
- Infiltration rates that depend upon the year of construction, as well as type and size of collection sewers.
- Stormwater contribution.

- Industrial waste contribution.

Before submitting the engineering report, discuss the flow rates with the appropriate regulatory agency.

1.2.5 Loading Rates

Indicate in the engineering report the loading rates, or strength of wastewater, entering the wastewater treatment plant. State the biochemical oxygen demand, suspended solids, and total grease and oil for domestic wastewater and industrial waste. Make allowances for septage that commercial haulers may contribute to the system. As appropriate, list other wastewater constituents and characteristics, such as nitrogen, phosphorus, metals, organic chemicals, temperature, and chlorides. List average and maximum values for these constituents in the engineering report. Where new facilities are proposed, base loading rates on typical wastewater characteristics for the population to be served.

1.2.6 Initial and Final Operating Conditions

Since the quantity and quality of wastewater can vary from facility start-up to the end of the design period, state the initial and final operating conditions in the engineering report. To do so, the engineer must assess the planned development of the contributory area. This assessment may affect the future of the facility, either in terms of expansion of existing treatment units or abandonment of the facility location.

1.2.7 Seasonal Variations

When appropriate, the engineering report should include an assessment of seasonal variations in the quantity and quality of the wastewater, as well as the impact of these variations on the receiving water and treatment process facilities.

1.2.8 Process Schematic

The engineering report should include a process schematic showing the proposed wastewater collection and treatment processes. The process schematic should identify the process, size (including tank volume), necessary dimensions, and secondary flow processes. It should also identify secondary processes such as biosolids, treatment and disposal, chemical application, and compressed air.

1.2.9 Mass Balance

The engineering report should include a mass balance of the recommended wastewater treatment alternative. The mass balance should address the breakdown of biological matter throughout each of the individual treatment units. The mass balance schematic should also include characteristics such as decay factors, residence time, detention time, and biosolids generation.

1.2.10 System Alternatives

The engineer must carefully consider all feasible designs for the facility. The initial evaluation should focus on the technical appropriateness of all alternatives. Those deemed to be appropriate should then receive an in-depth technical and economic evaluation. The operation and maintenance of each alternative should be assessed and documented, with an explanation of the advantages and disadvantages of each. Capital and operating costs for each alternative should be estimated separately, and then in combination, for a minimum 20-year life cycle. The engineer should recommend the best design and should document reasons for the selection.

1.2.10.1 Sewers

When evaluating sewer alternatives, the engineer should consider all practical alignments, taking into account current and future service areas, contributors, and flows. The engineer should determine sewer design life of 50 years, and should evaluate the operation, maintenance, and structural characteristics of different pipe systems, estimating the initial and lifetime costs of those systems. The engineer should recommend the best sewer alignment and pipe system, documenting the reasons for the selection.

1.2.10.2 Pumping Stations

When an existing or proposed sewer system layout requires pumping stations, the engineer should determine the best location. All types of pumping stations should be considered. The engineer should assess the operation and maintenance characteristics of all types found to be technically appropriate, and should include an estimate of the costs—both capital outlay and O&M—of each option. The mechanical equipment operating design life should be 20 years, but cost of the structure should be based on a life span of 50 years, with special attention paid to materials of construction. For large stations or stations in areas projected to grow substantially in 20–50 years, the engineer should consider replacement of pumps with larger-capacity units and/or installation of additional units during the operational and structural life spans of the station. Having considered all technical and economic factors, a design alternative should be recommended with documented reasons for the selection.

1.2.10.3 Wastewater Treatment Plant

The engineer should take the basis of design for the facility and consider all practical treatment process trains, assessing them for operational reliability and flexibility as well as other operation and maintenance characteristics. For facilities with multiple processes, the capital, operation, and maintenance costs for each alternative process train should be estimated; a comparison of sub-process alternatives, particularly for sludge stabilization and dewatering processes, is advised. The operational design life of the process units should be 20 years, but the engineer should consider a longer structural life where deemed appropriate, especially for materials of construction. After considering all technical and economic factors, the engineer should recommend a design alternative and document the reasons for the selection.

1.2.10.4 Combined Sewer Overflows

When a project involves combined sewers, either directly or indirectly, the engineer should address the frequency of combined sewer overflows (CSOs) and the mass of pollutants discharged. Policies on CSOs can be obtained from local and state authorities. For projects that involve the reduction or elimination of CSOs, all practical approaches to the problem, including sewer separation, excess flow storage, and partial or complete treatment, must be considered. The engineer should evaluate technically feasible approaches for treatment level, reliability, operation and maintenance characteristics, and capital, operating, and maintenance costs. For treatment equipment, the design life should be 20 years; for structures, the life span should be 50 years, with special attention paid to materials of construction. After considering all technical and economic factors, the engineer should recommend a design alternative and document the reasons for the selection.

1.2.10.5 Alternative and Innovative Technologies

An engineer may find that, after considering all appropriate design alternatives for a project, the best option is an alternative or innovative design. An alternative technology is one that has been proven effective and reliable for its intended purpose in a substantial number of applications, but does not appear in the various technical specifications found in this edition of TR-16. An innovative technology, by contrast, has not been proven effective and reliable for its intended purpose in a substantial number of applications, but has the potential to be successful.

When considering such a recommendation, the engineer should consult with local and state authorities concerning policies on alternative/innovative systems and proposals. In the engineering report, in addition to the normal technical and economic evaluation, the engineer should submit a detailed justification for proposing an alternative or innovative design. This justification should include the reasons for the selection, literature references, installation lists with operating data, lists of engineers who have designed such systems, and lists of state officials familiar with the design.

1.2.11 Economic and Financial Considerations

Economic and financial considerations are of vital importance in an engineering report. The steps explained below are critical in examining and presenting the total cost of a project, the techniques for raising the required funds, and, ultimately, the cost to the user.

a. Economic Comparison

The report should contain an economic evaluation of alternatives based upon accepted methods for determining cost versus useful life, and should consist of capital, operating, and maintenance expenses. Factors that enter into the selection of an appropriate economic formula include 1) whether the alternatives are independent and mutually exclusive, 2) whether they have equal or various life spans, and 3) whether costs are to be viewed in the present or future. The alternative that is most cost-effective overall should be the one selected.

b. Capital Costs

The report should present an estimate of capital costs that relate to physical improvements, including program development, financing, engineering, construction, and administrative and legal expenses (and contingencies). These costs are ultimately one-time expenditures, although they may be amortized and depreciated over a number of years.

c. Operating Costs

Operating costs are expenses incurred in the course of the ordinary activities of the facility. Those costs include utility, administration, and personnel expenses. List and estimate future operating costs of the project in the report.

d. Maintenance Costs

Maintenance costs are expenses incurred in preserving the service life of the facility. They include equipment replacement and maintenance, general housekeeping, etc. List and estimate these costs in the report in order to evaluate the long-term expenses incurred in maintaining the facility.

e. Funding Sources

The sources of funds used to finance a project can be diverse, including federal, state, and local grants and/or loans. Identify in the report those funding programs that are available to the owner.

f. Capital Cost Recovery

Capital cost recovery refers to the securing of funds for retiring debt incurred in the installation of facilities. Installation costs are generally passed on to the parties who benefit from the facility. Discuss, estimate, and evaluate the methods available for cost recovery (i.e., general taxation, assessments, and fixture charges) in the report.

g. User Fees

User fees finance the daily operation and maintenance of facilities and should be based on a reasonable life cycle. Methods for collecting fees are linked to water meter readings or a flat uniform rate based upon a user classification system. Discuss, estimate, and evaluate user fee methods in the report.

1.2.12 Environmental Considerations

a. Floodplains

The proposed facilities may be located adjacent to an area that is subject to upland or tidal flooding every 100 years or less. The report should evaluate the presence of floodplains, discuss the controlling elevations and the effects of abnormally high water caused by ice jams, and state what precautions against flooding are incorporated in the design.

Delineation of floodplains should account for historical precipitation, stream flow and tidal data as well as projections of future flooding due to climate change for the life of the project. Refer to Paragraph 1.2.1.h.

b. Wetlands

The proposed facilities may be located adjacent to inland, coastal, or riverbank wetland areas subject to federal and/or state regulations. The report should evaluate the presence of wetlands, identify buffer requirements, and discuss their effects on the project as well as available measures for mitigation.

c. Air Emissions

The report should discuss air emissions associated with wastewater conveyance, pumping, treatment, and disposal. Where emissions could affect air quality, the report should identify, discuss, and recommend technologies and evaluate measures for mitigation.

d. Solid Wastes

Solid wastes resulting from wastewater treatment processes must be handled, transported, and disposed of in accordance with federal and/or state regulations. The report should identify, discuss, and determine the cost of the approved treatment technologies or alternative/innovative techniques.

e. Protected Species of Fauna and Flora

The report should discuss federal and/or state regulations pertaining to the presence of protected species of fauna and flora. If protected species are identified or suspected within or adjacent to the project area, the report should discuss and evaluate the potential effects on the project and measures to mitigate those effects.

f. Mitigation During Construction

When references are made in this chapter to mitigation measures that should be discussed and evaluated in order to reduce environmental impacts, those references pertain to measures to be taken during the construction phase of a project. Therefore, the report should discuss, in detail, the methods to be used during construction to mitigate environmental concerns.

g. Environmental Permits

The permitting of a project can have a significant impact on the project's schedule and overall cost, and should be considered in the engineering report. A list of all significant permits that will be required for construction should be included.

1.2.13 Operating Considerations

To a significant degree, the ability of an operator to maintain a wastewater treatment facility in compliance with discharge permit limitations is a function of the degree to which the operator is able to accommodate changes in loading conditions and maintain and repair plant equipment. The engineering report should make it clear that adequate process flexibility is provided so that critical treatment process elements can be taken off-line without a major disruption or the need to bypass a key process element. In addition, potential emergencies should be anticipated, and accommodations for minimizing their potential effects should be considered. The design features and practices outlined below, which relate to these operating considerations, should be described in the report.

1.2.13.1 Hydraulics

Perform head loss calculations under extreme peak flow conditions on all flow-carrying elements to ensure that surcharging from downstream to upstream units will not occur.

Whenever possible, eliminate on/off pumping cycles that cause peak type flows to the process units. To minimize hydraulic peaks, consider variable-speed pumping.

In addition to ensuring the hydraulic passage of peak flows to a wastewater treatment facility, provide adequate flow-splitting devices when multiple process units are used. When possible, provide adjustable weirs or gates, allowing the operator to balance flows accurately among process units. Avoid dependence on channel geometry for flow splitting.

Provide slide gates or flow isolation valves for maintenance and repair of a single process unit. Where only a single process unit is provided and redundancy does not exist, provide a means of bypassing such units. For example, in the case of a mechanical bar screen, provide a bypass channel.

1.2.13.2 Flexibility

Accommodating a number of variations in plant conditions and operating modes is essential to the successful operation of a wastewater treatment plant. Duplication of process units can provide redundancy, allowing one process unit to be taken off-line for repair or maintenance without any impact on treatment. To accommodate future needs, space for adding equipment when necessary should be provided. In addition, isolation of various process units and related equipment from the treatment train must be provided, including isolation valves and/or gates at the influent and effluent side of unit tankage, as well as pumping units within the treatment process.

In dealing with process components with optional modes of operation, provide flexibility in utilizing those modes. For example, in the activated sludge process, it should be possible to pump recirculated sludge to either the aeration tanks or to primary clarifiers. Providing such flexibility in a treatment plant design allows operating staff the ability to use either approach. Flexibility should also be provided to allow variation of raw wastewater feed points as well as points of recirculated sludge return.

In the design of aeration systems, vary the air supply to the treatment process to accommodate both long-term and diurnal variations in plant loadings and oxygen requirements, as well as to allow for energy conservation. Consider the use of multiple fixed-speed blowers or centrifugal blowers that can provide a range of air requirements to the system or variable-speed blowers. With mechanical aeration systems, consider variable speed drives on the motors with DO control.

In addition to providing flexibility in the air source, provide flexibility in air piping systems with valves that allow the air supply rate to be adjusted to meet the variable oxygen demand within the process unit; DO monitoring systems with vari-speed drive motors to vary blower input should also be considered. This flexibility is of particular importance in plug flow reactors, where tapered aeration may be advantageous to overall process performance.

1.2.13.3 Winter Conditions

Because of the severe climate conditions that exist in New England, two key considerations are operator safety and the potential freezing of equipment. Freezing of equipment could result in damage to the equipment or loss of a treatment unit from the treatment train.

Railings with safety chains at rail openings should be provided on all process units. Avoid smooth walkway surfaces above open tanks; consider broom-finished concrete or grating instead. Ensure appropriate federal and state safety requirements are considered when designing means of access and egress.

In small treatment facilities where extremely low flows may occur and the potential for freezing is high because of low flow conditions, provide enclosures of process units or filleting of concrete tanks to accommodate temporary winter covers. In treatment process units where a significant freeboard exists above the liquid level, provide a means for an operator to climb out of the process unit in case of a fall.

Take winter conditions into account when determining the location and routing of moving equipment such as conveyers in order to minimize freezing and associated process interruption. Frostproof hose bibs and yard hydrants should be specified in areas where freezing could occur. Consider heat tracing of piping only as a last resort.

Take snowplowing operations into account, providing adequate space in the plant layout for stockpiling of snow. Avoid creating areas where snow cannot be plowed easily. Take measures to minimize the effect of snow or ice sliding from roof surfaces near doors, walkways, or process units.

1.2.13.4 Emergency Conditions

Potential emergencies should be considered in the design of wastewater treatment works. During emergencies as well as routine operations, primary concerns are personal safety and the ability to maintain the process equipment efficiently. Designs should include consideration of operations activities that may occur after daylight hours. Effective drainage inside and outside of buildings is key to avoiding icing issues and health impacts, and to ensuring safe working conditions.

Designs should avoid creating “confined space” conditions whenever possible. Emergency access and egress for emergency vehicles should be included in the engineering report as well as recommendations for permanent safety features (e.g., sprinklers, fire hydrants, and alarm systems).

In areas where hazardous chemicals are stored or used, provide appropriate emergency equipment such as eye wash stations and emergency showers. Ensure all areas where emergency equipment is located have appropriate signage and means of access and egress for emergency personnel. In areas of the plant where powdered or granular chemicals that can generate dust are handled, provide adequate ventilation. At plants that use chlorine gas, chlorine gas detection alarm systems should be provided with consideration for redundancy of the system.

The potential for flooding of the treatment plant site should be evaluated. Recognize the need for locating process units above potential flood levels to avoid possible process unit and equipment damage or process interruption. When eliminating the potential for process interference is not practical due to high receiving stream levels under flood conditions, provide emergency effluent pumping facilities. Consideration should also be given to the use of berms or dikes to protect structures from flooding.

Wastewater facilities susceptible to flooding should consider implementing a flood monitoring protocol to enable advance warning of rising water. For example, an upstream river gauge can provide effective warning of a pending flood condition if a correlation between water levels at the upstream gauge and WWTP can be established. Spring snowmelt and heavy rain events can have major flooding impact on downstream facilities.

Any basement structure in a building located in a flood plain should consider including a flood alarm.

An emergency power generator or alternative secondary, backup or emergency power source should have enough fuel to run under full load or peak flow for at least 48 hours or under normal operating conditions for at least 96 hours, whichever requires the greater amount of fuel to supply power to critical equipment in the event of a power outage at the wastewater treatment facility, pumping stations, and facilities in the system responsible for conveying flow to the plant. Use local utility records to determine historical outage durations and to determine which process units should be powered by the emergency power source.

1.2.14 Energy Conservation

a. General

Given the high energy requirements and costs associated with wastewater treatment, pay particular attention to incorporating energy conservation in the design of wastewater treatment facilities. Such considerations should be made during the preliminary evaluation of treatment process alternatives, as well as in the selection of individual pieces of process equipment. All motors must be premium efficiency except those that are used infrequently. Incorporate power factor correction into all designs.

The careful selection of pumping units can also result in significant long-term power savings. Closely evaluate the energy consumption of solids handling systems, taking measures to allow flexibility of operation. For example, staging of equipment should allow for energy conservation.

b. Energy Audits

On projects that involve the upgrade of existing facilities, perform an energy audit to determine the overall theoretical kW-h use and peak demand. This audit should include a list of all equipment in the facility, along with rated motor HPs and duty schedules. On large equipment, consider measuring power usage with a watt meter to obtain accurate figures.

c. Aeration

Energy conservation in aeration systems is extremely important because an aeration system is typically the largest single energy user in the treatment process. Energy-saving measures such as variable and multiple staged single-speed blowers, high-speed turbo blowers, two-speed mechanical aerators, continuous DO monitoring, and time clock operation can be used for energy conservation at wastewater treatment facilities. The relative oxygen transfer efficiency of alternative aeration systems should also be considered.

d. Energy Management Systems

Load shedding devices, commonly referred to as energy management systems, should be considered for lockout of certain process operations during periods of peak energy demand, minimizing demand charges from the local utility.

In addition, evaluate the potential for using separate meters to monitor major energy use areas of the plant.

e. Heating Energy

In terms of space heating, give consideration to gaining heat recovery from blower rooms. At plants where anaerobic digestion is part of the treatment process, consider possible uses for surplus gas and other waste heat.

1.3 Contract Drawings/Plans

1.3.1 General

All plans should bear a suitable title, showing the name of the owner, sewer district/institution, a drawing number, the scale in feet (or suitable measure), a graphical scale, the called or magnetic north, the date of preparation, name of the surveyor who conducted the survey, name of the engineer and imprint of his or her registration seal, and all revision dates. The plans should be clear, legible, and drawn to a scale that permits information to be shown plainly. Standard drawing size is 24 inches by 36 inches. Indicate the datum used, the year it was established, and its relation to mean sea level datum (United States Geological Survey or National Geodetic Vertical Datum).

Plans should consist of general views, specific plan areas, elevations, sections, and details. Together with the specifications, these provide information for the contract and construction. Include existing information on the plans, and draw dimensions, equipment, piping, structures, and valves to scale on the plans. Include information about subsurface material on the plans.

Appropriate production software (AutoCAD, TurboCAD, etc.) should be agreed upon with the owner prior to the start of contract drawing preparation.

Before initiating the final design, the engineering report should be consulted to confirm the basis of design and reevaluate the design criteria. Any variation from the engineering report should be noted and discussed with the owner and regulatory agency. Reasons for variations from the engineering report include the receipt of additional information after drafting the engineering report, revised regulatory agency criteria, and constructability and cost-effectiveness issues.

1.3.2 Sewers

Submit a comprehensive plan of existing and proposed sewers for projects that involve new sewer systems or substantial additions to existing systems. This plan should include boundaries of the area to be sewered, existing and proposed streets, bodies of water, a north arrow, and appropriate scale. The plan should show the location, size, and direction of flow for all existing and proposed sanitary sewers and existing combined sewers. Make appropriate cross references to more detailed plan sheets.

1.3.2.1 Plan View

Submit detailed plan views of the proposed sewers at a typical scale of 40 feet to the inch but no more than 60 feet to the inch. All plan views should appear over corresponding profiles on the same plan sheet. Plan views should show:

- North arrow, scale, and match lines, where appropriate.

- Title blocks identifying the project, owner, and engineer.
- Location of existing and proposed streets, pertinent rights-of-way, and both permanent and construction easements for the work.
- Location of all known existing structures and utilities that may interfere with construction of the proposed works.
- Length, size, type, and direction of flow of all existing and proposed sanitary sewers and existing combined sewers. Clearly distinguish existing structures from proposed work. Number and station all proposed sewer structures and special features to correspond to profile views.
- Adequate benchmarks and limits of construction.
- Existing and proposed topography in the vicinity of the work. Include information on the type of surface, where appropriate.
- Basement floor or slab elevations where building connections are proposed.

1.3.2.2 Profile View

Submit detailed profile views of the proposed sewers, using a horizontal scale of 40 feet to the inch and a vertical scale of not more than 10 feet to the inch. Use the same horizontal scale for both profile and plan views, and locate both on the same sheet. Profile views should show:

- A datum plane referenced to permanent benchmarks shown on the plan view.
- Title block identifying the project, owner, and engineer.
- Horizontal scale, vertical scale, and match lines, where appropriate.
- Existing and proposed ground surface elevations, type of surface, and locations of existing and proposed streets.
- Length, size, slope, and type of pipe.
- Stationing, invert, and ground elevations for all sewer structures.
- Location and elevation of all known underground structures and utility crossings that may interfere with construction.
- Stream crossings, if applicable.
- Boring locations and groundwater elevations, if available.

1.3.2.3 Manholes and Other Structures

Detailed plan and profile views should include stationing, invert, and ground elevations for all manholes and other structures such as depressed sewers (inverted siphons), concrete encasements, elevated sewers, and valves. Plan sheets should reference construction sheets for details of special structures, where appropriate.

1.3.2.4 Details and Section Views

Plans should include details and section views for all proposed piping, manholes, special structures, stream crossings, outfalls, thrust blocks, valves, etc., at a scale sufficient to clearly describe the nature of the design. Detail and section views should reference technical specifications, where appropriate.

1.3.3 Pumping Stations

On contract plans for pumping stations, provide sufficient detail for construction and for contractors to estimate costs and make a bid. The plans should permit equipment suppliers to propose and price appropriate components and systems, including approvable equal substitutes. Avoid specification details that are not essential to the design and operation of the system and its components, allowing contractors and equipment suppliers to propose systems, components, and construction techniques that satisfy the design criteria and are economical.

Include location and overall sewer system maps on contract plans to allow contractors and regulators to understand how a pumping station fits into the wastewater system and to specify the station's relationship to natural and manmade features on and around the site.

Prepare contract plans on full-size plan sheets using scales appropriate to the component(s). Clearly display the scale on each sheet and detail. Use the same scale for related views and sections to facilitate comparison. Supply a complete legend list to identify all lines and symbols. Clearly label all views and cross sections on the overall plans, elevations, and section drawings. Place the design basis, performance points, and construction notes on the sheets.

1.3.3.1 Plan View

Include the pumping station at the ground level (site plan) and all other appropriate elevations on the plan view. For small and wet well stations, the ground-level view may be adequate. For large and dry well stations, views at various elevations are appropriate. For stations with more than one level (floor), supply a plan for each level using the same orientation for each view. Specify overall structure dimensions.

Include all major system components on the plan views. For all but the smallest stations, show all piping, valving, and electrical and control components at the same scale as other components. For more complicated stations, depict piping and electrical systems schematically. Show valving and electrical component schedules.

1.3.3.2 Elevations

On the elevation view of the pumping station, show the dry and wet wells and all other tanks and components to scale, using a section through the principal components. When size and complexity dictate, provide elevations through more than one cross section. Make vertical sections for areas with complex details. Show piping and valving at the same scale as other components. Where clearances are limited, show all components in a section.

Specify elevations for all principal structural components, such as the bottom of the excavation, top of the foundation, top of the slab, ground level, and all pipe inverts. Provide overall dimensions of structures. Show critical operating elevations, such as pump control levels, emergency storage, and overflow heights. Show all above-grade structures.

1.3.3.3 Sections

Depending on the size and complexity of the station, provide horizontal and vertical (plan and elevation) sections. The number and location of these sections will depend on the complexity of the design and the need for describing the design and construction to contractors and reviewers. Generally, sections should use the same scale as the comprehensive views, except where enlarged views are necessary for detail and clarity. All sections need to be identified in the details and on the comprehensive view.

1.3.3.4 Details

Provide details of crucial and complicated portions of the station. Make the scale of a detail appropriate to its purpose. Clearly identify details and their reference points on the plan and elevation sheets, using a consistent numbering and/or lettering system.

1.3.3.5 Emergency Operating Provisions

The engineer should pay special attention to possible malfunctions at a pumping station, considering carefully all likely causes of interruption of station operation and providing for those contingencies. Wastewater utility, local, and state officials should be consulted for emergency operating policies.

- Design stations to withstand permanent damage from power outages, storm events, and 100-year floods, as well as ice jams under flood conditions.
- Design stations to function during conditions of record floods of the past 20 years or for the time period generally recommended by the regulatory agency reviewing the plans.
- Design stations to prevent the discharge of sewage or backup of sewage into service connections during power outages of at least four hours duration or the greatest outage of record in the area. Stations should also be designed to facilitate temporary pumping around malfunctioning equipment. For power outages, stationary or portable generators should be furnished. For equipment failures and power losses, provide for portable pumping. At a minimum, provide completely valved portable pump connections in a dry pit on the discharge force main.

1.3.4 Wastewater Treatment Plant

Provide construction drawings showing construction details, illustrating the proposed location of all process-related plant elements, including process units, piping, valves, metering devices, and mechanical equipment.

1.3.4.1 General Layout

Submit drawings showing the layout of the proposed wastewater treatment plant and major process units, including:

- Site grading and drainage.
- Size and location of plant structures and utilities.
- Property lines.
- Schematic flow diagram showing the flow through various plant units.
- Influent sewer, yard, and outfall piping, including pipe size, material, location, and elevation of all conduits.
- Test boring locations.

1.3.4.2 Hydraulic Profile

Prepare a hydraulic profile that shows pipe and channel sizes and inverts throughout the treatment plant, as well as key process unit elevations, including control device elevations such as weir crests and flume bottoms. Prepare the hydraulic profile in graphic form for ease of interpretation. Show water surface elevations under average, peak, and low flow conditions at various process units along the profile, as well as at control structures and channels.

1.3.4.3 Operational Considerations

Carefully consider the wastewater discharge permit limits in the selection of a treatment process. Factors that influence the selection of a treatment process include flow, waste characteristics, and use of receiving waters. In plant upgrades, the location and topography of the plant site as well as the effect of industrial wastes likely to be encountered may also determine the process used.

Take long-term needs into account when designing sludge handling systems. Also, provide flexibility for final disposal options and potential future changes. The plant design should achieve the longest possible useful life; incorporate flexibility and convenience of operation, and minimize energy expenditures, maintenance, and capital and operating costs.

All unit operations must be maintained during the construction process.

1.3.4.4 Process Details

1.3.4.4.1 Construction Drawings

Provide detailed plans that show the size, material, proposed location, and orientation of all process-related equipment and associated process piping and appurtenances. Such equipment includes the following:

- Process units
- Interior process piping and valving
- Metering devices
- Mechanical and manual screens and/or grinders
- Clarifier and/or thickener mechanisms
- Control devices such as weirs and flumes
- Pumps and motors
- Diffused aeration systems
- Blowers and/or mechanical aerators
- Sludge thickening and/or dewatering equipment
- Chemical feed systems
- Disinfection equipment
- Odor control equipment
- Instrumentation and control systems

Carefully consider pipe hanger and support details, including elevations, and clearly state this information on the construction drawings.

Cautionary Note: For all drawings, conduct a constructability review to examine all disciplines for possible conflicts. Details that seem to be a minor component of the construction drawings can lead to significant problems in the field, which can result in significant claims and additional costs to the owner.

1.3.4.4.2 Bypasses

Except where duplicate units are available, provide bypass capability so that each major unit of the plant can be removed from service independently. The design should allow for maximum treatment and convenient operation when any given unit is out of operation. Pay particular attention to solids retention, sludge handling, and disinfection during bypass operations. The acceptability of bypasses should be checked with the appropriate review agency.

1.3.4.4.3 Dewatering

Provide a means to dewater each process unit, preferably by gravity drain. Give due consideration to preventing tanks from floating.

1.3.4.4.4 Emergency Power Facilities

Provide a standby power source, where necessary, to ensure uninterrupted operation of primary treatment and disinfection facilities during a power outage (or the level of operation required by the regulatory agency).

1.3.4.5 Mechanical

Mechanical drawings should include all necessary construction details for environmental support systems at the wastewater treatment plant, including layout and sections along with details for materials of construction and type and size of ducts, as well as equipment details for the following elements:

- Plant plumbing, including potable water, plant water, plumbing fixtures, and floor and roof drain systems.
- Components of the ventilation system, including air ducts, exhaust fans, and louvers. Provide ventilation in accordance with applicable codes in areas where sewer gases may be generated or dry chemicals or powdered carbon are handled.
- Heating system components, including the heating plant, baseboard and/or unit heaters, control systems, and fuel tanks. Consider local regulatory requirements when designing fuel storage tanks.
- If air conditioning is to be provided, include details showing the nature and extent of the air conditioning system.

1.3.4.6 Electrical

Electrical drawings should show the necessary elements of power distribution, as well as lighting, instrumentation, and control systems. The following electrical system elements should be included on the drawings:

- New power entrance requirements as appropriate. Coordinate entrance requirements with the local power utility.
- The power distribution system, depicted on the plans in adequate detail to facilitate construction. Include a “one-line diagram” for all electrical equipment provided at the wastewater treatment plant. In addition, include a site layout showing power distribution to yard equipment and local control devices on a suitable site plan.
- Lighting systems for each area of the plant, including location and type of fixture, as well as switching locations. Give consideration to outdoor yard lighting, where appropriate.
- Instrumentation and control drawings, provided to the extent necessary based on the complexity of the system. Provide control and alarm system details, including configuration of alarm and control panels.

1.3.4.7 Instrumentation

The need for detailed and clear instrumentation and control drawings has increased dramatically as a result of the increase in sophistication of these systems. In addition, some instrumentation and control systems are provided as a package, whereas others are custom designed.

Owner (municipality) involvement is critical as owners often have specific desires related to the level of sophistication to be provided. Adequate detail, therefore, should be provided in the construction drawings.

Instrumentation drawings should include:

- Location and type of control devices provided at various points in the treatment plant, including float switches, conductance strips, and gas detection systems. Provide a process instrumentation diagram that schematically depicts the location and type of all sensing elements, as well as local indicating devices, transmitting devices, and recorders. This drawing should serve as a master plan for the instrumentation and control system installation.
- When the level of sophistication warrants, ladder diagrams that indicate the source and terminus of control signals from control devices to an alarm panel. Supervisory control and data acquisition (SCADA) systems should be considered.
- Details of the alarm panel, including layout and configuration.

With regard to alarm systems, coordinate with the municipality to determine the appropriate means and receiving agency for telemetering of alarm systems.

1.3.4.8 Structural and Architectural

Provide adequate details on the structural and architectural drawings to facilitate construction. Details to be provided include:

- Plan sections and details of each element of the plant, including reinforced concrete, steel, and timber construction.
- Construction details, including construction joints, and typical reinforcing details or reinforced concrete. Pay special attention to the location and type of waterstop provided in process units where liquid is to be contained.
- Architectural details, depicting materials and method of construction of roof systems, walls, doors, and windows.
- Interior and exterior finishes. Select finishes that require low maintenance.

Check structural and architectural drawings against other drawings so that conflicts and obstructions do not exist. The locations of pipes and air ducts especially should not conflict with beams and columns.

1.3.4.9 Laboratory

Treatment plants should consider including a laboratory for analyzing the proposed treatment process and conducting operating control tests. The laboratory should have sufficient floor area, bench space, equipment, and supplies to perform all self-monitoring analytical work required by discharge permits. Additionally, the lab should be able to perform the process control tests necessary for proper operation and control. Use fume hoods when odors or hazardous vapors are present. Consider air conditioning. Include the facilities necessary to support industrial pretreatment programs. In the layout, provide for expansion if more analytical work is needed as permit limits change.

When possible, locate the laboratory on ground level, accessible to sampling points. The lab should not be located near vibrating machinery or other equipment that might have adverse effects on the performance of analytical balances or other laboratory equipment.

1.3.4.10 Sections and Details

Adequate sections and details should be provided in the construction drawings to allow construction to proceed smoothly and in accordance with applicable national and local building codes. In treatment process units, care should be taken to provide adequate reinforcing at wall and cover penetrations. The placement and type of waterstops should also be considered carefully in the design of process units.

Carefully consider pipe hanger and support details, including elevations, and clearly state this information on the construction drawings. Piping hanger systems should be designed by the engineer rather than the construction contractor. (See Cautionary Note at 1.3.4.4.1.)

1.4 Technical Specifications

1.4.1 General

Complete technical specifications for the work should accompany the plans. Technical specifications should be clear and concise. They should include, but are not limited to, all construction information that the builder needs that is not shown on the plans, such as details of the design requirements, including the quality of materials, workmanship, and fabrication of the project. Technical specifications should include, where appropriate, lists of required manuals, tools, chemicals, spare parts, and calibration equipment. The specifications should also include requirements for testing products either before delivery or upon completion of the work.

1.4.2 Format

The specifications should comply with the guidelines of the latest format of the Construction Specifications Institute (CSI). Include in the specifications a table of contents that is cross-referenced to other specification sections and plans, where appropriate.

1.4.3 Alternates and Equivalents

Where alternates are included in the contract documents, clearly describe the quality, materials, and workmanship for each. The specifications should define the terms “equivalent,” “equal to,” or “approved equal” and should provide a clear method for determining equivalent products under the contract.

1.4.4 Operations and Maintenance (O&M) Manuals

1.4.4.1 Draft Manual

Prior to start up of the system, the contractor should provide draft copies of an O&M manual for the project. The documents should be provided in both hard copy and electronic format. The manual should include, at the least, start-up instructions, process flow diagram(s), electrical schematics, instrumentation and controls diagrams, material safety data sheets (MSDSs), safety instructions, troubleshooting guides, manufacturers’ literature, staffing plan, etc.

1.4.4.2 Final Manual

The final O&M Manual should include any changes that were identified during the start-up and final construction process.

1.4.5 Start-Up Services

Where the contract documents require start-up services, clearly define the party(ies) responsible for providing these services, the services to be provided, duration of the services, and minimum qualifications of start-up personnel.

1.4.6 Operator Training

Where the contract documents require operator training services, clearly define the party(ies) responsible for providing operator training, the nature of the training, duration of the services, and minimum qualifications of training personnel. The draft O&M manual should be used as the basis for the operator training program. Any training presentations, including those prepared using Power Point or other graphics software, should be provided in both hard copy and electronic format. Many owners require recording of training for future reference and training purposes; consider including a standard specification that requires all training to be recorded.

1.4.7 Performance Guarantee

Where the contract documents require a performance guarantee, clearly define the performance period, required minimum performance standards, the form of the guarantee instrument, acceptable guarantors, and acceptable proof that the parties are authorized to enter into such an agreement.

1.4.8 Mechanical and Equipment Warranties

Wastewater equipment manufacturers offer “standard” warranties on their equipment. In many cases, these warranties become effective when the equipment is shipped. It is not unusual, especially on large projects, for contractors to have equipment shipped early in the process and then store the material until it is ready to be installed. This may result in a significant reduction or expiration of the time available on a manufacturer’s warranty.

In addition, some equipment, such as membranes, is offered with extended warranties. Consideration must be given to the wording of such warranties since some are offered with a predetermined number of years, while others are prorated and decrease in value over a period of time. In all cases, ensure the owner has a manufacture date of all equipment and system components. This will assist in asset management and is needed in the event of failure or malfunction.

1.5 Field Engineering

1.5.1 Shop Drawing Review

Procure field engineering services prior to the start of construction. One key component of field engineering services should be the review of products and shop drawings submitted by the contractor. When a significant delay has occurred between completion of the design and initiation of construction, the equipment that was specified may no longer be available or more acceptable technology may have been identified. These possibilities should be considered before construction begins.

Provide the contractor with a list of submittals prior to the start of construction. It is the contractor’s responsibility to review the materials of construction and equipment proposed for the project.

In addition, the contractor should review the shop drawings.

The engineering consultant should review the submittals, returning the required number to the contractor. The engineering consultant should review the plans and specifications for general compliance. Only those submittals reviewed and accepted by the engineering consultant should be used by the contractor to procure equipment and materials.

The engineering consultant should keep a log of the submittals, which includes the following:

- Date of submittal
- Number of copies submitted
- Referenced specifications
- Submittal number
- Final disposition of shop drawing (i.e., reviewed, rejected, and resubmitted)
- Transmittal date to contractor
- Number of copies returned to contractor

1.5.2 Record Drawings

During construction, the contractor should submit record drawings. The record drawings should indicate, at a minimum, the location of structures installed by the contractor and any materials, utilities, and other items that were not identified on the plans. Indicate the dimensions of permanent structures on the record drawings, including the locations of underground items or items that cannot be seen in the field. The record drawings should be prepared by the engineering consultant from his or her field observations and from information submitted by the contractor. The record drawings should bear the name of the engineer and an imprint of the registration seal. Submit a copy of the record drawings to the owner and regulatory agency.

For ease of review and approval, it is suggested that record drawings be provided electronically as a separate layer on the electronically provided design documents.

References – Chapter 1

Consortium for Energy Efficiency (CEE), *Energy Efficient RFP Guidance for Water and Wastewater Projects*, 2010

Great Lakes-Upper Mississippi River Board, “Recommended Standards for Wastewater Facilities” 2014 Ed., 2014.

NYSERDA, *Water and Wastewater Energy Management Best Practices,* March 2010

U.S. EPA, EPA’s ENERGY STAR Portfolio Manager (website): www.energystar.gov/waterwastewater

U.S. EPA, *Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities,* EPA 832-R-10-005, September 2010

U.S. Government US Form 330: http://contacts.gsa.gov/webforms.nsf/0/21DBF5BF7E860FC185256E13005C6AA6/$file/SF%20330.pdf

Water Design-Build Council, The Municipal Water and Wastewater Design-Build Handbook, 2nd Edition, 2010

WEF Manual of Practice No. 32, *Energy Conservation in Wastewater Treatment Facilities*, 2009

CHAPTER 2

SANITARY SEWERS/ WASTEWATER COLLECTION SYSTEMS

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2.1 Design of Sanitary Sewers

This chapter provides guidance on the design and construction of sanitary sewers. Sanitary sewers include all gravity flow components of a wastewater collection system.

2.2 Design Capacity and Design Flow

2.2.1 Design Factors

In determining the required design parameters of sanitary sewers, the following factors must be considered:

- Peak hourly wastewater flow
- Additional peak flows of industrial and commercial wastes
- Maximum groundwater infiltration
- Topography of immediate area
- Difficulty of installation

2.2.2 Design Period

In general, wastewater collection systems should be designed for a life span of 50 years, and interceptor sewers should be designed to handle the maximum 50-year build-out tributary population. Communities should plan ahead for repair or replacement after 50 years of use. Consider the maximum capacity of uses such as institutions and industrial parks.

2.2.3 Design Flow

Submit to reviewing agency a detailed description of procedures used for sewer design.

2.2.3.1 Flow Related to Water Consumption

When available, use existing wastewater flow and/or water consumption data as a basis for sewer design. If such data are not available, consider using flow data from a similar community or estimating flows based on the per capita usage described below or on the total number of bedrooms and square footage of non-residential uses served.

2.2.3.2 Per Capita Flow

Where actual flow data cannot be obtained, residential flows from new collection systems should be based on an average daily per capita flow of not less than 70 gallons per day (0.27 m^3/day).

2.2.3.3 Infiltration

Add an appropriate allowance to the capacity of sanitary sewers for infiltration due to normal aging of piping systems. An allowance of 250–500 gpd/in. diameter/mile of sewer (0.24–0.48 m^3/cm of pipe diam/km/day) is suggested as a normal range of infiltration. Amounts in excess of this estimate may be allowed if supporting documentation is provided. Evaluate soil and groundwater conditions in determining projected infiltration rates.

2.2.4 Peak Design Flow

Generally, sanitary sewers should be designed on a peak hourly design flow basis. The peak hourly flow rate is defined as the largest volume of flow to be received during a one-hour period and expressed as volume per unit time.

Wastewater flow consists of four components: domestic, commercial, industrial, and institutional. Where existing data are unavailable, peak domestic design flow may be determined using the ratio of peak to average daily flow as described in Figure 2-1 (from the Water Environment Federation/American Society of Civil Engineers Manual of Practice (WEF/ASCE) publication, *MOP-FD-5 Gravity Sanitary Sewer Design and Construction*). Commercial, institutional, and industrial flows will generally have a different, lower peaking factor, depending on locations in a system and hours of operation.

When designing sewers, increased wet weather flow due to infiltration and inflow (I/I) must be considered. Refer to guidance included in 1.2.1.h *Infiltration/Inflow*. The area to be served should submit evidence that excessive I/I does not exist. If a reduction of I/I is proposed, a careful evaluation of the anticipated flow reduction should be made. Flow increases due to the elimination of sewer bypasses and backups should also be evaluated.

2.3 Details of Sewer Design and Construction

2.3.1 Minimum Size

No public gravity sewer should be less than 8 inches in diameter (200 mm).

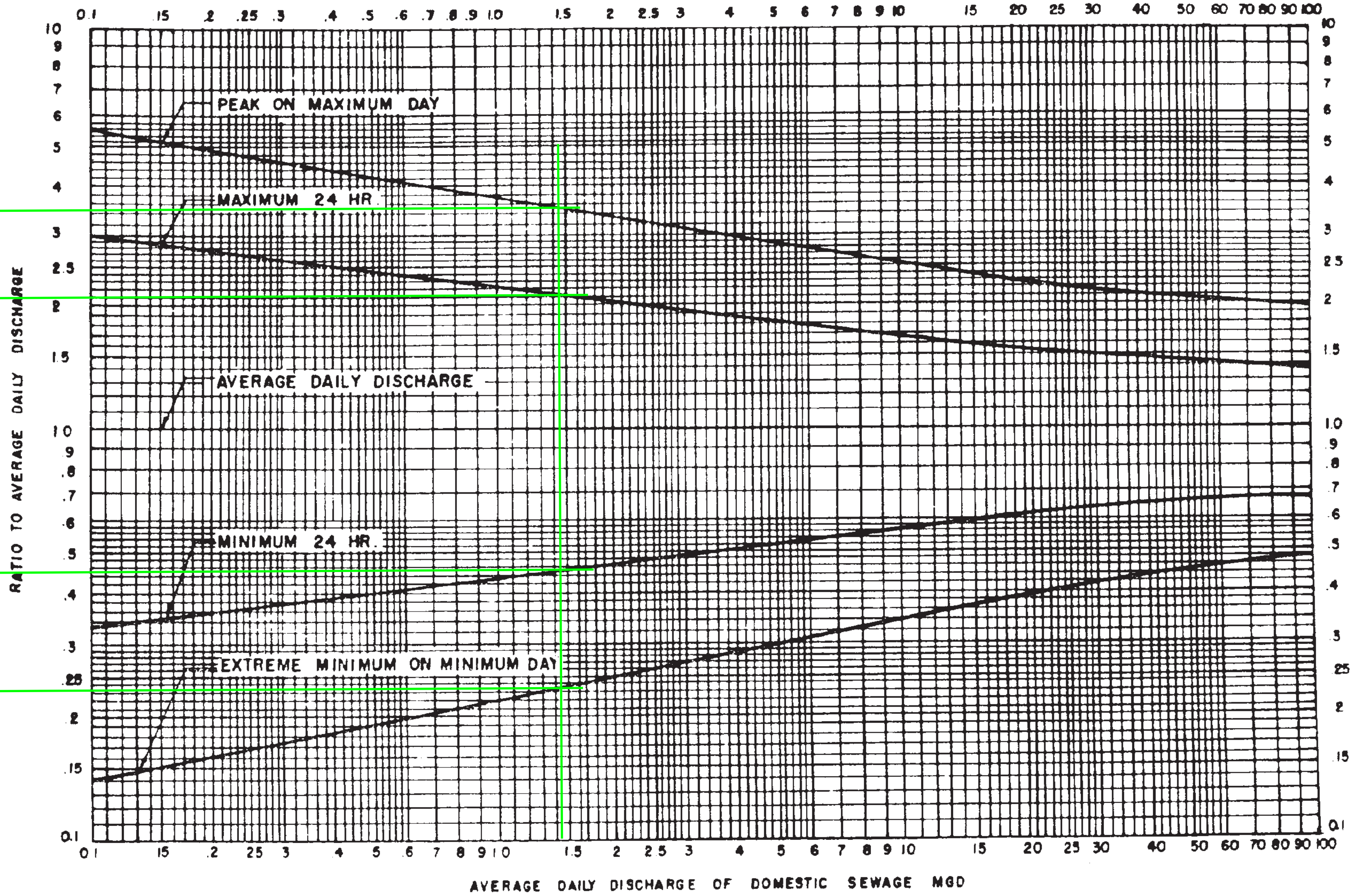
2.3.2 Depth

In general, sewers should be deep enough to drain basement fixtures and to prevent freezing. Provide insulation for sewers that cannot be placed deep enough to prevent freezing.

For house connections, chimneys (vertical pipe) should be considered when the sewer main is greater than or equal to 12 feet deep or the drop between the house connection and the main is greater than or equal to 3 feet. This should be considered only if the chimney is economical and meets minimum cover requirements for pipe protection. The design of chimneys should consider the vertical loads that will be exerted on the sewer main and fittings; an effective design transfers such loads from the pipe to the adjoining bedding and ground to prevent over-insertion, fracture, or misalignment.

Figure 2-1

Ratio of Extreme Flow to Average Daily Flow



RELATION OF EXTREME DISCHARGES ON MAXIMUM AND MINIMUM DAYS TO THE AVERAGE DAILY DISCHARGE OF DOMESTIC SEWAGE

(FROM MOP9 " SEWER DESIGN & CONSTRUCTION")
ASCE & WPCF

2.3.3 Buoyancy

Where high groundwater conditions are anticipated, the buoyancy of sewers should be considered. The floatation of pipe should be prevented with appropriate construction.

2.3.4 Fats, Oils and Grease

In locations where fats, oils, and grease (FOG) problems are anticipated, such as downstream of restaurants or at wastewater pumping stations, grease traps or other devices should be included in the plumbing and/or sewer design to address the problems. Grease trap designs must often conform with local design standards and requirements, such as building and plumbing codes and sewer use ordinances.

2.3.5 Slope

2.3.5.1 Recommended Minimum Slopes

All sewers should be designed and constructed to give a velocity (when flowing full) of not less than 2.0 feet per second (0.61 m/s) based on Manning's formula using an "n" value of 0.013. (A reviewing agency may permit the use of other "n" values if deemed justified on the basis of research or field data.) The following minimum slopes may be used only if absolutely necessary because of grade restrictions; greater slopes are desirable.

Sewer Size	Minimum Slope in Feet per Foot (m/m)
8 inches (200 mm)	0.004
10 inches (250 mm)	0.0028
12 inches (300 mm)	0.0022
14 inches (350 mm)	0.0017
15 inches (375 mm)	0.0015
16 inches (400 mm)	0.0014
18 inches (450 mm)	0.0012
21 inches (525 mm)	0.0010
24 inches (600 mm)	0.0008
27 inches (675 mm)	0.00067
30 inches (750 mm)	0.00058
36 inches (900 mm)	0.00046
42 inches (1050 mm)	0.00037
48 inches (1200 mm)	0.00031

2.3.5.2 Minimize Solids Deposition

Select the pipe diameter and slope for the greatest practical velocities to minimize settling problems. The use of oversized sewers to justify flatter slopes is discouraged. If a proposed slope is less than the minimum slope required for the smallest pipe in a system, the design engineer should calculate the actual depths and velocities at minimum, average, and maximum day and peak hourly flow for each section of the sewer and submit this information to the reviewing authority.

2.3.5.3 Slope Between Manholes

Sewers should be laid out with a uniform slope between manholes.

2.3.5.4 High Velocity Protection

Design sewer pipes at a slope so the resulting velocities are no greater than 10 feet per second (3.0 m/s) to minimize scouring of the pipe invert. If velocities are expected to exceed this limit in a steep section of pipe, the engineer should consider the use of appropriately designed sewer manhole drop structures. In circumstances where velocities exceed 10 ft/s by necessity, special attention should be given to other hydraulic parameters, including hydraulic jumps and minor losses (manholes, bends, etc.) and the anchoring of pipes by concrete collars, etc., on the steep stretch of sewer. The calculated velocity should be derived using the actual anticipated peak hourly flow and hydraulic elements related to the depth of flow.

2.3.5.5 Steep Slope Protection

Securely anchor sewers on 15 percent slopes, or greater, to prevent displacement.

2.3.5.6 Impervious Dams

Impervious dams should be considered every 300 feet to control the flow of groundwater within pipe bedding material when:

- The surrounding native material is considerably less pervious than the pipe bedding material.
- The pipe bedding could produce a hydraulic head of 25 feet on pipe gaskets and joints during periods of high groundwater flow.
- Sewers are constructed downstream of waterway and wetland crossings.

2.3.6 Alignment

In general, sewers 30 inches (750 mm) or less in diameter should be laid out in a straight line, and alignment should be checked with a laser beam. Curvilinear alignment of sewers larger than 30 inches (750 mm) may be considered on a case-by-case basis, provided the pipe manufacturer's maximum allowable pipe joint deflection limits are not exceeded.

2.3.7 Changes in Pipe Size

When a smaller sewer joins a sewer of a larger diameter, lower the invert of the larger sewer enough to maintain the same energy gradient. One way to do this is to place the 0.8 depth point of both sewers at the same elevation. When the diameter ratio of the smaller sewer to the larger sewer is equal to or greater than 0.8, it is permissible to match crowns.

2.3.8 Materials

Sewer pipe materials include vitrified clay, cast iron, and asbestos concrete, which are typically found in older systems, but should not be used in the design of new systems. Reinforced concrete, pre-stressed concrete, ductile iron, and polyvinyl chloride are typically found in newer systems. Other materials, such as high density polyethylene or polypropylene, may also be considered. Material considerations include pipe strength, stiffness, corrosion resistance, and ease of installation. Materials for sewer construction should be appropriate for local conditions, including the character of industrial wastes, septicity, soil characteristics, external loadings, and problems such as abrasion and corrosion.

All sewers should be capable of withstanding damage from superimposed loads. Make proper allowances for soil and potential groundwater conditions, as well as trench width and depth. Where necessary, special bedding, haunching and initial backfill, concrete cradles, or other special construction elements should be used.

Appropriately sized couplings that comply with ASTM standards should be used when joining dissimilar pipe materials.

2.3.9 Installation

2.3.9.1 Standards

Specifications for installation should include appropriate requirements based on criteria and standards established by the industry. Requirements for pipe and methods of backfilling should not cause damage to a pipe or its joints, impede cleaning operations and future tapping, create excessive sidefill pressures and deflection of the pipe, or seriously impair flow capacity.

2.3.9.2 Trenching

The trench should be wide enough to allow for pipe to be laid out and jointed properly, and for the bedding and haunching to be placed and compacted adequately to support the pipe. When wider trenches are specified, appropriate bedding class and pipe strength should be used.

To determine the minimum trench width needed in unsupported, unstable soil, consider the size and stiffness of the pipe, the stiffness of the embedment and in situ soil, and depth of cover.

Ledge rock, boulders, and large stones should be removed, providing a minimum of 4 inches (102 mm) below and on each side of all pipe(s).

All water entering excavations should be removed until completion of the work. No sanitary sewer should be used for disposal of trench water, unless specifically approved by both the engineer and the reviewing agencies on a case-by-case basis.

2.3.9.3 Bedding, Haunching, and Initial Backfill

Bedding classes A, B, and C, or crushed stone as described in the American Society of Testing Materials standard ASTM C12, should be used for all rigid pipe. Such bedding supports the anticipated load based on the type of soil and the potential groundwater conditions.

Materials for bedding, haunching, and initial backfill, or classes I, II, or III as described in ASTM D2321, should be used for all flexible pipe. Such bedding supports the anticipated load based on the type of soil and the potential groundwater conditions.

2.3.9.4 Final Backfill

Final backfill should be of a suitable material removed from the excavation except where other material is specified. Do not use debris, frozen material, large clods or stones, organic matter, or other unsuitable materials for final backfill within 2 feet (610 mm) of the top of a pipe.

2.3.9.5 Trenchless Technologies

Below are descriptions of some of the more commonly used trenchless technology techniques.

2.3.9.5.1 Jack and Bore and Pipe Jacking

The jack and bore method is a process of simultaneously jacking sections of casing pipe through the earth while removing the spoils inside the casing by means of a rotating flight auger. A boring machine applies both thrust to the casing pipe and torque to the rotating auger. The auger rotates inside the casing as it is being jacked. Since augers can damage any interior liners or coatings, the standard casing material used with auger boring is steel pipe. Casing diameters up to 60 inches can be installed by this method. Installation lengths of several hundred feet are feasible.

Pipe jacking is a similar method in that casing sections are pushed into the earth with a boring machine. However, hand excavation rather than augers is used to remove spoils from the interior of the casing. As human entry is required, the minimum pipe diameter used in this method is normally 36 inches. Diameters of over 60 inches can be installed, with installation lengths similar to the jack and bore method. Casing materials can be steel, reinforced concrete, or fiberglass.

Both methods can be used to install casing pipe in a variety of ground conditions. However, where cobbles and boulders or rock are encountered, the jack and bore method becomes impractical due to the need to remove augers whenever an obstruction is encountered. Neither method is commonly used for stream crossings or very wet soils where the probability of cave-ins is high.

Both methods require construction of a jacking pit on one side of the obstacle to be crossed. The pit should be approximately 15–20 feet wide and 35–40 feet long. Where right-of-way is limited, pit dimensions may require construction equipment to work on both sides of the obstacle, or temporary easements may have to be obtained.

Jacking is a feasible method for highway and railroad crossings, or for other projects where an open cut installation is not desired or allowed.

2.3.9.5.2 Microtunneling

Microtunneling is an extension of the pipe jacking technique. A remotely controlled microtunnel boring machine (MTBM) is coupled to a jacking pipe at the back of the machine. The MTBM is driven from a drive shaft to a receiving shaft by means of hydraulic jacks, with lengths of pipe added as the machine is driven forward. Soil excavated by the boring machine is carried to the ground surface through a slurry pipe. The term “micro” is a misnomer because the technique can be used to install pipe from twelve inches to twelve feet in diameter. The maximum length of installation, or drive, can be in the range of 1,500–2,000 feet.

Microtunneling is a very effective installation technique when soil geology is variable across the length of drive. An MTBM can employ a variety of cutting heads—blades for soft soil, picks for hard soil/soft rock, and disc cutters for hard rock. The MTBM is capable of balancing the slurry pressure against the soil pressure at the face of the machine. Because MTBMs are capable of pressure balancing, microtunneling is suitable for installations under waterways, in rock, and in mixed soil media. This technique is also useful when extremely accurate line and grade installations are required.

A drive shaft is required on one side of the obstacle to be crossed. The shaft will have dimensions similar to that of a pipe jacking shaft, and may be constructed in a circular manner.

The pipe installed by microtunneling can be used as a casing pipe or as a carrier pipe. Human entry into the tunnel is not required; hence, the minimum diameter can be less than 36 inches. Types of pipe that can be installed by microtunneling include steel, prestressed concrete cylinder, and fiberglass. Recent pilot tests indicate that ductile iron pipe with modified joints may also be installed by microtunneling.

On a cost per foot basis, microtunneling is more expensive than open cut, pipe jacking, or horizontal directional drilling. Microtunneling becomes cost-effective when soil conditions are difficult or mixed media, when deep open cut excavations would be required, or when the required installation length exceeds that capable of being installed by pipe jacking.

2.3.9.5.3 Horizontal Directional Drilling

Horizontal directional drilling (HDD) is a trenchless construction method that can be used to install pipelines where surface disturbances are discouraged, prohibited, or more costly. HDD allows a pipeline to be installed under an obstacle, working entirely from the ground surface, and with control over horizontal and vertical alignments. Typically, HDD is used to cross physical features such as water bodies, highways, and environmentally sensitive areas. Basic elements of a horizontal directional drill installation include:

- Installation of a pilot bore hole using a drill rig along a designed and guided drill profile.
- Enlargement of the pilot hole by pushing and pulling successively larger reaming tools through the hole.
- Preparing the product pipeline along the ground surface.
- Pulling the product pipeline back through the drill hole.

High density polyethylene (HDPE) and steel are the most commonly used materials for the product pipeline. For smaller diameter (24 inches and smaller) and shorter length crossings (1,500 feet and less), HDPE has the advantage of being lighter to pull, corrosion resistant, and capable of being installed to a tighter bending radius. Steel is commonly used for larger diameter and longer crossings, or where internal and external loadings exceed the capacity of HDPE. Installation lengths of more than 5,000 feet have been successfully completed using HDD.

The most desirable soil conditions to drill through are clays and sands. HDD crossings can be constructed through rock, but the drilling process is slower. Because of their unpredictable nature and location, the most difficult soils to drill through are cobbles and boulders. Such rocky geology in an area does not rule out the use of HDD; however, soil borings must be performed should this method be considered for a specific crossing or section of alignment.

The HDD method does permit pipelines to be installed along both a horizontal and vertical curvature.

2.3.10 Testing

2.3.10.1 Deflection

Deflection tests should be performed on all flexible pipes. The tests should be conducted after the final backfill has been in place for at least 30 days. The delay allows for permit stabilization of the pipe system.

Appropriate pipe deflection standards from ASTM should be reviewed as well as considerations from the manufacturer of a particular pipe. Typically, however, no pipe should exceed a deflection of 5 percent. If deflection exceeds 5 percent, the pipe should be replaced.

The rigid ball or mandrel used for a deflection test should have a diameter of not less than 95 percent of the base inside diameter or the average inside diameter of the pipe as specified by ASTM. The pipe should comply with ASTM D2122 Standard Test Method of Determining Dimensions of Thermoplastic Pipe and Fittings. The tests should be performed without mechanical pulling devices. Other testing devices such as electronic deflectometers or calibrated video cameras may be considered.

2.3.10.2 Leakage Tests

The specifications should include a requirement for leakage tests, including appropriate water or low-pressure air testing. The testing method should cover the range in groundwater elevations during the test and during the design life of the sewer.

Water (Hydrostatic) Test: The leakage (exfiltration or infiltration) should not exceed 100 gallons per inch of pipe diameter per mile per day (0.019 m^3/cm of pipe diam./km/day) for any section of the pipe system. Perform an exfiltration or infiltration test with a minimum positive head of 2 feet (610 mm).

Air Test: Air testing, if used, should conform to test procedures described in ASTM C828-86 for clay pipe or ASTM C924 for concrete pipe, or those procedures approved by the regulatory agency.

2.3.10.3 Alignment Tests

Perform a lamp test for the correctness of horizontal and vertical alignment on each length of pipe between manholes. This test should be completed after all upstream work has been completed and after a final backfill has been in place at least 30 days. Water should be introduced to the pipe tested. Standing water should not be observed during the test.

2.3.10.4 Television Inspection Tests

Television inspection may be appropriate for some pipe installations. When used, television inspection must conform to standards of the National Association of Sewer Service Companies (NASCCO) Pipeline Assessment Certification Program (PACP), and Lateral Assessment Certification Program (LACP).

2.4 Manholes

2.4.1 Location

Manholes should be installed at the end of each line; at all changes in grade, size, or alignment; and at all pipe intersections. Distances between manholes should not be greater than 400 feet (120 m) for sewers measuring 15 inches (375 mm) or less in diameter, or 500 ft (15 m) for sewers 18–30 inches (450 to 750 mm) in diameter. Distances up to 600 ft (183 m) may be approved in cases where adequate modern cleaning equipment is provided. Greater distances may be permitted for larger sewers or for those carrying a settled effluent, but only with prior approval of the reviewing agency.

2.4.2 Drop Type

Provide a drop pipe for a sewer pipe with an invert entering a manhole more than 24 inches (61 cm) above the manhole invert. Where the difference in elevation between the incoming sewer and manhole invert is less than 24 inches (61 cm), the invert should be filleted to prevent solids deposition.

Encase outside drop connections in concrete. When necessary, secure inside drop connections to the interior wall of the manhole to provide access for cleaning.

2.4.3 Diameter

The minimum diameter should be 48 inches (122 cm) for standard manholes and 60 inches (153 cm) for inside drop manholes. Structure openings and manhole frame and cover dimensions should be coordinated as appropriate for ease of access and to suit applicable regulations and/or requirements of the state in which the work is to be performed. Larger openings should be provided for manholes that house equipment.

2.4.4 Materials

Manholes should be precast concrete with barrel sections, cones, and bases manufactured in compliance with ASTM C478, and should have gasketed joints. Manholes can also be poured-in-place concrete. Other types of manholes are also allowed, subject to approval of the reviewing agency. In some locales, it may be prudent to install locking manhole covers or some other means to eliminate access to the collection system. This may be necessary in more remote locations or in areas with security requirements. Consider these concerns early in the design of a system.

2.4.5 Flow Channel

The flow channel through manholes should conform in shape and slope to that of the sewers entering and leaving the manholes. Construct the top of the flow channel so the flow will remain in the channel under peak conditions. Form or shape the channel walls to the full height of the crown of the outlet sewer and so as not to obstruct maintenance, inspection, or flow in the sewers. When curved flow channels are required, including branch inlets, increase minimum slopes to maintain acceptable velocities. Provide a minimum 0.1-foot drop through the manhole.

2.4.6 Bench

Provide a bench on each side of every manhole channel. The bench should have a slope of no less than 0.5 inch (13 mm) per foot (305 mm) and no greater than 1.0 inch per foot. No lateral sewer, service connection, or drop manhole pipe should discharge onto the surface of the bench.

2.4.7 Buoyancy

Where high groundwater conditions are anticipated, consider buoyancy of manholes, and prevent floatation with appropriate construction.

2.4.8 Watertightness

Solid or watertight manhole covers should be used in areas subject to flooding. Manhole lift holes and grade adjustment rings should be sealed with a non-shrinking mortar or other material approved by the reviewing agency. A bituminous coating may also be used on the exterior. Inlet and outlet pipes should be joined to the manhole with a gasketed, flexible watertight connection or with another watertight connection arrangement that allows for differential settlement of the pipe and manhole.

2.4.9 Inspection and Testing

The specifications should include a requirement for the inspection and testing of manholes for leaks or damage. Leakage tests may include appropriate water or vacuum testing.

Water (Hydrostatic) Testing: The leakage exfiltration rate should not exceed 1 gallon per vertical foot of manhole section for a 24-hour period. A period of time may be permitted, before beginning the test, to allow for absorption of water into the concrete manhole.

Vacuum Testing: Conduct vacuum tests on a sealed manhole at an initial test pressure of 10 inches of mercury. The vacuum drop should not exceed 1 inch of mercury over the period of time as follows:

0 to 10-foot deep manholes	–	2 minutes
10- to 15-foot deep manholes	–	2.5 minutes
> 15-foot deep manholes	–	3 minutes

2.4.10 Corrosion Protection

Corrosion protection for interior surfaces of manholes or other structures should be considered if high concentrations of hydrogen sulfide or other corrosive constituents are anticipated in wastewater flows originating from long force mains or other sources. Additional guidance can be found in this report in Chapter 10: Odor and VOC Control as well as the Water Environment Federation's Manual of Practice No. 25, *Control of Odors & Emissions from Wastewater Treatment Plants*.

2.5 Inverted Siphons (Depressed Sewers)

Inverted siphons are depressed sewers designed to flow full and under pressure. They generally are used to avoid obstacles, such as utilities, railways, subways, and streams. Depressed sewers should have no less than two barrels with a minimum pipe size of 6 inches (150 mm), and should be provided with manholes at both ends for convenient flushing and maintenance. Manholes should be vented and have adequate clearances for cleaning equipment and for inspection and flushing. The design should provide for sufficient heads and pipe sizes to secure velocities of at least 3.0 feet per second (0.92 m/s) for average flows under initial conditions to keep the pipe(s) clear of settleable solids. Inlet and outlet details should be arranged so normal flow is diverted to one barrel and so that either barrel may be taken out of service for maintenance. Consider providing a hose connection to the siphon for flushing purposes.

2.6 Aerial Crossings

Provide appropriate support for all joints and pipes used for aerial crossing. The supports should withstand frost heaves as well as overturning, settlement, flooding, thermal expansion, vibrations, and other loads that may act against the piping. Take measures to prevent freezing (e.g., insulation, heat traces, or increased slope). Provide expansion joints between above-ground and below-ground sewers. Where buried sewers change to aerial sewers, evaluate special construction techniques, such as the required length of casing pipe embedment into the adjoining soil embankment and placement of supports, to minimize damage from frost heaves. For aerial stream crossings, consider the impact of flood waters and debris. The bottom of a pipe should be no lower than the 50-year flood elevation level. Ductile iron pipe with restrained mechanical joints is recommended.

2.7 Protection of Water Resources

2.7.1 Location of Sewers in Streams

2.7.1.1 Cover Depth

The top of all sewers entering or crossing streams should be sufficiently below the natural bottom of the streambed to protect the sewer line. In general, the following cover requirements must be met:

- 1 foot (305 mm) of cover where the sewer is located in rock.
- 3 feet (914 mm) of cover in other material. In major streams, more than 3 feet (914 mm) of cover may be required.
- In paved stream channels, place the top of the sewer line at least 1 foot (305 mm) below the channel pavement.

2.7.1.2 Horizontal Location

Position sewers located along streams sufficiently outside of the streambed to allow for stream widening in the future and for the prevention of siltation during construction. Consideration should be given to armoring the stream channel in the vicinity of the sewer to prevent channel erosion and to avoid the possibility of exposing the sewer.

2.7.1.3 Structures

Locate sewer manholes or other structures outside of streams whenever possible. Where structures must be located in a stream, they should not interfere with the free discharge of flood flows.

2.7.1.4 Alignment

Sewers should cross streams perpendicular to the flow without a change in grade. Design sewer systems to minimize the number of stream crossings.

2.7.2 Construction

2.7.2.1 Materials

Sewers entering or crossing streams should be watertight and free from changes in alignment or grade. Joints should be restrained to prevent movement from stream forces. In major streams, provide ball-and-socket or restrained joints designed for hard service applications. For smaller streams, provide mechanical joints with retainer glands.

Backfill materials should be stone, coarse aggregate, washed gravel, or other materials that will not readily erode, cause siltation, damage pipe during backfill, or corrode the pipe. In large stream crossings, place riprap over the sewer pipe to prevent erosion.

2.7.2.2 Siltation and Erosion

Use construction methods that will minimize siltation and erosion. The design engineer should include in the project specifications the construction methods to be used for sewers in or near streams. Such methods should control siltation and erosion by limiting unnecessary excavation, including disturbing or uprooting of trees and vegetation, dumping of soil or debris, or pumping silt-laden water into a stream. Specifications should require cleanup, grading, planting, and restoration of all work areas to begin immediately after construction is complete.

2.8 Protection of Water Supplies

2.8.1 Cross Connections

No physical connection should exist between a public or private potable water supply system and a sewer or any appurtenance that would permit the passage of wastewater or polluted water into the potable supply. No water pipe should pass through or come into contact with any part of a sewer manhole.

2.8.2 Relation to Water Works Structures

Sewers should be located far away from public water supply wells or other potable water supply sources and structures (check with state or local wellhead protection policies). Engineering plans should show all existing waterworks units, such as basins, wells, or other treatment units that are within 200 feet of the proposed sewer or within the minimum distance required by the reviewing agency.

2.8.3 Relation to Water Mains

2.8.3.1 Horizontal Separation

When possible, lay out sewers at least 10 feet (3.0 m) from any existing or proposed water main. If local conditions prevent a lateral separation of 10 feet, the reviewing agency may make an exception on a case-by-case basis when supported by data from the design engineer. Such an exception may allow the sewer to be installed closer than 10 feet to a water main, provided the sewer is laid out in a separate trench with the top (crown) of the sewer at least 18 inches (46 cm) below the bottom (invert) of the water main.

2.8.3.2 Vertical Separation

Whenever sewers must cross water mains, lay out the sewer so the top of the sewer is at least 18 inches (46 cm) below the bottom of the water main. The sewer joints should be equidistant and located as far away as possible from the water main joints. When the sewer cannot meet the above requirements, relocate the water main to provide for this separation or reconstruct it with mechanical-joint pipe for a distance of 10 feet (3.0 m) on each side of the sewer. One full-length water main should be centered over the sewer so that both joints will be as far from the sewer as possible.

Where a water main crosses under a sewer, adequate structural support should be provided for the sewer to maintain line and grade.

Note: When it is impossible to achieve horizontal and/or vertical separation as stipulated above, both the water main and sewer should be constructed of mechanical-joint cement-lined ductile iron pipe or another equivalent that is watertight and structurally sound. Both pipes should be tested to ensure that they are watertight. Alternatively, pipe sleeves and/or concrete encasement should be considered.

2.8.3.3 Water Reuse Lines

Typically, potable water lines should have the same horizontal and vertical separation from reuse lines as from sewer lines. If there are potable, reuse, and sewer lines in the same street, protection priority goes to potable water, then reuse and finally sewer lines.

2.9 Alternative Collection Systems

Alternative collection systems can reduce construction costs, including pipe and excavation costs. Alternative systems also allow for easier construction in cases of high groundwater levels or ledges. However, these systems generally are more complicated than conventional gravity systems, and they can have significantly higher operating and maintenance costs.

In general, there are two main categories of alternative collection systems: vacuum sewer systems and pressure sewer systems. Each requires different pressures to transport wastewater flow, as well as different pipe materials.

2.9.1 Vacuum Sewer Systems

A vacuum sewer system is essentially a pressure system, in that differential air pressure is used to create flow. Vacuum systems are often proposed as collection systems for flat land surfaces and for cases where high groundwater levels and construction difficulties exist. There have been instances in colder climates where condensation in a valve pit has caused ice crystals to form on controllers and thereby prevented the valves from properly opening and closing. Valve pits should be insulated in cold climates.

2.9.1.1 Piping Design

Vacuum sewers should handle the peak flow from dwellings. Size the pipe using the Hazen-Williams formula for full-bore flow. A C-factor of 150 for PVC should be used. Within a system, the flow consists of 2 parts of air to 1 part of liquid. For vacuum sewer pipelines, use the equivalent of Class 200, SDR 21 PVC piping or greater to provide the necessary working pressure rating for the system, and to provide durability during installation. Piping should be deep enough to prevent freezing, and should be installed in a saw tooth pattern.

2.9.1.2 Collection Station Design

Nomenclature

N_v = Number of valves connected to collection station

Q_{max} = Station peak flow, gpm (L/s)

Q_a = Station average flow, gpm (L/s)

Q_{min} = Station minimum flow, gpm (L/s) = Q_a/z

Q_{dp} = Discharge pump capacity, cfm (L/s)

Q_{vp} = Vacuum pump capacity, cfm (L/s)

Q_{vpe} = Effective vacuum pump capacity, cfm (L/s)= $Q_{vp} - k_1N_v$

k_1 = 0.15 cfm (0.07 L/s)

V_o = Operating volume of collection tank, gallons (L)

V_{ct} = Collection tank volume, gallons (L)

V_{rt} = Reserve tank volume, gallons (L)

t = Cycle time of discharge pumps, minutes (s)

z = Ratio of average station flow to minimum flow

2.9.1.3 Vacuum Pumps

The following minimum vacuum pump sizes (Q_{vp}) are recommended:

For sewers up to 3,000 feet (914 m) long:

$$Q_{vp} = \frac{5\,Q_{max}}{k_2} + k_1 N_v$$

For sewers over 3,000 feet (914 m) long:

$$Q_{vp} = \frac{6\,Q_{max}}{k_2} + k_1 N_v$$

Where $k_2 = 7.5\ \text{gal/ft}^3\ (1\ \text{L/s})$

These formulas are provided for guidance only. Other factors to consider include type of vacuum pump, vacuum pump efficiency, temperature of sewage, type and temperature of service liquid (if applicable), and altitude at which a vacuum pump is to operate.

2.9.1.4 Discharge Pumps

Each sewage discharge pump capacity is 20 percent greater than the design peak flow:

$$Q_{dp} = 1.2\,Q_{max}$$

Motors are sized using the procedure for force mains. However, 25 feet (7.6 m) of additional head is required to pump against the vacuum in a collection tank.

2.9.1.5 Collection Tank

The operating volume of a collection tank is the sewage accumulation required to restart the discharge pump. Operating volume should be sized so that at minimum design flow, the pump will operate once every 15 minutes, as represented by the following equation:

$$V_o = 15\left(\frac{Q_{min}}{Q_{dp}}\right)(Q_{dp} - Q_{min})$$

Total volume of the collection tank is 3.0 times the operating volume with a minimum size of 400 gallons (1,500 L). After fixing the operating volume, the designer should check to ensure an excessive number of pump starts per hour will not occur.

2.9.1.6 Standby Power

Provide standby power for use during emergency conditions. One hundred percent standby power is required.

2.9.1.7 Length of Collection Lines

Lengths of collection lines are governed by two main factors: static lift and losses. Total available head loss is 13 feet (4.0 m). Therefore, the sum total of static lifts and friction lost must not exceed this figure.

2.9.2 Pressure Sewer Systems

Wastewater can be conveyed to a pressure sewer using various approaches, such as septic tank effluent pumping (STEP) or grinder pumps. A pressure main is common to both systems. Pressure sewer systems contain other components such as isolation valves, anti-vacuum valves, air release valves, and cleanouts.

2.9.2.1 Pressure Sewer Main

Layout: The branched configuration of a pressure sewer is similar to that of a conventional gravity sewer system. Looped piping is not recommended and should not be permitted. Pipe routing should include long radius sweeps no less than those recommended by the pipe manufacturer. Pressure pipes should be deep enough to prevent freezing.

Pipe Size: Size the diameter of a pressure sewer so it provides a cleansing velocity based on the system's average daily flow. Consideration should also be given to system retention times to provide sufficient fluid changes to reduce the potential for odor generation. Guidance for pipe sizing is provided in WEF's Manual of Practice *FD-12 Alternative Sewer Systems*.

Pipe Material: Use the equivalent of Class 200, SDR 21 PVC piping or greater or HDPE SDR 11 in pressure sewers to provide the necessary working pressure rating for the system, and to provide durability during installation.

2.9.2.2 Isolation Valves and Check Valves

To allow isolation of individual STEP or grinder units, consider isolation valves at points where system expansion is projected and at key locations such as property lines.

A valve box with a redundant check valve should be provided at property lines to protect properties from flooding. (This does not apply to properties connected to a gravity sewer system.)

2.9.2.3 Air and Vacuum Valves

To release air trapped in pressure lines or to prevent system siphoning or vacuum conditions, include site air and vacuum valves at appropriate locations. Air release/vacuum valves should be located in a manhole or structure to allow access for repair and maintenance. Consider automatic air release valves to reduce a system's operations and maintenance costs.

Also, place air release manholes at high points in a system and at least 14 pipe diameters downstream of locations where hydraulic jumps occur. Hydraulic jumps form in sections where a pipeline intersects with a hydraulic grade line. Air bubbles formed by hydraulic jump conditions are carried downstream with wastewater flow.

2.9.2.4 Cleanout Connections

Provide a means for cleaning out pressure mains at sags and other locations where debris can accumulate and clog lines. Provide proper valving to conduct required maintenance at terminal ends of branches or zones, intersections, sharp bends, and low and high points; cleanout valves should be installed at least every 1,500–2,000 feet in all lines, even those without bends or elevation change.

2.9.3 Grinder Pump Systems

Pumping equipment must include an integral grinder capable of handling a reasonable quantity of foreign objects that may find their way into a building's sewerage system, since such systems are usually installed without septic tanks. The grinder pump must be capable of processing foreign objects without jamming, stalling, or overloading, and without making undue noise. The grinder should provide a positive flow of solids into the grinding zone. Grinder pump stations should be of the wetwell type.

The following items should be considered in the design of grinder pump systems.

2.9.3.1 Design of Pump Station

Access: Construct the service access for outside installation of the same material, and at least as thick as the tank. The access should have an opening at the surface with a minimum inside diameter of 24 inches (61 cm); its cover should be securely lockable. The size of the manhole must allow for the performance of maintenance and repair functions.

Tank: Construct each tank of concrete, high density polyethylene, or custom-molded, fiberglass-reinforced polyester resin using a filament wound process, layup and spray technique, or other approved process that will ensure a smooth and resin-rich interior surface designed for twice the maximum loading.

The tank should be furnished with one PVC closet flange or one flexible inlet flange suitable for connection to the household gravity line. At a minimum, the tank wall and bottom should be able to withstand twice the anticipated maximum pressure exerted on the tank, either from soil loadings or buoyancy forces. All station components must function normally when exposed to these loadings. Tanks should be sized to prevent accumulation of solids and designed to permit mixing during pumping actions.

Electrical Equipment: Wiring and electrical connections should be NEMA-rated for the environment in which they are to be placed.

All seals and joints should pass factory tests to ensure they are watertight. Proper service disconnects and circuit protection devices to permit lock-out and tag-out safety protocols should be provided. Motor protection devices such as high amperage and automatic thermal overload protection should also be provided.

2.9.3.2 Pumps

Pump Removal: The grinder pump should be readily removable without the need for manual disconnection of piping.

Grinder: The grinder should be positioned immediately below the pumping elements, securely fastened to the pump motor shaft, and driven directly by the same motor. The grinder should be a rotating type with a stationary hardened and ground stainless steel shredding ring that carries stainless steel cutter bars. This assembly should be dynamically balanced, and capable of operating without objectionable noises or vibrations over the entire range of recommended operating pressures.

Pump Opening: The grinder should be capable of reducing all components in normal domestic sewage, including a reasonable number of foreign objects (e.g., paper, wood, plastic, glass, and rubber). Objects should be reduced to finely divided particles that will pass through the passages of the pump and a minimum 1.25 inch (32 mm) diameter discharging pipe.

Intake: The grinder should be positioned so solids are fed into it from the bottom in an upward flow, reducing the possibility of overloading or jamming. Sufficient turbulence should be created to keep the tank bottom free of permanent deposits or sludge banks.

2.9.3.3 Check Valve and Anti-Siphon Valve

Equip the grinder pump with a check valve that is installed in a horizontal position on the discharge pipe. This valve should provide a full-ported passageway when open.

Equip the grinder pump with a gravity-operated, integral anti-siphon valve with corrosion-resistant moving parts and an opening no less than 60 percent of the inside diameter of the pump discharge piping.

2.9.3.4 Ventilation

Provide adequate ventilation in accordance with local and national codes.

2.9.3.5 Controls and Alarms

Use non-fouling sensing devices to detect wastewater levels for initiating pump operation and to detect high water levels. Level sensing devices are recommended. (Mercury float type switches should be avoided and are banned in some regions.) Sensing devices should not be located near flows entering the well. Alarm indicators should include an audible alarm (with a "silence" feature) and a visual light.

2.9.4 Septic Tank Effluent Pump (STEP) Systems

2.9.4.1 Septic Tanks

Septic tanks should be made of durable material and hold a minimum of 1,000 gallons. Tanks should provide a detention time of 24 hours based on the average daily design flow of the source. Septic tanks should meet all other local and state requirements.

2.9.4.2 Pumping Facilities

Centrifugal pumps or semi-positive displacement pumps may be used to pump effluent from a properly designed septic tank into a collection system. The facilities used to lift the wastewater flow should meet the criteria presented above for grinder pump systems, except that a grinder type pump is not required. STEP pump units should be capable of handling 1.25 inch diameter solids. A minimum of two pumps is recommended per installation, with the pumps sequenced to operate with a lead pump on and a lag pump on when needed. A third, standby pump is desirable when feasible; pumps should alternate as lead, lag, and standby.

2.10 Sewer System Investigation and Rehabilitation Techniques

2.10.1 General

This section is intended to provide a general description of sewer system evaluation and rehabilitation techniques. For more specific requirements and procedures, see the reference materials available from the National Association of Sewer Service Companies (NASSCO; www.nassco.org) or access the WEF/ASCE Manual of Practice FD-6 *Existing Sewer Evaluation and Rehabilitation*. Guidelines for conducting sewer investigation and rehabilitation programs may also be available from the state in which the work is performed.

Selection of a rehabilitation method should be based on a detailed analysis of existing system conditions, including identification of the need for rehabilitation, assessment of the outcomes of component failure, evaluation of the physical installation, assessment of expected performance attributes and requirements of potential rehabilitation technologies, and analysis of costs. Use any one or a combination of several analysis techniques to determine the need for rehabilitation of pipe systems.

2.10.2 Flow Analysis

Perform flow analysis to determine whether an existing or rehabilitated conduit will have sufficient capacity to accommodate required flows. Flow monitoring should provide quantitative data that establish existing average and peak flows as well as the existence and magnitude of infiltration, inflow, or exfiltration. Existing flow analysis and future flow forecasts should also be performed to determine the required hydraulic capacity of the pipeline. If insufficient capacity exists, and would not be sufficiently increased by the beneficial hydraulic impacts of potential rehabilitation methods, explore alternative improvements.

2.10.3 Sewer Pipe Analysis

The principal method used to evaluate the physical condition of existing sewer pipe is inspection by closed-circuit television (CCTV) systems. CCTV inspection should be performed using full-color, digital, high-resolution video equipment with accurate distance measurement. Display distance measurements by attaching a direct reading distance meter to the coaxial camera cable. The meter should have an accuracy of 0.1 feet over the length of the sewer.

A CCTV inspection is performed by manually pulling or using a remote control to direct a television camera through a sewer line in either direction at a speed no greater than 30 feet per minute, stopping as necessary to ensure proper documentation of the sewer's condition. Flow should be minimized or suspended altogether to provide the most comprehensive observations possible. For short reaches in smaller pipelines, it may be possible to briefly stop flow using sewer plugs without causing pipeline surcharging. On larger pipelines with diameters of 60 inches or greater, it may be possible to perform the inspection by using hand-held video recording equipment.

Keep a record of the inspection on a digital video disc (DVD), labeled with headings noting location, direction, date, and firm performing the work. Written logs and digital still photographs should supplement the video, estimating rates of infiltration and describing the internal condition of the pipeline.

CCTV inspection must conform to standards of the NASSCO Pipeline Assessment Certification Program (PACP), Manhole Assessment Certification Program (MACP), and Lateral Assessment Certification Program (LACP). CCTV operators must have a valid certification of completion from a NASSCO PACP course, and be listed in the national database.

2.10.4 Cleaning

Prior to internal observation, it is necessary to clean the host pipeline so a complete scope of existing conditions can be viewed and a suitable substrate prepared for performing rehabilitation procedures.

Cleaning requirements and the amount of effort involved may vary depending on pipe age, slope, service, and physical integrity.

During cleaning, analyze liquids and solids removed from pipelines to determine hazardous components. Disposal of such hazardous components must be done by appropriate methods.

2.10.5 Temporary Flow Management

Existing or potential pipeline flows must be managed during internal inspection, cleaning, and rehabilitation activities. A flow management plan must be prepared to ensure the work program is not adversely affected. Flow management requirements may vary greatly depending on the type of system being evaluated or rehabilitated—i.e., separate sanitary or storm drainage systems, combined systems, or process waste pipelines.

A number of different flow management methods may be used to satisfy work program needs. These methods include:

- Flow division through parallel or other available piping systems
- Stoppage of flows for the duration of a procedure when sufficient storage exists in upstream facilities
- Bypassing flows around a work site

In all instances, consider all flow sources, as well as their magnitude, frequency, and timing when selecting an appropriate flow management method. Contingency plans must be developed to identify backup procedures for coping effectively with extreme or adverse conditions.

2.10.6 Safety

Pipeline rehabilitation typically involves personnel entering confined spaces, many of which have potentially hazardous atmospheres. Therefore, contract documents should require implementation of safety plans by all contractors and subcontractors involved. These safety plans should address procedures for confined space entry, including permitting and all other appropriate regulatory requirements established by OSHA and other applicable federal, state, and local programs.

2.10.7 Service Connections

Prior to rehabilitation, both active and inactive service connections should be identified using dye testing and other complementary procedures. After rehabilitation active services should be restored and inactive services may be sealed, if desired.

2.10.8 Pipeline Rehabilitation

Selection of a pipeline rehabilitation technique depends on several factors, including condition of the host pipe, hydraulic capacity before and after rehabilitation, and number of service laterals. Basic trenchless pipeline rehabilitation methods include sliplining, cured-in-place products, segmental pipe lining, spiral wound pipe lining, close-fit pipe lining, and pipe bursting. Tunneling options and pipe removal (microtunneling) may also be considered. Where applicable, rehabilitation may involve simple repairs and maintenance such as grouting and sealing, or point repairs.

2.10.9 Manhole Rehabilitation

Rehabilitation of sewer manholes may be required because of excessive leakage or structural concerns. Repairs may include using pressure pointing or chemical grouting to fix critical spots, or renovating the entire structure by monolithic surfacing techniques or by installing a new manhole.

2.11 Safety

Make adequate provisions to protect workers involved with construction and maintenance. In general, the design and construction of sewers and sewer rehabilitation work should meet all prescribed local, state, and national safety laws and codes. WEF’s Manual of Practice No. 1, *Safety in Wastewater Works*, covers safety in detail.

References – Chapter 2

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CHAPTER 3

WASTEWATER PUMPING STATIONS

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3.1 General

3.1.1 Design Capacity

A wastewater pumping station should handle the projected peak wastewater flows of a POTW's tributary sewer collection system. This information is included in a community's wastewater facility plan or other engineering report and any applicable updates or amendments. When appropriate, pumping stations should accommodate future expansion. Refer to Section 2.2 for flow estimating guidance.

3.1.2 Site Layout

Stations and all ancillary equipment must be readily accessible to personnel and service vehicles during all weather conditions. It is preferable to locate stations off right-of-ways.

3.1.3 Flood Protection

Wastewater pumping stations, including all electrical and mechanical equipment, should be protected from physical damage by waters at or above the 100-year flood elevation, and should remain fully operational and accessible during a 25-year flood. All entrances and/or unsealable openings of a station should be above the 100-year flood elevation. These flood elevations should be determined from the best available information from sources such as the Federal Emergency Management Agency, U.S. Army Corps of Engineers, and local regulations and ordinances. Federal and state regulations regarding floodplain and floodway obstructions should be examined. Some agencies, such as USDA Rural Development, may request or require consideration of the 500-year floodplain. Potential effects of long term climate change should also be considered.

Existing wastewater pumping stations, including all electrical and mechanical equipment, should be protected from physical damage by flood conditions as noted in Section 1.2.1.h.

3.1.4 Environmental Considerations

Wastewater pumping stations should be designed with sensitivity to the environmental conditions of a site. Visual impacts, architectural style, security, noise levels, odor control, and landscaping should be considered carefully in station design. In addition, a designer should evaluate potential effects on wetlands; historic or prehistoric sites; rare, threatened or endangered plant and animal species; groundwater source protection areas; hazardous waste sites, etc. Online environmental mapping tools may be available for use with this process.

3.1.5 Energy Considerations

Wastewater pumping stations are significant users of electrical energy. Designs should minimize energy consumption and lifecycle costs. Designers should consider energy required for pumping, heating and ventilation, and lighting. Designers should also minimize total dynamic head (TDH) to reduce pumping energy demands where possible, without compromising hydraulic design.

3.2 Design

3.2.1 Types of Stations

In general, wastewater pumping stations fall into three major categories: wetwell/drywell, submersible, or suction lift. The type of station most appropriate for any project will depend on owner preference and site constraints.

3.2.2 Structural Design

3.2.2.1 Earthquake Loads and Uplift Forces

Stations should be designed to withstand earthquake loads and uplift (buoyancy) forces resulting from high groundwater conditions.

3.2.2.2 Separation

Wet and drywells, including their superstructures, should be completely separated. Common walls should be sealed against gas leaks and flooding of dry wells.

3.2.2.3 Equipment Removal

Provisions should be made to allow for removing all equipment (i.e., pumps, motors, valves, mechanical screens, motor control centers, etc.) from a station. Access openings, hatches, and/or skylights should be sized accordingly. Portable or permanent hoisting devices should be provided.

3.2.2.4 Substructure

Station substructures should be constructed of reinforced concrete; either cast-in-place or precast is appropriate. Small, prefabricated stations may be constructed of a variety of materials. Steel substructures should be protected from corrosion via cathodic protection systems unless soil conditions are known to be non-aggressive.

3.2.2.5 Access

Suitable, safe, and separate means of access should be provided for dry and wetwells. Stairways and/or ships ladders are preferred for drywells and are required for wetwells containing either bar screens or mechanical equipment that requires inspection or maintenance. Consider providing stairway landings in deep pumping stations. In general, a stairway or ladder should have a landing with railings every 12 vertical feet or less. The most stringent local, state, and federal safety codes should govern, and consideration must be given to confined space entry requirements.

3.2.3 Pumps

3.2.3.1 General

As a minimum, two pumps should be provided, with each pump capable of handling peak design flows. Where three or more pumps are provided, overall station capacity should be capable of handling peak design flow when any one pump is out of service. Where flows are highly variable with infrequent high peak flows, consideration should be given to relying primarily on smaller service pumps that operate at higher electrical efficiencies, while using larger pumps to handle peak loads only.

Pumps should be designed specifically for wastewater use. They should be solids handling and capable of passing at least a 3-inch diameter sphere. Pump suction and discharge openings should be a minimum of 4 inches in diameter. Each pump should have a dedicated intake isolation valve, a dedicated check valve, and a dedicated discharge isolation valve.

When designing pumps, except for submersible pumps and screw pumps, the net positive suction head (NPSH) available must be at least six feet greater than the NPSH required by the pump.

The Hydraulic Institute, a non-profit organization of pump manufacturers, is a resource for additional information related to pump and wetwell design.

3.2.3.2 Pumping Rate

In general, major pumping stations, especially those operated as part of POTWs, should balance the rate of incoming wastewater with the rate discharge as closely as possible. (One possible exception to this is a pumping station operated in conjunction with a lagoon treatment works.)

For smaller stations with adequate wetwell storage capacity, the pumping station can be used as an opportunity to equalize flows, resulting in smaller downstream infrastructure and lower energy consumption.

3.2.3.3 Types of Pumps

3.2.3.3.1 Flooded Suction Pumps

Centrifugal pumps should be used in the drywell/wetwell configuration for flooded suction pumping stations. The pump casing and suction elbow should be provided with a clean-out access port. Impellers should be enclosed or semi-open. To ensure primed pump conditions, the wetwell level should not drop below the top of the pump impeller casing under normal operating conditions.

3.2.3.3.2 Submersible Pumps

Submersible pumps often have lower pump efficiency. However, they may be used when warranted by project constraints. It should be possible to remove and replace submersible pumps without dewatering the wetwell or disconnecting piping. Pumps should be of the pull-up design, using a lifting cable or chain and guides for pump removal. The pump should be connected to the fixed discharge piping with a self-locking coupling. In submersible pump installations, the discharge check and isolation valves should not be installed in a wet well.

Dry-pit submersible pumps may also be used in a wetwell/drywell configuration when flood risks cannot be mitigated. All electrical gear and other critical equipment must be kept above the 100-year flood elevation.

3.2.3.3.3 Suction Lift Pumps

Suction lift pumping stations generally require a smaller footprint than flooded suction, and may therefore provide capital cost savings. Suction lift pumps should be self-priming or vacuum-priming. The pump equipment compartment (or drywell) should be above grade and above or offset from the wetwell. The combined total of dynamic suction lift at the pump-off elevation and required net positive suction head at design operating conditions should not exceed 22 feet (6.7 m).

Self-priming pumps should be capable of rapid priming and repriming at the "Lead Pump On" elevation. Such self-priming and repriming should be accomplished automatically under design operating conditions. Suction piping must be of a diameter not exceeding the size of the pump suction and must not exceed 25 feet (7.6 m) in total length. Priming lift at the "Lead Pump On" elevation should include a safety factor of at least 4 feet (1.2 m) from the maximum allowable priming lift for the specific equipment at design operating conditions.

Vacuum-priming pumping stations should be equipped with dual vacuum pumps capable of automatically removing all air from a suction lift pump. The vacuum pumps should be adequately protected from sewage damage.

3.2.3.3.4 Dry-Pit Submersible Pumps

Dry-pit submersible pumps are designed to run in dry conditions without external cooling or seal water. Their ability to continue to operate if necessary in wet conditions results in lower overall efficiency (in general) than other pumps, but means they are an option for pumping galleries or stations where flooding risks cannot be mitigated. All electrical gear and other critical equipment must be kept above the 100-year flood elevation.

3.2.3.3.5 Screw Pumps

Screw pumps can provide an efficient, low maintenance alternative to the pumps discussed above. However, they are suitable only for low-lift situations, and cannot discharge to a force main.

Covers or other means to block direct sunlight must be provided as necessary to eliminate adverse effects of temperature changes. Other requirements: a positive means of isolating individual screw pump wells, and an automated system that lubricates submerged bearings without pump well dewatering.

3.2.4 Wetwells

3.2.4.1 Divided Wells

When the continuity of pumping operation is important, a wetwell should be divided into two sections that are properly interconnected and gated to facilitate repair and cleaning. When a single wet well is utilized, a valve or other means of stopping incoming flow must be provided on the influent gravity sewer.

3.2.4.2 Storage Capacity

The effective storage capacity of a wetwell should be based upon the recommended number of pump starts per hour and the design filling time. The effective volume of the wetwell should be based on a filling time of 30 minutes or less under design average-daily-flow rates. Use the pump manufacturer's recommendations to determine the frequency of starts.

Where the anticipated tributary wastewater flows are significantly less than the design average flow, provisions should be made so the filling time under initial conditions does not exceed 30 minutes (i.e., providing a divided wetwell or shortening the wetwell operating range). Stations with variable-speed pumping that matches incoming flow rates are likely to have smaller wetwells than stations with fixed-speed pumps; however, prevention of septic conditions should still be examined.

3.2.4.3 Pump Protection

Pumping stations serving separated sanitary wastewater for sewers less than 30 inches in diameter do not require screening for large solids. Stations serving combined sanitary and drainage systems, or sanitary wastewater from sewers 30 inches in diameter or greater, must be equipped with pump screening, including trash racks, screens, and grinders (one or more of each). Design criteria and sizing of these devices is presented in Section 5.1.1 (Screening Devices).

3.2.4.4 Grit

Wetwells for wastewater pumping stations should avoid operational problems caused by grit accumulation, primarily by having adequate floor slope.

3.2.4.5 Floor Slope

A wetwell floor should have a minimum slope of 1-to-1 to the hopper bottom. The horizontal area of the hopper bottom should be no greater than is needed for proper installation and function of pump suction pipes. Steeper floor pitch angles and self-cleaning wetwell features may be considered. All wetwell designs should include adequate access provisions for removal of accumulated materials.

3.2.4.6 Air Entrainment

Configuration of a wetwell and pump inlets should eliminate the possibility of vortexing. Intake pipes should be flared, preferably with the inlet opening facing down. To avoid air entrainment into a pump, wetwell inlets should be located to preclude the possibility of sewage falling directly onto the pump or pump intake.

3.2.4.7 Wastewater Channels

Wastewater channels located in wetwells should be covered with nonskid, corrosion-resistant grating. The grates should be installed flush with a floor that is capable of supporting anticipated loads. All channels should be drained when not in use. Where the side meets the floor of a channel, fillets should be provided.

3.2.5 Drywells

3.2.5.1 Automatic heating and dehumidification equipment should be provided in all drywells. Electrical requirements should meet those outlined in subsequent sections of this chapter. Lighting should be provided in all drywells.

3.2.5.2 A drywell should include a sump pump to remove extraneous water. The discharge pipe of the sump pump should be equipped with dual check valves, and should be pumped to the wetwell above the high water level. Water ejectors connected to a potable water supply should not be used. All floor and walkway surfaces should slope to a point of drainage. Pump seal leakage should be piped or channeled directly to the sump.

3.2.5.3 A drywell should be isolated from a wetwell to prevent humid, corrosive, and potentially dangerous sewer gases from entering the drywell. All wall penetrations between the wetwell and drywell should withstand water and gas leaks, and should be located as high as possible to prevent leaks into the drywell. Access to the wetwell should not be located in the drywell.

3.2.6 Valves

3.2.6.1 Shutoff valves should be placed on the suction line and discharge line of each pump (except on submersible, self-priming, and vacuum-primed pumps, which do not require valves on the suction side). A check valve should be placed on a horizontal section of each discharge line between the pump and shutoff valve.

3.2.6.2 Whenever possible, valves should not be located in wetwells. If valves must be located in a wetwell, they should be accessible without entering the wetwell.

3.2.7 Controls

3.2.7.1 Level Sensing Devices

Level sensing devices should be located or protected to prevent disturbance by flows entering the wetwell or by the suction of pumps.

3.2.7.2 Pump Alternation

Pumps should be automatically alternated to prolong life and balance wear. Running-time meters should be installed to verify proper alternation.

3.2.7.3 System Controls

Controls that automatically adjust the flow and pacing of multiple pumping stations to optimize energy efficiency and reduce operations and maintenance costs throughout a collection system are gaining market acceptance. These controls are changing rapidly, and it is beyond the scope of this report to catalog their features. Collection system designers should investigate options at the time of design.

3.2.7.4 Alarm Systems

Alarm systems should be provided for all pumping stations. At a minimum, the alarm system should be activated in any one of the following cases:

- High water in wetwell
- Low water in wetwell
- Loss of one or more phases of power supply
- High water level in pump room sump
- Loss of alarm transmission line
- Loss of air pressure in bubbler tube system/level sensing trouble or failure
- Standby power failure

- Pump malfunction, including shaft seal failure
- Intrusion

Alarms for other station equipment or other operating conditions should be considered. Designers should consider the suitability of redundant monitoring and/or control systems.

The power source for an alarm system should include an uninterruptible power supply (UPS). The alarm should signal at a municipal facility that is manned 24 hours a day. If no such facility is available, alternative arrangements should be made, such as an autodialer with a list of cell phones, or a 24-hour answering service. Alarm systems should indicate the alarm condition that exists.

3.2.8 Odor Control

Consider the use of odor control devices when a station is located in close proximity to a residence or other inhabited area.

For small stations (< 300 gpm), a vent with an activated carbon filter or a small, exterior drum scrubber on a concrete pad may be adequate. For larger stations, chemical addition or a biofilter may be more appropriate.

For a detailed discussion of odor control, see Chapter 10 - Odor and VOC Control.

3.2.9 Grease Control

An abundance of grease in a sewer collection system often becomes lodged in the wetwell of a pumping station, as this is often the first quiescent spot in a system. Grease can clog float switches, contribute to odor problems, cause corrosion, and generally result in increased maintenance. In extreme circumstances, grease can form a self-supporting “shelf” in a wetwell, resulting in false readings from ultrasonic level transducers.

It is preferable to reduce the amount of grease in a collection system by implementing a fats, oils, and grease (FOG) control program, which encourages the use of BMPs, prohibits or strongly discourages the use of garbage grinders, and mandates grease traps at restaurants and other significant sources of grease.

If grease cannot be controlled at the source, it can be mitigated by:

- aerating the wetwell; since this can lead to odor problems, care should be taken not to entrain air into the pump volute.
- providing a mechanical mixer in the wetwell.
- re-circulating a portion of the pumped flow back into the wetwell for surface agitation; care must be taken not to interfere with ultrasonic level transducers.
- using pump control telemetry to vary the liquid depth, preventing shelf formation.

3.3 Ventilation

3.3.1 General

Adequate ventilation should be provided for all pumping stations. Where a pump pit is below the ground surface, mechanical ventilation is required, especially when screens or mechanical equipment requiring maintenance or inspection are located in the wetwell. However, the wet and drywell ventilation systems should not be connected. In pits more than 15 feet (4.6 m) deep, multiple inlets and outlets are desirable. Switches for the operation of ventilation equipment should be marked and located conveniently. Consider automatic controls where operation is intermittent, and when control of odors within the pumping station is necessary. If odors are a problem, an odor control system may be needed.

Typical ventilation requirements range from 6 to 12 to as many as 30 complete air changes per hour. Area classification and subsequent ventilation requirements are governed by NFPA 820, OSHA, and appropriate federal, state and local regulations. Because ventilation systems can significantly impact energy costs, designers should use provisions in the codes that allow for lower heating requirements and fewer air changes when pump stations are unoccupied. Designers should also design pump stations to minimize heating by use of insulation, remote control of heating systems via SCADA, solar thermal heating, and other measures employed by the green building industry.

3.3.2 Wetwells

Ventilation may be either continuous or intermittent, and must be done in accordance with requirements of the regulatory agencies listed above. Hazardous gas detection equipment should be provided. All mechanical equipment must be suitable for the area classification as designated by NFPA 820.

3.3.3 Drywells

Ventilation may be either continuous or intermittent, and must be done in accordance with requirements of the regulatory agencies listed above. Heating is required, and dehumidification is desirable. Ventilation provided to declassify an area must be continuous.

3.4 Flow Measurement

At medium and large pumping stations, suitable devices for measuring and recording wastewater flow and power consumption should be installed. Running-time meters are acceptable for measuring flow at small stations.

3.5 Water Supply

Water under pressure should be considered for cleanup at a pumping station. Water may also be needed for mechanical seals and other process needs. A reduced pressure zone backflow preventer or other approved device should be installed on the water service entering the station. Any potable water supply should not be directly connected to wastewater equipment, piping systems, or fixtures.

3.6 Electrical

3.6.1 Electric Equipment

Electrical systems should be designed and installed in strict conformance with the latest edition of the National Electrical Code. Electrical equipment in enclosed places where gas may accumulate should be noncorrosive and in compliance with the National Electrical Code requirements for the area classification as determined by NFPA 820.

Designers should confirm the phase and voltage of the available electrical service, especially in remote locations.

Designers should consider energy efficiency when selecting electrical equipment, including the use of soft starts and/or VFDs.

3.6.2 Submersible Pump Motors

3.6.2.1 Electrical supply and control circuits should allow disconnection at a junction box located at or accessible from outside a wetwell. Terminals and connectors should have watertight seals located outside of the wetwell, and should be protected by separate strain relief.

3.6.2.2 The motor control center should be located outside of the wetwell, above the 100-year flood elevation, and protected by a conduit seal or other appropriate sealing method meeting the requirements of the National Electrical Code for the area classification as determined by NFPA 820.

3.6.2.3 The pump motor should meet the requirements of the National Electrical Code for the area classification as determined by NFPA 820.

3.6.2.4 Submersible pump motors that are totally submerged during all operational modes (including maintenance cycles) are not required to protect against explosions.

3.6.2.5 Power cords for pump motors should be flexible and serviceable under conditions of extra hard use. Ground fault interruption protection should de-energize the circuit in the event of a failure in the electrical integrity of the cable.

3.6.2.6 Power cord terminal fittings should be provided with strain relief appurtenances, and should facilitate field connecting.

3.6.2.7 Where electrical equipment is at a facility that is in or near a 100-year flood elevation, give consideration to whether or not the electrical equipment should be elevated to avoid impacts from potential flooding to elevations indicated in Section 1.2.1.h.

3.6.3 Variable Frequency Drives

3.6.3.1 Variable frequency drives (VFDs) should be provided in pumping stations where they can provide an operational benefit (such as flow pacing or to accommodate widely varying flows) or increased energy efficiency.

3.6.3.2 VFDs should comply with IEEE 519 guidelines for harmonic distortion within the system (i.e., to a standby generator) or back to the electric utility company. Harmonic filters may be used to compensate for distortion.

3.6.3.3 VFDs should be located above the 100-year flood elevation and as close to pump motors as practical. VFD manufacturers should be consulted for limitations on the distance between pump motors and VFDs.

3.7 Force Mains

3.7.1 Minimum Size

Force mains should measure a minimum of 4 inches (10.2 cm) in diameter. Smaller sizes (2–3 inches) may be considered for small grinder systems or STEP systems.

3.7.2 Velocity

At average pumping rate, velocity in excess of 3 feet per second (0.91 m/s) should be maintained to re-suspend solids deposited in a pipeline between pumping cycles. Evaluate friction losses at peak flow to confirm adequate force main size.

3.7.3 Variable Terrain

As far as possible, the alignment and depth of a force main should provide a constant upgrade profile. Depth must be sufficient to prevent freezing. Pipe insulation and structural shielding may be used when sufficient burial depth cannot be achieved.

3.7.4 Air Relief, Air Inlet and Vacuum Relief Valves

An automatic air relief valve should be placed at all relative high points in the force main. Automatic air inlet valves, vacuum relief valves, and combination air/vacuum valves should be considered in force mains where surge conditions and water column separation may occur.

3.7.5 Drain Valves

Consider placing drain valves at all relative low points in the force main. These valves should be connected to gravity sewers or provided with connections for vacuum pumper trucks.

3.7.6 Termination

Force mains should enter a gravity sewer at a point not more than 1–2 feet (0.3–0.6 m) above the flow line of the receiving manhole. The terminus of a force main should be the highest point along its length.

3.7.7 Leakage Testing

Leakage tests should be performed on all newly installed piping.

3.7.8 Surge Control and Relief

Surge control and relief measures should be used on force mains where surge conditions and water column separation may occur. Mitigation measures vary and may include use of VFDs, electrical soft start/soft stop controls, slow closing check valves, surge tanks, air inlet valves, vacuum relief valves, and combination air /vacuum valves.

3.7.9 Residence Time

Wastewater residence time in force mains should be limited to prevent septic conditions and the production of objectionable odors and H_2S gas.

3.8 Operation During a Power Failure

For operation during a power failure, an independent engine-generator type source of electric power should be provided for electrically driven pumps. This source should be automatically activated when any phase of the power supply fails or upon any fluctuation in voltage, especially when the extent or duration of the failure or fluctuation would cause damage to motors.

Standby generator installations should comply with all applicable federal, state and local requirements as well as NFPA 110, ASCE 7, NEC 701, and UL 2200. Consider installing a standby generator inside a building or sound-attenuating enclosure if the pumping station is located near a residential area.

Small Pumping Stations: For small pumping stations, storage (including system storage) that equals the maximum expected amount of wastewater for a 24-hour period is an alternative or a portable standby generator may be used. A portable engine-driven pump that can be readily connected to a force main is another option.

3.8.1 Controls

Provisions should be made for automatic and manual startup and cut-in. The controls should be such that upon automatic startup under emergency conditions, shutdown can be accomplished only manually, except in conditions that would damage the generator or engine.

3.8.2 Size

Unit size should be sufficient to start up and run all pumps needed to handle peak flows as well as lighting, ventilation, pump controls, and sump pump.

3.8.3 Exerciser

Engine controls should be equipped with an automatic exerciser that may be set on any selected schedule to start a generator, run it under no-load conditions, and shut it off without activating the alarm system. This exerciser does not relieve the operator from the responsibility of regular inspections of the pumping station.

3.8.4 Fuel Supply

Generators should have enough fuel to run under full load (or peak station flow) for at least 48 hours and under normal operating conditions for at least 96 hours. (The fuel should be sufficient to support whichever of these two circumstances requires the greatest amount of fuel.) Fuel should be stored in a double containment type tank with leak detection measures in accordance with federal, state and local regulations.

3.9 Safety

Adequate provisions should be taken to protect operators and visitors from hazards. In general, the design and construction of pumping stations should meet all prescribed local, state, and federal safety laws and codes. Safety provisions should include the following:

- Handrails at openings, stairways, and other hazardous areas
- Safety grating for observing wet wells
- Guards around belt drives, gears, rotating shafts, and moving equipment
- Warning signs as appropriate
- Provisions for power lockout controls at all pumps and equipment
- Eye-wash stations where chemicals are used
- Adequate lighting in all areas of pumping station
- Provisions for confined space entry in accordance with OSHA and regulatory agency requirements
- Visual beacons to signal alarm conditions or the detection of hazardous gases
- First aid equipment
- Fire extinguisher

3.10 Overflows and Bypasses

3.10.1 Overflows

Overflows are not allowed at pumping stations serving separated sanitary and drainage collection systems. Overflows are discouraged for pumping stations on combined sanitary and drainage systems. If overflows are allowed, a pumping station must be equipped with a check valve to prevent entry of animals or surface waters. Overflows must also be monitored with flow detection switches connected to a SCADA system.

3.10.2 Bypasses

Pumping station bypasses in the form of auxiliary wetwell and force main connections are desirable to allow truck-mounted or other pumping systems to temporarily replace a pumping station for purposes of major maintenance or station renovation. Bypasses should be adequately sized, provided with secure caps, sufficient plug valves for isolating the pumping station, and provisions for draining the bypass piping at the cessation of bypass operations.

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CHAPTER 4

WASTEWATER TREATMENT WORKS

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4.1 Plant Location

In general, a new wastewater treatment facility should be built as far as possible from a developed area or an area where development is likely. Other considerations, such as the direction of prevailing winds, susceptibility to flooding, regionalization options, traffic, and environmental impacts should also be factored into the selection of the plant's location. If a sensitive location must be used, special consideration must be given to plant design, the type of plant, and provisions for odor control. The plant must be readily accessible in all seasons.

The considered treatment plant site should be evaluated for potential effects on wetlands; historic or prehistoric sites; rare, threatened, and endangered plant and animal species; groundwater source protection areas; hazardous waste sites; etc.

4.1.1 Minimum Suggested Buffer Distances

Suggested buffer distances from residential properties are as follows:

- Stabilization lagoons: 600 feet from any residence
- Aerated lagoons: 400 feet from any residence
- Processing units in conventional treatment plants and sludge processing facilities: 300 feet from any residence

Other buildings, such as industrial warehouses or commercial facilities, may have shorter buffer distances than those listed above. This depends on occupancy, use, and other relevant factors.

4.1.2 Flooding

Treatment plants should provide for uninterrupted operation and be protected from physical damage as noted in Section 1.2.1.h. All first floors, tank walls, and structural openings should be protected from damage at the 100-year flood elevation. Provide floodproofing (e.g., stoplogs at garage entrances, raised motor drives and pumps, lab cabinets with positive latching systems to prevent lab chemicals from mingling with floodwaters, storage at the highest practical elevation in a facility, and adequate structural strength to buildings) to above the 100-year flood elevation. All facilities should be constructed outside of coastal velocity flood zones.

Consult with FEMA or the agency's local or state designee regarding permissible encroachments and restrictions on building obstructions in regulatory floodways and flood plains. For plants located in flood plains, hydraulic modeling of pre- and post-construction conditions may be required by regulatory authorities.

Existing treatment plant design should consider the possibility that flood elevations may rise in the future due to changing weather patterns or global climate change. Refer to Paragraph 1.2.1.h regarding flood protection criteria for treatment plants.The possible vulnerability and the differential cost of increasing the level of protection to above the current 25-year and 100-year flood levels should be weighed in selecting the level of flood protection. The designer should confirm the latest estimate of 25-year and 100-year flood levels at the plant site. Some agencies, such as USDA Rural Development, may request or require consideration of the 500-year flood plain.

4.2 Treatment Goals and Effluent Quality

The required degree of treatment should be based on effluent requirements and water quality standards established by the responsible state agency and/or appropriate federal regulations, including discharge permit requirements. Consult with regulatory agencies regarding potential future discharge limitations, and include provisions for any treatment processes required to meet anticipated limits.

4.3 Design

The plant design should provide flexibility for operating within the expected range of wastewater characteristics and volumes.

4.3.1 Type of Treatment

In deciding on the type of treatment, consider existing and projected flows and loads; flow composition; character and use of receiving waters; location, topography, and constraints of the plant site; present and future effluent limits; the effect of industrial wastes likely to be encountered; ultimate sludge disposal, capital, and operating costs; sustainability; and the type of supervision and operation to be employed at the plant.

4.3.2 New Processes and Equipment

Some more recently developed wastewater treatment processes and equipment are not included in this document, but this omission does not mean they are unsuitable for use; reviewing authorities should in fact encourage the development of new methods or equipment for treatment of wastewater. However, new processes and equipment can only be used with the reviewing authority's approval. For a new process or product to be approved, operational reliability and effectiveness must be demonstrated via suitable piloting or process demonstration under design load conditions. For approval, the reviewing authority may require the following:

- Monitoring observations, including operating test results and engineering evaluations demonstrating the efficiency of the process or product.
- Detailed descriptions of the test methods.
- Additional testing, including composite samples taken under various strength and flow rates, such as diurnal variations, and waste temperatures taken over a sufficient length of time to demonstrate performance under climatic and other conditions that may be encountered.
- Appropriate testing to be conducted and evaluations to be made under the supervision of a competent process engineer other than one employed by the process/product manufacturer or developer.

- Process reports or other documentation from installed, operating systems utilizing the process or product.

4.3.3 Waste Characterization

4.3.3.1 Domestic Wastes

Strength/Concentration: When possible, the strength of domestic wastes should be based on historical records or sampling. If such records are not available, the strength should be based on an average daily contribution of 0.20 pounds of suspended solids and 0.17 pounds of carbonaceous BOD per capita. When garbage grinders are prevalent in the service area, average TSS and BOD loadings should be increased to 0.25 and 0.22 pounds per capita per day, respectively. Total nitrogen and total phosphorus loadings should be based on an average daily contribution of 0.04 and 0.006 pounds per capita per day, respectively. These same loading rates can be used for future loading projections. The concentration of domestic contributions should be based on the above per capita contributions and a flow of not less than 70 gallons per capita per day and not more than 100 gallons per capita per day, unless historical data indicate use outside of this range. The designer, when estimating future flow, should consider local and state regulations concerning mandatory low-flow toilet and conveyance system rehabilitation. If public water systems are within the collection system area, the systems' water use per capita can be used to project future flow increases related to new construction.

4.3.3.2 Industrial Wastes

When appreciable amounts of industrial wastes are involved, the quantity and character of the waste should be determined on an industry-by-industry basis using chemical analyses from pretreatment programs. The characterization should include conventional pollutants (BOD and TSS), nutrients, pH, alkalinity, and nonconventional parameters present in the waste. In the absence of existing pretreatment programs, waste characterization programs should be undertaken.

4.3.3.3 Nonconventional Pollutants

Influent metals, toxics, and other nonconventional parameters should be established when critical to the protection of receiving waters.

4.3.3.4 Septage

The design basis should include volume and characterization of septage expected to be received during the planning period of the facility. In the absence of specific data, domestic septage strength should be based on 6,000 mg/L BOD, 15,000 mg/L TSS, 700 mg/L total nitrogen, and 250 mg/L total phosphorus. Appropriate peaking factors should be used to account for seasonal variations in septage quantities from the specific service area. For a summary of the typical variation of septage quality, refer to Chapter 12, Table 12.1.

4.3.4 Design Loading

4.3.4.1 Design Period

The design period should be 20 years. Expansion expected to occur beyond the 20-year planning period should be considered when laying out and designing major treatment units and plant hydraulics.

4.3.4.2 Design Flows

Design flows should be the sum of domestic, commercial, industrial, and I/I flow throughout the design year. Stormwater flow should be included for plants with combined sewers in the service area.

Design flow values should be determined and explicitly indicated on the construction drawings for the following:

- Annual average flows
- Peak hourly flow (dry weather and wet weather if service area includes combined sewers)
- Maximum daily flow (dry weather and wet weather if service area includes combined sewers)
- Maximum monthly flow
- Minimum monthly flow
- Minimum daily flow

Ensure that the definition of “design flow” is explicitly stated and is consistent with the definition included in the facility’s existing or pending discharge permit.

4.3.4.3 Influent Loading

Total influent loads of TSS, BOD, TKN, and total phosphorus should be the sum of domestic, commercial, industrial, and septage loads throughout the life of the facility. To facilitate process modeling, it is suggested that total COD influent loads also be determined. Design loadings should be explicitly indicated on the construction drawings.

4.3.4.4 Loading Variability

Treatment and solids handling processes should accommodate the maximum and minimum expected variations in loadings. Sampling and analysis is recommended for existing plants to identify the variability in influent loading. When data justifying alternative values is not available, the following factors should be used for influent variability. (Table from WEF MOP No. 8, *Design of Municipal Wastewater Treatment Plants,* which states that the results of a survey of plant data indicates these factors typically vary by plant capacity.)

	Max. day	Max. 30-day
TSS	1.9	1.3
BOD	1.6	1.26
TKN	1.4	1.24
Total P	1.36	1.20

4.3.4.5 Flow Equalization

Facilities for the equalization of flows and organic shock load should be considered at all plants that are critically affected by surge flows and loadings.

4.3.4.6 Sidestreams

Flow streams returned to the liquid treatment process as a result of the processing of sludge, scum, and other floatable objects must be characterized as to flow, BOD, solids, and nutrients. The recycling of nutrients from anaerobic digestion dewatering facilities can have a significant impact on the liquid stream process. Provision of sidestream treatment to reduce the recycling of nutrients should be considered. Sidestreams with high solids loadings should preferably be returned to liquid treatment facilities before primary treatment but after influent pumping.

4.3.4.7 Mass Balances

A mass balance should be performed and included in the design documentation. This ensures proper consideration of sidestreams and proper sizing of treatment and solids handling units, including all major liquid treatment and solids handling processes.

The mass balance can be prepared for average conditions and appropriate peaking factors used for peak design conditions. The mass balance must include flow, BOD, TSS, and nutrient loadings to each appropriate process and for all sidestreams. It is suggested that the mass balance also include COD to facilitate process modeling.

4.3.4.8 Wastewater Process Simulation Models

A wastewater process simulation model should be developed as a design tool for biological treatment processes. It is preferred that the model encompass other treatment processes, including sidestreams, that impact biological processes such as primary treatment and sludge treatment. The model should be calibrated using plant data and detailed influent wastewater characterization, as described in WEF MOP No. 31, *An Introduction to Process Modeling for Designers*.

4.3.5 Plant Hydraulics

Hydraulic profiles of each treatment process should be included in the construction drawings. The profiles should indicate water surface elevations for peak hourly, average, and minimum hourly design flows against high and normal levels of the receiving waters. The hydraulic design should allow peak hourly flows, including associated sidestream flows, to be passed through the plant with the largest or longest flow path of each unit process removed from service and with the receiving water at the 100-year flood elevation. Peak flows should be able to pass through the plant when the largest pump or other piece of mechanical equipment is out of service.

Note that the projected design flood elevations may change over the life of the wastewater treatment facility due to effects from climate change. See Section 1.2.1.h for flood protection guidelines for potential conditions that are not yet reflected in current flood studies.

A minimum velocity of 2.0 feet per second at design average flow and 1.5 feet per second at minimum flow should be provided in channels carrying unsettled wastewater unless wastewater is mixed to prevent sedimentation of solids. Mixing should be considered for all channels carrying activated sludge mixed liquor or return activated sludge. Hydraulic profiles should identify areas of vulnerability—e.g., structures and buildings that could be rapidly flooded at peak flows due to catastrophic mechanical failure or electrical (and backup power) failure. Due to the possibility of such events, consideration should be given to providing hydraulically operated gates that close under certain conditions to protect equipment and infrastructure.

4.3.6 Conduits

Piping and channels should be designed to convey peak future flows. The influent sewer should be designed for free discharge. Buried valves should be avoided, if possible. The bottom corners of channels should be filleted, with the elimination of pockets and corners where solids can accumulate. Suitable gates, made of corrosion-resistant materials, should be placed in channels to seal off unused sections that might accumulate solids. Stop plates are permitted in place of gate valves or slide gates. Channels that may not be used for considerable periods of time should have valved drains. Design of major piping and channels should provide for future expansion per Section 4.3.8.

4.3.7 Number and Arrangement of Units

Components of a plant should be arranged for the greatest operating convenience, flexibility, and economy, and for the installation of future units. Facilities should minimize connecting and recycle conduits. Similar unit processes should be grouped together. Whenever possible, potential sources of emissions should be isolated and located away from sensitive receptors.

Multiple units should be provided for all critical components. The use of multiple units of the same size, make, and model facilitates maintenance and reduces spare parts inventory. For pumps and mechanical equipment, including solids handling systems and odor control equipment, provide one standby unit in addition to those units required to handle peak design flow or load. Standby process tanks are generally not required for clarifiers, aeration tanks, fixed film reactors, filters, and chlorine contact basins.

4.3.8 Provisions for Future Expansion

The design and layout of treatment facilities, including building interiors and mechanical layouts, should include provisions for future expansion and/or upgrades. Locations set aside for future facilities should be indicated on construction drawings. Plant hydraulics, sizing of conduits connecting unit processes, flow distribution, and electrical distribution systems and duct banks should be designed and located to provide for expansion. Plugs, blind flanges, slide gates, and valving should be designed to facilitate expansion with minimal disruption to operating facilities.

4.3.9 Flow Distribution

Distribution devices should ensure control of organic, solids, and hydraulic loading to plant process units. Positive scum and foam removal should be provided in all channels and distribution structures that have a trapped-free surface.

Flow distribution devices should be adjustable. To provide distribution to individual treatment units, use inlet weirs in properly designed distribution boxes or influent channels with outlet ports or weirs that impart sufficient head loss to ensure equal distribution among all units. Automatic rate controlling valves for flow distribution should be avoided. Also, effluent weirs and flow route symmetry should not be relied upon for flow control. Influent flow to each unit should be controlled by slide gates with visible status indication.

Process effluent splitter boxes, which generally collect flow from different sources (e.g., primary effluent, return sludge, internal recycle for BNR facilities), should be evaluated based on the size of the facility and the flow volumes.

Deep well construction to provide appropriate mixing is critical for secondary processes, especially those utilizing biological nutrient removal.

4.3.10 Proprietary Equipment

In general, equipment and system selection for a publicly funded project should seek to identify more than one suitable manufacturer or vendor. The options may include equipment or a system that is proprietary (i.e., available from only one supplier), and in some cases, the proprietary option may be the most appropriate and advantageous to include in a design. These proprietary systems tend to be among the most technologically advanced and efficient systems commercially available and their use should not be discouraged.

The project's design documentation should include a justification for the selection of proprietary equipment, and the reviewing authority may require submittal of this documentation as part of the project review process. When project bid documents include a proprietary system or piece of equipment, awarding authorities must ensure that the form of procurement complies with state and local bidding law.

4.3.11 Control Philosophy

The facility's philosophy regarding control should be identified and communicated early in the design process. In defining their approach to control, the principals in the design process should consider such matters as regulatory requirements, discharge limits, plant complexity, staffing requirements, operator sophistication, and cost. For each major process, process and instrumentation control diagrams should be developed in the initial stages of design to help identify and communicate the required instrumentation and methods of control.

4.3.12 Sustainability Considerations

Sustainability (i.e., the conservation of resources) is an important design consideration. The following are provided as example considerations, though this is not a comprehensive list. The designer is encouraged to consider these and other sustainable features in a project.

4.3.12.1 Water Conservation

The designer should ascertain the water conservation policies of water and wastewater utilities, as well as those of local and state governments.

- Reduced Flow Plumbing

  The designer should examine the local plumbing code and actual plumbing practices as part of the development of design flows and loads described in Section 4.3.4. When reducing wastewater flow through the use of low-flow plumbing fixtures (e.g., waterless urinals) or other water conservation methods is economical, the designer should include in the engineering report a detailed evaluation of the impacts of implementing a low-flow fixture ordinance, and recommend adoption of appropriate technologies for water conservation. Any process systems with operational requirements that are solely dependent upon potable water for seal water supply should be carefully considered before design commences.

- Reclaimed Wastewater Reuse

  When the wastewater utility or other governmental entity has an established plan for the reuse of treated wastewater effluent, or the designer believes there is potential for economic reuse of effluent, the designer should include an evaluation of reuse options in the engineering report. In facilities where reclaimed effluent use already exists and a complete replacement of the piping network is not feasible, designers should include filters on all reclaimed water lines to remove any material built up in the lines; this should be done regardless of the existing quality of the effluent.

- Water-Efficient Landscaping

  Project landscaping should utilize native species to reduce watering needs.

4.3.12.2 Energy Conservation

a. General

- Designers should pay particular attention to incorporating energy conservation in the design of wastewater treatment facilities. Such considerations should be made during the preliminary evaluation of treatment process alternatives, as well as in the selection of individual pieces of process equipment. For example, use high-efficiency motors except in cases where the motors are used infrequently. Incorporate power factor correction into all designs.

- Aeration and pumping require more energy than any other aspect of wastewater treatment. Pay particular attention to minimizing energy needs in these areas. When possible, place pumps and aeration equipment in such a way as to minimize the distance that air and water must travel and to minimize frictional losses in the system. Design facilities to minimize pumping to the extent possible.

b. Energy Audits

On projects that involve the upgrade of existing facilities, perform an energy audit, including a plant energy balance, to determine overall energy use and peak demand, including thermal energy from natural gas, oil, digester gas, etc. This audit should include a list of all equipment in the facility, along with motor HP ratings and duty schedules. Evaluate large pieces of equipment with data-logging equipment over adequate time periods to measure energy use with various flows and in different plant conditions. Many electric and gas utilities will fund part or all of an energy audit.

c. Aeration

Energy conservation in aeration systems is extremely important because the aeration system is typically the largest single energy user in a wastewater treatment facility. Measures such as variable and multiple staged single-speed blowers, high-speed turbo blowers, two-speed mechanical aerators, continuous DO monitoring and control, and time clock operation can be used to save energy. The relative oxygen transfer efficiency of alternative aeration systems should be considered. Energy savings may also be obtained through the use of control systems that provide “floating” blower air system pressures so air flow is adjusted to meet the need at any given time; more complex monitoring systems that provide for automatic dissolved oxygen setpoints also aid in energy conservation.

The aeration system should be designed for efficiency. The quantity, type, and layout of air distribution devices (diffusers, mixers, etc.) is an important factor in total system energy use. Efficiency of the blowers, compressors, or other devices that supply air to the distribution system plays an equally important role. Designers should take steps to size equipment so it operates efficiently during the normal range of flows experienced at the plant.

Further guidance on optimizing aeration systems is available in WEF MOP No. 32: *Energy Conservation in Water and Wastewater Facilities*, and U.S. EPA’s *Evaluation of Energy Conservation Measures for Wastewater Treatment Facilities*.

d. Energy Management Systems

- To minimize demand charges from the local utility, load shedding devices, commonly referred to as energy management systems, should be considered for lockout of certain process operations during periods of peak energy demand,.
- Use of individual motor watt and other electrical consumption indicators is encouraged. The information provided by such devices helps identify energy consumers based on operational experience, and assists in troubleshooting. The use of separate meters to monitor areas of major energy use in the plant should be considered.

e. Heating Energy

- Consider designing for heat recovery from blower rooms.
- At plants where anaerobic digestion is part of the treatment process, consider possible uses for surplus gas and other waste heat.
- Consider the use of heat recovery units when exhausting rooms at high ventilation rates, and pay particular attention to provisions in regulations that allow for reduced ventilation rates under certain conditions, such as low temperatures or when spaces are unoccupied.
- Consider the use of heat recovery units that draw heat from plant effluent.
- Consider the use of solar thermal heating units on south-facing walls with limited shade.

f. Instrumentation and Control Systems

To help match supply with demand, use instrumentation and automated control systems such as:

- DO probes in aeration systems.
- Level sensors in sludge holding tanks.
- Nitrate probes (when adding supplemental carbon).
- Flow-paced UV disinfection systems.

g. Lighting

- Consider motion sensors on lights in non-process buildings.
- Use high-efficiency fixtures.
- Reduce reliance on artificial light through the use of windows, translucent panels, skylights, dormers, light shelves, etc. Use sensors to turn off lights when adequate daylight is present.

4.3.12.3 Site Considerations

a. Consider reducing “heat island” effects through the use of sloped roofs and/or light colored (white) roofing materials, and by minimizing paved areas. Plant trees for shading.

b. *Light Pollution:* Limit exterior lighting to that required by local codes or as needed for safety. Consider light timers or light sensors as appropriate. Ensure exterior lighting is designed so necessary outside work can be done safely in all weather conditions; this is particularly important at facilities with multiple shifts.

c. *Stormwater Design*: Where no local codes exist, consider keeping stormwater quantities that leave the site to preconstruction levels or lower. Use current best management practices (BMPs) for stormwater, available from EPA and the applicable state stormwater design manual or from the International Stormwater BMP Database.

d. *Proximity to Partnerships:* Plants to be built in industrial areas should be designed to maximize the potential for mutual benefits; for example, a plant built near an industrial incinerator may be able to capture waste heat from the incinerator for plant operations. Conversely, plant effluent may be able to be used instead of potable water in a nearby industrial operation.

4.3.12.4 Design Considerations for Non-Process Buildings

New wastewater treatment facilities often include structures that are entirely devoted to non-process uses, such as office space, laboratories, and training and conference rooms. Consider referencing LEED (Leadership in Energy and Environmental Design) documents as part of the design of these structures as well as the applicable recommendations above.

4.4 Plant Details

4.4.1 Installation of Mechanical Equipment

The installation and initial operation of major items of mechanical equipment must be supervised and certified by a representative of the manufacturer.

4.4.2 Bypasses

Design: Bypass structures and piping should allow each unit in a plant to be independently removed from service. Bypassing may be accomplished by using duplicate or multiple treatment units in any stage and isolating the equipment with gates or stop plates. The bypass design should facilitate plant operation during unit maintenance and emergency repair, and should minimize deterioration of effluent quality. Solids retention, sludge handling, and disinfection should be considered; bypasses that allow raw or insufficiently treated wastewater to be discharged directly to receiving waters must not be allowed to occur.

Combined Sewers: With the consent of the approving authority, bypasses may be included in facilities with combined sewers in their tributary area, allowing a portion of the primary effluent to bypass secondary and advanced treatment unit processes and proceed directly to disinfection. Regulations on combined sewer flows vary by state, and regulatory agencies should be involved in planning such bypasses.

Temporary During Construction: If it is deemed necessary to bypass a particular process unit during construction associated with a plant upgrade or expansion, the specifications accompanying construction drawings should include a detailed description of plans for meeting the requirement to maintain plant operations; the sequence of construction should be delineated, showing how this sequence will limit the number of units that may be removed from operation. Such temporary bypasses should be discussed with regulatory agencies during the design process.

4.4.3 Dewatering and Flotation Protection

A means of unit isolation and dewatering should be provided for all process units. Each tank should be able to be drained individually. The drain time for each tank should not exceed 6 hours for plants that are staffed one shift per day, or 14 hours for plants that are staffed two shifts per day. Drain times should not be so rapid that the drainage flow, in combination with the plant influent flow, overloads the plant. As required, tanks should be protected against flotation by underdrains and flap valves. Tanks can also be protected against flotation by building a heavier slab.

4.4.4 Plant Construction Materials

As many of the constituents present in wastewater (such as hydrogen sulfide and other corrosive gases, greases, and oils) can corrode, carefully consider the materials used to construct the plant. This is particularly important when selecting metals and paints. Dissimilar metal contact should be avoided to minimize galvanic action.

4.4.5 Plant Paint and Equipment Identification

Paints containing lead or mercury must be avoided. The use of low VOC paints should be considered. To facilitate identification of piping, particularly in large plants, different lines should be color-coded, with the flow stream labeled and direction of flow indicated. Directional arrows should be added at a frequency and in locations to easily convey the information. These arrows, which are generally added when painting occurs, will assist future operations staff during emergencies, while contributing to a safer environment overall. If a facility lacks an established color scheme, see the recommendations in WEF MOP No. 8: *Design of Municipal Wastewater Treatment Plants,* Table 10.25.

Connecting pumps and equipment should be painted in accordance with the same color scheme. All pumps, motors, and equipment should be identified with brass or stainless steel nameplates, indicating manufacturer, model, serial number, horsepower, and capacity, as applicable.

4.4.6 Operating Equipment for the Plant

Plant operators should have access to a complete collection of tools, accessories, and spare parts. Storage space and workbench facilities should be available; for large equipment, consider a garage.

4.4.7 Site Access

Plant roads must provide access to all delivery and loading points. Roads intended for two-way traffic should have a minimum pavement width of 24 feet. Curve radii should accommodate the largest vehicles expected on-site. All grades, including ramps, should not exceed 8–10 percent, as governed by local regulations.

Provide turnarounds, fire lanes, and guard rails in accordance with local requirements. Provisions should be made for the removal and storage of snow.

Adequate parking should be provided for plant personnel, including disabled employees, and visitors.

4.4.8 Security

Site security has become an essential consideration in facility design. At an absolute minimum, access to the plant site must be controlled with a perimeter fence and lockable gate(s). Remotely controlled gates, with card access, should be considered. For high-profile, larger facilities, a manned security station may be appropriate.

Consideration should be given to equipping all doors with proprietary lock systems to eliminate the possibility of unauthorized key replication. Motor control centers and other such rooms where electrical components and instrumentation are maintained should have security systems that provide limited access, as part of the overall security plan. Buildings may be equipped with one door with a card reader, with other doors locked at all times (with appropriate emergency egress); this approach enhances security, particularly at buildings located away from a facility’s main structures.

4.4.9 Grading and Landscaping

As with other areas of construction, landscaping practices are evolving to become more sustainable. Consider using sustainable landscaping practices such as those recommended in LEED ratings systems. Such practices emphasize the use of native species, a reduction in hardscapes, minimal conventional turf, etc. Landscaping practices and stormwater management practices are interdependent and should be addressed at the same time.

Upon completion of heavy construction activities, the plant grounds should be graded and seeded. All-weather walkways should be provided for access to all units. All stairways should be covered. When possible, steep slopes should be avoided to prevent erosion. Surface water should not be permitted to drain into any unit. Drainage systems should be provided to handle surface runoff. Drains in areas contaminated by sludge or wastewater should discharge to treatment facilities for processing.

Landscaping should be compatible with areas adjacent to the plant. Use of landscaping techniques to screen treatment facilities from adjacent areas should be considered; however, the operator's view of units should not be obstructed. Provide landscaping that does not require extensive weeding or special care. (For small plants under part-time operation, consider an approach to landscaping that minimizes the need for maintenance of the plant's grounds.) Do not plant deciduous trees and shrubs near open process units or outside air intake louvers. Areas to be mowed should have a slope that does not exceed 3 horizontal to 1 vertical.

4.4.10 Outside Lighting

Outside lighting should provide approximately 50 lux to site entrances, accessways, and local areas requiring maintenance activities or operator inspection. The use of lighting that prevents light pollution of neighboring properties should be specified. Local zoning codes must be reviewed. Design of outside lighting systems should consider sustainability as described in Section 4.3.12.2 (g) and security requirements.

4.4.11 Floor Slope and Drainage

Floor surfaces in rooms subject to spills or requiring washdown should slope to a point of drainage, preferably at a rate of 1/4 inch per foot. Additional drains should be added to facilitate cleaning and provide a safe work environment. Drains near pumps and other process units should be located near the source of the liquid to be removed to avoid tracking chemicals and other flows through the area. Provide berming within a room where appropriate, and provide drains of a sufficient size to remove liquids quickly.

4.4.12 Access Hatches

Access hatches should be provided for removal of machinery and equipment. Consider whether waterproof hatches should be provided in areas subject to washdown, and provide for frame drainage when required.

4.4.13 Equipment Access and Operation and Maintenance

Provisions should be made for maintenance and removal of equipment. A minimum of 3 feet of clear space should be provided around process equipment, including pumps.

Consider how equipment will be brought into and out of a space, both during and after construction. Consider whether forklifts or other heavy equipment may be used and provide sufficient clearance where feasible. Provide monorails, cranes, or lifting hooks for hoisting of equipment, and provide equipment drop zones where needed.

4.5 Chemical Feed Systems

4.5.1 General

This section describes design considerations that generally apply to chemical feed systems. Refer to other chapters for additional design considerations applicable to specific applications.

General equipment design should allow for the continuous supply of accurate amounts and rates of chemicals throughout the range of feed requirements. The chemical-contact materials and surfaces should be resistant to the aggressiveness of the chemical solution, with corrosive chemicals being introduced in a way that minimizes the potential for corrosion. Chemicals that are incompatible should not be stored or handled together.

Each chemical used in a facility should be conducted from the feeder to the point of application in one or more separate conduits, with chemical feeders being as near as practical to the feed point. Chemical feeders and pumps should operate at no less than 10 percent of the feed range, and the appropriate operating range should be confirmed with equipment manufacturers.

4.5.2 Chemical Feed Systems Design

4.5.2.1 Number of Feeders

Where chemical feed is needed to maintain process capacity, a minimum of two feeders (including one on standby) should be provided. The standby unit or a combination of units of sufficient capacity should be available to replace the largest unit during shutdowns. If a booster pump is required, provide duplicate equipment and, when necessary, standby power.

A separate feeder should be used for each chemical applied, and replacement parts should be available to replace all feeders, which are subject to wear. Consider a separate feeder for each chemical feed application point to ensure accurate dosing to each point without relying on flow distribution or rate controllers.

4.5.2.2 Control

Feeders may be manually or automatically controlled, with automatic controls being designed to allow override by manual controls.

Means of measuring such variables as flow, pH, residual chlorine, nitrate-nitrogen, and oxidation reduction potential (required to pace or trim chemical feed rates) should be provided, and an indication of the variable measured should be readily readable.

Feed Rates: Chemical feed rates should be adjustable based on appropriate control parameters. A weighing scale should be provided for volumetric dry chemical feeders, with enough accuracy to measure increments of 0.5 percent of load.

4.5.2.3 Dry Chemical Feeders

Dry chemical feeders should measure chemicals volumetrically or gravimetrically and provide adequate solution water and agitation of the chemical in the solution tank. The feeders should also provide gravity feed from solution tanks and should completely enclose chemicals to prevent emission of dust.

4.5.2.4 Positive Displacement Solution Pumps

Positive displacement type solution feed pumps should be used to feed liquid chemicals or chemical slurries where appropriate. Pumps must be sized to exceed maximum head conditions found at the point of injection; ensure the design accounts for dynamic losses, especially through small-diameter pipe or tubing.

4.5.2.5 Water Supply

In-plant water supply should be ample in quantity and adequate in pressure, and should provide a means for measurement when preparing specific solution concentrations by dilution.

4.5.2.6 Chemical Storage and Feed

a. Location

Where possible, chemical feed equipment should be located in a separate, dedicated room to reduce potential hazards and exposure. The length of feed lines can be minimized by locating the equipment near points of application. The equipment should be readily accessible for servicing, repair, and observation of operation. Ensure that there are adequate openings (i.e., overhead doors, removable window panels) to remove and replace tanks as required.

b. Storage

Space should be provided for at least 30 days of chemical supply under average design conditions, where appropriate. Chemicals should be stored in a convenient location that allows for efficient handling. Storage conditions should be environmentally controlled as required by the specific chemical. Where chemical purchase is by truckload lots, a minimum storage volume of one truckload plus the volume that will be used from the time of order to delivery of chemical (assume seven days) is required.

Storage of chemicals for intermittent use, such as metal salts for wet weather treatment, should be designed to provide for maximum demand; it is important to factor in the time it takes to receive a shipment of the chemical.

For liquid chemicals, the storage tanks and pipelines that are used must be intended for the specific chemicals in use and not for alternates. Chemicals should be stored in covered or unopened shipping containers, unless the chemical is transferred to an approved storage unit.

Liquid chemical storage tanks should have a liquid level indicator, an overflow and receiving basin, and a secondary containment system (with alarm) capable of storing accidental spills or overflows. Refer to Section 4.5.3 for guidance on containment area sizing.

c. Solution Tanks

Solution tanks should be situated and protective curbs provided so that chemicals from equipment failure, spillage, or accidental drainage can be positively contained and safely managed. A means to maintain a uniform strength of solution that is consistent with the nature of the chemical solution should be provided in a solution tank. Continuous agitation should be provided to maintain slurries in suspension. Two solution tanks of adequate volume may be required to assure continuity of supply of a chemical. It should be possible to measure the solution level in the tank.

Subsurface locations for solution tanks should be free from sources of possible contamination and ensure positive containment of chemical spills, overflows, and leaks. They should also ensure positive drainage of groundwater, surface water, and accumulated water.

Covering: Chemical solutions should be kept covered, with access openings of large tanks being curbed and fitted with overhanging covers.

Overflow Pipes: When provided, overflow pipes should be turned downward, with the end screened. The pipes should have a freefall discharge to a positive containment vessel, be located where visible, and be marked appropriately, designating their origin tank. An overflow pipe should terminate in a water-filled sump if odors or hazardous fumes may be expected and/or if a chimney effect could be created between the overflow and the vent system.

Acid Storage Tanks: Tanks used for storing acid must be vented to the outside atmosphere through separate vents, with each tank having a valved drain to protect against backflow.

d. Day Tanks

Day tanks, generally sized to hold no more than a 30-hour supply, should be provided at facilities requiring bulk storage of liquid chemicals. A means that is consistent with the nature of the chemical solution should be provided to maintain uniform strength of solution in a day tank. Continuous agitation should be provided to maintain chemical slurries in suspension.

Gauges: Translucent tanks, through which liquid level can be observed in a gauge tube or through a sidewall, should be scale-mounted or have a calibrated gauge painted or mounted on the side. For opaque tanks, a gauge rod, which extends above a reference point at the top of the tank and is attached to a float, may be used. The ratio of the area of the tank to its height must be such that unit readings are meaningful in relation to the total amount of chemical fed during a day.

Pumps: Hand pumps may be used for chemical transfer from a carboy or drum. A tip rack may be used to permit withdrawal from a spigot into a bucket. If using motor-driven transfer pumps, provide a liquid level limit switch and an overflow from the day tank. Use of a manual, spring-return run switch on motor-drive transfer pumps is recommended to help eliminate overfilling of day tanks.

Labeling: Tanks should be properly labeled to indicate the chemical contained.

e. Feed Lines

Feed lines should be as short as possible; constructed of durable, corrosion-resistant material; easily accessible for their entire length; protected against freezing; and readily cleanable. When feed lines are overhead, a means of capturing and controlling leaks should be provided, thus preventing possible exposure. When conveying gases, feed lines should slope upward from the chemical source to the feeder. Feed lines should be designed consistent with the scale-forming or solids-depositing properties of the carriage water, chemical, solution, or mixtures that they convey. Feed lines should be labeled and color-coded (see Section 4.4.5).

f. Handling

To minimize excessive lifting by operators, it is suggested that carts, elevators, hoists, and other appropriate means for lifting chemical containers be provided.

Disposal: Empty bags, drums, or barrels should be disposed of by an approved procedure that will minimize exposure to dusts.

Transfer: Provision must be made for the proper transfer of dry chemicals from shipping containers to storage bins or hoppers; the transfer must be done in a way that minimizes dust entering a room where sensitive equipment is installed.

Equipment: To avoid exposure to dust and other potential problems, use vacuum pneumatic equipment or closed conveyor systems, facilities for emptying shipping containers in special enclosures, and/or exhaust fans and dust filters that put hoppers or bins under negative pressure.

Measuring: Provision should be made for measuring quantities of chemicals used to prepare feed solutions.

g. Housing

Floor surfaces should be smooth, impervious, and seamless; slip-proof; and well drained with a minimum slope of 3 inches per 10 feet.

Vents from feeders, storage facilities, and equipment exhaust should discharge to the outside atmosphere above grade and away from air intakes. Vents from dry chemical feeders should be filtered to reduce spreading of dusts.

4.5.2.7 Operator Safety

Assure compliance with OSHA regulations (including 1910.119) where toxic and/or hazardous compounds are handled. Complete material safety data sheets (MSDSs) for each chemical used or stored in a facility should be conspicuously posted in areas where exposure to the chemical could occur.

Ventilation: Special provisions should be made for ventilation of feed and storage rooms that contain hazardous chemicals.

Respiratory Protection Equipment: Respiratory protection equipment that meets the requirements of the National Institute for Occupational Safety and Health (NIOSH) should be available where hazardous materials are handled. The equipment should be stored in a convenient location, but not in a room where hazardous material is used or stored. The respirators should use compressed air, have at least a 30-minute capacity, and be compatible with or identical to units used by the fire department responsible for the plant.

Protective Equipment: At least one pair of rubber gloves, a dust respirator of a type certified by NIOSH for toxic dusts, an apron or other protective clothing, and goggles or face mask should be provided for each operator.

An emergency shower and eye-washing device should be installed where strong acids and alkalis are used or stored. Ensure that water flushing is compatible with the applicable MSDS and that a water holding tank which allows water to come to room temperature is installed in the water line feeding the emergency shower and eye-washing device. Other methods of water tempering may be considered. Additional protective equipment should be provided as necessary.

4.5.2.8 Specific Chemicals

Requirements for the storage and handling of specific chemicals commonly used in wastewater treatment are included in other chapters of this document.

4.5.3 Hazardous Chemical Handling

4.5.3.1 Containment Materials

Materials used for storage, piping, valves, pumping, metering, splash guards, etc., should be selected with careful consideration to the physical and chemical characteristics of the applicable hazardous or corrosive chemical.

4.5.3.2 Secondary Containment

It is recommended that the volume of the containment area be no less than 125 percent of the tank volume. Chemical storage areas should be enclosed in dikes or curbs that will contain the stored volume until it can be safely transferred to alternative storage or released to wastewater at controlled rates that will not damage facilities, inhibit the treatment processes, or contribute to pollution in receiving waters. Liquid polymer should be similarly contained to help prevent spills, particularly in areas with slippery floors (and on walkways in particular). Nonslip floor surfaces are desirable in polymer-handling areas. (Floors covered with polymer become slick when wet.)

4.5.3.3 Eye-Wash Fountains and Emergency Showers

Eye-wash fountains and showers using potable water should be available in the laboratory and on each floor or work location involving hazardous or corrosive chemical storage, mixing (or slaking), pumping, metering, and transportation (unloading). The eye-wash fountains and showers should be located as close as practicable to sites where chemical exposure may occur, and must be fully usable in all weather conditions.

Eye-wash fountains should be supplied with water of moderate temperature (50–90°F (10–32°C)), separate from the hot water supply, and suitable to provide 15–30 minutes of continuous irrigation of the eyes.

Emergency showers should be capable of discharging 30–50 gpm (1.9–3.2 L/s) of water at moderate temperature at pressures of 20–50 psi (1.41–3.52 kgf/cm^2). The eye-wash fountains and showers should be no more than 25 feet (7.6 m) from points of hazardous chemical exposure.

4.5.3.4 Protective Equipment

Personal protective equipment should be worn to protect the worker's body against contact with known or anticipated chemical hazards as per EPA levels of protection, to include level A, B, C, and D, as appropriate.

4.5.3.5 Splash Guards

All pumps or feeders for hazardous or corrosive chemicals should have guards that will effectively prevent spray of chemicals into space occupied by personnel. The splash guards are in addition to guards intended to prevent injury from moving or rotating machinery parts.

4.5.3.6 Piping, Labeling, Coupling Guards, and Location

All piping containing or transporting corrosive or hazardous chemicals should be identified with labels every 10 feet, with at least two labels in each room, closet, or pipe chase associated with hazardous chemical storage or transport. Color coding may also be used (see Section 4.4.5), but is not an adequate substitute for labeling. All connections (flanged or other type), except those adjacent to storage or feeder areas, should have guards that will direct any leakage away from space occupied by personnel. Pipes containing hazardous or corrosive chemicals should not be located above shoulder level except where continuous drip collection trays and coupling guards eliminate the potential for chemical spray or dripping onto personnel.

4.5.3.7 Protective Clothing and Equipment

The following items should be available and used for all operations and procedures where the use of protective clothing or equipment will minimize hazards to personnel:

- Respirators, of the air supply type recommended for protection against chlorine
- Chemical workers' goggles or other suitable goggles (safety glasses are insufficient)
- Face masks or shields for use over goggles

- Rubber gloves
- Rubber aprons with leg straps
- Rubber boots (leather and wool clothing should be avoided near caustics)
- Safety harness and line

4.5.3.8 Warning System and Signs

Systems should be provided for automatic shutdown of pumps and sounding of alarms when failure occurs in a pressurized chemical discharge line.

Warning signs alerting staff of the need to wear goggles should be located near chemical unloading stations, pumps, and other potentially hazardous areas.

4.5.3.9 Dust Collection

Dust collection equipment should be provided to protect personnel from dusts that are harmful to the lungs or skin and to prevent polymer dust from settling on walkways.

4.5.3.10 Container Identification

The identification and hazard warning data included on chemical shipping containers, when received, should appear on all containers (regardless of size or type) used to store, carry, or use a hazardous substance. Sewage and sludge sample containers should be adequately labeled to include the following:

- Sample point number
- Warnings for harmful bacteria and hazardous/toxic material
- Warnings for skin contact and consumption

4.6 Essential Facilities in Wastewater Treatment Plants

4.6.1 Emergency Power

There are certain facilities that require power at all times, and these "essential" facilities are dictated by whether the facility requires Reliability Class I, Class II, or Class III as defined in U.S. EPA's *Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability*, Technical Bulletin EPA-430-99-74-001. These essential facilities may include preliminary treatment, influent pumping, primary treatment, aeration equipment, intermediate pumping, disinfection, effluent pumping, critical lighting and ventilation (excluding odor control), and sludge processing required to keep primary treatment units functional. Emergency power should be provided for SCADA and critical control systems; this is a low power demand, but the loss of control systems can significantly affect the ability to recover from power outages. The use of a battery power system (uninterruptable power supply or UPS) is recommended for SCADA and other control systems. Additionally, the reviewing authority may require full power at all times for secondary waste discharge systems that discharge to critical stream segments, such as upstream of bathing beaches or public water supply intakes.

Two separate and independent sources of electrical power should be provided. The sources can be two separate utility substations or a single substation with on-site generators. On-site generators may provide a more reliable source of backup power should regional utility outages, impacting more than one utility substation, occur. At a minimum, the backup power source should be sufficient to operate all essential facilities, including critical lighting and ventilation, during peak wastewater flow.

4.6.2 Water Supply

4.6.2.1 General

An adequate supply of potable water under pressure should be provided for use in the plant (including in the laboratory, laundry, and lavatory/locker areas), and for fire protection and general cleanliness around the facility.

4.6.2.2 Total Facility Containment

All potable water supply mains should be protected against contamination with an approved reduced-pressure-zone backflow preventer.

4.6.2.3 In-Plant System Protection

No additional backflow protection is needed on potable water lines serving lavatory sinks, water closets, laboratory sinks (if protected against back siphons), showers, drinking fountains, and slop sinks (if protected against back siphons). However, where the potable water supply will be used for purposes other than those listed above, a backflow protection device that meets the requirements of the local authority is required.

Consider minimizing the number of backflow devices required by providing a separate nonpotable, in-plant water system using a single backflow protection device. An OSHA-approved sign should be permanently posted at all sill cocks, hose bibs, and other applicable fixtures on the nonpotable system, indicating that the water is not safe for drinking.

4.6.2.4 Separate Potable Water Supply

In situations where it is not possible to provide potable water from a public supply, provide a separate well. The location and construction of the well must comply with requirements of the appropriate state agency. Requirements governing the use of the supply are contained in Sections 4.6.2.2 and 4.6.2.3.

4.6.2.5 Separate Nonpotable Water Supply

Where a separate nonpotable water supply will be provided (such as plant effluent water), a backflow prevention device will not be necessary; however, all sill cocks and hose bibs should be posted with a permanent OSHA-approved sign indicating the water is not safe for drinking.

4.6.2.6 Hydrants

Hydrants for fire protection and hydrants for yard use should be clearly distinguished from one another with different paint colors, and should have different-sized nozzles for hose connections. The locations of hydrants for fire protection and the locations of backflow prevention devices should be approved by the local fire department.

4.7 Wastewater Flow Measurement

4.7.1 Liquid Flow Streams

Suitable facilities for measuring, recording, and totaling the flow of wastewater should be provided. Principal flow measuring equipment must be installed at the influent and effluent ends of the treatment facility. Care must be taken to measure the influent raw wastewater prior to any recycling of the wastewater within the plant. Where this is not possible, a separate means of measuring the recycled wastewater should be provided. Wet-weather flows receiving only primary treatment should be separately metered at the discharge of the primary treatment system.

Plant influent flow measurement should be of the "true" influent, not including sidestream returns. In those rare cases where this is infeasible due to the configuration of the incoming collection system or some other hydraulic constraint, it is permissible, at the discretion of the approving authority, to measure both the influent-plus-sidestream flow and the sidestream flow, and then do the appropriate subtraction to determine influent flow.

4.7.2 Sludge Streams

Adequate facilities for measuring, recording, and totaling the flow of return activated sludge, primary sludge, waste secondary sludge, and other major sludge streams should be provided.

4.7.3 Flow Measurement Equipment

All flow measurement equipment should be sized to perform effectively over the full range of expected flows, and should be protected against freezing. Flow measuring equipment should ensure that the required hydraulic conditions necessary for accurate measurement are provided. Conditions that upset the normal hydraulic conditions necessary for accurate flow measurement should be avoided. These include turbulence, eddy currents, inadequate straight runs prior to metering, and air entrainment. For critical flow metering equipment, consider designing a bypass around the meter to allow for removal for servicing, particularly in scenarios where no redundancy exists and in installations with smaller diameter piping. While such access for servicing may not be a critical concern in new construction, it is important and is often limited by a failure to anticipate the need.

4.8 Plant Outfalls

4.8.1 Outfall Discharge

For surface water discharge facilities, the outfall should discharge to the receiving stream in a way that is acceptable to the approving authority. Consideration should be given in each case to the following:

- Preference for free fall or submerged discharge at the site selected.
- Use of cascade aeration of effluent discharge to increase dissolved oxygen.
- Limited or complete across-stream dispersion to protect aquatic life.
- Plant growth in the immediate reaches of the receiving stream.
- Generation of hydropower at the outfall if there is sufficient drop in elevation.
- Impact of the mixing zone on the receiving waters; in particular, consider the impact as it corresponds to stipulations in the regulatory agency's classification system for water bodies.

4.8.2 Protection and Maintenance

The outfall should be constructed to protect against flood waters, tide, ice, or other hazards to ensure its structural stability and freedom from clogging. Outfall structures should prevent backflow during high tide or flood conditions. New outfall structures may require permitting through the U.S. Army Corps of Engineers, FEMA, and/or local designee such as the state environmental agency. A manhole should be provided at the shore end of all gravity outfalls extending into the receiving waters. When designing an outfall, consider hazards to navigation.

4.9 Protection of Plant Staff and Visitors

To ensure that visitors and plant staff are protected from hazards, the following should be provided:

- A fence and signs around the plant, and a formal visitor sign-in station designed to discourage unauthorized persons from entering.
- Hand rails, guards, safety netting, and barricades around tanks, trenches, pits, stairwells, floor openings, maintenance access areas, and other hazardous structures.
- Gratings over spaces that provide access for maintenance.
- First aid equipment, including universal precaution equipment (gloves, gowns, aprons, masks, and protective eyewear) as per Centers for Disease Control (CDC) guidelines.
- Appropriately placed warning signs and labels as per OSHA and state requirements for slippery areas, nonpotable water fixtures, low head clearance areas, open service manholes, hazardous chemical storage areas, flammable fuel storage areas, and confined spaces.
- Personal protective equipment as per OSHA standard 1910: Subpart I, to include:
  - Eye and face protection.
  - Respiratory protection.
  - Head, hand, and foot protection.
  - Electrical protective devices.
- Portable blower with adequate flow rate to be intrinsically safe and explosion-proof if used in hazardous areas with sufficient hose and manway duct adapter.
- Portable lighting equipment complying with National Electric Code requirements.
- Gas detectors certified for use in locations designated as Class 1, Division 1, Group A, B, C, and D, per NFPA 820.
- Adequate ventilation in pump stations, in accordance with NFPA 820.
- Provisions and equipment for the control of hazardous energy as per OSHA and state requirements.
- Provisions and equipment for permit-required confined space entry as per OSHA and state requirements.
- Fire-protecting systems, life safety systems, and smoke detection systems, in accordance with federal and state law.

4.10 Sampling

4.10.1 Sampling Sites

All personnel should be able to access sampling sites, which should not be located in confined space areas. Sampling sites should be free of tripping, slipping, and falling hazards. Sampling locations should be marked so all operators and lab technicians take samples at the same locations. For personnel safety, railings and nonslip floor surfaces should be present at sampling sites.

Regulatory agencies may have established requirements regarding locations of influent and effluent sampling, for reporting purposes. Select sampling locations and depths that are representative of average influent and effluent constituent concentrations. Avoid sampling influent, especially, from locations where solids may collect. Consider effects of sidestreams and septage or other trucked outside wastes. Influent samples must be taken before the entrance of sidestreams.

Automatic samplers should be located in readily accessible areas. These samplers should be housed in an enclosed and, if needed, heated structure to prevent freezing. If appropriate, the sampling sites should have a supply of electrical power with a ground fault interrupt. Batteries should be available in the event of a power outage.

4.10.2 Sampler Types

All sample buckets should be made of an inert substance such as hardened plastic, stainless steel, or a Teflon-coated material, with the specific choice depending on which types of tests will be performed.

To generate flow-weighted composite samples, composite samplers should be connected to a signal for flow measurement, if possible. If readings can be obtained only on circular or strip charts, then the composite sampler should have 24 discreet sampler bottles that take samples every hour; the sampler should require composite samples to be manually produced.

4.10.3 Sample Preservation

All samples should be preserved and all holding times should be maintained as outlined in *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WEF, 2005) or EPA protocols. In addition to following standard methods, holding times and temperatures should conform to 40 CFR 136.

Samplers should be able to preserve a sample at less than or equal to 43°F (6°C), when necessary, whether using a refrigerated sampler or one in which ice can be placed. Refrigerated samplers are preferred.

4.11 Laboratory Equipment and Needs

4.11.1 General

Wastewater facilities should include a laboratory adequate for all necessary on-site wastewater analysis, process control tests, discharge testing as required by permit, and quality control analysis. The laboratory's size should be determined by the size and complexity of the wastewater facility and the proposed laboratory staffing plan. The laboratory should have adequate floor space, cabinet space, counter space, analytical equipment, and supplies to perform all necessary analysis.

Adequate supplies, equipment, and space should be included for any industrial pretreatment program, and the possibility of future expansion should be incorporated into the lab's design.

4.11.2 Location and Floor Space

The laboratory should be within the treatment facility and easily accessible from all sampling sites. It should not be located near vibrating machinery or other equipment that might have adverse effects on the performance of the laboratory equipment and personnel.

Benchtop working surfaces should occupy approximately 35 percent of the total floor space. The minimum ceiling height should be 8 feet 6 inches (2.0 m). Heights should be extended for stills, distillation racks, hoods, emergency showers, and other items.

4.11.3 Furniture, Benchtops, and Sinks

Cabinets: The cabinets should be durable and, if flammable solvents are to be used, they should be vented and fireproof. For acid storage, use vented cabinets with corrosion-proof trays.

Cabinets should have drawers with stops to prevent accidental removal. Cabinets and benchtops should have the necessary utilities, such as vacuum, gas, air, and electrical fixtures, built into them and be easily accessible. Shelves should be adjustable.

If possible, cabinets hung on walls should have sliding glass doors. Storage space should be sufficient for all laboratory equipment, reagents, glassware, and general equipment. In areas where flooding is a possibility, cabinets should be designed to remain closed in the event of a flood to prevent chemicals and supplies from mixing into floodwaters.

Countertops: Benchtop working surfaces should occupy approximately 35 percent of the total floor space. Countertops should be made of a material resistant to typical laboratory-grade chemicals and should have splashbacks. Benchtops should be 36 inches (914 mm) wide, but when located in areas where sit-down operations are performed, may be 30 inches (760 mm) wide and include a kneehole space. Overhangs and drip grooves should be provided to keep liquid spills from running along the face of cabinets. Benchtops should be joined with chemical-resistant cements.

Sinks: A minimum of two laboratory-grade sinks should be provided (not including cup sinks). One of the sinks should have a drainboard. Hot and cold potable water should be provided. All sink drains should be made of acid-resistant material.

Balance Tables: A balance table should be of adequate size and weight to minimize vibrations that could affect balance readings. The table should be located in an area relatively free of drafts and away from other equipment that could interfere with the use of the balance.

Note: Additional cabinet and benchtop space should be provided if advanced treatment and/or industrial monitoring and wastewater analysis is performed.

4.11.4 Fume Hoods and Ventilation

Fume Hoods: Fume hoods should be provided for all laboratories in which acidic, basic, solvent, or noxious fumes may be present. The rate of air flow through the fume hood should be at the prescribed industry rate, and the hoods should not be located where there is substantial air disturbance, such as near an HVAC inlet or outlet. If hoods are located near a door, an additional means of egress should be provided.

The types of substances used in the laboratory, and the production of fumes or vapors by these substances, should dictate the hood materials and hood used. If perchloric acid is to be used, a perchloric acid fume hood and necessary plumbing will need to be installed.

A cup sink and any necessary utilities should be incorporated into the design of the hood. All electrical switches, electrical outlets, utility handles, and hood adjustment switches should be located outside of the hood. Light fixtures should be explosion-proof, and all electrical outlets should include a ground fault interrupt.

Lights, ductwork, and fan materials should be corrosion-resistant to the fumes and gases expected in the fume hoods. To prevent fumes designated for a particular hood from entering an adjacent hood, exhaust ducts from multiple fume hoods should not have one common manifold. Exhaust ducts should discharge outside the laboratory building and away from traveled areas.

Canopy hoods should be installed over benchtop areas where steam baths, muffle furnaces, or hot plates are used.

Exhaust fans should be explosion-proof. Exhaust air velocity should be checked when the hood is installed.

Ventilation: Laboratories should be ventilated properly with external air supply for 100 percent makeup volume. Separate exhaust ventilation should be provided. Ventilation outlets should not be located near ventilation inlets. Additionally, laboratory air supply vents should not be located directly over sensitive equipment. Exhaust ventilation should be provided for all hoods. Energy efficiency or heat exchangers in the ventilation system should be considered, as frequent air changes can significantly impact energy costs.

4.11.5 Floors and Doors

Floor surfaces should be slip-resistant and fire-resistant, as well as highly resistant to acids, alkalis, solvents, and salts.

The laboratory should have at least two exit doors, with glass windows for easy visibility, to allow for straight egress. Panic hardware should be used.

4.11.6 Electrical

All electrical outlets near any source of water should be installed with ground fault interrupts. Line voltage regulations should be considered for delicate laboratory instruments. A 240/120 volt power supply should be made available. Laboratory equipment that uses 240 volts should be considered for electrical savings.

4.11.7 Plumbing

Gooseneck faucets should be supplied for laboratory sinks, where applicable. Before plumbing is installed, consider the types of substances that may be disposed of in the drain lines. If needed, acid- or chemical-resistant waste drain lines should be used. To prevent cross-connections, a control program is recommended. If appropriate, neutralization tanks should be used.

4.11.8 Gases, Vacuum Cleaning, and Air Supply

If necessary, natural gas should be supplied to the laboratory. Digester gas should never be used. Suitable gas outlets should be provided. A source of suction for vacuuming should be provided along with appropriate outlets. A clean source of pressurized air should be supplied to the laboratory. Air filtration may be needed for applications such as measuring BOD.

4.11.9 Laboratory Reagent Water

Reagent water should be provided to the laboratory. Class I water should be available for reagent preparation and other critical solutions. Class II water should be provided for all other general tasks. These waters should be provided by deionization or distillation. Incoming water should be pretreated by a method such as softening.

In all laboratories, a dishwasher with steam wash and deionization water rinse may be appropriate.

4.11.10 Reagents and Storage

Sufficient space should be available for storage of all reagents, chemicals, and laboratory solutions. Storage space should allow for the segregation of noncompatible substances. A flameproof cabinet should be supplied for all flammable substances. A vented, corrosion-proof cabinet should be provided for all concentrated acid solutions.

4.11.11 Laboratory Equipment and Supplies

All analytical testing to be performed by a facility should be set forth in a list that is made available. This list and the latest edition of either the *Standard Methods for the Examination of Water and Wastewater* or EPA's *Analytical Procedures Manual* should guide the selection of equipment, supplies, and reagents needed to carry out laboratory testing related to permit requirements, in-house process control, and industrial monitoring (if analysis is performed in-house). Extensive input from laboratory personnel should also influence the selection of supplies. A digital analytical balance with a 0.1 milligram sensitivity should be provided. The laboratory should contain adequate cabinet and drawer storage space to store equipment and supplies.

Note: Some of the required analytical tests may be so elaborate as to make it more cost-effective to have these tests performed by an outside laboratory.

4.11.12 Hazardous Waste Storage and Disposal

Provisions should be made for storing hazardous materials, such as COD waste and concentrated metal solutions. Appropriate containers should be used, with a secure space provided for storage of containers.

4.11.13 Safety Equipment

All laboratories should be equipped with safety items such as full face shields, goggles, first aid kits, fire extinguishers, fire blankets, emergency showers, eye-wash stations, thermal gloves, chemical-resistant gloves, chemical spill kits, protective clothing, and aprons.

All eye-wash and emergency showers should have connections to potable water. These facilities should be located within a reasonable distance of, but not immediately adjacent to, areas of potential chemical exposure. Eye-wash stations should be supplied with water at moderate temperatures, and should provide at least 30 minutes of continuous irrigation of the eye. The emergency showers should be capable of discharging 30–50 gallons of water per minute at pressures of 20–50 pounds per square inch.

Signs should be posted indicating where fuels and flammable, caustic, acidic, highly reactive, and other potentially dangerous materials are stored. Post “No Smoking” signs in appropriate places. Space should be provided to post and store material safety data sheets (MSDSs) for all reagents used in the laboratory.

Fire extinguishers should be supplied as listed in the fire codes.

4.11.14 Office Space

Space for administrative work related to the laboratory should include a benchtop or desk area for performing necessary calculations and filling out paperwork. Space for file cabinets should be provided.

4.12 Personnel and Administrative Facilities

Treatment facilities should include sufficient administration, meeting/conference, kitchen/dining, and locker areas for employees. Supervisors need office space to carry out management tasks, including completion of paperwork, ordering of supplies, scheduling of work, and review and/or disciplining of employees. The administrative area should also include space to safely store plans, specifications, and training material related to the facility. In locations where flooding may occur, consider storing plans and other vital records above the 100-year flood level (e.g., on the second floor).

All employees need a clean area in which to prepare meals and eat. At a minimum, a lunch room with a kitchenette should be provided.

Locker rooms with toilets and showers for male and female employees are essential in wastewater treatment facilities. Locker rooms should provide at least two full-size vented lockers per employee as well as space to store foul weather gear and personal protective equipment used to respond to spills within the facility. Laundry areas should be considered, especially for larger plants.

The floor area of these facilities will vary with the size of the plant, number of employees, and work schedules. For plants with 24-hour staffing, more space will be needed since two shifts must share locker and office facilities during shift changes.

To facilitate communication, consideration should be given to locating the facility's control room near the office space devoted to management and supervisory staff.

References – Chapter 4

American Public Health Association, *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WEF), 21st Edition, 2005

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CHAPTER 5

PRELIMINARY AND PRIMARY TREATMENT

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5.1 Pretreatment

5.1.1 Screening Devices

Screens should be installed to protect pumps and treatment facilities. If installation of screens or handling of screening devices is impractical, comminuting/grinding devices can be used. However, such devices have limitations, as described in section 5.1.1.3.5.

5.1.1.1 Location

The appropriate location of screening devices with respect to pumping and grit removal facilities varies, depending on the physical characteristics of the facilities. In determining location, the primary factor should be protection of downstream equipment. In selecting the location, type, and opening size, consider the effects of backwater caused by head loss through screens.

5.1.1.2 Combined Sewer Systems

Peak flows during wet weather conditions can differ significantly from flows during average dry weather conditions; peak wet weather flows are intermittent and typically have short durations. Combined sewer systems can convey large objects that may be difficult to remove and may cause damage to screens. Wet weather flow can contribute several times the coarse screenings seen during dry weather flow in separate sewer systems.

5.1.1.3 Design and Installation

5.1.1.3.1 General

Whenever possible, screening devices should be located in weatherproof enclosures. If this is not an option, provide heat tracing and insulation to ensure operability of equipment under extreme temperatures, and make provisions for protecting screenings from windy environments. Consider electrical classification of the space in accordance with NFPA 820 and evaluate whether explosion-proof or other specialty motors and controls are required, as is customary. When flooding might occur in an area containing motors, consider using elevated, immersible, or submersible drive motors; or flood-proof hydraulic drive systems. Adequate lighting must be provided.

Examine whether bar-type screens with long narrow openings are adequate, or whether perforated plate or cross-wire mesh screens may be required to prevent debris from passing sideways through the long openings. The need for such additional screening is largely dictated by the sensitivity of downstream processes.

Mechanically cleaned screening devices, such as chain-driven, reciprocating rake, catenary, continuous belt, and rotating drum mechanisms, are generally recommended over manually cleaned devices wherever feasible. Combined sewer systems especially should be provided with mechanically cleaned devices since large quantities of wet weather debris are difficult for operators to handle manually. More frequent bar screen cleaning is highly recommended during wet weather events to prevent blinding. Bar spacing is a critical consideration; smaller openings may blind more easily during wet weather flow due to the large range of particle size.

Electrical equipment, particularly equipment that runs continuously, should be designed with energy efficiency in mind. Use automated controls where practical, install premium efficiency motors, and ensure motors are properly sized.

Screening devices should be readily accessible for inspection and maintenance.

5.1.1.3.2 Trash Racks

Unobstructed openings between bars should be 1.5–3 inches (3.8–7.6 cm) wide. Trash racks need be considered only in situations where logs and other large floating trash might be present, such as in combined sewers.

5.1.1.3.3 Manually Cleaned Screens

Unobstructed openings between bars should be 1–2 inches (2.5–5 cm) wide. Manually cleaned screens should be placed on a slope of 30–45 degrees with the horizontal. The design and installation of screens should provide for convenient cleaning and draining of raked material.

5.1.1.3.4 Mechanically Cleaned Screens

Unobstructed openings between bars are generally 0.25–1.5 inches (0.6–3.8 cm) wide. Some downstream treatment processes, including integrated fixed-film activated sludge (IFAS) media and membrane bioreactors (MBRs), require finer screening (as low as 1–2 mm in both directions). To avoid excessive head loss and damage to very fine screens, multiple stages with screens of progressively smaller openings are typically required. Close coordination with manufacturers of sensitive downstream treatment processes is essential.

5.1.1.3.5 Comminution/Grinding

In general, removal of objectionable material by screening is desirable. When this is not feasible, however, comminution/grinding devices may be installed to chop or shred material below the surface of the wastewater. Follow manufacturer's data and ratings for channel dimensions, capacity ranges, upstream and downstream submergence, and horsepower requirements. Comminution capacity should be adequate to handle peak flows with acceptable head loss, with the resulting ground pieces being small enough to prevent blinding of downstream process-equipment openings. Gravel traps should precede comminution devices not equipped with grit removal equipment.

Provisions should be made for cleaning areas downstream of the comminution devices, which may accumulate deposits of plastics and ropes, or balls of rags. Grinding is not a desirable option upstream of sensitive processes, as reaggregation of ground material is a possibility. Grinding may also be problematic upstream of pumps as rags or stringy materials may pass through grinders and clog pumps.

5.1.1.3.6 Velocities

Screen chambers should provide good velocity distribution across and through the screen. Approach velocities in screen channels should be at least 1.3 feet per second at minimum flows (2.0 ft/sec is preferred if possible), or 2.5 ft/sec during diurnal peak flow periods. Approach velocities in screen channels serving combined systems should be at least 3 ft/sec during storm flows. Velocities through openings of mechanically cleaned screens should be 2–4 ft/sec. Velocities through manually cleaned screens should be limited to 1–2 ft/sec. The velocity through openings should be calculated from a vertical projection of the screen openings on the cross-sectional area between the invert of the channel and the flow line.

5.1.1.3.7 Channels

Entrance channels should provide equal and uniform distribution of flow to screens. Channels should be equipped with necessary gates to isolate flow to and from any screening unit. Channels preceding and following the screens should be shaped to eliminate deposition of solids. For combined sewer systems, special channel configurations, or multiple channels, may be required to provide appropriate approach velocities during peak flows but minimize solids deposition during low flow conditions.

5.1.1.3.8 Bypass Screens

Installations using mechanically cleaned screens or comminution devices should include multiple units or a manually cleaned bypass screen. In facilities with two or more mechanically cleaned screens, the design should allow any one unit to be removed from service without sacrificing the capability of other screens to handle peak design flows. Where a manually cleaned bypass screen is used, overflow to the bypass channel should occur when the influent channel is flowing at a depth corresponding to the maximum design flow through the screen or comminution device. Overflow to the bypass screen should be passive, such as over a weir; mechanical requirements should be minimized. Bypass screens should have openings small enough to protect downstream equipment, and a level indicator and alarm should be installed to notify plant staff of flow going through the bypass screen channel.

5.1.1.3.9 Wet Weather Flow Screens

Treatment requirements for wet weather flow (and stormwater) are becoming more strict. Generally, the screen types discussed above are used for screening of wet weather flow at existing treatment facilities. There are also screens developed particularly for preliminary treatment of wet weather flow before the flow is discharged as combined sewer overflow (CSO) at upstream (satellite) discharge points. CSO screens are typically designed to screen materials from CSO discharges and automatically return the screened material directly into the dry weather flow stream for conveyance to a downstream treatment facility; this practice negates the need to handle screened material at an upstream facility. Types of screens include static, self-cleaning, horizontal, and vertical.

5.1.1.4 Access and Ventilation

It is essential to provide stairway access or ladders for screens located in pits, as required by building codes and/or OSHA. Pits should have adequate lighting and ventilation, ample space for maintenance, and convenient and adequate mechanical means for removing screenings.

Screening devices installed in a building where other equipment or offices are located should be isolated from the rest of the building. Screening areas must be adequately ventilated, and should be accessed through separate outside entrances. Wall penetrations between screening areas and other building areas should be sealed against gas leaks.

Fresh air should be forced into enclosed screening areas and pits. Dampers should not be used on exhaust or fresh air ducts. Obstructions in ducts, including fine screens, should be avoided. Consult NFPA 820, OSHA, or other applicable codes and guidelines regarding ventilation of the space. If continuous ventilation is not possible, intermittent ventilation capable of providing frequent air changes must be provided. Where spaces requiring frequent air changes are to be heated, measures to increase energy efficiency should be considered to reduce future operating costs. Such measures include effluent-source heat pumps, solar thermal heating, reduced frequency of air changes during cold temperatures as permitted by applicable codes, and heat exchangers. It is also helpful to keep the volume of space that needs continuous ventilation to a minimum.

Switches for operating ventilation equipment should be marked and conveniently located. Ventilation equipment that is intermittently operated should be connected into the lighting system. Fan wheels should be fabricated from nonsparking material. Gas detectors should be provided in accordance with applicable codes and be appropriate for the electrical classification of the space, in accordance with NFPA 820 or other applicable codes and guidelines.

So that large screening equipment can be removed when necessary, it is important to outfit buildings with skylights or removable wall panels.

5.1.1.5 Safety Devices

All open channels should be protected by guard railings and/or deck gratings with adequate provisions taken to facilitate cleaning and maintenance.

Mechanical screening equipment should have sufficient removable enclosures to protect personnel against contact with moving parts and to prevent dripping in multiple-level installations. A positive means of locking out each mechanical screen for maintenance should be provided. When main control panels are located in a separate room, it is recommended that a local disconnect and emergency stop button be installed in close vicinity to the screen.

5.1.1.6 Screenings Handling and Conveyance

There should be adequate facilities for removal, handling, storage, and disposal of screenings. Separate grinding of screenings with return to the wastewater flow should not be considered. Disposal of screenings must be performed in accordance with federal, state, and local regulations; note that some states may require screenings to be disposed of as special wastes, meaning disposal may not be allowed at municipal landfills.

In combined sewer systems, the quantity of screenings captured during storm events may be significantly higher, relative to the flow, than during dry weather flow conditions, especially in smaller wastewater treatment facilities.

Manually-cleaned screens should be accessible via a platform from which screenings can be raked easily and safely. This platform should consist of a perforated plate for drainage of the raked screenings.

Hoses should be provided to facilitate cleaning of screening and storage areas. In facilities where conveyors are used to convey screenings from the screens to a processing location, the conveyors should provide drainage of screenings. When sluice troughs are used to convey screenings, adequate drainage should be provided at the collection location. Enclosed conveyance systems such as pneumatic ejectors should be designed with clean-out valves and high-pressure water service at all curves in the system's route.

When required by regulatory authorities or where practical, screenings wash presses should be provided to reduce the organics and water in screenings and to minimize the volume of screenings for disposal. Grinders may also be added to wash press devices. Presses may discharge dewatered screenings to containers or bagging devices, per plant preference. Verify that specified containers are small and light enough to be maneuvered in the available space.

5.1.1.7 Control Systems

Monitoring and instrumentation is discussed in Chapter 13. Note the following considerations specific to screening facilities.

5.1.1.7.1 Cleaning Cycle Triggers and Timing Devices

Most mechanically-cleaned screens should have cleaning cycles triggered by preset high-water levels or differences in water levels. Some mechanical units are operated primarily by timing devices; these should have auxiliary controls that initiate cleaning at preset high-water levels even if the time interval has not been met.

5.1.1.7.2 Electrical

Electrical systems and components in enclosed spaces where hazardous gases may accumulate must meet the requirements of the National Electrical Code for Class I, Division 1, Group D. Refer to NFPA 820.

5.1.1.7.3 Alarms

Alarms should be provided for high upstream water levels and screen start/fail/jam conditions. Some manufacturers offer sensors on mechanical cleaning arms and wash compactors that sense jams and attempt to clear them with an auto-reverse function before alarming and shutting the equipment down.

5.1.1.7.4 Auxiliary Equipment

Auxiliary equipment, including spray wash, conveyors, ejectors, and screenings compactors, should be interlocked with operation of the screen.

5.1.1.7.5 Manual Override

Manual overrides should be provided for all automatic controls.

5.1.2 Grit Removal

Grit removal is a key step in the treatment process at wastewater facilities, except those that rely on natural processes to allow grit and biosolids to settle on the bottom of lagoons or those that apply grit directly to land. Many older facilities may not be configured with dedicated grit removal; instead, grit is collected with primary settled sludge that is then degritted. If a plant is designed without grit removal facilities, the plant should have enough area and hydraulic head so grit removal may be added at a later date.

5.1.2.1 Location

5.1.2.1.1 General

The location of grit removal facilities should be determined by the effects of grit on downstream treatment units and other plant design factors. It is generally preferred to have grit removal located ahead of influent pumps; however, specific design situations such as the need to place grit removal at great depths may warrant other arrangements.

5.1.2.1.2 Outside Facilities

Grit removal facilities installed outdoors should be protected to prevent freezing.

5.1.2.1.3 Housed Facilities

Consult NFPA 820, OSHA, or other applicable codes and guidelines regarding ventilation of the space. Consider odor control facilities. Electrical equipment located in enclosed grit removal areas where hazardous gases may accumulate should meet requirements of the National Electrical Code of Class I, Division 1, Group D. Explosion-proof gas detectors should be provided in accordance with applicable codes. Refer to NFPA 820.

5.1.2.2 Design Factors

5.1.2.2.1 General

The effectiveness of a grit removal system should be commensurate with the requirements of subsequent treatment units. Accepted practice is to provide for removal of 95 percent of particles with a specific gravity of 2.65 that pass through a 65 or larger screen mesh (approximately 235 microns). Existing plant data should be used with caution when designing upgrades to grit removal systems, as accumulated grit in a collection system typically gets washed into a plant in large quantities during high flow events. The size and quantity of grit particles may be significantly greater in combined sewer systems compared to separate sewer systems, especially during storm or snowmelt conditions. In such situations, grit systems may prove to be inadequate if the increase has not been anticipated. Grit characterization studies performed by firms engaging in such work should be considered when grit characteristics and average particle size are unknown.

5.1.2.2.2 Inlets and Outlets

Inlet turbulence should be minimized in all types of grit removal units. Influent flow to aerated grit chambers should be introduced on the same side of the tank as the aeration devices; the flow should be parallel to and at the top of the spiral flow pattern created by the aeration. Vortex removal systems are most effective when they create a smooth flow pattern into the tank; this is critical to minimize turbulence at the inlet of the chamber. Therefore, inlet and outlet configurations on vortex systems should be closely coordinated with the manufacturer.

5.1.2.3 Type and Number of Units

Grit can be removed in grit chambers or by centrifugal separation of primary sludge. Acceptable grit chambers include aerated, vortex (including induced vortex and multi-tray vortex units), detritus, and horizontal flow (velocity control tanks) units. Plants serving combined sewer systems should have at least two mechanically cleaned grit removal units. A single, manually or mechanically cleaned grit chamber with bypass is acceptable for small plants serving sanitary sewer systems. Large plants serving separate sewers should, at a minimum, have at least one mechanically cleaned unit with bypass.

Facilities other than channel-type operations should have adequate and flexible controls for velocity and/or air supply devices, and possess grit removal and collection/washing equipment. When deciding between velocity and air supply devices, consideration should be given to lifecycle costs, including energy costs. In general, if both systems provide the same level of treatment, the system with the lower energy costs should be chosen.

5.1.2.3.1 Detritus or Square Tank Grit Removal Systems

Detritus or square degritting tanks were some of the earliest grit chambers employed in wastewater treatment plants. These tanks are designed to use a constant-level, short-detention-time settling method that will settle both heavy organics and grit. As such, they require a grit-washing step to remove trapped organic material from collected grit. Designs should incorporate a grit auger and a rake that removes and classifies grit from the grit sump to a grit washing/dewatering and organics return system.

Detritus tanks are sized on an overflow rate based on particle sizes. Design considerations for tank depth include minimizing the horizontal velocity and turbulence while maintaining a short detention time (typically less than one minute). An additional 6–10 inches of depth should be provided for the raking mechanism. These tanks are typically designed to remove 95 percent of the 100 mesh (150 microns) particles at a facility’s peak flow.

As this type of grit removal system relies on well distributed flow into the tank, inlet weirs, vanes, or deflectors should be employed to generate an even flow pattern straight across the tank to the outlet weir. These systems may also be impacted by turbulence or short circuiting under higher flow conditions, thus the overflow rate should be designed with a factor of safety of 2.0. Detritus tanks are not recommended for highly variable flow conditions unless flow equalization is employed.

5.1.2.3.2 Horizontal Flow (Rectangular Tank) Grit Removal Systems

Another early grit removal system is horizontal flow grit chambers, which use proportional weirs or rectangular control sections (such as Parshall flumes) to vary depth of flow and to maintain a flow stream velocity of 1 ft/sec. Chain and flights are used to scrape grit up an inclined slope for dewatering or into a hopper for removal by pump, auger, or chain-and-bucket elevator.

These tanks are typically designed for a detention time of 60 seconds with a velocity of 1 ft/sec though the tank. It is important to modify design criteria according to the settling velocity of the target grit particle and to use the flow control section/depth relationship of the tank to govern the length of the specified channel. The length of the channel must include an allowance for inlet and outlet turbulence, therefore it is recommended that the designed length incorporate a factor of safety of 50 percent increase of the calculated tank length for a typical application is recommended.

5.1.2.3.3 Aerated Grit Chambers

Aerated grit chambers should have outlet baffles designed to minimize short circuits. Flow through the tank should be perpendicular to the spiral flow pattern.

Horizontal flow chambers should control velocities as close as possible to 1 ft/sec. Detention should be based on the size of particles to be removed.

A chamber length-to-width ratio ranging from 3:1 to 8:1 is necessary, with longer tanks providing better grit removal. A width-to-depth ratio of 0.8:0.9 is necessary to prevent short-circuiting down a quiescent central core not affected by the roll pattern.

A floor slope of 30 degrees is recommended to ensure quick movement of grit into the longitudinal grit collection sump and to prevent reentrainment of fine grit by the spiral roll. Inadequate floor slope is a common design error in aerated grit chambers, and should be carefully considered, particularly in retrofits or upgrades to existing facilities.

Aerated grit facilities should be provided with variable air flow rates in the range of 3–8 standard cubic feet per minute for every foot of tank length. Providing some combination of variable speed blowers, valves, and flow meters to adjust air flow is good engineering practice and helpful for facilities that experience wide ranges in influent flow. Specific design requirements for aeration blowers, diffusers, process piping, and control systems are detailed in Chapter 6 and 13 of this report.

Minimum hydraulic detention time should be 3–10 minutes based on design peak hourly flow rate. It is not unusual to design aerated grit chambers with hydraulic detention times of 15 minutes and more, particularly if there is a need to capture fine grit with a size profile greater than 65 mesh (approximately 235 microns).

Motors should be appropriately sized, built to premium efficiency standards, and be equipped with automated controls to minimize runtime and demand where appropriate. Air supplying motors should be located as close as practical to the grit chamber and be connected in the most direct manner to minimize losses to friction.

5.1.2.3.4 Mechanical Vortex Grit Removal Systems

Mechanical vortex grit removal relies on a mechanically enhanced vortex flow pattern in shallow, short-detention-time circular tanks to capture grit solids in a center hopper. At the end of the inlet flume, a ramp causes grit that may already be on the flume bottom to slide down along the ramp until reaching the chamber floor where the grit is captured. At the center of the chamber, adjustable rotating paddles maintain proper circulation within the chamber for all flows and help lift organics out of the grit sump. The vortex flow pattern creates a quiescent central zone in the tank where the grit that settles is captured, while organics stay in suspension. Grit solids are removed from the center hopper by top-mounted, self-priming pumps or by below-grade, flooded-suction pumps.

Generally, the straight inlet channel length into a vortex grit chamber should be seven times the width of the inlet channel or 15 feet, whichever is greater. However, designers are encouraged to consult the system manufacturer to confirm these minimum requirements prior to design.

The ideal velocity in the influent channel is 2–3 ft/sec. This range should approximate flows of 40–80 percent of peak flow. The minimum acceptable velocity at low flow conditions is 0.5 ft/sec, because at lower velocities, grit will not be carried into the chamber for removal. If velocities as low as 0.5 ft/sec will be experienced, provisions for flushing are necessary to move settled grit into the tank. It is important that the flushing system not wash grit through the grit chamber.

5.1.2.3.5 Induced Vortex Grit Removal Systems

Induced vortex grit removal systems are fundamentally different from mechanical vortex systems, because the vortex is created by the force of incoming flow. As a result, the basins are smaller in diameter than mechanical systems, but require the flow into them to be pumped to create the force necessary to drive grit removal. In addition to a smaller footprint, these systems can be designed to remove a higher percentage of fine grit than other grit removal systems.

Because significantly more head loss is required to drive the process, these systems are typically installed on a platform or other support structure to fit within the hydraulic profile of the rest of a facility. According to MOP-8, the range of head loss for these units is 16–23 feet for removal of 95 percent of 25μm grit (>400 mesh).

5.1.2.3.6 Multi-Tray Vortex Grit Removal Systems

The multiple-tray vortex system is a proprietary system that uses a flow distribution header for distributing influent over multiple conical trays stacked on top of each other. The tangential feed into the trays establishes a vortex flow pattern in which solids settle into a boundary layer on each tray and into a center underflow collection chamber for pumped removal. The system applies plate-settler technology to grit removal by using the stacked trays to create a large, concentrated surface area in a short settling distance.

At new facilities, the multiple-tray system can be installed in a concrete basin with a smaller footprint than mechanical or induced vortex systems. In existing facilities, the multi-tray system may be able to be retrofitted into existing grit chambers or equalization basins.

5.1.2.4 Grit Classifiers/Washers

The need for classification and washing of removed grit should be determined based on the method of grit removal and the means of final grit disposal. For all grit classification and washing processes, an adequate supply of high pressure water should be provided for process work, grit-chamber cleaning, and grit handling.

Cyclone separator sizing is based on the cycled feed flow rate and grit slurry solids concentrations. Cyclones work best at feed concentrations of less than 1 percent solids. The centrifugal action created in the cyclone separators increases the solids content to an average of 5–15 percent. Approximately 90–95 percent of the feed flow rate discharges through the vortex finder at the top of the cyclone. This flow volume reduction saves transportation and storage, and reduces the required classifier size.

Grit classifiers, either inclined screw or escalator, wash grit by separating degradable organic matter from collected grit. Classifiers are sized based on settling velocity of the particles to be settled, feed flow capacity, and grit-raking capacity. For a target particle size and flow rate, the design engineer should select a minimum pool area and overflow weir length. The classifier slope must then to checked to ensure removal of the desired marginal particle size. Flatter slopes will remove finer grit particles.

Conical grit washer technology represents advancement in grit slurry processing. Stainless-steel, conical-shaped vessels are used to capture grit slurry, and various systems are used to wash organics from the grit. Rotating arms within the vessel slowly mix the settled grit, which is vigorously washed by a washing jet at the bottom of the unit activated by a solenoid valve on a timer. Lighter organic material continuously overflows the unit, and heavier organic material is blown off at regular intervals from a midlevel overflow. These washers can produce grit with low organic content (below 5 percent). The surface flow velocity, including the wash water, should be less than 0.02 ft/sec; the weir overflow rate should be maintained at less than 160 ft^2/sec.

5.1.2.5 Grit Pumping and Conveyance

Grit slurry pumps for removing grit from chambers typically are sized to meet high head requirements of cyclone separators, static head, and pipe-and-fitting friction losses required to remove grit from the separation chamber and convey it to the classifier/washing units.

Because head loss through a typical cyclone classifier is a function of flow rate and size, the manufacturer’s pressure and flow rating information should be consulted when pumping grit into a cyclone classifier.

It is imperative that grit pumps be specified to function for an acceptable period of time in the highly abrasive environment where they are employed. Hardened casings, volutes and wear items should be specified whenever possible. In addition, vortex or recessed impeller style pumps are recommended. The use of rubber pinch-type check valves is also encouraged, since swing-type check valve wear is common in grit pumps.

In addition to grit pumps, conveyance systems typically include shaftless screw augers and conveyor belt systems. These systems must be designed to accommodate the peak discharge rate from the grit removal or classification system, and require integral control systems that automatically start the conveyance system when grit is being produced.

The following list presents general considerations for discharge piping for grit pump systems:

- The length of grit pump suction piping should be minimized, and flooded suction pumps should be used whenever possible.
- Horizontal and vertical bends should be minimized to reduce abrasion, and plugging and long radius bends should be used.
- Cleanouts and removable couplings should be placed at bends to readily clear blockages. Wyes can be used at bends to provide a combination gradual bend/cleanout.
- A pipe velocity of 3–6 ft/sec should be maintained to keep grit and other solids moving while minimizing pipe abrasion.
- Discharge piping with nominal diameters of at least 4 inches should be used to avoid high scouring pressures and velocities that would cause excessive wear.
- Facility water connections should be considered for flushing of the suction lines and pumps.
- Discharge piping should be glass-lined ductile iron (DI) wherever possible, and connection points should be Victaulic™ or a similar type of quick-release connection.

A facility must provide conveyance and storage for off-site disposal of grit that has been classified and washed. Disposal bins, roll-off containers, and dumpsters may be used. If grit is transported directly to trucks or dumpsters, the container should have enough capacity to handle daily peak grit loads in the event that replacement trucks cannot arrive or leave due to inclement weather or other interruptions in service. It is advisable to provide two storage bays in the event one container is full and cannot be removed due to a truck breakdown. Grit storage areas should be enclosed to prevent grit freezing and to contain odors. Odor control for this area is a design factor that must be considered, and is addressed in Chapter 10 of this text.

All grit handling areas should have impervious, nonslip working surfaces with drains. Grit transport equipment should have protection against freezing and loss of material.

5.1.2.6 Combination Grit/Screening Units

Recent advances in process and control technology as well as a better understanding of grit and screening removal constraints has led to the development of several grit and screening combination units. Since these systems are proprietary, each system manufacturer will provide engineers with assistance in ascertaining the proper fit for a particular project. As with all proprietary technology, care in the selection and specification process should be taken by the designer to ensure the application of this technology is appropriate, is capable of functioning as required, and is approved by the regulatory authority. Generally, proprietary combination systems will perform better at smaller facilities and at plants that do not employ combined sewers.

5.1.3 Flocculation and Preaeration

5.1.3.1 Flocculation

Flocculation of wastewater by air or mechanical agitation, with or without chemical addition, may be needed in certain situations, such as when a facility needs to increase the removal of suspended solids and BOD in primary settling tanks, condition wastewater for better biological treatment due to the presence of industrial wastes, and improve the performance of secondary settling tanks following an activated sludge treatment process. Units should be designed so removing one unit from service will not interfere with normal operation of the remainder of a plant.

Flocculation can be accomplished in separate units or in baffled areas of channels or other tanks. Aerated grit chambers and aerated distribution channels may promote flocculation of unsettled wastewaters. Detention times for flocculation should be 20–60 minutes depending upon the wastewater and process intent. Velocity gradients should be maintained at 50–80 ft/sec. Polymers, if used, should be added to wastewater as a dilute solution at a point that promotes adequate mixing and sufficient contact time to create the desired floc.

5.1.3.2 Preaeration

Preaeration of unsettled wastewater can be used to promote flocculation and reduce septicity. Aerated grit chambers and/or aerated distribution channels for primary sedimentation can be used for preaeration. Preaeration used to promote flocculation and reduce septicity time should be conducted for 10–15 minutes at an airflow rate of 0.1–0.4 ft^3/gal. Note that addition of air to raw wastewater will strip hydrogen sulfide and volatile organics from wastewater. Therefore, covers and odor control of emissions should be considered. In addition to odor and VOC emission concerns, careful consideration must be given to the effects preaeration may have on any pre-anoxic nutrient removal systems (see Chapter 6), such as the Modified Ludzack Ettinger (MLE) process.

5.1.4 Scum and Grease Removal

Scum and grease quantities and chemical composition are highly variable and depend on several factors. On average, the dry-weight scum quantities from a typical facility are approximately 5 mg/L. The variability of the composition of scum is dependent on the degree and type of industrial development, eating establishments, commercial kitchens, local demographics in the collection area, and a municipality's implementation (or not) of a fats, oils, and grease (FOG) program for its collection system. Composition will also depend on recycled plant side streams and the scum removal efficiency of upstream processes.

Scum and grease removal should be included as a process in the pretreatment stage or, at a minimum, as a process integrated into primary treatment at all wastewater treatment plants. All trapped, free surfaces should have a means for removing floating materials. Avoid recycling removed materials and scum-concentrating streams back to the liquid treatment facilities. Chlorination should be provided for any streams that are recycled.

Scum and grease removal is typically performed in primary and secondary clarifiers. (Further details on these systems are included in the remaining sections of this chapter and also in Chapter 6.) Nutrient removal treatment plants that do not have primary clarification should use dedicated grease and scum collection systems to prevent the excessive foaming that can occur in the secondary treatment processes downstream.

Collection and movement of grease and scum is typically achieved using progressing cavity pumps, plunger pumps, pneumatic ejectors, submersible chopper, and/or recessed impeller centrifugal pumps. Any design of grease and scum storage and removal equipment should include measures to keep the scum tank or hopper contents mixed during pumping to prevent scum from crusting or coning. This typically includes keeping storage facilities heated in some manner to keep grease and scum in a liquid state. In addition, a hopper should be relatively small in size to minimize holding times, and should have a sloped tank bottom.

Typically, scum and grease removed from primary treatment wastewater is combined with the side stream flow of primary settled solids. This side stream can be stored onsite for shipping and offsite processing or processed onsite along with solids generated from secondary sedimentation basins. If grease and/or scum in the primary solids side stream is deemed detrimental to successful processing of that material, separate facilities for storage and offsite disposal of the scum and grease need to be provided. Options for disposal include aerobic or anaerobic digestion, bulk liquid shipping to larger facilities for dewatering and solids stabilization, fuel for sludge incineration, and liquid or solid landfill application. Chemical fixation of scum and grease with lime-based products such as cement kiln dust or soluble silicates has been used to stabilize scum prior to handling and disposal.

5.2 Primary Treatment

5.2.1 Number of Units

Multiple primary treatment units capable of independent operation should be provided in all plants. In small plants where two tanks are furnished, tanks should be oversized so each tank has roughly two-thirds of the total design capacity of the plant. When three or more tanks are used, the system should be able to pass peak flows with one tank out of service.

5.2.2 Types of Units

Primary clarifiers should achieve solids separation, skimming, and collection and removal of settled sludge, floatable objects, and grease. Primary sedimentation tanks can be rectangular or circular.

5.2.3 Settling Tanks

5.2.3.1 Inlets

Inlets should be designed for flow distribution in accordance with section 4.3.9. Inlets should dissipate the inlet velocity to prevent short-circuiting. For rectangular tank influent channels, corner pockets should be eliminated and corner fillets used where necessary. Provisions should be made for removing floating materials in inlet structures and channels. Mid-tank baffles may also be considered as a means of limiting short-circuiting, though sludge collection considerations should be carefully evaluated and pilot testing performed to confirm the expected treatment performance of a specific design.

5.2.3.2 Surface Overflow Rates

Average surface overflow rates for primary tanks should not exceed 600 gallons per day per square foot (gpd/sf) for plants having an average design flow of 1 million gallons per day or less. Higher surface settling rates may be permitted for larger plants, but they should not exceed 1,200 gpd/sf unless reduced primary removal rates are provided in the design loadings for subsequent secondary treatment units. Surface overflow rates for peak hourly flow should not exceed 3,000 gpd/sf.

If activated sludge is wasted to primary tanks, average overflow rates should be limited to 600–800 gpd/sf, and peak hourly overflow rates limited to 1,200 gpd/sf.

5.2.3.3 Tank Geometry

Rectangular tanks: Length should not exceed 300 feet (91.4 meters). A minimum length of 50 ft (15.2 m) is desirable. At very small facilities, the minimum length of flow from inlet to outlet should not be less than 10 ft (3.1 m). Length-to-width ratios should provide optimum use of tank volume. Minimum sidewater depths should be 10 ft (3.1 m), although 12 ft (3.7 m) is preferred except in very small units. Sidewater depths should not be less than 10 ft (3.1 m) if activated sludge is wasted to primary tanks. The use of clarifiers as a primary means of wasting activated sludge is not recommended.

Circular tanks: Minimum length of flow from inlet to outlet should not be less than 10 ft (3.1 m). Sidewater depths should be 10–16 feet (2.4–4 m) except in small installations.

Freeboard: Walls of settling tanks should extend at least 6 inches (15.2 centimeters) above surrounding ground and provide not less than 12 in (30.5 cm) of freeboard. Additional freeboard or the use of wind screens is recommended where large settling tanks are subject to high-velocity winds that can cause tank surface waves and inhibit scum removal.

5.2.3.4 Scum Collection

Full surface mechanical scum collection, including baffling, should be provided. Provisions should be made for convenient scum removal, including automatic equipment if feasible. Provisions should be made for the discharge of scum with sludge, if appropriate, or the separate discharge of scum if floating materials may adversely affect sludge handling and disposal. Beaching plates provided for scum collection should have sufficient submergence to retard ice formation during cold weather.

5.2.3.5 Weirs

Overflow weirs should be adjustable. Single weirs at the periphery or end of a settling tank are preferred. Multiple weir troughs, if provided, should be placed sufficiently far apart to avoid excessive upward velocity between troughs. Weirs may be straight-edged or V-notched.

Weir troughs should prevent submergence at design peak hourly flow and maintain a velocity of at least 1 foot per second at one-half design average flow.

5.2.3.6 Submerged Surfaces

The tops of troughs, beams, and similar construction features that are submerged should have a minimum slope of 1.4 vertical to 1 horizontal. The underside of such features should have a slope of 1-to-1 to prevent accumulation of scum and solids.

5.2.3.7 Sludge Collection and Removal

Chain and flight sludge collectors in rectangular tanks should have a horizontal velocity of 2–3 feet per minute with flights at least 10 feet (3 meters) on center. Flights in cross-collectors should have a horizontal velocity of 2–4 ft/min with flights at least 5 ft (1.5 m) on center.

Direct Pump Suction: Direct pump suction should be used to remove sludge from primary settling tanks. Appropriate equipment for viewing and sampling the sludge should be provided, along with means for measuring sludge flow. Sludge hoppers should have sludge withdrawal lines at least 6 inches (15.2 centimeters) in diameter with individual valves. Suction pipe lengths and bends should be minimized. Access for rodding, pigging, or flushing withdrawal lines should be provided. Suction-type sludge collectors should not be used for primary sludge.

Sludge Hoppers: Sludge hoppers should be accessible for maintenance from the operating level. The minimum slope of the side walls of sludge hoppers should be 1.7 vertical to 1 horizontal. Clearance between the end of the sludge draw-off pipe and the hopper walls should be sufficient to prevent bridging of solids. Hopper bottoms should have a maximum dimension of 2 ft (61 cm). Multiple hoppers should be considered for tanks greater than 10 ft (3 m) in width. Cross-collectors may be used in lieu of multiple hoppers.

Sludge Quantities: The quantity and characteristics of primary sludge will vary depending on the nature of the influent flow and the design of the clarifiers. Typical TSS removal efficiencies in traditional clarification systems is 40–70 percent with 60 percent usually used for planning purposes at general facilities. BOD removal efficiencies can be expected to be 25–40 percent.

Chemically assisted primary treatment (Section 5.3 below) can increase primary sludge mass by 50–100 percent beyond a traditional clarifier. CSO-influenced facilities will also see increased primary sludge production, with the amount and nature significantly influenced by the extent of upstream screening and grit removal processes.

(Refer to Chapter 11 for more details on solids treatment and handling.)

Protective and Servicing Facilities: All settling tanks should be easily accessible to operators performing maintenance and protection activities. Features that increase accessibility include stairways, walkways, handrails, and slip-resistant surfaces.

5.3 Chemically Assisted Primary Treatment

5.3.1 General

Metal salts with or without polymers may be used to increase removal efficiency within primary settling tanks and to provide more consistent performance at higher overflow rates than those presented in Section 5.2.3.2. Performance can be expected to improve with polymers. Chemical coagulants are added during a rapid mix step accomplished with inline blenders, air or mechanical mixers, or baffles in small tanks or pipes. Chemical addition is followed by a flocculation step completed in channels or tanks. Using the appropriate velocity gradient, or mixing intensity, in each step is important in order to avoid under- or over-mixing; the goal is proper dispersion of chemicals versus vector breakup of solids/floc. Literature indicates a gradient of roughly 300 feet/second–feet should be sufficient for rapid mixing, depending on the mixing configuration. However, some research suggests improved results from higher gradients (up to 1,000 feet/second-feet).

The addition of chemicals will result in increased production of primary sludge that is more difficult to thicken and dewater than conventional primary sludge. It is important for the designer to consider that the addition of chemicals to the primary tanks may impact biological phosphorus removal and denitrification capability, and sludge settling of subsequent secondary processes.

5.3.2 Pilot Testing

Design criteria for—and the economics of—chemical addition to primary settling tanks varies with the characteristics of the wastewater. Pilot and/or jar testing should be performed to determine design criteria, chemical requirements, and mixing gradients.

5.3.3 Construction Materials

Primary sludge pumps and appurtenances, and chemical delivery and other mechanical equipment should be designed to operate with the chemicals used at a facility.

5.3.4 Odor Control

Adding metal salts to influent wastewater or to primary clarifiers can result in decreased sulfide concentrations and reduced odor emissions.

5.4 Wet Weather Treatment

5.4.1 General

Preliminary and primary treatment of wet weather flow may be performed by a facility's customary preliminary and primary treatment processes or by separate dedicated wet weather flow treatment facilities. These wet weather facilities may be located at a wastewater treatment facility itself or, in a combined sewer system, at satellite locations upstream. The level of wet weather treatment required should be coordinated with the appropriate regulatory authority.

Wet weather preliminary and primary treatment is accomplished using technologies discussed in Sections 5.1, 5.2 and 5.3, along with swirl and vortex separators and high rate clarification, discussed below.

5.4.2 Peak Flows and Number of Units

Design criteria should incorporate the full range of potential hydraulic conditions—that is, the ratio of peak wet-weather flow rate to dry-weather flow rates. Wet weather flows are highly variable, and extreme peaks are typically sustained for only a very short duration. The design of flow capacities of preliminary and primary treatment processes should consider this highly variable range of flow. For dedicated wet weather facilities, redundant processes that allow for continued functionality during repairs or maintenance may not be practical or necessary in all flow situations since maintenance can be performed during dry weather to ensure reliable activation and performance.

In some treatment processes, there may be storage capacity for holding some stormwater for treatment as wet weather flows subside.

Flow pumping, if required for preliminary and primary treatment processes, should be designed to provide a smooth, gradual transition of flow into the processes.

In systems that provide some storage to hold stormwater for treatment in the dry weather train, consideration should be given to how the flow is returned and the time required to empty storage tanks. Operation protocols may call for reducing wet weather discharge volumes; therefore, as wet weather flows into a facility diminish, dewatering capability should be provided to remove flow from storage tanks as fast as possible so the facility is prepared for a new wet weather event. All returned flows should be directed to the beginning of preliminary treatment to remove grit.

5.4.3 Management

High and low flow conditions should be evaluated during design to ensure that control systems (manual or automatic) are established for proper start-up, operation, and performance of preliminary and primary treatment devices during a storm event. Wet weather treatment systems may be used multiple times in any one year or not at all, depending on location, storm events, and upstream conditions. Design criteria and equipment selection should consider this variability. Corrosion protection should be considered for all equipment that may be intermittently exposed to flow.

Wet weather treatment facilities should be automated or remotely controlled, to the extent practical, especially at satellite locations; it is recommended that manned operations be minimized, due to the variability of rainfall and storm flow conditions. This variability can result in multiple activation and deactivation cycles during a single storm event.

The design should include provisions for rapid dewatering and flushing of preliminary and primary treatment systems dedicated to wet weather treatment after storm events to minimize odors and to ensure the equipment and process is readied for a subsequent storm event. This post-storm procedure necessarily involves manned operations.

5.4.4 Swirl and Vortex Separators

Physical separation of solids and liquid in wet weather flow can be achieved by swirl and vortex separator technologies. Tangential inlets create a rotary flow direction within the device that helps to separate solids by gravity and centripetal forces. Vortex separators are sometimes combined with sedimentation, disinfection, and screening, as combined processes or in one vessel, to provide treatment of wet weather flows. The technologies are proprietary to each system and design criteria should be coordinated with the manufacturer. Pilot testing to confirm the expected treatment performance is recommended due to the variability of design conditions and technology applications.

5.4.5 High-Rate Clarification

High-rate clarification combines the techniques of chemically enhanced sedimentation with solids contact/recirculation, and lamella plate or tube settlers to achieve rapid solids removal. Typically, high-rate clarification systems can achieve comparable solids/pollutant removals within a much smaller footprint than conventional primary treatment systems. High-rate clarification systems have also proven to be effective with the wide flow and pollutant variability and intermittent activation characteristics of wet weather flow. These systems can be off-line but activated quickly to achieve high removal rates within 15-20 minutes of operation and can be deactivated. The compact nature of the processes reduces the cleanup required after wet weather subsides and the process is deactivated.

High-rate clarification systems are generally proprietary, compact, and pre-engineered. Design criteria, including overflow rates, should be developed with the manufacturer and based on pilot testing. Depending on the process, significant preliminary treatment is required—possibly fine screening with an opening size of at least 0.25 inches (6 millimeters) to ensure that the high rate clarification system will not be overwhelmed by excessive material or debris. Sludge removal and handling, ancillary equipment and containment, chemical storage, buildings, and process control systems should be coordinated with the manufacturer.

5.5 Flow Equalization

5.5.1 General

Flow equalization may be considered where significant variations in flow rates and organic mass loadings are expected.

5.5.2 Location and Use

Equalization basins should be located downstream of screening and grit removal facilities. Equalization has been used upstream of plant influent in combined sewer systems as a means of storage to reduce the frequency of sanitary sewer overflows or CSOs. Equalization storage may be used as a method of primary sedimentation (and disinfection contact) for wet weather flows.

5.5.3 Type

Flow or waste strength equalization can be provided by using in-line or side-line configurations.

5.5.4 Size

Equalization capacity should be sufficient to dampen expected flow and strength variations to the extent that is economically advantageous. Sizing for wet weather conditions will depend on the design criteria for CSO reduction.

5.5.5 Mixing and Aeration

Aeration or mechanical equipment should maintain adequate mixing to provide blending of tank contents, and to prevent deposition of solids and wastewater from becoming septic. Mechanical mixing equipment for unsettled wastewater should provide 0.15–0.30 horsepower per 1,000 cubic feet of storage volume. Air mixing equipment should provide 10–30 standard cubic feet per minute for every 1,000 cubic feet of storage volume. Aeration equipment should maintain a minimum dissolved oxygen content of 1.0 milligrams per liter at all times. Baffling may be necessary to maintain proper mixing. Air mixing using positive displacement blowers should be provided for variable volume systems.

A variety of low-energy mixing solutions exist but as of the writing of this report, their acceptance in the market is varied. Design engineers should investigate low-energy mixing technologies using resources such as the WEF Manual of Practice #9 and the U.S. EPA guidance on Energy Conservation Measures for Wastewater Treatment Facilities. New mixing systems certainly merit consideration if they are found to use less energy than the horsepower per unit volume ranges noted above and are proven to provide effective mixing in field trials, computation fluid dynamic modeling, or other analysis.

5.5.6 Controls

Inlets and outlets should be equipped with accessible external valves, stop plates, weirs, or other devices to permit flow control and the removal of individual units from service. Means of measuring discharge flow rates and liquid levels should be provided, as well as instrumentation to control discharge rates.

5.5.7 Access

Suitable access should be provided to facilitate cleaning and maintenance of equipment.

5.5.8 Drainage

Flow equalization tanks should allow the entire contents of the tanks to be drained and introduced to the remainder of the treatment process.

5.5.9 Cleaning

High-pressure ejector guns that utilize nonpotable water should be provided for cleaning basins (greater than 1 million gallons per day) after use.

References – Chapter 5

NFPA 820: Standard for Fire Protection in Wastewater Treatment and Collection Facilities, 2008 Edition

WEF Manual of Practice No. 8, *Design of Municipal Wastewater Treatment Plants*, 5th Edition, 2010

CHAPTER 6

BIOLOGICAL TREATMENT PROCESSES

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6.1 General Concepts

6.1.1 General

Biological treatment systems can be configured to achieve a variety of treatment levels depending on influent wastewater characteristics and effluent limits. The information included in this chapter provides basic criteria and information relative to the design of biological treatment processes. The references listed at the end of the chapter are an excellent source of more detailed information that should also be considered when evaluating and designing biological treatment processes.

Fixed growth systems differ from suspended growth systems in a number of ways. In general, fixed growth systems are easier to operate and more resistant to shock loads, but less flexible than comparable suspended growth systems. Pollutant diffusion into suspended growth flocs occurs around the full particle while fixed growth systems have much less biomass surface area in contact with the pollutants and thus diffusion can be a limiting factor in these systems. Control of growth rate has a significant influence on the types and numbers of microorganisms in a system. Suspended growth systems can be managed to control growth rate, which is inverse to solids retention time (SRT). In fixed growth systems, growth rate is more difficult to control because biomass remains in the system as long as it remains attached to the media.

6.1.2 Energy and Life Cycle Considerations

Biological treatment systems commonly account for a significant percentage of a treatment plant's energy use, chemical usage, and personnel time. Therefore evaluation and design of facility improvements involving biological treatment should include a careful evaluation of energy consumption and overall life-cycle costs. Process and equipment selection for biological treatment should include a detailed life-cycle cost evaluation that, at a minimum, takes into account capital cost, energy, chemicals, equipment maintenance, and system operating time as well as indirect aspects such as greenhouse gas emissions.

All projects requiring a facility plan, facility plan amendment, comparison of alternatives, facility modification, or a facility reevaluation for capacity rating should include system design alternatives that are scalable as system throughput increases; when operated together, component units and major subsystems should function in an energy-efficient manner over the expected facility lifetime. To be scalable, system designs should consider installation of multiple units of a system component (e.g., drive, motor, pump, aeration facility blower).

6.2 Fixed Growth Systems

6.2.1 Overall Considerations

A fixed growth system is a biological wastewater treatment process that consists of biomass attached to inert media. Fixed growth systems are also known as fixed film and attached growth processes. Fixed growth systems can be combined with suspended growth systems within an integrated reactor system either in a hybrid configuration or sequentially without intermediate clarification. Regardless of the configuration, a true fixed growth system does not contain any suspended growth component.

6.2.2 Overall Process Design Considerations

Historically, empirical equations have been used to determine process sizing of fixed growth systems. These empirical approaches generally provide a reasonable approximation of system sizing requirements. However, when large or sophisticated systems are required, a greater level of detail and accuracy may be warranted. Many mechanistic biofilm models are available for evaluation and design of fixed growth systems. These models can be a powerful tool for designers but have limitations that must be understood to minimize the risk of improper application. The designer should choose a model carefully, collect a sufficient level of wastewater and process parameter data, and complete an appropriate level of model calibration and verification to demonstrate model accuracy. An empirical approach should always be used to provide independent confirmation that the model results are reasonable.

Biological carbon and ammonia (nitrogen) oxidation generally function as sequential processes in fixed growth systems. In general, the BOD_5 must be less than 20 mg/L before nitrifying bacteria will become a significant fraction of the biomass present. Thus, it is advantageous to configure fixed film systems into a number of stages, with more stages warranted as treatment requirements become more stringent. Design loading rates can be influenced by a number of factors such as type of media, wastewater characteristics, temperature, dissolved oxygen, and pH. Design loading rates for wastewater at 20^{o}C should be as follows:

- An organic loading rate in the range of 1.0 to 3.0 lb BOD_5/d/1,000 ft^2 of media surface area can reduce the BOD_5 below 30 mg/L. Loading rates below 2.0 lb BOD_5/d/1,000 ft^2 are capable of achieving lower effluent BOD_5 concentrations and should allow for the onset of nitrification.
- An ammonia-nitrogen loading rate of 0.1 to 0.3 lb/NH_3-N/d/1,000 ft^2 of media surface area can reduce ammonia nitrogen to less than 2 mg/L (provided BOD_5 is already removed).
- Rates of denitrification depend on the nature of the carbon source utilized in the process and range from 0.03 to 0.8 lb NO_3-N/1,000 sf media-d.

Design loading rates can change dramatically as temperature changes. Thus, temperature correction factors should be applied where appropriate.

The following are common considerations for attached growth systems:

- Where primary settling tanks are not used, it is important to effectively remove grit, debris, excessive oil, and grease and to provide a high degree of screening prior to secondary and/or tertiary treatment.
- Adequate alkalinity is required for all nitrogen removal processes. Therefore, a minimum effluent alkalinity of 50–100 mg/L as $CaCO_3$ should be maintained.

6.2.3 Trickling Filters

6.2.3.1 General

Trickling filters are aerobic fixed growth reactors. The reactors contain media that in older systems consisted of rock media but in modern trickling filters typically consist of plastic media. A rotating flow distributor distributes secondary influent over the top of the media; the wastewater then "trickles" down through the media and underdrain system. As wastewater flows over the media, attached biomass develops that can reduce carbonaceous and/or nitrogenous oxygen demand in accordance with water quality standards and objectives, or the biomass can condition the wastewater for subsequent treatment processes. Biomass thickness increases to a point where it detaches or "sloughs" off the media and is transported downstream for solids separation. Trickling filter performance can be enhanced by staging the units, adding an activated sludge step, or improving secondary clarifier performance. Information related to systems combining trickling filters and activated sludge is included in Section 6.4.

6.2.3.2 Hydraulics

Distribution: Wastewater is typically applied using rotary distributors but other suitable devices that provide uniform distribution may also be used, including fixed nozzles. Rotating distributors can be hydraulically or electrically driven. Hydraulically driven distributors must be carefully designed to ensure the distributor arm will rotate over the whole range of flows. Electrically driven arms are becoming more common as they are easier to design and may allow a facility to lower energy costs through reduced recirculation rates; the rates can be lower because they are based on the needs of the filter media rather than the hydraulic needs of the distributor arm.

Clearance: A minimum clearance of 12 inches between media and distribution arms should be provided.

Flows: The piping system, including dosing equipment and distributor, should provide enough capacity for the design peak hourly flow, including recirculation. Continuous flow should be maintained to filters in service, and recycle capacity should be provided in the range of 0.5 to 4.0 times average design flow.

Wind Break: In regions where winters are extreme, higher walls should be provided around the trickling filter to minimize icing of water sprays.

6.2.3.3 Media

Quality: The media may be manufactured material, crushed rock, or slag. Manufactured media can be configured in vertical sheets, cross-flow sheets, or random pack and should resist ultraviolet (UV) degradation, disintegration, erosion, aging, all common acids and alkalis, organic compounds, and fungus and biological attack. Such media should be structurally capable of supporting a person's weight or, if not, a suitable means of access should be provided to allow for distributor maintenance. Rock media should be durable, resistant to spalling or flaking, and relatively insoluble in wastewater.

Depth: Trickling filter media depth is dependent on the weight of the media and attached biomass and should have a minimum depth of 6 feet above the underdrains. Rock and/or slag media depths should not exceed 10 feet, and manufactured filter media depths may be 25 feet or greater but should not exceed manufacturer recommendations. Forced ventilation should be considered for deep and covered filters.

6.2.3.4 Underdrainage System

Purpose: The underdrain system serves two purposes—it allows wastewater to leave the trickling system media and allows air to be distributed into the media. The underdrain can be concrete (typical for rock media systems), fiberglass (typical for synthetic media systems), or other materials suitably designed to support the media.

Arrangement: The underdrainage system should cover the entire floor of the filter. Inlet openings should have an unsubmerged gross combined area equal to at least 15 percent of the surface area of the filter.

Hydraulics: The underdrains should have a minimum slope of 1 percent. Effluent channels should produce a minimum velocity of 2 feet per second at design average flow rates, including recirculated flows.

Ventilation: The underdrainage system, effluent channels, and effluent pipe should permit free passage of air. The size of drains, channels, and pipe should be such that not more than 50 percent of their cross-sectional area will be submerged under the design peak instantaneous flow, including proposed or possible future recirculated flows.

Forced ventilation should be provided for covered trickling filters to ensure adequate oxygen for process requirements. Airflow should be uniformly distributed across the surface of the trickling filters by using a pipe manifold; windows or simple louvered mechanisms should be arranged to ensure air distribution throughout the enclosure. The ventilation facilities should provide for operator control of air flow in accordance with outside temperatures.

Flushing: Provisions should be made for flushing the underdrains unless high-rate recirculation is used. In small rock and slag filters, a peripheral head channel with vertical vents is acceptable for flushing purposes. Inspection facilities should be provided.

6.2.3.5 General Design and Operational Considerations

Redundancy: At least two trickling filters should be provided if trickling filtration is the only biological treatment process at the facility or if the facility is larger than 5 mgd.

Flooding: Appropriate valves, sluice gates, or other structures should enable flooding of filters comprising rock or slag media for filter fly control.

Freeboard: A freeboard of 4 feet or more should be provided for tall, manufactured media filters to contain windblown spray. On covered filters, provide at least 6 feet of headroom for maintenance of distributors.

Winter Protection: Covers are recommended where a high level of treatment efficiency during cold temperatures is required or where odor control is warranted.

Odor Control: Due to the nature of the trickling filter process, release of odorous compounds is enhanced as flow is trickled over the media. Consideration should be given to adding chemicals upstream of the process or covering the filters and then capturing and treating the air.

Recirculation Flows: Devices for measurement of the recirculation rate should be provided. Elapsed time meters and pump-head recording devices are acceptable for facilities treating less than 1 mgd. The design of recirculation facilities should provide for both continuity of service and recirculation ratios. Reduced recirculation rates for periods of brief pump outages may be acceptable depending on water quality requirements.

Recirculation Pumps: Provide a minimum of two pumps with variable-frequency drive (VFD) capability.

Mercury Seals: In the past, many trickling filters were manufactured with mercury in the rotary distributor seals. Any such units still in use should be replaced by new, mercury-free models. All mercury must be disposed of properly.

Pilot Testing: Pilot testing should be performed in situations where trickling filters are being added to treat wastewater with a significant industrial component.

Maintenance: All distribution devices, underdrains, channels, and pipes should be installed to facilitate proper maintenance, flushing, or drainage. Ease of distributor seal replacement should also be considered in the design.

Pretreatment: Typically, trickling filters are preceded by preliminary or primary treatment to remove excessive solids and FOG loading.

6.2.3.6 Process Design

General: Many models have been developed to predict trickling filter performance, starting with the National Research Council (NRC) formula in 1946. There are at least eight other models in use and each has its strengths and weaknesses. For example, the NRC and Galler–Gotaas equations are commonly used in the design of rock media trickling filters. Others such as the Schulze, Eckenfelder, and Chartered Institution of Water and Environmental Management formulas are used for both rock and synthetic media.

Loading: Trickling filter design should consider peak organic load conditions, including the oxygen demands that occur because of sidestream flows from sludge processing and handling. Short-duration, high strength loads should be dampened via equalization or other methods. The volume of media should be based upon the design maximum month BOD_5 or TKN (Total Kjeldahl Nitrogen) organic loading rate rather than the average BOD concentration. Nitrogen loadings should take into account assimilation of ammonia into biomass and ammonification of organic nitrogen present.

Carbonaceous Removal: Characteristics of different trickling filter designs are presented in Table 6-1. However, absent any significant limiting conditions, removal rates will typically fall in the ranges presented in Section 6.2.2.

Nitrification: Systems designed to provide either combined carbon-nitrogen oxidation or nitrification alone must consider a number of factors inherent with the trickling filter process including:

- Nitrification in trickling filters will only occur substantially if the soluble carbonaceous matter (BOD_5) is very low.
- The design must incorporate impacts of lower air and wastewater temperatures on nitrification, particularly since the temperature of wastewater passing through trickling filters typically drops significantly during cold weather.
- Trickling filters with low organic (BOD_5) loading are more susceptible to predatory organisms (snails, worms, fly larvae). Measures should be included to mitigate the impacts of predators on trickling filter performance.
- In lieu of using models to determine design requirements of trickling filters, the guidelines in Table 6-1 can be used for sizing trickling filters for nitrification.

Table 6-1 **TRICKLING FILTER CLASSIFICATIONS**

Design parameter[a]	Roughing	Carbon oxidizing ($cBOD_5$ removal)	$cBOD_5$ and nitrification	Nitrification
Media Typically used	Vertical Flow	Rock, cross-flow or vertical flow	Rock, cross-flow or vertical flow	Cross-flow
Media Specific Surface Area (sf/cf)	31 to 40	14 to 68	14 to 68	30 to 68
Wastewater source	Primary effluent	Primary effluent	Primary effluent	Secondary effluent
Hydraulic Loading gpm / sq ft	0.9 to 2.9	0.25 to 1.5	0.25 to 1.5	0.6 to 1.5
BOD_5 and NH_3 - N load				
lb BOD_5 / d·1000 cu ft	100 to 220	20 to 60	5 to 15	NA[b]
lb NH_3-N / d·1000 sq ft	NA[b]	NA[b]	0.04 to 0.2	0.1 to 1.5
Effluent quality (mg/L, unless noted)	50 to 75% filtered $cBOD_5$ conversion	15 to 30 mg/L $cBOD_5$ and TSS[c]	<10 $cBOD_5$ <3 NH_3-N[c]	0.5 to 3NH_3-N
Predation	No appreciable growth	Beneficial	Detrimental (nitrifying biofilm)	Detrimental
Filter flies	No appreciable growth	No appreciable growth	No appreciable growth	No appreciable growth
Depth (ft)	3 to 20	5 to 40	5 to 40	5 to 40

[a] gpm/sq ft x 58.674 = $m^3/m^2 \cdot d$ (cubic meter per day per square meter of trickling filter plan area); lb BOD_5 /d/1,000 cu ft x0.0160 = $kg/m^3 \cdot d$ (kilograms per day per cubic meter of media); and lb NH_3-N/d/1,000 sq ft x 4.88 = g/m^2d (grams per day per square meter of media).

[b] Not applicable

[c] Concentration remaining in clarifier effluent stream

6.2.4 Rotating Biological Contactors

6.2.4.1 General

Rotating biological contactors (RBCs) are a biological treatment process with media attached to a rotating horizontal shaft. RBCs are typically an aerobic process used for BOD removal and nitrification, but they can also be submerged to accomplish denitrification. However, use of submerged RBCs for denitrification is not actively being incorporated into new designs. In the aerobic process, the disks are partially (40 percent) submerged and alternately exposed to air and wastewater as the disk rotates.

RBCs should not be used as a roughing step for heavy organic loadings. However, they are well suited for secondary treatment standards and in conjunction with additional processes can help to achieve BOD and TSS limits below 10 mg/L as well as nitrogen limits.

The primary advantages of the RBC process are rapid recovery from shock loads, low energy costs, and operational simplicity.

6.2.4.2 Pretreatment

Pretreatment and sedimentation facilities should precede RBCs and can include fine screens, grit removal, and primary settling tanks to remove screenings, scum, grit, and suspended solids.

Flow equalization improves the efficiency of treatment and should be considered when peak-to-average ratios are greater than 2.5. Flow equalization should be considered for nitrifying facilities.

6.2.4.3 Hydraulics

Provide positive influent flow control to each unit or flow train, including positively controlled, alternate, flow distribution systems such as step feed, where appropriate.

Flow equalization improves the efficiency of treatment and should be considered when peak-to-average ratios are greater than 2.5. Flow equalization should be considered for nitrifying facilities.

6.2.4.4 Media and Shafts

Media density can vary by installation—low density media (100,000 sq feet per shaft) is used for cBOD removal and higher density media (150,000 sq feet per shaft) is typically used for cBOD polishing and nitrification.

Media should allow for portions to be removed for cleaning and/or replacement without requiring the entire shaft assembly to be removed from the tanks.

Provisions should be provided for removing a shaft from the enclosure housing the system.

Variable rotational speeds in the first and second stages should also be provided, including speed reversal to remove excess biofilm treatment trains. It is important to also provide supplemental air to enhance biomass sloughing from media. Incorporate positive air flow metering and control to each shaft when supplemental air or air drive units are used.

6.2.4.5 General Design and Operational Considerations

Redundancy: A minimum of two trains are required for redundancy. However, a single train may be adequate if the system is divided into at least two sections that can be hydraulically isolated for maintenance.

Staging: Nitrification will not commence until BOD reduction has taken place to a point where nitrifiers can outcompete heterotrophic bacteria. When carbon and nitrogen oxidation are combined, an aerobic RBC should be divided into multiple stages. Initial stages should be used for BOD reduction and latter stages for nitrification. The separation of stages can be achieved by employing baffles within one RBC or by utilizing multiple physically-separated RBCs. Consult with the RBC manufacturer to determine the number of stages necessary for the condition in question.

Baffles: Baffles are commonly used to separate RBC shafts into stages. Where possible, provide removable baffles and tank fillets to minimize dead spaces.

Recirculation: The capability to recirculate RBC or secondary effluent to RBC influent should be provided.

Covers: RBCs should be covered in individual shaft enclosures or the entire facility may be housed in a building. Enclosures must prevent excessive loss of heat from the wastewater and avoid exposing the biomass to subfreezing ambient temperatures. Enclosures also must protect plastic media from UV degradation and aid in preventing the development of algae on outer surfaces. Covers must provide adequate ventilation. Enclosed structures must be protected from corrosion because of high humidity. Enclosures should allow for the removal of one shaft and disks without interfering with the plant operation. Covers should allow for the operator to have access to all RBC parts for observation and maintenance. Confined space entry issues should be considered in the design.

Biofilm Thickness Control: An evenly distributed biofilm is desirable to avoid unbalanced weight distribution and potential premature shaft failure. Electronic load cells should be provided on at least the first stage shafts to monitor biofilm thickness.

Maintenance: All mechanical components, channels, and pipes should be installed to facilitate proper maintenance, flushing, or drainage. Ease of media and shaft repair or replacement should be considered in the design.

6.2.4.6 Process Design

General: Many models have been developed to predict RBC performance including those developed by the manufacturers Envirex, Lyco, and Walker. In addition, models have been developed for carbon oxidation in RBCs; these include the Monod kinetic model, second-order model, and empirical model.

Loading: RBC design should consider peak organic load conditions, including the oxygen demands that occur because of sidestream flows from sludge processing and handling. Short-duration, high strength loads should be dampened via equalization or other methods. The volume of media should be based upon the design maximum month BOD_5 or TKN organic loading rate rather than average BOD concentration. Nitrogen loadings should take into account assimilation of ammonia into biomass and ammonification of organic nitrogen present.

Carbonaceous Removal: RBCs for carbonaceous BOD_5 removal should use standard density shafts and should be loaded at a maximum month organic loading rate in the range of 1.0 to 3.0 lb BOD_5/d/1,000 ft^2 of media surface area. Higher density shafts can be used in downstream shafts where a higher level of treatment is required. Loading rates below 2.0 lb BOD_5/d/1,000 ft^2 are capable of achieving lower effluent BOD_5 concentrations and should allow for the onset of nitrification. Specific design criteria should be developed in consultation with the manufacturer and should be adjusted for coldest month temperature.

First Stage Loading: To minimize biomass overload on shafts, the first stage of an RBC system should not be loaded at greater than 6.0 lb BOD_5/d/1,000 ft^2 or 2.5 lb soluble BOD_5/d/1,000 ft^2.

Nitrification: Systems designed to provide either combined carbon-nitrogen oxidation or nitrification alone must consider that nitrification in RBCs will only occur substantially if the soluble carbonaceous matter (BOD_5) is very low. The required media area for nitrification is in addition to that required for BOD_5 removal. An ammonia-nitrogen loading rate of 0.1 to 0.3 lb/NH_3-N/d/1,000 ft^2 of media surface area can reduce ammonia nitrogen to less than 2 mg/L (provided BOD_5 is already removed). Specific design criteria should be developed in consultation with the manufacturer and should be adjusted for coldest month temperature.

Predation: Fixed film systems with low organic (BOD_5) loading are more susceptible to predatory organisms (snails, worms, fly larvae). Measures should be taken to mitigate the impacts of predators on RBC performance and the impacts that a proliferation of predators may have on operating staff in adjacent work areas.

6.2.5 Moving Bed Biofilm Reactors

6.2.5.1 General

A moving bed biofilm reactor (MBBR) uses small buoyant plastic media that are uniformly distributed throughout the reactor through the use of mechanical mixing or aeration. The media support a biofilm growth and can be either aerobic (for carbonaceous removal and nitrification) or anoxic (for denitrification). The media are held in the tank by a physical barrier such as a screen or sieve that retains the media but allows water and sloughed solids to pass through to downstream unit processes.

A true MBBR has no suspended growth component and thus no return sludge. In addition, no backwashing is required. MBBRs can be configured to meet a wide range of treatment requirements, provide continuous flow operation, and sustain only modest head loss across media and media retention devices.

6.2.5.2 Media

Many manufacturers make MBBR media, which are typically recycled or virgin high-density polyethylene, and are slightly buoyant with a specific gravity approximately 5 percent less than that of water. Currently available media have bulk specific surface areas that range from 137 ft^2/ft^3 to 365 ft^2/ft^3 (area for biomass to attach/volume of media).

Biofilm growth typically occurs on the inside of the media. This is the portion of the media that is protected from interaction with other media and wall collisions. The bulk specific surface area represents this protected portion of the media.

Media Density (fill ratio): The media in an MBBR typically occupy 25 to 67 percent of the liquid volume. Therefore, the net specific surface of media in any given tank is determined by multiplying the bulk specific surface area of the media by the fill ratio. The product obtained represents the specific surface of media available for biomass attachment for a specific volume of a reactor tank.

Media Removal: Accommodations to remove media should be provided to allow for maintenance on submerged mechanical components. A recessed impeller pump can be provided to transfer media to another basin or temporary storage container. If media are transferred to another active basin, the best way to determine if the proper amount is transferred back is to drain both MBBRs to ensure both have equal media height.

6.2.5.3 Aeration Systems

When designing an MBBR aeration system, the designer should pay particular attention to the following requirements:

- Provide sufficient airflow to meet mixing and process requirements (carbon and nitrogen oxidation).
- Properly quantify oxygen transfer efficiency.
- Provide aeration that promotes a rolling pattern that will uniformly mix and maintain the media in suspension, particularly at the effluent end of the tank, to avoid clogging of media retention screens.

- Ensure piping and diffusers can withstand the weight of the wet media and biofilm when tanks are dewatered.

Aerobic MBBRs typically use coarse bubble aeration because it requires less frequent cleaning and maintenance as well as provides more vigorous mixing. If the designer is considering fine bubble aeration, it is important to carefully weigh the improved aeration efficiency possible with fine bubble systems versus the increase in diffuser maintenance costs.

Some aerobic MBBR systems are designed to operate at dissolved oxygen concentrations higher than typically used with activated sludge (4-6 mg/L). The media process sizing and aeration delivery system must be carefully coordinated in order to provide adequate dissolved oxygen concentrations to meet process goals.

6.2.5.4 Mechanical Mixing

Mixers used with MBBRs should be specifically designed for the task, and possess the appropriate components including a stainless steel, backward curved propeller.

Contrary to their positioning in activated sludge systems, submersible mixers used in MBBRs are typically mounted near the surface of the reactor for optimal mixing. This is due to the buoyancy of the media. Mounting a submersible mixer near the tank bottom is not recommended.

6.2.5.5 Media Retention Screens and Sieves

Media screens or sieves are typically constructed of stainless steel and are configured as horizontal, cylindrical, or vertical flat plate sieves. Sieve orifice sizing depends on the type and size of media used; typically, however, orifices are 1/4 in (6 mm) or smaller.

Approach Velocity: The approach velocity is the rate at which flow approaches the media retention sieves. At a rate of 1.1 ft/min, media distribution should not be impacted by approach velocity. However, when peak hourly flows result in approach velocities higher than 1.9 ft/min, media will tend to migrate to the media retention screens, increasing system head loss and reducing biological treatment efficiency. The designer should consult with the media system manufacturer to determine the acceptable range of approach velocities for the specific system proposed.

To adequately contain media within the process, the designer should carefully consider the full range of hydraulic conditions that may be encountered at the facility. The designer should consider the use of a passive secondary screen to serve as a backup to the primary containment screen, or consideration should be given to providing some type of upstream hydraulic relief to avoid a media sieve overload or overflow.

6.2.5.6 Other Design Considerations

The designer should consider a number of other factors when designing an MBBR system:

Preliminary Treatment: Without proper preliminary treatment, the MBBR screens may be subject to blinding. MBBR reactors must be provided with 1/4 in (6 mm) influent screens when coupled with primary treatment or 1/8 in (3 mm) screens when primary treatment is not included. Scum must be removed upstream of the MBBR.

Redundancy: At least two MBBR trains are required for redundancy.

Foaming: Defoaming agent may be needed at startup. Ensure the chemical is compatible with the media.

6.2.5.7 Process Design

General: MBBRs can be configured to remove BOD_5, nitrify, or denitrify. Process models have been developed to estimate performance of these systems. Removal rates provided in this section are typical ranges that may be expected.

Loading: MBBR design should consider peak organic load conditions, including the oxygen demands that occur because of sidestream flows from sludge processing and handling. Short-duration, high strength loads should be dampened via equalization or other methods. The volume of media should be based upon the design maximum month loading of the parameter(s) of concern to meet monthly discharge limits and should also consider peak loadings that correlate to weekly and peak daily limits, if applicable. Nitrogen loadings should take into account assimilation of ammonia into biomass and ammonification of the organic nitrogen present.

Carbonaceous Removal: MBBRs are defined as high, medium and low rate, depending on the level of performance required. Table 6-2 illustrates the ranges of rates under these criteria. It is important to note that most systems that are designed to operate in the medium rate and above will not generate a biomass that will flocculate and settle well. Systems designed at these loading rates cannot rely on solids removal via gravity settling alone and will likely require chemical addition or other processes such as dissolved air floatation or filtration.

Nitrification: Designers of systems providing either combined carbon-nitrogen oxidation or nitrification alone must consider that nitrification in MBBRs will only occur substantially if the soluble carbonaceous matter (BOD_5) is very low; nitrification will not proceed until carbon is exhausted. The designer must also consider that elevated dissolved oxygen concentrations may be warranted to enhance the nitrification rate. Providing MBBR systems with multiple stages to achieve nitrification and subsequent denitrification is good practice.

MBBRs readily remove biodegradable soluble organic carbon and can be classified as low rate, medium rate, and high rate as shown in Table 6-2. Normal and high rate reactors are typically used for carbon removal only. Low rate systems are most commonly used in conjunction with downstream nitrification reactors.

Typical MBBR loading rates for BOD_5 removal are as follows:

Table 6-2 **MBBR Design Criteria for BOD_5 Removal**

Loading Criteria	Typical Loading Rate (lb BOD_5/1,000 sf media-d)	Estimated Removal Rate (%)
High Rate	> 4	75–80%
Medium Rate	1 to 3	80–90%
Low Rate	< 1.0	>90% (preceding nitrification)

The designer should adjust the loading rates based on actual design temperature.

As with many fixed film systems, organic load has a significant impact on the capabilities of an MBBR to nitrify. Table 6-3 presents nitrification loading parameters.

Table 6-3 **MBBR Design Criteria for Nitrification**

BOD Load (lb BOD_5/1,000 sf media-d)	Estimated Nitrification Rate (lb NH_4-N/1,000 sf media-d)
0.2 to 0.4	0.14 to 0.24
0.4 to 0.6	0.06 to 0.16
> 1.0	None

Denitrification: MBBRs can be used to achieve denitrification using the carbon present in either influent or primary effluent flow (pre-denitrification) or from an external carbon source such as methanol, ethanol, glycerin, or a blended product such as Micro-C (post-denitrification). The nature of the wastewater characteristics, in particular the carbon source, will have a significant influence on the rate of denitrification, with rates using either of these types of sources presented in Table 6-4. MBBR systems that employ pre-denitrification are likely to be configured similar to the Modified Ludzack-Ettinger process, with the biomass attached to the media taking the place of the MLSS typical in the suspended growth version of this process. Under any configuration (pre- or post-denitrification), it is critical to address the following:

- *Nitrate:* The quantity of nitrate directed to the reactor must be sufficient to meet the treatment goals and must be fed to the reactor to the capacity of the system.
- *Carbon:* Sufficient organic carbon must be present and be readily biodegradable.
- *Biomass:* An adequate amount of biomass must be available to act on the organic carbon and nitrate.
- *Dissolved Oxygen:* DO must be mostly excluded from the reactor such that it does not inhibit denitrification.

Table 6-4 **MBBR Design Criteria for Pre-Denitrification**

Estimated Denitrification Rate (lb NO_3-N/1,000 sf media-d)	Facility
0.08 to 0.20	Ullensaker, Norway; Full Scale
0.03 to 0.10	Fredrikstad, Norway; Pilot Scale
0.05 to 0.16	Crow Creek, WY; Pilot Scale

MBBR Design Criteria for Post-Denitrification with Supplemental Carbon

Estimated Denitrification Rate (lb NO_3-N/1,000 sf media-d)	Source
0.2 to 0.8	Rusten et al., 1996

Given that aerobic MBBRs used for nitrification are often designed to operate with higher dissolved oxygen concentration (4–6 mg/L), attention must be given to ways to minimize DO transfer to either upstream or downstream anoxic reactors. Post-denitrification MBBRs can follow either fixed or suspended growth nitrification systems. As with any nutrient removal process, low effluent limits demand that a high percentage of both soluble and particulate fractions are removed. Chapter 7 of this document includes information on solids removal processes that may be beneficial in achieving low TSS and nutrient limits.

6.2.6 Biological Filter Processes

6.2.6.1 General

Biological filter processes have historically been referred to as biological aerated filters (BAFs) or denitrification filters. While the acronym BAF is still used, it now stands for biologically active filter, a term that encompasses both aerobic and anoxic filters.

There are various types of BAFs, with most characterized by three primary criteria:

- Direction of flow (upflow or downflow)
- Media density (heavier or lighter than water)
- Biological environment (aerobic or anoxic)

BAFs can also be configured as continuously backwashed filters or static filters that do not require backwashing. However, these configurations have seen limited application in New England. Design criteria for continuously backwashed filters should be based on the manufacturer's criteria, and pilot testing may be warranted. With the exception of static filters, all BAFs act as both a biological treatment and physical solids separation process. Backwashing is required periodically to remove solids that accumulate due to filtration and biological growth.

6.2.6.2 Flow Configuration

Flow configuration determines many of the physical components of a BAF system. Described below are the alternatives and their differences.

Downflow filters generally require sunken media that are heavier than water and use countercurrent backwashing. Backwashing is typically accomplished using a combination of compressed air and effluent water. Larger solids are predominately captured on the surface, and no significant pretreatment beyond that for conventional filtration is required. Due to challenges associated with countercurrent aeration and liquid flow, downflow BAFs are used predominately for denitrification. Because denitrification produces nitrogen gas bubbles that can become trapped in the sunken media, periodic "bumping" (a brief backpulse of flow) is required to free nitrogen bubbles from the media.

Upflow filters can use either sunken or floating media. Sunken media systems require flow distribution typically in the form of nozzles below the media, while floating systems use a retention system above the media that both holds the media in place and ensures that effluent is removed over the entire area of the filter. With both types of media, backwashing is accomplished using both air and water. Systems with floating media often employ periodic backwash pulses to maintain hydraulic capacity. Upflow BAFs can be used for both aerobic and anoxic operations, depending on process requirements. These systems are commonly placed in series to achieve sequential treatment steps. Given the small openings associated with flow distribution and/or media retention, a high level of solids pretreatment is typically required.

6.2.6.3 Media

The media used in a BAF are typically mineral media or plastic media. Mineral media are typically heavier than water, while plastic media typically have a specific gravity slightly less than that of water. The media need to be durable as they are constantly cycling between states of supporting a biofilm and of being scoured to remove the biofilm. Media occupy only a portion of the filter depth and have a bulk specific surface area ranging from 70 to 500 ft^2/ft^3.

6.2.6.4 Aeration Systems

Blowers or compressors may be used to supply air to the aerobic BAF. Diffuser systems can consist of perforated sparge piping or a nozzle arrangement in the filter underdrain system. Oxygen transfer through the air distribution system is greatly enhanced to the intimate contact with the biomass and the circuitous route taken by air through the filter media. These filters function essentially as plug flow reactors; the dissolved oxygen at the filter surface is not necessarily representative of that in the middle of filter media depth. As head loss through the filter can change substantially during the progression from a clean to a dirty filter, blowers must be able to operate over a range of discharge pressure conditions. It should be noted that oxygen uptake rates are typically higher in a BAF than those observed in activated sludge systems. This is due to the two mechanisms of oxygen transfer at work in a BAF. In addition to the transfer of oxygen into water, air bubbles are in direct contact with the biofilm.

6.2.6.5 Backwashing Facilities

Backwash system requirements depend on the specific system under consideration but typically include the following major components: a clearwell, a mudwell, backwash pumps, and air scour blowers. With regard to clearwell and mudwell sizing as well as equipment redundancy, backwash systems for BAFs should meet the requirements for "Rapid Rate, Automatically Backwashed Sand Filters" in Section 7.2.10.2 of this document.

Continuously backwashed filters utilize compressors for their backwash cycles and do not necessarily require dedicated clearwells and mudwells.

Large backwash tanks may require mixers to maintain solids in suspension when returning flow to the plant. These solids are typically returned to primary clarifiers to enhance BOD removal and to help improve primary sludge characteristics for pumping. However, in some BNR configurations, backwash solids may be returned to biological reactors to augment a system's biomass.

Very large facilities (greater than 25 mgd) may find separate treatment of backwash to be advantageous. Processes such as dissolved air flotation thickeners and ballasted flocculation may be appropriate for sidestream treatment of filter backwash water.

The designer should be aware of two additional considerations relative to BAF backwash:

- Many systems require that effluent flow stops during the backwash cycle, and this condition should be accommodated in the upstream and downstream processes.
- Backwash from the filter must be accounted for in the hydraulic and pollutant loadings of a plant's recycle streams.

6.2.6.6 Other Design Considerations

When designing a BAF system, the designer should consider a number of other factors:

- *Preliminary Treatment:* Fine screening should be provided upstream of BAF systems. Dedicated automatic screens should be provided if the facility runs the risk of leaves being present in influent to the BAF or if the facility has some unscreened or poorly screened sidestreams. Consideration should be given to omitting fine screens for downflow BAFs in situations where the upstream treatment components provide protection from large solids particles.

- *Redundancy:* Redundancy requirements for BAF systems depend on the type of filter and many other site specific conditions, especially effluent requirements. Redundancy should be provided consistent with the filter redundancy requirements noted in Section 7.2.10.
- *Supplemental Carbon Addition:* Denitrification using BAFs requires the addition of a supplemental carbon source such as methanol, ethanol, acetic acid, or other blended proprietary product. Supplemental carbon addition is a key element for successful denitrification and must be done with precision; underdosing will limit nitrogen removal and overdosing can result in high effluent BOD. An integrated process control system with on-line analyzer is required with denitrification filters. Many forms of automated control are available, but a system with both feed-forward and feedback capability should be considered, especially in systems with total nitrogen limits less than 5 mg/L.
- *Low Effluent P Limits:* With regard to systems that must also meet low effluent total phosphorus limits, care should be taken to provide adequate soluble, reactive phosphorus in the MBBR so as to not limit the denitrification rate.

6.2.6.7 Process Design

General: BAFs can be incorporated into nearly all levels of biological treatment and can be configured for BOD_5 removal, nitrification, denitrification, or any combination of these processes. Given the nature of the BAF process, which includes filtering with biological treatment, the process is typically most cost-effective in tertiary treatment configurations.

Due to the physical characteristics and interactions between particles, BAFs are sized based on pollutant removals per volume of media provided. Although BAF models have been developed, they are not in widespread use, and sizing criteria is mostly empirical based on specific characteristics of the media.

Loading: Biologically active filter design should consider peak organic load conditions, including the oxygen demands that occur because of sidestream flows from sludge processing and handling. Short-duration, high strength loads should be dampened via equalization or other methods. The volume of media should be based upon the design maximum month loading of the parameter(s) of concern to meet monthly discharge limits and should also consider peak loadings that correlate to weekly and peak daily limits, if applicable. Nitrogen loadings should take into account assimilation of ammonia into biomass and ammonification of organic nitrogen present.

Carbonaceous Removal: Characteristics of different BAF design criteria are presented in Table 6-5.

Nitrification: Designers of systems providing either combined carbon-nitrogen oxidation or nitrification alone must consider a number of factors inherent with any fixed film process including the following:

- Nitrification in BAFs will only occur substantially if the soluble carbonaceous matter (BOD_5) is very low (BOD_5<125 lb/1,000 cf of media per day).
- With BAFs that provide sequential steps of treatment, it is important to carefully account for organic loading and dissolved oxygen carry-over from the upstream process.

Denitrification: Because hydraulic detention time in BAFs is limited, supplemental carbon addition must be closely matched to nitrate loading and removal.

BAFs have a wide range of types of filters and thus a range of loadings and performance. Tables 6-5 – 6-8 provide typical design criteria for BAFs used for secondary treatment, nitrification, and denitrification:

Table 6-5 **BAF Design Criteria for BOD_5 Removal**

Type	Volumetric Loading (lb/d/1,000 cu ft) (at 20°C)	Hydraulic Loading (gpm/cu ft)	Removal Efficiency
Upflow sunken or floating media, backwashing	BOD: 94–370 TSS: 50–220	1.2–6.6	BOD: 65–90% TSS: 65–90%
Submerged, non-backwashing	BOD: 50–94 (at 20°C)	0.8–5	BOD: 85–95%

Table 6-6 **BAF Design Criteria for Nitrification**

Type	Volumetric Loading (lb/d/1,000 cu ft) (at 20°C)	Hydraulic Loading (gpm/cu ft)	Removal Efficiency
Upflow sunken or floating media, backwashing (following primary treatment)	BOD: <94–188 TSS: <62–100 NH_3-N: <62–100 (20 C)	1.2–5	BOD: 70–90% TSS: 65–85% NH_3-N: 65–75%
Upflow sunken or floating media, backwashing (following secondary treatment)	BOD: <62–125 TSS: <62–100 NH_3-N: <62–100 (20 C)	1.2–8.2	BOD: 40–75% TSS: 40–75% NH_3-N: 75–95%
Submerged, non-backwashing (following secondary treatment)	NH_3-N: 12–56 (20 C)	0.8–5	NH_3-N: 85–95%

Table 6-7 **BAF Design Criteria for Pre-Denitrification**

Type	Volumetric Loading (lb/d/1,000 cu ft) (at 20°C)	Hydraulic Loading (gpm/cu ft)	Removal Efficiency
Upflow sunken or floating media, separate BAF stages (pre-denitrification + nitrification)	NO_3-N: 62–75	4–12	NO_3-N: 75–85%
Upflow, floating media combined anoxic/aerated BAF stage	NO_3-N: 62–75	4.9–8.8	NO_3-N: 70% (w/ supplemental carbon), 85% (w/o supplemental carbon)

Table 6-8 **BAF Design Criteria for Post-Denitrification**

Type	Volumetric Loading (lb/d/1,000 cu ft) (at 20°C)	Hydraulic Loading (gpm/cu ft)	Removal Efficiency
Downflow, sunken media	NO_3-N: 20–200	2–3.5 (avg) 5–7.5 (peak)	NO_3-N: 75–95%
Upflow, sunken media	NO_3-N: 50–300	4–14	NO_3-N: 75–95%
Moving bed, continuous backwash	NO_3-N: 20–120	2–4 (avg) 6 (peak)	NO_3-N: 75–95%

6.2.7 Solids Separation For Fixed Growth Systems

Other than BAFs that include their own physical separation process, all fixed growth systems require some manner of physical separation of solids that are sloughed from the media. It is important to note the inherent physical differences between solids formed in a fixed growth system and those in a suspended growth system; fixed growth system solids generally are much lower in concentration and do not have the same flocculation tendencies as activated sludge. This often results in substantial challenges to fixed growth system performance relative to effluent solids, colloidal material, and turbidity that may impact downstream processes such as disinfection. It has also been documented that clarifier depth has a correlation with performance of fixed growth system solids separation.

Solids separation is accomplished in a number of ways for fixed growth systems including clarification, floatation, or direct filtration. Clarification is most commonly used and may consist of traditional clarifiers as well as systems augmented with inclined plates or tubes. Where fixed growth systems are employed at facilities that must also meet stringent phosphorus removal requirements, ballasted flocculation/sedimentation can serve as the solids removal step.

Design of traditional secondary clarifiers for fixed growth systems, including trickling filters, RBCs, and MBBRs, should be based on the following minimum criteria:

- A minimum of two units are required.
- Clarifiers must have a minimum side water depth of 12 feet. The following overflow rate sizing criteria is based on a side water depth of 12 feet. Should a shallower depth be present in existing units, hydraulic capacity should be downrated.
- Clarifiers must be sized to provide an average overflow rate (at maximum month flow) of 600 gpd/sf(12 feet deep units).
- Clarifiers shall be sized to provide a peak hourly overflow rate of 1,200 gpd/sf (12 feet deep units).
- Clarifiers for fixed growth systems should be provided with flocculation facilities as part of the clarifier or immediately upstream, with provisions for chemical addition to improve settling.

6.3 Suspended Growth Systems (Activated Sludge)

6.3.1 Overall Considerations

Suspended growth biological treatment or activated sludge is a treatment process used in a wide variety of configurations where wastewater is amenable to biological treatment. Biological reactors, clarification, and solids return are all components of the process, which must be designed as an integrated system. The design and operation of each component has a direct impact on the size and operating performance of each of the other components. The process can operate as a continuous flow or as a batch process. The activated sludge process was originally developed as a fill-and-draw batch process.

The activated sludge process may be used to remove suspended solids as well as carbonaceous and/or nitrogenous oxygen demand and nutrients (nitrogen and phosphorus). The choice of process will be influenced by the degree and consistency of treatment required, type of waste to be treated, proposed plant size, anticipated degree of operation and maintenance, local factors, and operating and capital costs. Designs should maximize process flexibility while maintaining design intent, process reliability, and effluent quality.

The process requires competent operating supervision, including routine laboratory control and proper control of waste and return sludge.

The guidelines presented here are specific to plants treating predominantly domestic wastewaters. Wastewaters with a significant industrial fraction warrant special attention such as pilot studies and modeling to establish the basis of design.

6.3.1.1 Pretreatment

Where primary settling tanks are not used, the effective removal of grit, debris, excessive oil, and grease or the screening of solids should be accomplished before activated sludge treatment.

Primary treatment will likely remove a significant portion of particulate biodegradable carbon. Consideration should be given to the impacts of particulate carbon removal on downstream processes, plant capacity, and upgrade costs.

6.3.1.2 Scum and Floatable Material

Designs should include provisions so that floating materials from the suspended growth reactor tanks and clarifiers can be directly removed from the treatment facilities, avoiding the recycling of foam-causing microorganisms. Configurations that promote foam trapping in the reactor tanks should be avoided. Consider providing the capability to chlorinate foam either on tank surfaces or in pumped lines.

6.3.2 Selectors

6.3.2.1 Types and Use

Selectors, or flow patterns within the aeration tanks, can be used to combat the growth of filamentous organisms and to enhance the settling of mixed liquor. Incorporating selectors into an activated sludge process may reduce the size of the clarifier required.

Selectors can be anaerobic, anoxic, or aerobic. Each should provide a substrate concentration gradient, a high initial F/M ratio, and adequate time for bioabsorption of soluble organic substrates.

F/M ratios in selectors (as described below in Section 6.3.2.2) are determined using the following definitions:

- F = COD (or equivalent BOD) under maximum month design conditions for the first-stage selector. The same F is used for F/M calculations of all of the selector compartments.
- M = total mass of compartments considered. Mass for the first compartment is MLSS concentration multiplied by the volume of the first compartment. Mass for the second compartment is MLSS concentration multiplied by the volume of the first two

compartments. Mass for the third compartment is MLSS concentration multiplied by the volume of all three compartments.

6.3.2.2 Design Criteria for Selectors

Aerobic Selectors: A three-compartment design should be used. The F/M ratio of the first compartment is critical. Compartments should be sized to provide the following F/M ratios:

First compartment	12 pounds COD/per pound MLSS per day
Second compartment	6 pounds COD/per pound MLSS per day
Third compartment	3 pounds COD/per pound MLSS per day

This design will provide two equally sized compartments followed by a third compartment with twice the volume of the first compartment.

Avoid higher initial loadings to the first compartment or viscous-bulking activated sludge may be produced.

Aerobic selectors should have the capacity to maintain a minimum of 2 milligrams per liter of dissolved oxygen (DO). Provisions should be made to satisfy oxygen uptake rates of at least 50–60 milligrams of oxygen per gram of MLSS per hour.

Anoxic Selectors: Anoxic selectors are used in nitrifying activated sludge systems. A portion of the nitrified mixed liquor must be recycled to the anoxic zone for denitrification. Sufficient nitrate must be recycled for removal of the soluble COD, and dissolved oxygen levels should be maintained at 0.5 mg/L or lower. Independent mixing should be provided, and upstream and recycle oxygen inputs should be minimized. Air should not be used for mixing anoxic selectors.

A single-stage design with an F/M of 1–2 pounds COD/per pound MLSS per day should provide excellent control of settling.

More efficient denitrification can be achieved with a three-compartment configuration. Compartments should be sized to provide the following F/M ratios:

First compartment	6 pounds COD/per pound MLSS per day
Second compartment	3 pounds COD/per pound MLSS per day
Third compartment	1.5 pounds COD/per pound MLSS per day

Compartments must be mixed with mixers or by very low aeration rates. If low aeration rates are used, the DO must be kept below 0.5 mg/L.

Anaerobic Selectors: Anaerobic selectors should be divided into three compartments with the same F/M ratios as anoxic selectors. The hydraulic retention time required in the anaerobic selector zones depends on the incoming wastewater characteristics and typically ranges between 0.75 to 2.0 hours.

Anaerobic selectors must be provided with mixers, and air should not be used for mixing anaerobic selectors. Dissolved oxygen, nitrate, and nitrite from upstream and recycle sources should be minimized.

6.3.3 Reaction Tanks

6.3.3.1 General

Size: The size and configuration of suspended growth biological reactors is a function of the influent wastewater and treatment process goals. Process design for various treatment goals is presented separately in this chapter.

Energy: The activated sludge process requires significant energy use to meet aeration demands. Energy costs and equipment must be carefully evaluated. Alternate operating modes in diffused aeration systems can result in inefficient use of energy.

Carbon Oxidation and Nitrification: Activated sludge systems can be used for carbonaceous and nitrogenous BOD removal in single sludge systems.

Nutrient Removal: Activated sludge systems can be used in single and separate sludge configuration to remove carbon, nitrogen, and phosphorus.

Dimensions: The dimensions of each aeration tank should allow for effective mixing and use of air. Ordinarily, liquid depths should not be less than 10 feet or more than 25 feet.

All aeration tanks should have a freeboard of not less than 18 inches. Greater heights are desirable. Aeration tanks with mechanical aerators require a minimum freeboard of 3–5 feet, depending on aerator size and type.

If diffused aeration is used, a minimum 4:1 length:width ratio should be maintained. Alternatively, use three square reactors in series.

Volume: Total aeration volume should be divided among two or more units capable of individual operation. A minimum of four independent aeration tanks should be provided in all plants where the average daily design flow exceeds 20 mgd. Facilities that experience substantial seasonal variations in loading should have a suitable number of independent aeration tanks to provide operating flexibility on a seasonal basis.

Height: All aeration tanks should have a freeboard of not less than 18 inches. Greater heights are desirable. Aeration tanks with mechanical aerators require a minimum freeboard of 3–5 feet, depending on aerator size and type.

Redundancy: Total aeration volume should be divided among two or more units capable of individual operation. Facilities that experience substantial seasonal variations in loading should have a suitable number of independent aeration tanks to provide operating flexibility on a seasonal basis.

Inlets and Outlets: Inlets and outlets for each aeration tank should be equipped with valves, gates, stop plates, weirs, or other devices for controlling the flow to any unit and for maintaining relatively constant liquid levels and hydraulic equalization between aeration tanks. Provisions should be made to facilitate draining and cleaning. Tanks should be designed to prevent surface trapping of foam or scum.

Froth and Foam Control: Water spray systems or other approved means of froth and foam control should be provided. Froth and foam control systems must be protected from freezing. Chlorine addition to froth and foam control sprays may be helpful in reducing the growth of foaming organisms. Aeration tanks should be designed to allow for free surface flow and to prevent foam trapping.

6.3.3.2 Aeration Equipment

6.3.3.2.1 Oxygen Requirements

Aeration systems should be sized for the maximum daily oxygen requirements (taking into account plant sidestreams, and seasonal variations in temperature and humidity) while maintaining an aeration basin DO concentration of 2 milligrams per liter. In the absence of specific plant data, the maximum daily oxygen requirement can be calculated by multiplying the average daily demand for domestic wastes by 1.85. Aeration equipment must also provide thorough mixing of the aeration basin contents. Mixing requirements are as follows:

- Fine bubble, full-floor coverage: 0.12 scfm per square foot of tank area.
- Spiral roll: 20–30 scfm per 1,000 cubic feet of tank volume.
- Mechanical aeration: 0.5 horsepower per 1,000 cubic feet of tank -volume.
- Independent mixing of aerated zones should be considered wherever portions of aeration tanks are designed to operate under mixing-limited conditions for extended periods.

The type of aeration that best fits a facility should be determined by evaluating the existing facilities, design flows and loadings, reactor tank configuration, and oxygen delivery requirements of the process.

6.3.3.2.2 Oxygen Supply

In lieu of detailed process calculation and modeling, oxygen supply should be designed based on 0.85–1.2 pounds of oxygen per pound of BOD removed plus 4.2 pounds of oxygen per pound of ammonia nitrogen oxidized at maximum daily loading conditions. The lower range of oxygen required for BOD oxidation applies to low-SRT systems; the higher range to extended air systems. Oxygen for nitrate formation does not need to be supplied to non-nitrifying systems. However, nitrification can be difficult or impossible to avoid during warm weather months. Systems designed without capacity for ammonia oxidation should consider including capabilities for cyclic operation and independent mixing to limit nitrification. These requirements are exclusive of air requirements for channel mixing and other air use demands.

6.3.3.2.3 Size of the Aeration System

The basis used for determining the size of the aeration system, including supporting calculations, should be completed during the design. The following factors should be considered during aeration design:

- Standard oxygen transfer efficiency of system provided
- Field or dirty water transfer efficiency
- Alpha and beta factors
- Correction factors of oxygen saturation for plant altitude, diffuser submergence, and ambient temperature
- Minimum DO concentration
- Aeration system SRT
- Diffused air systems

a. Blowers

Blower capacity must be based on the air volume required during summer temperature and humidity conditions. The size of motors for centrifugal compressors must be based on summer air flow rates and the coldest expected winter temperature (or other means provided to control mass air flow rate and prevent motor overload). Motor sizing for rotary positive-displacement units does not require a cold weather correction. Temperature and pressure gauges should be incorporated into the blower design.

Control of blower output should match the diurnal organic load variation and resultant oxygen demand. Blowers should be capable of turndown to minimum expected air-demand conditions. Blowers should be provided in multiple units to meet maximum air demands, even with the largest unit out of service. Seasonal requirements and operating flexibility should be considered. Independent mixing of aerated zones should be considered wherever portions of aeration tanks are designed to operate under mixing-limited conditions for extended periods.

Blowers should be designed as a system to maximize the wire-to-air efficiency and to minimize energy consumption. Blower controls should be incorporated into the system, providing sufficient ability to meet oxygen demand in the various tanks in service through multiple blowers, variable blower output, dissolved oxygen monitoring, air flow measurement, and automated control valves.

Intake and discharge silencers should minimize nuisance noise from blowers. Noise control measures should also be incorporated into the design of the blower room.

An adequate number of air filters of appropriate capacities should be provided and arranged to ensure the air supply is free from dust, thereby preventing damage to blowers and the clogging of diffusers.

b. Piping

The size of air piping should be based on maximum expected summer temperatures and in-line velocities of 2,000–2,500 feet per minute. Higher velocities can be used, but head losses will result in increased power consumption and noise levels.

Piping exposed to operators (within 7 feet of the floor) should be insulated and wrapped or otherwise treated to protect operators from accidental burns.

Air piping systems should withstand expansion caused by a range of temperatures, from minimum winter to maximum summer blower discharge.

Valve seals and gaskets, insert flow meters, and any other nonmetallic components should withstand maximum expected summer blower discharge temperature. Piping for fine bubble systems should have non-scaling interior surfaces to prevent diffuser clogging.

Flow meters should measure total air flow to the aeration tanks. Measuring devices should total and record, as well as indicate, flows.

Valving should allow for variation in air flow rates to various aeration tanks and for isolation of aeration tanks, flow meters, and other appurtenances. Moisture blowoffs should be provided at points where pipe size changes and at system low points.

c. Diffusers

The number of diffusers should be based on specific diffuser capabilities and oxygen transfer rates. The basis of the diffuser design should be developed along with other requirements during design.

The diffuser design must provide for maximum and minimum air flow rates while maintaining tank mixing.

The spacing and arrangement of diffusers should comply with oxygenation requirements throughout the tank and expected process operating modes. If alternate operating modes such as plug flow and step feed are provided, the diffuser layout must be arranged so as to accommodate each mode but not to overly compromise efficiency in typical operating mode.

The diffuser arrangement should facilitate adjustment to the diffuser density. Full-floor coverage systems should have 10 percent additional diffuser holders to facilitate installation of additional diffusers or rearrangement of the diffuser pattern if operating conditions warrant.

Individual diffusers grids should be equipped with control valves for throttling or complete shutoff.

6.3.3.2.4 Mechanical Aeration

Motors, gear housings, bearings, grease fittings, etc., should be easily accessible and protected from inundation from liquids and spray as necessary for proper functioning of the unit. The aerator mechanism and associated structure should be protected from splashed liquids that, in winter, could freeze the equipment.

The aerator should have at least three different speed settings to allow the operator to adjust the amount of oxygen transferred to the system. The use of variable-frequency drives for dissolved oxygen monitoring and control of aerator speed should be considered.

6.3.3.2.5 Pure Oxygen

The design of pure oxygen systems differs substantially in many respects from that of air systems, and system suppliers should be consulted for assistance. The design basis should be submitted to the reviewing authority. The sizing of the aeration basin volume and clarifiers is no different than for air systems. Properly designed pure oxygen activated sludge systems treating domestic wastes also require similar site areas as air systems.

6.3.3.2.6 Return Sludge Pumps

At least one pumping unit should be provided for each clarifier or stacked clarifier. The maximum required return sludge capacity should be available with the largest pumping unit out of service. Pumps can be placed on suction headers, but the arrangement and valving should be such that any one clarifier can be isolated with a single pump. Consider seasonal requirements and operating flexibility.

A positive suction head should be provided for all pumps.

The pumps’ suction and discharge openings should be at least 3 inches wide.

Return sludge pumps should be driven by variable frequency drives to allow the operating range identified in Table 6-10.

6.3.3.2.7 Return Sludge Piping

Suction and discharge piping should be at least 4 inches in diameter and should maintain a velocity of greater than 2 feet per second when operating at normal sludge return rates.

Suitable devices should be provided for sampling and measuring return sludge flow rates. Measuring devices should total, record, and indicate flows. Means should be provided to allow for measurement of return sludge flow rates from each clarifier. Portable, strap-on devices are satisfactory. Recording and totaling are not required.

Return/waste sludge pumps and piping should typically be provided to allow concurrent return and wasting.Capability should be provided for constant return rates and for automatic proportioning of return sludge to influent flow to the aeration tanks. Secondary effluent meters can provide influent flow measurement.

Provisions should be made for draining and flushing discharge lines.

6.3.3.2.8 Waste Sludge

Means for measuring, sampling, and controlling the rate of waste activated sludge flow should be provided. Measuring devices should total and record, as well as indicate, flows.

Waste sludge may be discharged to primary settling tanks, units for concentrating the waste sludge, storage tanks, digesters, or other devices for direct removal from the plant. Using primary tanks as the principal means of wasting should be discouraged.

Circular clarifiers should allow sludge wasting from the return sludge lines (return pump suction or discharge) or from the center of the clarifier.

Waste sludge facilities should have the capacity to pump the expected minimum and maximum rates of wasting. Maximum rates will vary among facilities, depending upon hours wasted per day and days per week. Daily wasting is recommended for facilities treating in excess of 1 mgd.

At plants with an average design flow of 10 mgd or less, waste sludge pumping facilities should normally be designed with a maximum capacity of 25 percent of the average design flow and should provide a minimum flow rate of approximately 80 gallons per minute (to allow a velocity of 2 feet per second in a 4 inch diameter pipe). At plants with an average design flow greater than 10 mgd, waste sludge pumping facilities should be based on the process design waste sludge quantity at maximum month flow and loading with waste sludge pumps operating no more than 12 hours per day. Waste sludge pumping systems should be capable of providing the required capacity even with the largest unit out of service.

Provisions should be made for draining and flushing discharge lines.

6.3.4 Bulking Sludge Control

All activated sludge designs should control bulking sludge. Preferably, selectors should be provided in accordance with Section 6.3.2.2.

Plant designs should include provisions for selectively killing filamentous microorganisms by adding an oxidizing agent to the return sludge. The designs should require the addition of 2–10 mg/L of chlorine per 1,000 mg/L of MVLSS in the aeration system to the return sludge. The point of addition should be well mixed and multiple locations of chlorine addition should be provided for operational flexibility. Progressive, controlled doses of chlorine are required. The mass dose should be spread over 24 hours.

6.3.5 Secondary Clarification

6.3.5.1 General

Secondary clarifiers should be designed as part of a system that includes and considers aeration basins and sludge return facilities. Conservatism in clarifier design will generally result in consistent, high-quality effluent. However, high solids residence times in clarifiers should be minimized to limit biological activity in sludge blankets. The implications of long solids residence times in clarifiers can be substantial relative to denitrification and/or secondary release of orthophosphate from biological phosphorus removal sludges.

6.3.5.2 Number of Clarifier Units

Multiple units capable of independent operation are desirable and should be provided unless equalization facilities or other provisions can ensure adequate treatment with a clarifier out of service. EPA reliability standards, as published in the agency's Technical Bulletin 430/99-74-001 *Design Criteria for Mechanical, Electrical, and Fluid Systems and Component Reliability,* should be met to the extent possible.

6.3.5.3 Types of Clarifier Units

Clarifiers for activated sludge can be rectangular or circular. Clarifiers should separate and concentrate mixed liquor; remove settled sludge; skim, collect, and remove scum and other floatable objects; and provide the required effluent quality.

Clarifier walls should extend at least 6 inches above the surrounding ground and should provide not less than 12 inches of freeboard. Additional freeboard or provisions for the addition of wind screens are recommended for larger clarifiers that may be subject to strong winds.

6.3.5.4 Design Criteria for Clarifiers

Clarifier surface area is the single most important aspect of clarifier sizing. Proper surface area ensures that the sludge settling velocity is not exceeded by the overflow rate. Design criteria for determining clarifier surface area should be based on solids flux analysis. Side water depth is important to absorb variations in blanket depth due to changes in flow, settling characteristics, and upstream process operation. Ultimately, solids loading capacity of the clarifiers will determine the allowable MLSS concentration in the suspended growth treatment process.

Design Flow: The design flow should be determined based on analysis of historical variations in flows with appropriate consideration for growth, inflow and infiltration impacts/reduction, and collection system characteristics. The design criteria should adequately define both the magnitude of high flows and the frequency of occurrence. The relationship between an extreme flow event and average flow conditions can be determined statistically from the historical flow record and applied to future flow projections. The design flow should be based not only on frequency of occurrence, but also the acceptable risk and available footprint. Also consider if there are any other relief points in the system, such as the ability to alter the operating mode of the process. Basing design on flows less than peak hourly flow warrants use of a safety factor. Examples of common approaches for determining design flow criteria for secondary clarifiers include:

- Maximum daily flow for period of record with a safety factor, typically 1.3 or 1.5.
- Peak hourly flow for period of record without a safety factor.

Analysis of historical flows to determine design criteria should be based on statistical analysis over a number of years (preferably a minimum of three) and use of the highest individual value or some frequency of recurrence (such as the flow condition exceeded 1 or 2 times per year).

The design flow can include a safety factor to buffer against uncertainty. A suggested factor of safety for range from 1.0 (no safety factor) to 1.1 at peak hourly flow and 1.3 to 1.5 at maximum daily flow. Higher factors of safety for longer flow periods (weekly, monthly or annual averages) are likely warranted.

Solids Flux Analysis: Clarifier area sizing should be based on solids flux analysis or a similar approach. Solids flux takes into account solids loading, hydraulic loading, MLSS concentration, and settleability (SVI). Common approaches include development of a series of state-point analyses (SPAs) that define tangents to the solids flux curve as critically loaded conditions; the SPAs are then combined into design and operating (D&O) charts that present sets of tangents as a family of curves on a single graph. Two such D&O charts are those proposed by Ekama (1984) and Daigger (1995). To define critically loaded conditions, solids flux analysis considers solids loadings, sludge settling characteristics (typically unstirred SVI), settled sludge and/or MLSS concentration, return sludge rates, and clarifier surface area. Methods for solids flux analysis can be found in most textbooks or published literature. Figure 6-1 presents the graphical approach developed by Daigger (1995) and described in Jenkins, et al (2003).

Identical design criteria is also presented in a different format using an approach encompassing two graphic components: (1) a graph illustrating peak hourly secondary clarifier capacity at varying MLSS concentrations and SVI and (2) a graph showing RAS ratio at maximum solids loading capacity at varying MLSS concentrations and SVI (Dombrowski, 2007). The D&O charts in Figures 6-2 and 6-3 depict capacity at critical solids loading with a safety factor of 1.0 (no additional factor of safety).

The SVI used should be based on some conservative value, such as the 95th percentile of historical SVI data. If historical SVI data is unavailable or if the plant is being upgraded or modified, an SVI of 150 mL/g should be used if the facility uses selectors and an SVI of 200 mL/g if selectors are not incorporated into the facility. Due to improved settling characteristics associated with some selector configurations, designs for systems with a selector can be based on an SVI lower than 150 mL/g if there is sufficient evidence or justification that a lower SVI will provide acceptable plant performance.

All of the above is summarized in Table 6-9, which relates return ratio, peak hourly flow surface overflow rate, and MLSS concentration for SVI values of 150 mL/g and 200 mL/g. These values are based on a series of state point analyses using the Veslind settling equations used to develop the Daigger (1995) D&O curves. A safety factor is not included, and the return ratio presented is in relation to the flow at critical loading (as defined above). The overflow rate is the forward flow divided by the surface area of the secondary clarifiers in service.

Figure 6-1

Secondary Clarifier Operating Diagram Using Unstirred SVI
Based on Daigger (1995)

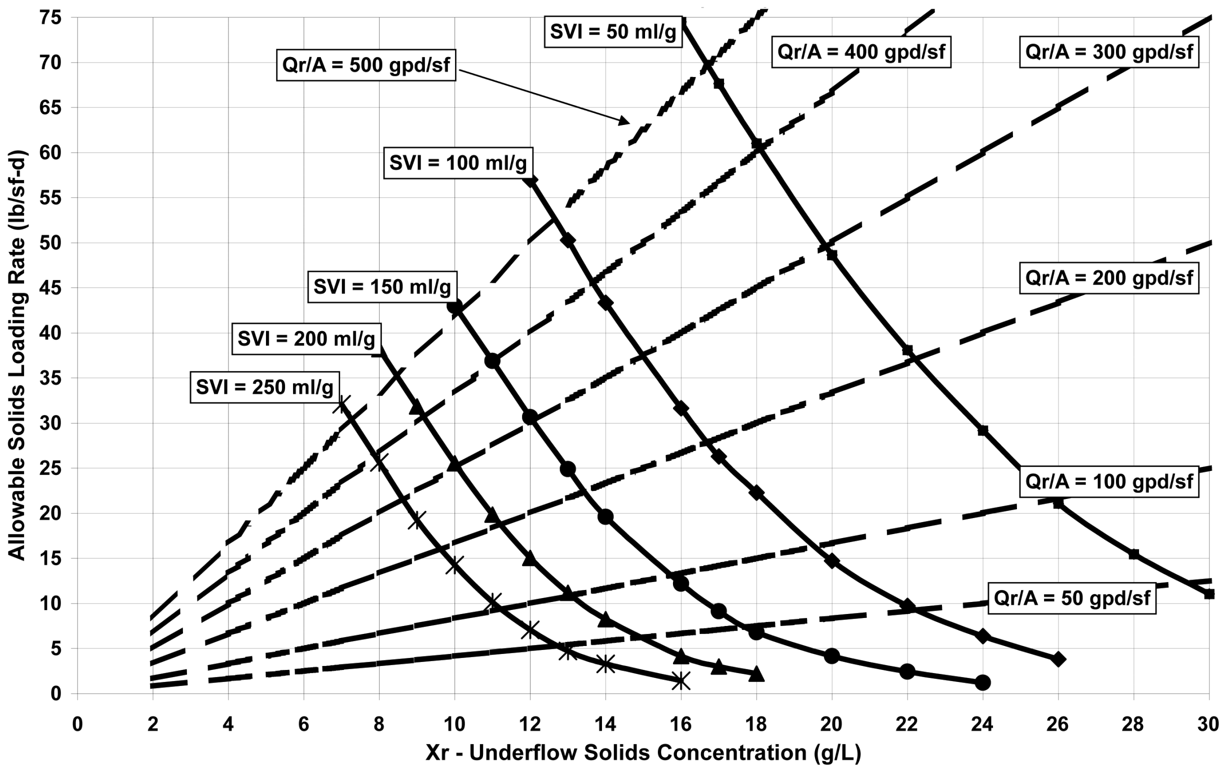


Table 6-9

Suspended Growth Secondary Clarifier Surface Overflow Rate and RAS Rate Under Critically Loaded Conditions at Peak Hourly Flow [(1)]

	SVI = 150 mL/g		SVI = 200 mL/g	
MLSS Concentration (mg/L)	Surface Overflow Rate at critical loading (gpd/sf)	RAS Rate at critical loading (% forward flow)	Surface Overflow Rate at critical loading (gpd/sf)	RAS Rate at critical loading (% forward flow)
1,500	2,100	14%	1,850	18%
2,000	1,710	22%	1,450	29%
2,500	1,400	30%	1,140	40%
3,000	1,140	40%	900	54%
3,500	930	52%	690	70%
4,000	760	64%	550	89%
4,500	610	79%	440	112%
5,000	510	95%	340	138%

(1) For use with determining peak hourly flow capacity of secondary clarifiers. These values do not include any factor of safety. Using a safety factor is recommended when using these values for lower design flow criteria, i.e., daily, monthly, or annual average conditions.

Figure 6-2 Secondary Clarifier Peak Hourly Flow SOR vs. MLSS Concentration & SVI at Critical Loading - Non-RAS Rate Limiting Conditions

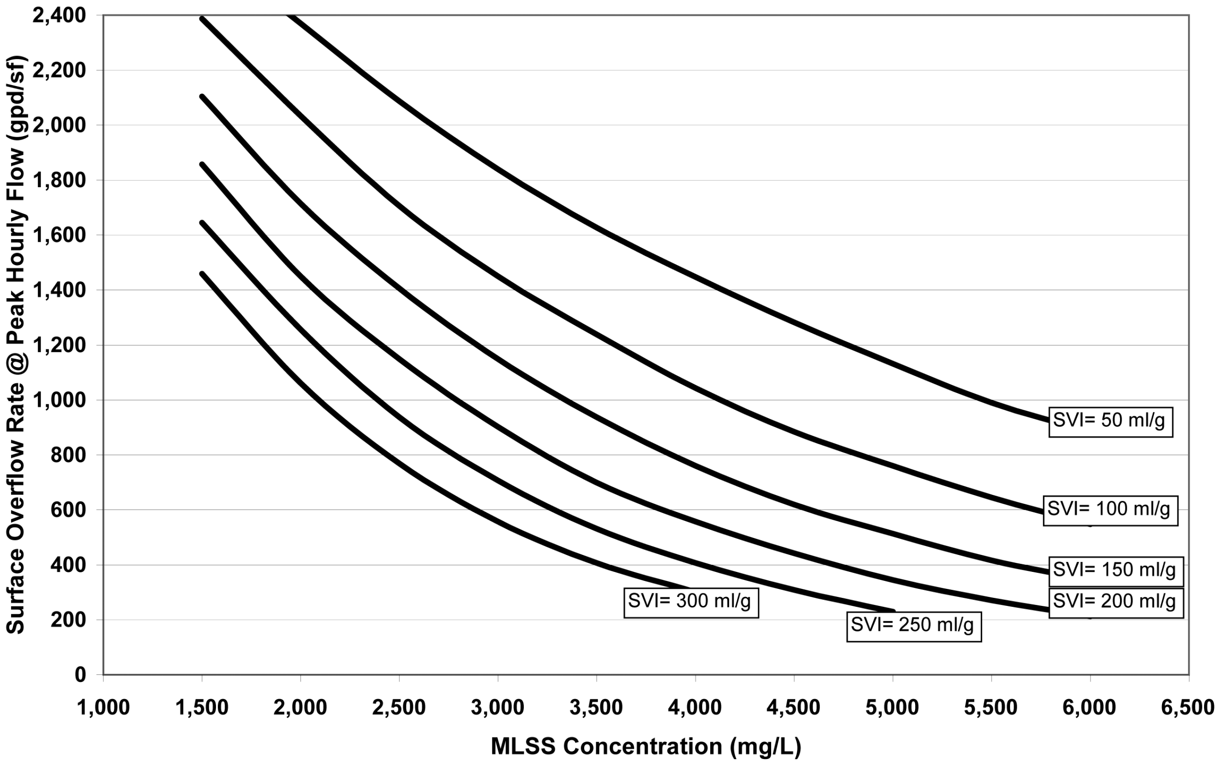
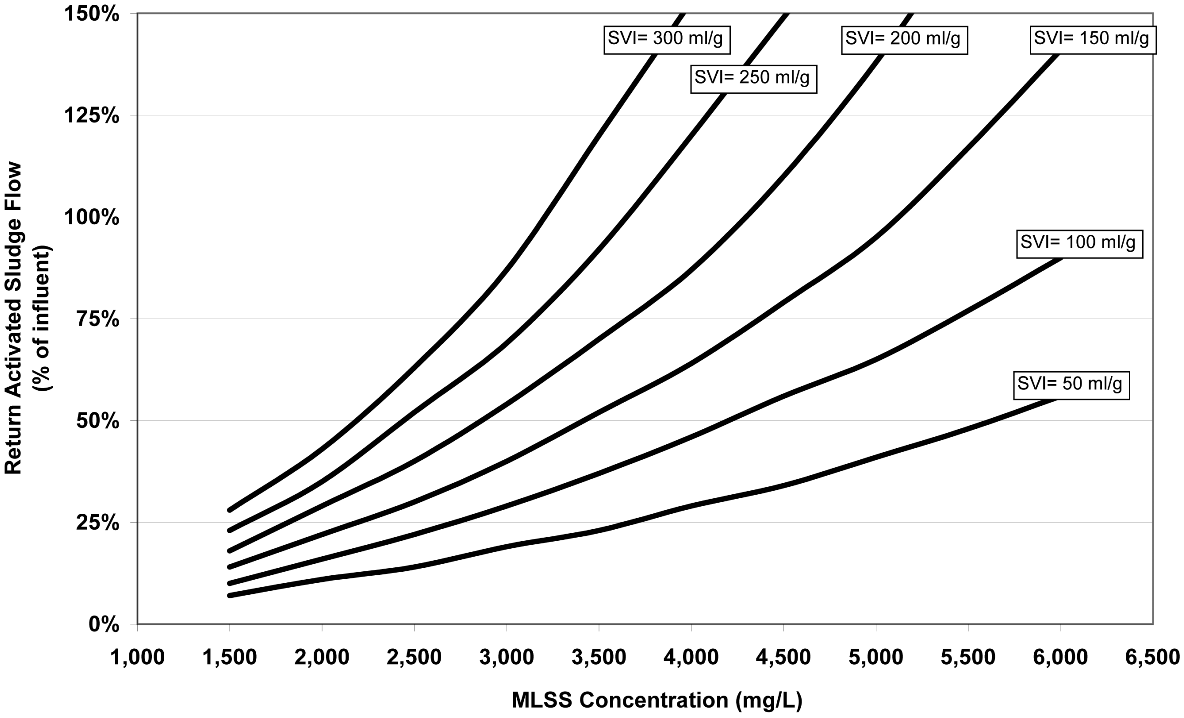


Figure 6-3 RAS Rate vs. MLSS Concentration & SVI at Critical Loading



Side Water Depth: Rectangular units should be designed with a side water depth of no less than 12 feet.

Recommended side water depths for circular units are as follows:

Up to 40 ft diameter	12 ft
40–75 ft diameter	14 ft
75–125 ft diameter	16 ft
Greater than 125 ft diameter	18 ft

Circular clarifiers should have a minimum bottom slope of 0.25 inch per foot. Systems that are not preceded by primary treatment should have minimum bottom slopes of 1 inch per foot.

6.3.5.5 Inlets

Inlets should minimize short circuits, provide effective velocity dissipation with minimum shearing of the biological floc, and distribute flow across the entire clarifier.

Circular, center-feed clarifiers with conventional center wells should use a riser-pipe inlet design that provides a maximum inlet velocity of 4–6 feet per second. Consider the effectiveness of the center well at low flows. Standard center well diameters should not exceed 25 percent of the clarifier diameter. The vertical dimension of the center well should be approximately 50 percent of the tank depth and extend below the elevation of the openings in the riser. The center well must not interfere with the sludge collector.

Minimize scum collecting in the inlet area and provide for its routine removal.

6.3.5.6 Outlet

V-notch weirs should be provided. The head over the base of the V-notch at peak hourly flow should be less than the depth of the notch to prevent overtopping of weirs. Weirs should be adjustable to compensate for any difference in settlement of the tanks.

Effluent launders should convey the maximum instantaneous flow without surcharging above the bottom of the V-notches of the clarifier effluent weirs. Launders should convey effluent in a free-flowing, open channel flow mode without any surcharging and without creating backwater conditions in the launder. Avoid excessively deep launders, which can interfere with flow through the clarifier.

Launder inverts should slope a minimum of 0.5 percent to allow for easy cleanup when a tank is drained. The effluent box should be located directly beneath the effluent channel, with the channel drop perpendicular to flow direction.

To reduce short-circuiting, interior baffles and peripheral baffles can be used to redirect density currents back to the center of circular clarifiers. Stamford baffles should be provided on all peripheral overflow clarifiers.

6.3.5.7 Sludge Collection

Sludge collection and withdrawal devices may consist of hydraulic manifold style, organ pipes, or spiral scraper style units and should accommodate the withdrawal of solids for minimum and maximum operating conditions. Rapid sludge removal systems in circular clarifiers should be designed so return rates can be directly varied by changes in return sludge pumping rates.

Spiral scrapers in circular clarifiers should be designed to provide adequate capacity to efficiently convey solids to the collection sump for transport.

Chain and flight sludge collectors in rectangular clarifiers should be designed with a minimum horizontal velocity of 2–3 feet per minute with flights at least 10 feet on center. Multiple-speed collectors with speed capability of 2–6 feet per minute should be considered for tanks with high solids loadings or long flight travel times.

6.3.5.8 Scum Removal

Effective baffling and scum removal equipment should be provided in each clarifier. Scum removal equipment should facilitate the positive movement of scum to scum hoppers. Scum hoppers should facilitate the flushing of scum from each hopper. Scum piping should be sized for proper movement of viscous foams. Consider including flushing water and chlorine addition to scum discharge lines.

Large clarifiers should be provided with dual skimmers, wider scum hoppers, and a minimum of 8-inch diameter scum hopper piping. Plants that are designed using BNR processes should include full radius scum collection.

6.3.5.9 Return Sludge Rate

The actual rate of return sludge withdrawal is a function of the concentration of mixed liquor suspended solids, settling of the activated sludge, and process control requirements. Sludge return rate capabilities should be designed within the following ranges of the maximum month design flow or as determined by solids flux analyses:

Table 6-10 **Return Sludge Pump Variable Frequency Drive Operating Ranges**

Type of Process	Minimum	Maximum
Conventional	15%	100%
Step aeration	20%	100%
Contact stabilization	30%	100%
Extended aeration	30%	150%

Suitable devices should be provided for sampling and measuring return sludge flow rates. Measuring devices should total, record, and indicate flows, and there should be a means of measuring return sludge flow rates from each clarifier. Capability should be provided for constant return rates and for automatic proportioning of return sludge to influent flow to the aeration tanks. Secondary effluent meters can be used in lieu of influent flow measurement.

6.3.5.10 Chemical Settling Aids

Use of chemical settling aids—metal salts, polymers—should be considered especially where peak hydraulic loadings in existing clarifiers are beyond the limits recommended herein or where effluent TSS concentrations of less than 15 mg/L are required. The engineer should compare the capital and long-term O&M costs of the chemical feed system with the capital and O&M costs of building an additional clarifier to accommodate infrequent peak flows. When selecting chemical settling aids, confirm that the chemical constituents are not toxic or prohibited from discharges.

6.3.6 Process Configurations Using Gravity Clarifiers

The predominant means of achieving suspended growth biomass separation is via gravity clarifiers. There are numerous shapes, loading rates, and feeding patterns possible with suspended growth that can be used to achieve a variety of treatment goals and objectives.

6.3.7 Sequencing Batch Reactors

Sequencing batch reactors (SBRs) were the configuration used to develop the original activated sludge process but were abandoned as the preferred configuration due to their higher operational requirements. However, as a result of the development of automated process controls in the 1980s and 1990s, SBRs have once again become a very common treatment technology, especially in plants smaller than 1.0 mgd.

6.3.7.1 General

SBRs and similar cyclical processes provide suspended growth biological treatment in a single tank on a time sequence basis in contrast to the multiple tank volume-based approach used by continuous flow processes. SBRs operate through a sequence of steps as described below:

- *Fill:* The basin receives wastewater, and biological treatment is initiated; aeration or mixing may be used.
- *React:* Filling of the tank is discontinued; some combination of mixing and aeration is used, depending on process goals.
- *Settle:* No wastewater enters the basin, and aeration and mixing are discontinued; quiescent settling takes place.
- *Decant:* Effluent is removed from the basin, typically just below the liquid surface; sludge wasting may take place.
- *Idle:* Little or no activity occurs, providing time flexibility to balance cycle times with other SBR basins; sludge wasting may take place.

Overall cycle times and the duration of the steps in the SBR sequence of operation are flexible and allow the process to be tailored to various levels of treatment, from secondary treatment to a moderately high level of nutrient removal. This process flexibility is a significant advantage of the process.

6.3.7.2 Preliminary and Primary Treatment

Primary clarifiers are not commonly used with SBRs. As with any process design, consideration should be given to using primary clarification, depending on the necessary management of biodegradable organic carbon relative to nutrient removal. High rate primary clarification may be warranted for some SBRs as a means of scum and floatables removal.

SBRs should be preceded by fine screens with clear spacing of 1/4 in (6 mm) or smaller to minimize the potential for floatable solids entering the SBR tanks.

Influent flow equalization provides an added measure of flexibility with the SBR process both in managing variations in flow and pollutant loading as well as in improving the ability to remove SBR basins from service for maintenance or when loadings are less than design level. Influent flow equalization may also be configured to provide scum or grease removal prior to entry into the SBR basins. Although each SBR application is different, influent flow equalization should be considered when variations in flow and/or load are substantial, and it is recommended with installations where fewer than three independent SBR basins are provided. Influent flow equalization tanks should be provided with mixing and/or aeration equipment.

Influent flow equalization basins should provide sufficient volume to accommodate a single SBR batch at the peak flow expected over the duration of an SBR fill phase.

6.3.7.3 Equipment and Downstream Treatment

Blowers for SBRs should provide the full range of capacity expected, and special consideration should be given to airflow at lower flows and loadings so as to minimize over-aeration detrimental to nutrient removal. To allow for adequate turndown, a minimum of two blowers should be provided where possible to meet the maximum day oxygen demand for any operating SBR. When nutrient removal is required, consideration should be given to providing independent aeration and mixing so both systems can run concurrently to optimize operating conditions. Blowers should be VFD-driven based on in-basin dissolved oxygen probes. SBR designs must consider that the total oxygen demand for the process may need to be delivered in less than 24 hours depending on the cycle configuration for each unit.

Aeration diffusers may be fine bubble, coarse bubble, or jet aeration. Consideration should be given to energy efficiency as well as to turndown capability relative to overall air distribution; also consider the ability to cap or plug diffusers at less than design conditions. Providing the capability of independent mixing during aeration is recommended.

Mechanical aeration can be considered with SBRs, but turndown or cyclic operation should be carefully addressed for nutrient removal applications.

Mixers should be provided for any system that requires nitrogen or phosphorus removal.

Decanters must be capable of removing the treated effluent at the design rate without drawing in surface material or the settled sludge blanket. To protect against solids washout, system design should provide a separation of 3 feet between the decanter and maximum sludge blanket. Decanters must also be capable of excluding solids during the aeration and mixing phases of the SBR cycle.

Instrumentation should be provided commensurate with the size of the system, influent conditions, and effluent permit requirements. Nutrient removal systems should provide a minimum of dissolved oxygen, pH, and oxidation reduction potential (ORP) probes in each basin connected to a SCADA system or SBR process control system. In lieu of an ORP probe, online nitrate monitoring may be provided.

Depending on the downstream configuration, post equalization should be considered. Post equalization with a minimum volume of one full SBR batch should be provided at facilities where advanced treatment levels require filtration or where UV disinfection is used.

6.3.7.4 Process Design

SBRs should be designed to provide adequate SRT for the required aerobic, anoxic, and anaerobic process conditions. Special consideration is necessary to adequately address the time sequence of the process steps, and the process design should be coordinated with the control features of the system, especially aeration.

6.3.8 Membrane Bioreactors

6.3.8.1 Introduction

Membrane bioreactors (MBRs) were first introduced to the water pollution control industry in the 1970s by Dorr-Oliver, a Stamford, Conn.-based company that was once a leading manufacturer in the wastewater field. An MBR incorporates a membrane to replace the secondary clarifier in the activated sludge process and generates an effluent that usually has the following characteristics:

Table 6-11 **MBR Typical Performance Data**[1]

Effluent BOD	mg/L	<5
Effluent TSS	mg/L	<0.5
Effluent NH_3	mg/L	<1
Effluent TN	mg/L	<10
Effluent turbidity	NTU	<1

[1] Metcalf and Eddy, Fourth Edition 2003, p 1127, 1128

Early membranes were energy intensive and failed to last long. However, improvements over the years have led to a considerable decrease in energy consumption, and membrane reliability has increased to the point that many manufacturers warranty their membranes for ten years or more. A key advantage offered by membranes is that they provide an absolute barrier to solids, preventing the discharge of most waterborne pathogens and most, if not all, suspended and colloidal solids. They can also operate without manual attention so can be completely automated, and they require a significantly smaller footprint than other, more conventional technologies. All this makes them an excellent treatment plant process option, especially when water reuse or high quality effluents are required.

MBRs are generally designed as proprietary systems, requiring the plant designer to establish certain minimum parameters that a membrane manufacturer must comply with when designing a system or sub-system. It is common practice for the plant designer to develop a set of requirements that various, pre-qualified manufacturers use as a basis for submitting competitive bids. These requirements should include the following:

Flow Rates: Membranes are designed to provide a positive barrier to solids, allowing effluent or permeate to pass through while retaining the solids in the reactor, from which they are either discharged to waste or returned to the reactor to maintain a biomass. The maximum flow through a membrane is called flux and is indicated as gallons per square foot per day (gfd). The design flux is set by the manufacturer, and as a result, the system must be designed to handle a facility's maximum daily flow or the membranes can be seriously damaged.

Water Temperature: As water gets colder and viscosity increases, the ability of membranes to filter the flow is seriously affected. In addition, as water temperature increases, solubility of the dissolved oxygen is reduced. As a result, a facility's minimum and maximum water temperatures must be provided to ensure adequate membrane area to accommodate cold weather flows and sufficient air supply to maintain minimum dissolved oxygen in warm weather.

Influent Characteristics: Manufacturers will frequently set limits on the amount of grit and fats, oils, and grease (FOG) that their membranes will accept, and therefore manufacturers need to be aware of a facility's influent characteristics. Generally FOG in excess of 50–100 mg/L may have an adverse impact on the MBR process. Fine screens with spacing of 1–3 mm are required, with the opening size depending upon the type of membrane. Fine screens are critical components and must be redundant to protect the systems. However, bar screens may also be suggested to protect downstream equipment.

Primary Treatment: Plants treating less than 20 mgd generally do not require primary clarifiers. The elimination of both primary and secondary treatment clarifiers as well as tertiary filters significantly reduces the plant footprint, a critical element in cases where land for expansion or upgrade is extremely expensive if even available.

Disinfection: Since TSS from an MBR is usually less than 1.0 mg/L, disinfection requirements are significantly less than for most other treatment systems. Operators are reminded that although a facility's fecal coliform may be at the non-detect level, fecal coliform is an "indicator organism" and some disinfection is still required for such waterborne contaminants as viruses.

Once a manufacturer has been selected, the project designer works with the vendor's design staff to develop a system that will meet the ultimate needs of the project. It is critical to ensure that all of the MBR system supplied components are compatible with the rest of the plant's equipment and control systems.

6.3.8.2 Basis of Design – Preliminary Treatment

Although the plant design is ultimately the responsibility of the project engineer, an MBR system design parameters are set by the vendor's design staff since they will usually be furnishing not only an equipment warranty but also a process warranty. As a result, the vendor will set limits not only on maximum daily flow but also peak flows, etc. Since many small MBR systems are designed with a single reactor vessel, it may also be necessary to include a minimum design flow to ensure a viable biomass. Unless significant seasonal changes allow removing one unit from service, at least two reactors capable of handling the entire plant flow must be provided. In some cases, three reactors, each capable of treating half the flow, may be incorporated in a design. In such a case, if one reactor is removed from service, the other two could handle the entire plant flow.

Screen types and the handling of screenings are very important. If nitrogen removal is required, screenings should be washed and the wash water returned to the process to provide carbon for denitrification. While not washing screenings reduces the organic load and oxygen requirement, it may create a problem with regard to disposal of the screenings.

Although primary clarification is not generally required, it may be beneficial to provide flow equalization. Like nearly every process, MBRs operate more efficiently under "steady-state" conditions. In addition to improving process efficiency, the membrane area required to treat the ultimate design flux (and required membrane area) may be reduced by dampening the peak flows.

MBR systems operate with a biomass ranging from 4,000 to 15,000 mg/L, though occasionally as high as 18,000 mg/L. Since the waste solids are introduced at 0.4–1.5 percent solids, the need for further thickening should be considered.

6.3.8.3 Basis of Design – Secondary Treatment

The biological processes that are incorporated into MBR systems are similar to those in conventional secondary systems with a few notable exceptions. MBR systems can be operated at higher MLSS rates and with shorter hydraulic retention times than other forms of secondary treatment.

They are generally designed to completely nitrify wastewater to ensure good filterability and minimize fouling. Although sludge settleability is not an issue, filamentous bulking can result in membranes being fouled with sludge. MLSS in the microfiltration reactors ranges from 4,000 to 15,000 mg/L.

Since MBR facilities operate with a much higher MLSS and shorter HRT, the amount of oxygen required is generally higher. Some system manufacturers may claim the oxygen transferred during the air scour operation as a partial source of the process air. Current practice is to design MBR systems for a minimum SRT to allow for complete nitrification.

To maintain a viable biomass and avoid a buildup of solids, MBRs require a much higher recirculation rate, approximately 4–5Q. The systems generally use low-head, high-volume pumps, which contribute to the high energy demand of MBRs. When multiple tanks are used for denitrification and/or biological phosphorus removal, multiple recycle streams are common to minimize the recycle of dissolved oxygen or nitrate (to anaerobic zones). Dissolved oxygen exhauster zones are also used prior to the recycle of MLSS.

For all immersed air MBRs, air scouring of membrane surfaces is used to reduce the buildup of solids, both organic and mineral.

In addition to air scouring, membranes are also subject to chemical cleaning and in some cases backwashing, as part of maintenance procedures.

6.3.8.4 Basis of Design – Nutrient Removal

In MBRs, removal of phosphorus and nitrogen is achieved by using the same processes, such as MLE and Bardenpho, as conventional technologies. (See Section 6.3.10.1.)

6.3.8.5 Operational Concerns

One of the major benefits of MBR systems is their ability to be automated. A well designed system with a preventive maintenance system can be staffed on a part-time basis with remote supervision.

6.3.9 Process Design for Suspended Growth Carbon Oxidation and Nitrification

6.3.9.1 Designing for Carbon Oxidation

Aerobic Systems: The biodegradable carbon in domestic wastewater is most efficiently oxidized aerobically. Aerobic activated sludge systems include aerobic tanks with mechanical or diffused air systems and pure oxygen systems.

Variations: A number of variations of the activated sludge process have been developed are presented in other references, including plug flow, complete mix, step feed, contact stabilization, and extended aeration. Guidelines provided herein apply to each.

Energy: The activated sludge process requires significant energy to meet aeration demands, and can account for 50–75 percent of a plant's energy expenditures. Energy costs related to the equipment must be carefully evaluated. Alternate operating modes in diffused aeration systems can result in inefficient use of aeration energy.

Volume: The size of the aerobic volume required for carbon oxidation can be calculated using the equation below combined with the empirical relationships for net yield. Reactor size should be determined based on maximum month conditions based on the limiting mixed liquor solids concentration, which is often dictated by the capacity of the secondary clarifiers (or those proposed), BOD loading, and the target SRT. The SRT should be calculated from the mass of solids under aeration divided by the mass of solids exiting the activated sludge system on a daily basis (equal to sludge wasted plus TSS in the plant effluent). Design SRTs can vary from approximately 2 days to greater than 20 days. Although activated sludge systems have been operated at SRTs almost as short as one day, minimum design SRTs should be no less than two days to avoid limiting operating flexibility of the plant. Designs for carbon oxidation should take into account that nitrification cannot be avoided under some operating conditions. Plants designed for low SRT operation (less than two days) require special attention from operators. Plants with an average design capacity of less than 5 mgd should have a minimum SRT of five days.

The aerobic volume required for carbon oxidation can be calculated as:

$$\text{Volume} = \frac{Y_{net} \text{ x } BOD_{rem} \text{ x } SRT_a}{MLSS \text{ x } 8.34}$$

where:

Y_{net} = Total suspended solids produced per lb BOD removed

BOD_{rem} = BOD removed (lb/day)

SRT_a = Aerobic solids retention time (days)

MLSS = Mixed liquor suspended solids (mg/L)

The unit solids production at any plant will be specific to the influent wastewater characteristics and the operating conditions of the plant. The net yield selected for design should be adequately supported and justified. Historical data can be used to determine net yield. However, if historical values are used, carefully scrutinize the data as well as the sampling locations, sampling methods, and analytical techniques used to generate the data. Published net yield values based on semi-mechanistic/semi-empirical equations are available in the literature and are valid alternatives to using historical data to determine or confirm net yield.

Historical net yield can range from 0.6 to 1.2 and is influenced by many factors. The quantity of inert suspended solids and the fraction of non-biodegradable particulate COD may significantly influence net yield. Chemical use for alkalinity supplementation or phosphorus removal will generate inert solids that need to be considered. The growth yield of heterotrophs is fairly consistent from plant to plant but will vary predictably with both temperature and operating SRT. Finally, the ability to accurately measure either BOD in the influent or solids in the waste stream and the variability of solids streams often introduces bias in the net yield calculation when it is based on historical data.

6.3.9.2 Designing for Nitrification

Nitrification is the aerobic oxidation of ammonia to nitrite and then to nitrate by two populations of autotrophic bacteria: ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB), collectively called nitrifiers. Carbon is obtained from CO_2 (no organic carbon required) for growth and acid is produced, consuming alkalinity, and potentially lowering pH. Nitrifiers are slow growing and sensitive to changes in temperature, dissolved oxygen, and pH, especially below 7.2 SU. Under typical influent nitrogen loading conditions at domestic wastewater treatment plants, the population of nitrifiers that will achieve full nitrification is modest compared to the overall mass of solids in the system.

The critical design parameter to ensure nitrification is the washout aerobic SRT, defined as the aerobic SRT at which nitrifiers are reproducing at the same rate as they are being removed from the system. To maintain a population of nitrifiers in the system, the solids removal rate (via waste sludge and effluent) must be less than the sum of the growth rate and decay rate of the population under the conditions provided. The washout aerobic SRT can be determined as detailed in EPA's 1993 *Nitrogen Control Manual and WEF's MOP 29: Biological Nutrient Removal (BNR) Operation in Wastewater Treatment Plants*.

Because washout aerobic SRT is an inherently unstable operating condition, this parameter is typically increased by a process design factor, typically a factor of 1.5–2.5 times the washout SRT. The process design factor is applied to the washout SRT to determine a target aerobic SRT that accommodates variations in flow, load, and operating practices and that includes a safety factor, depending on the specifics of the plant and permit requirements.

EPA's 2010 *Nutrient Control Design Manual* includes a checklist (Table 10-5) that provides an excellent starting point for engineers and reviewers evaluating nitrification and denitrification design.

6.3.10 Biological Nutrient Removal (BNR) by Suspended Growth Systems

6.3.10.1 Overview

Both nitrogen and phosphorus (nutrients) are removed from wastewater biologically through assimilation into biomass during the oxidation of organic compounds. This section addresses nutrient removal over and above the nutrients removed via assimilation during typical secondary treatment.

Influent and primary effluent wastewater contains total nitrogen predominately as organic nitrogen and ammonia, which combined are measured as Total Kjeldahl Nitrogen (TKN). The separation of these two nitrogen compounds varies by plant and often varies seasonally. Regardless, the majority of organic nitrogen in wastewater is converted to ammonia via facultative and aerobic bacteria in sewers and treatment processes such that ammonia is the predominate form of nitrogen that exists in the biological treatment process. Ammonia is oxidized through the nitrification process in two steps: The aerobic oxidation of ammonia to nitrite followed by the conversion of nitrite to nitrate in a process collectively called nitrification. A more detailed discussion of nitrification has been presented previously in this chapter.

The autotrophic nitrifying bacteria are not as efficient in growing new cell mass compared to the majority of bacteria in the system and consequently do not remove much nitrogen in sludge. Nonetheless, the process can be very efficient at oxidizing ammonia and nitrite under aerobic conditions even though the nitrification process only converts the nitrogen to nitrate and does not remove total nitrogen from wastewater. To remove total nitrogen from wastewater, the denitrification process is required to convert nitrate into nitrogen gas.

Denitrification is the reduction of nitrate to nitrogen gas by heterotrophic bacteria that utilize organic carbon as substrate and nitrate as the terminal electron acceptor, which is analogous to bacteria using oxygen for respiration. However, because heterotrophic bacteria are more efficient when using oxygen than nitrate, the presence of dissolved oxygen in the bulk liquid of a treatment process will inhibit denitrification. In addition to requiring an anoxic environment with little or no dissolved oxygen, denitrification requires an ample supply of biomass, organic carbon, and nitrate.

Denitrification is most commonly incorporated into suspended growth processes in a single sludge configuration with pre- and/or post-denitrification stages. Two representative processes that illustrate denitrification configurations are the Modified Ludzack-Ettinger (MLE) and Bardenpho processes shown in Figures 6-4 and 6-5. The MLE process is typically a two-stage system that incorporates a pre-denitrification step followed by aeration to achieve carbon oxidation and nitrification. As with most suspended growth processes, return activated sludge is recycled from the secondary clarifier back to the beginning of the process, the pre-denitrification tank. To recycle nitrates formed via aeration, mixed liquor is recycled from the end of the aeration tanks at a typical rate of 200–400 percent of forward flow. Organic carbon is provided via the influent or primary effluent BOD_5, although supplemental carbon may be added to a pre-denitrification reactor. Theoretically, 2.86 lbs of BOD are required to remove 1 lb of nitrate-nitrogen. In practice, however, 4–6 lbs of BOD are generally necessary when influent wastewater is used. The impact of nitrate recycle on the theoretical maximum denitrification possible is shown in Figure 6-6, although the recycle of dissolved oxygen from the downstream aeration zone will generally limit the range of effective recycle to 400 percent or lower. In situations where dissolved oxygen is not maintained low adjacent to recycle pumping, effective recycle flow rates should be reduced.

The Bardenpho process is essentially an MLE process followed by a post-denitrification reactor. The post-denitrification reactor in this configuration is used to polish effluent nitrates to a lower level than otherwise possible with an MLE configuration. Biomass is present as mixed liquor, and nitrate is that remaining at the end of the aeration zone. Organic carbon is either that that amount stored in the MLSS (endogenous respiration) or more commonly, a supplemental carbon source. (Information on supplemental carbon addition is presented in Section 6.3.11.) It is common to add a small aeration zone at the end of the Bardenpho process to increase dissolved oxygen, remove any residual organics, and improve MLSS settling characteristics.

Phosphorus in wastewater exists only in liquid and solid form and does not readily volatilize. Therefore, the only way to remove phosphorus from the liquid phase of wastewater is to convert it into a solid that can be removed via a physical separation process such as sedimentation or filtration. Phosphorus is typically removed from wastewater by enhanced biological phosphorus removal (EBPR), chemical precipitation (described in detail in Chapter 7), or a combination of both.

EBPR is accomplished through the use of phosphorus accumulating organisms (PAOs), which are specialized heterotrophic bacteria. As they cycle between anaerobic and aerobic conditions, PAOs can accumulate phosphorus far in excess of that needed for normal cell function and growth. This phosphorus storage ability of PAOs is a function of their ability to absorb and store volatile fatty acids (VFAs) under anaerobic conditions at the expense of energy stored in polyphosphate bonds, with the phosphorus released to the liquid phase. Following return of these bacteria to aerobic conditions, they are able to use the stored carbon (VFAs) for cell growth and to restore their phosphate reserves and more, preparing the organism for its next anaerobic cycle. Phosphorus is removed from

Figure 6-4 **MLE Process**

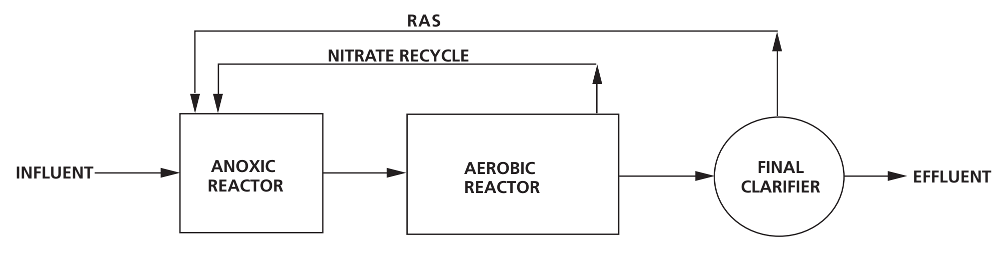


Figure 6-5 **Bardenpho Process**

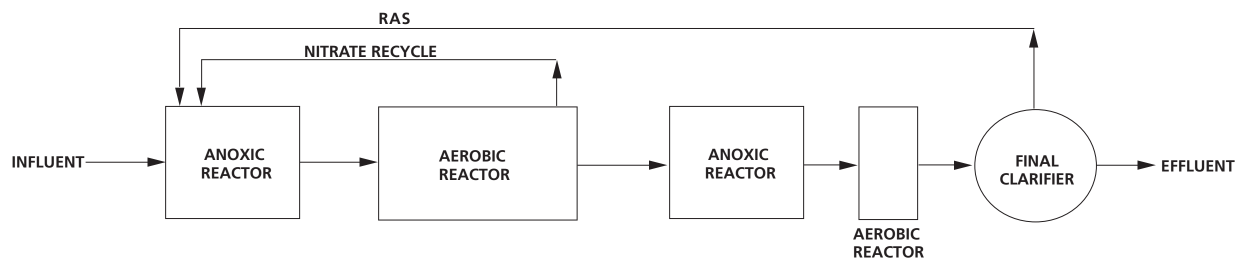
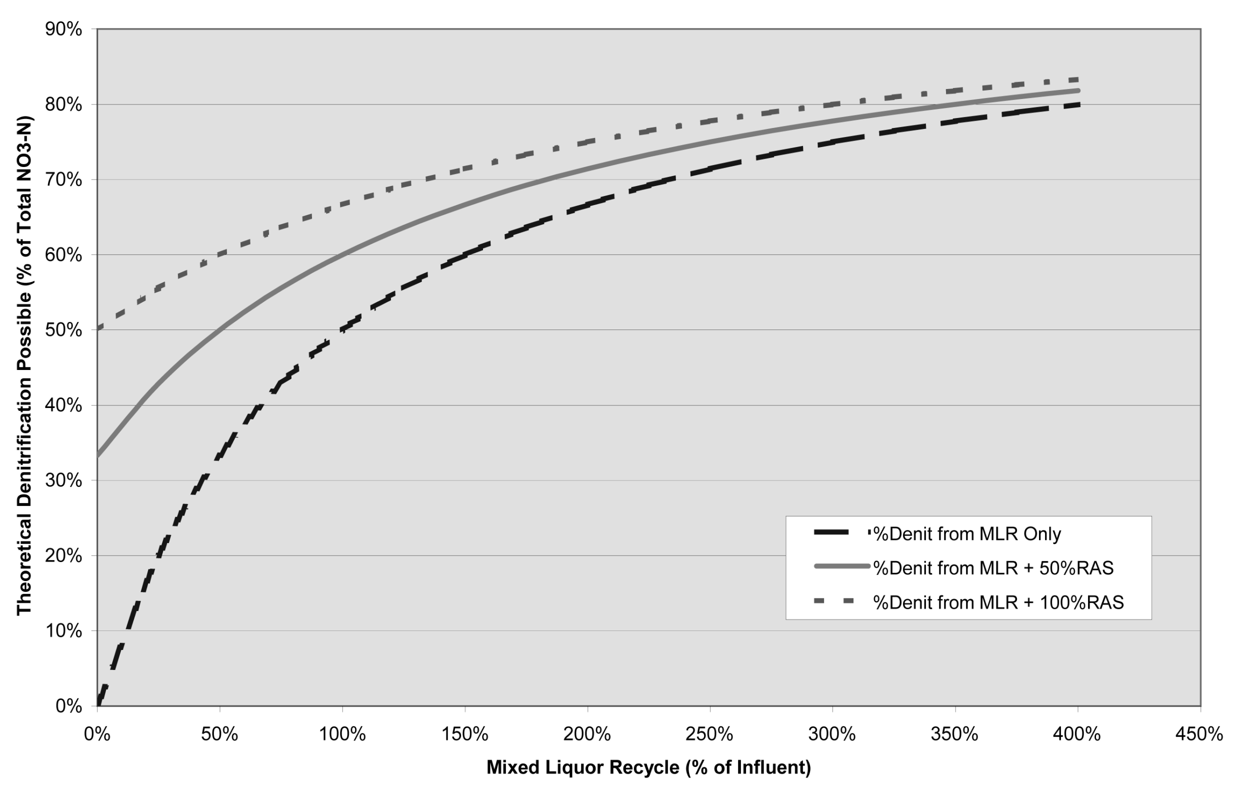


Figure 6-6 **Denitrification Potential-Modified Ludzack-Ettinger Process**



the system as sludge is wasted from the process. Because phosphorus can be released under anaerobic conditions, PAOs in waste sludge must be handled carefully to avoid a secondary release that would return phosphorus to the liquid treatment train. In addition, PAOs are high in phosphorus content and require effective solids removal to avoid high levels of effluent particulate phosphorus. In addition to needing an environment free of oxygen and nitrate, the anaerobic zone of an EBPR process requires:

- Biomass
- Organic carbon, preferably VFAs, with a chemical oxygen demand to phosphorus (COD:P) ratio of at least 40:1

EBPR is typically incorporated into suspended growth systems via the addition of an anaerobic zone at the beginning of the process train. The most important aspect of this configuration is the creation of the proper metabolic conditions to promote the EBPR process, and in particular, maintaining anaerobic conditions with a sufficient amount of readily biodegradable organic carbon present. See Section 6.3.11 for information on the addition of supplemental readily biodegradable organic carbon. For greater detail than can be provided in this document on the biochemical fundamentals of nitrogen and phosphorus removal from wastewater, see the references provided at the end of this chapter.

6.3.10.2 Process Selection

In selecting a BNR process or combination of BNR processes for an upgrade or new plant, the engineer must consider the following criteria:

- Influent wastewater characteristics, including fractions of chemical oxygen demand (COD), nitrogen, phosphorus, alkalinity, and temperature
- Solids handling processes and nutrient load from sidestreams, especially the impact of anaerobic digesters, phosphate release, and struvite generation
- Seasonal variations in the influent wastewater characteristics caused by industrial contributors, population changes, and septage (where applicable)
- Existing and anticipated annual and seasonal discharge limitations
- Existing and anticipated treatment and solids handling facilities at the plant site
- Available footprint at the site
- Construction cost and operating costs, including energy requirements
- A lifecycle assessment of products imported to a plant and solids exported from or to a plant, comparing biological versus chemical nutrient removal

A summary of typical suspended growth BNR processes is included in Table 6-12. Figures depicting the various processes can be found in the references at the end of this chapter.

6.3.10.3 Process Design Approach

It is strongly recommended that designs for nutrient removal be based on and developed using a combination of practical design criteria and mechanistic models that have been incorporated into dynamic wastewater process simulators. The use of a combination of techniques is most likely to produce a robust design that addresses the often competing biological and chemical processes. Complete accounting of changes in alkalinity, pH, soluble substrate, nitrogen, and phosphorus species is critical to identifying limitations in specific process applications. However, the use of process models requires careful calibration. Guidance for the use of process simulators can be found in this chapter's references.

Generally, the following steps are employed for evaluations and designs with calibrated process simulators to achieve both nitrogen and phosphorus removal:

- Characterize influent wastewater.

Table 6-12 **Typical Design Parameters for Single-Sludge Nitrogen Removal Systems Designed to Remove Nitrogen from Treated Municipal Wastewater**

Parameter	MLE	Bardenpho	Cyclical Aeration	Oxidation Ditch
HRT, h			8 to 16	12 to 24
• Primary Anoxic	3 to 6	3 to 6		
• Primary Aerobic	5 to 10	5 to 10		
• Secondary Anoxic		2 to 4		
• Secondary Aerobic		1 to 2		
Total	8 to 16	11 to 22		
MCRT, days (aeration volume only)	6 to 12	8 to 16		
F/M, g BOD^5 applied/g MLVSS	0.15 to 0.25	0.15 to 0.20	0.15 to 0.20	0.15 to 0.20
MLSS	2,000 to 4,000	2,000 to 4,000	2,000 to 4,000	2,000 to 4,000
% Volatile	65 to 80	65 to 80	65 to 80	65 to 80
Nitrate Recycle, %Q	100 to 300	100 to 300	None	None
RAS Recycle, %Q	50 to 100	50 to 100	50 to 100	50 to 100
Effluent TN, mg/L	8 to 10	4 to 6	8 to 10	4 to 8

Note: The HRTs shown exclude recycle flows and are typical for primary effluent with COD of 250 mg/L and BOD^5 of 100 mg/L for a temperature range of 8 to 248C.

- Establish process flow diagrams and approximate sizes using simplified methods.
- Establish the nitrification requirement and the washout and target aerobic SRTs.
- Establish the intended MLSS concentration in concert with available and proposed clarifiers.
- Size aerobic zone.
- Add anaerobic and anoxic volumes according to the ratios in Table 6-13, as appropriate.
- Add internal recycles according to the guidance in Table 6-14, as appropriate.
- Adjust process volumes as needed.
- Adjust the design to tune the aeration used and to reflect the use, if warranted, of supplemental carbon sources.

Tables 6-13 and 6-14 are good starting points for approximate criteria for initial process sizing. However, the empirical relationships between influent characteristics, unit sizes, process flow rates, and operating parameters are approximate rules of thumb to be consulted with caution for design purposes. While designs based on these equations may be valid most of the time for typical, steady-state influent and operating conditions, they are not necessarily the most efficient, effective, or robust designs in terms of applicability to certain influents or reliability for achieving certain effluent standards.

Table 6-13 **Common BNR Process Sizing “Rules Of Thumb” at Typical Domestic Wastewater Strengths, Recommended Recommended Operating SRTs, and Common MLSS Concentration**

Process	Description	Sizing guidance	1st zone	2nd zone	3rd zone	4th zone	5th zone
Modified Ludzack-Ettinger (MLE)	Nitrification and denitrification. Influent to the anoxic zone. Aerobic recycle from aerobic to anoxic zone. Clarifier return to anoxic zone.	Metabolic condition	Anoxic	Aerobic			
		HRT range (hours)	1 to 3	4 to 8			
		Ratio	1.0	3.0			
4-Stage Bardenpho	Nitrification and denitrification. Influent to the anoxic zone. Aerobic recycle from aerobic to anoxic zone. Clarifier return to anoxic zone.	Metabolic condition	Anoxic	Aerobic	Post-anoxic	Reaeration	
		HRT range (hours)	1 to 3	4 to 8	2 to 4	0.5 to 1.0	
		Ratio	2	6	3	1	
5-Stage Bardenpho	Nitrification, denitrification, phosphorus removal. Influent to the anaerobic zone. Aerobic recycle from aerobic to pre-anoxic zone. Clarifier return to anaerobic zone.	Metabolic condition	Anaerobic	Pre-anoxic	Aerobic	Post-anoxic	Reaeration
		HRT range (hours)	0.5 to 1.5	1 to 3	4 to 12	2 to 4	0.5 to 1.0
		Ratio	1.5	3	10	4.5	1
Modified University of Capetown (MUCT)	Nitrification, denitrification, phosphorus removal. Influent to the anaerobic zone. Aerobic recycle from aerobic to anoxic zone; anoxic recycle from pre-anoxic to anaerobic zone. Clarifier return to pre-anoxic zone.	Metabolic condition	Anaerobic	Pre-anoxic	Anoxic	Aerobic	
		HRT range (hours)	2 to 4	1 to 2	1 to 2	4 to 12	
		Ratio	2.5	0.5	1.5	5.5	
Modified Johannesburg (MJHB); Johannesburg (JHB)	Nitrification, denitrification, phosphorus removal. Influent to the anaerobic zone. Aerobic recycle from aerobic to anoxic zone. Anaerobic recycle to the pre-anoxic zone (not included in the original JHB process). Clarifier return to anaerobic zone.	Metabolic condition	Pre-anoxic	Anaerobic	Anoxic	Aerobic	
		HRT range (hours)	0.5 to 1.0	2 to 4	1 to 3	4 to 8	
		Ratio	1.0	5.0	4.0	10.0	
A2/O (3-Stage Phoredox)	Nitrification, denitrification, phosphorus removal. Influent to the anaerobic zone. Aerobic recycle from areobic to anoxic zone. Clarifier return to anaerobic zone.	Metabolic condition	Anaerobic	Anoxic	Aerobic		
		HRT range (hours)	0.5 to 1.5	1.5 to 2.5	4 to 8		
		Ratio	1.0	2.0	5.0		
A/O (Phoredox)	Phosphorus removal only. Influent to the anaerobic zone. Clarifier return to anaerobic zone.	Metabolic condition	Anaerobic	Aerobic			
		HRT range (hours)	1 to 2	4 to 8			
		Ratio	1.0	4.0			

Rules of thumb regarding hydraulic residence time (HRT) for each metabolic zone are included in Table 6-13, but these HRT ranges are based on specific kinetics for typical domestic influent wastewater characteristics with typical MLSS concentrations. For unique wastewaters or wastewaters with a high industrial component, or for process designs with atypical design MLSS concentrations, the HRT rules of thumb likely do not apply. Applicability of the suggested ranges must be confirmed through use of a mechanistic model. Table 6-14 includes typical rules of thumb for recycle rates and solids retention time. To reemphasize: The HRTs, volume ratios, recycle rates, and SRTs presented in Tables 6-13 and 6-14 are starting points for design and may not necessarily be the most efficient for a given application.

Table 6-14 **Common BNR Process Rates And SRTs at Typical Domestic Wastewater Strengths And MLSS Concentrations**

	RAS rate	Aerobic recycle	Anoxic recycle	Anaerobic recycle	Total SRT
MLE	50% to 100%	200% to 400%			10 to 20
4-Stage Bardenpho	50% to 100%	200% to 400%			10 to 20
5-Stage Bardenpho	50% to 100%	200% to 400%			10 to 20
MUCT	80% to 100%	100% to 200%	100% to 200%		10 to 20
MJHB; JHB	80% to 100%	100% to 200%		10% to 50%	10 to 20
A2/O	25% to 100%	200% to 400%			15 to 25
A/O	25% to 100%	none			3 to 5

6.3.10.4 Checklists for Reviewing BNR Designs

EPA’s 2010 *Nutrient Control Design Manua*l includes two tables (10-5 and 10-6) that provide an excellent starting point for engineers and reviewers evaluating a BNR (total nitrogen and phosphorus) design. A review of these EPA checklists before initiating design or design review is recommended.

6.3.11 Supplemental Carbon Addition

6.3.11.1 General

If insufficient soluble readily biodegradable COD is available in influent wastewater, a supplemental carbon source will be required for denitrification or for EBPR. Supplemental carbon can be supplied by an external source, with the carbon shipped to the facility, or it can be supplied by an internal source, i.e., generated onsite. The benefit of using external sources is that it is not necessary to install process tanks and associated equipment. Disadvantages of external sourcing include high operating costs due to the regular purchase of product and the installation of storage tanks and feed equipment. Internal sources have low operating costs, but capital cost is high due to the design and construction of process tanks and equipment.

External carbon sources include methanol, ethanol, glucose, corn syrup, glycerin, and proprietary mixtures such as Micro-C. Internal sources include fermentate from fermented primary solids and the aqueous stream from WAS lysis technologies. Internal source generation typically requires specialized process design or proprietary equipment.

6.3.11.2 Design Considerations

Local, state, and federal health, fire protection, and safety codes that are appropriate, based on a product's properties, must be followed when designing product storage, off-loading, and pumping and feed systems. Product properties will also determine the proper materials of construction, due to compatibility requirements. The intended nitrogen removal season and local climate need to be taken into consideration so facilities can be designed to keep the chosen product from freezing. Table 6-15 shows typical product properties for various external supplemental carbon sources.

Table 6-15 **Typical Product Properties for Various External Supplemental Carbon Sources**

Product	Typical strength/ composition	NFPA rating			Freezing point, C	SG
		Health	Fire	Reactivity		
Methanol	100% Methanol	1	3	0	-97°	0.79
Ethanol	100% Ethanol	1	3	0	-114°	0.79
Acetic Acid	100% Acetic Acid	3	2	2	17°	1.05
Corn Syrup	50% Glucose solution	0	0	0	12°	1.22
Micro C-G	100% Micro C-G	0	0	0	-8°	1.20
Glycerin	80% Glycerin, 20% water	1	1	0	18°	1.19

6.3.11.3 Sizing Considerations

Sizing of storage facilities will depend on the duration of product use, target effluent nitrogen concentration, efficiency of the denitrification process (without supplemental carbon), product shelf-life, shipment flexibility, and product cost. The carbon dose will ultimately be determined during full-scale operation; it is difficult to predict exactly how much will be needed, and fine-tuning should be expected.

6.3.11.4 Kinetic and Stoichiometric Considerations

The carbon from virtually all external and internal sources can be used by ordinary heterotrophs, which are prolific in mixed liquor, for denitrification. The exception is methanol, which can only be utilized by methylotrophs for denitrification. The use of methanol, therefore, requires an acclimatization period. In addition, methylotrophs are relatively slow growing organisms, having growth rates about equal to nitrifiers, so higher anoxic solids residence times are required for methylotrophs than for ordinary heterotrophs, especially in low temperatures.

The stoichiometry of nitrate reduction depends on which carbon source is used. Certain carbon sources denitrify more nitrate per unit COD than others. The range is between 3.6 and 7.0. Table 6-16 lists common product concentrations and COD:N removal ratios.

Table 6-16 **Common Product Concentrations and COD:N Removal Ratios**

Product	gCOD/L	COD:N ratio
Methanol	1,200	4.6
Ethanol	1,650	4.7
Acetic Acid	1,100	3.6
Corn Syrup	700	5.6
Micro C-G	650	6.5
Glycerin	1,800	7.0

6.3.11.5 Other Considerations

All carbon sources except methanol can also be used by polyphosphate accumulating organisms (PAOs) for enhanced biological phosphorus removal, simplifying chemical use if both nitrogen and phosphorus removal are at some point required.

All carbon sources are degraded aerobically, so product used in excess of denitrification requirements in an upstream anoxic zone passes through to an aerobic zone and is degraded there, essentially wasted.

All carbon sources contribute to the mass of solids in a system at a constant solids residence time, simply due to the increased organic load.

Overdosing of supplemental carbon in a downstream anoxic zone will result in product breakthrough and a violation of the effluent BOD permit. Therefore, feed pumps should be calibrated so the supplemental carbon source is just sufficient to meet the stoichiometric requirement for denitrification. Consider varying the supplemental carbon feed rate by manual adjustment or flow pacing with on-line nitrate analyzers.

6.4 Integrated Biological Treatment Systems

This section provides information on integrated treatment systems that are a combination of fixed and suspended growth treatment technologies previously discussed in this chapter.

6.4.1 Overall Considerations

Integrated biological treatment (IBT) processes comprise a group of treatment systems that are coupled in an attempt to take advantage of the strengths and minimize the limitations of the parent processes. These systems are generally classified into two groups:

- In coupled systems, two independent biological treatment processes, one being a fixed film process, are joined sequentially, such as in the trickling filter/solids contact (TF/SC) process. In almost all cases, the fixed film component precedes the suspended growth portion of the system.
- In integrated fixed film/activated sludge (IFAS) systems, the fixed film and suspended growth processes are combined in the same process tanks.

In coupled systems, the typical combination employs a fixed growth process to significantly reduce soluble carbonaceous oxygen demand, followed by a suspended growth system to complete treatment. Depending on effluent requirements, treatment may include further carbon oxidation, nitrification, denitrification, chemical phosphorus removal, and solids flocculation to reduce effluent TSS and improve turbidity. Coupled IBT processes are typically used for carbon oxidation and nitrification and rarely for total nitrogen or EBPR.

The IFAS processes have been developed with a focus on maximizing the treatment capacity of a given volume of suspended growth reactors by the addition of media to increase the concentration of biomass without necessarily increasing solids loading on secondary clarifiers. IFAS systems are readily capable of being incorporated into carbon oxidation and nitrification plants but are most commonly used for nutrient removal, especially for total nitrogen removal. IFAS systems designed for EBPR rely on the suspended growth component to achieve that treatment step.

See earlier sections of this chapter for information on design aspects of the parent processes associated with coupled and IFAS systems.

6.4.2 Trickling Filter Systems

The advent of coupled IBT systems resulted from the struggle faced by numerous trickling filter facilities in meeting the secondary treatment requirements of the Clean Water Act. These trickling filter systems were capable of providing soluble BOD removal but often struggled with flocculation of sloughed solids and resultant capture of fine particles, which negatively impacted performance. There are various permutations of trickling filter-based systems, which differ with respect to how much treatment is provided by the fixed growth component, whether solids are recycled through the trickling filter, and if intermediate clarification is provided between the fixed and suspended growth portions of the system.

6.4.2.1 Trickling Filter/Solids Contact

The trickling filter/solids contact (TF/SC) process utilizes a lightly or moderately loaded trickling filter to provide for complete carbon oxidation and adds a solids contact step to improve flocculation to enhance solids removal during gravity sedimentation. Typically clarification is provided only after the solids contact step.

6.4.2.2 Roughing Filter/Activated Sludge

The roughing filter/activated sludge (RF/AS) process includes a heavily loaded trickling filter to reduce soluble organics followed by larger activated sludge reactors capable of treating a greater portion of the soluble organics and providing nitrification. The RF/AS process has commonly been used to expand an overloaded trickling filter plant or to provide pretreatment (often for a stronger industrial wastewater) via trickling filter addition to an existing activated sludge facility. Typically the only clarification step in the process occurs after the activated sludge reactors.

6.4.2.3 Activated Biofilter

The activated biofilter (ABF) process combines a lightly loaded fixed growth system with secondary clarification and solids recycle directly over the fixed growth media. Because of the solids recycle, fixed film media density is typically reduced to prevent clogging, with redwood baffles being the most commonly used media. An independent suspended growth reactor is not included, which can cause difficulties in cold weather.

6.4.2.4 Biofilter/Activated Sludge

The biofilter/activated sludge (BF/AS) process can be classified as either an RF/AS process with solids recycle to the filter or an ABF process with an activated sludge tank between the fixed growth reactor and the clarifier. Similar to ABF, BF/AS is limited in the type of media that can be used in the fixed growth reactor, and the recycle of solids generally reduces oxygen transfer to the flow across the media.

6.4.2.5 Trickling Filter/Activated Sludge

The trickling filter/activated sludge (TF/AS) process is very similar to RF/AS, with a key addition: intermediate clarification between the trickling filter and activated sludge reactors. The trickling filter solids removal step is a key feature because the sloughed solids have a significant impact on the capabilities of the downstream activated sludge system, especially relative to nitrification and oxygen demand.

6.4.2.6 Process Design for Carbon Oxidation and Nitrification

Designing IBT systems for carbon oxidation is a function of balancing the capability of each of the two major components of the system so treatment goals are achieved. Often the key to system performance is creating a biomass that flocculates and settles well. The initial fixed growth step has been shown to act as a selector to improve overall sludge settleability. The second step necessary to good effluent quality is a successful activated sludge stage that creates a well flocculated biomass. In general, systems should provide a suspended growth step with an aerobic SRT of no less than two days in order to provide a flocculant biomass, with four days or more preferred. When calculating the aerobic SRT, it is critical that the design of an IBT system properly account for the sloughed biomass entering the system.

Although nitrification is possible with many IBT configurations, most are intended to function for carbon oxidation only. This is predominately due to two reasons:

1. Nitrification in fixed growth reactors does not commence until the soluble BOD is essentially exhausted.
2. Unless intermediate settling is included, all solids sloughed from the fixed growth reactor are transferred to the suspended growth reactor, adding to sludge production and resulting in the reduction of a system's ability to maintain a sufficiently long aerobic SRT for nitrification.

The one specific exception to the non-use for nitrification is the TF/AS system, which includes intermediate clarification and has historically been used for upgrading trickling filter plants for nitrification. In such a case, the suspended growth reactor must be sized to provide sufficient aerobic SRT to nitrify. Note, however, that since most of the organic carbon has been removed from the system prior to activated sludge, sludge production will be negligible, making it difficult to develop a flocculant biomass. To alleviate this problem, it is possible to allow a modest amount of primary effluent to bypass the trickling filters and flow directly to the activated sludge.

Denitrification is not commonly practiced within the limits of the IBT configuration because the main driver for pre-denitrification—primary effluent organic carbon—is utilized in the fixed growth component. As a result, systems that use an IBT configuration typically utilize a separate post-denitrification process to achieve total nitrogen limits. Phosphorus removal in IBT processes is achieved via chemical precipitation consistent with that used in fixed growth, suspended growth, and tertiary systems. EBPR cannot be readily applied to most IBT processes.

6.4.2.7 Mechanical and Ancillary Systems

Physical components incorporated into an integrated trickling filter/suspended growth system are similar to the components typically used in individual trickling filter and activated sludge systems.

6.4.3 Rotating Biological Contactor Systems

6.4.3.1 General

Incorporating the rotating biological contactor (RBC) process into an IBT configuration is similar to designing for trickling filter configurations, with two notable differences:

1. The RBC process tanks can accommodate activated sludge passing through the tanks and media without risk of clogging, and the tanks inherently allow some volume for biological solids to reside in and react with the wastewater. In most cases, the volume provided in RBC reactor tanks is enough to allow the process to perform as a rotating biological contactor/solids contact (RBC/SC) system. In addition, the flexibility to incorporate suspended growth through the RBC process allows the system to be configured in an MLE mode to accomplish total nitrogen removal, if sufficient aerobic and anoxic SRTs are provided.
2. The RBC process is not well configured to act as a roughing filter due to shaft loading concerns. As a result, it should not be configured as a roughing filter process.

6.4.3.2 Mechanical and Ancillary Systems

Physical components incorporated into an integrated RBC/suspended growth system are similar to those typically employed in individual RBC and activated sludge systems.

6.4.4 Integrated Fixed Film/Activated Sludge Systems

6.4.4.1 General

Incorporating attached growth (fixed film) media into biological treatment reactors is a way to either increase the capacity or improve the level of treatment possible in a process. Unlike increasing MLSS in a suspended growth reactor, adding IFAS media to an aeration tank does not necessarily increase solids loading on secondary clarifiers.

Free-floating plastic media are the predominate type of media used in IFAS systems, and their use and function are exactly as described earlier in the discussion of MBBRs (Section 6.2.5). Free-floating plastic media have a density slightly less than water, and this density increases as biomass attaches. The media are added to reactor tanks with fill ratios ranging from 25 to 67 percent of the tanks' volume, depending on process requirements. Media are retained in the tanks by use of media retention screens or sieves that have openings smaller than the media and are typically 1/4 in (6 mm) or smaller. In IFAS configurations, particularly in systems that incorporate nutrient removal with high recycle rates, media retention sieve design should be carefully considered. Media must be mixed by diffused aeration or mechanical mixers and can be configured to work in an aerobic or anoxic environment.

Other media types used in IFAS systems include sponge and corded media. Sponge media are a type of free-floating media that are shaped like small cubes. They are retained in reactor tanks by screens but, unlike plastic media, must be recirculated within the basin due to their tendency to migrate to retention screens. The recirculation enhances biomass sloughing, which is also accomplished by additional pumping and aeration. In addition to the process aeration requirements, the employment of sponge media requires the use of an air knife to continuously clean the media retention screens to prevent clogging.

Corded media systems consist of rope, mesh, or sheet material that is physically restrained in the tank by use of a frame structure and serves as a site for fixed growth attachment. Corded media have been used predominately in aerobic environments for carbon oxidation and nitrification. Some degree of denitrification has been found to occur in the media racks, though this effect has not been well quantified. The use of fixed media eliminates the need for media retention screens, but in some cases, fixed media systems have been plagued by predation by red worms.

6.4.4.2 Process Design for Carbon Oxidation, Nitrification, and Nutrient Removal

As with any IBT configuration, it is crucial when developing process design criteria for an IFAS system that the designer understands the balance and synergy between the attached and suspended growth biomass components. Defining that balance is challenging and requires the use of the manufacturer's empirical data and process modeling to estimate process performance levels. Example design approaches for nitrification and nutrient removal are provided in WEF's MOP 35: *Biofilm Reactors*.

6.4.4.3 Mechanical and Ancillary Systems

Physical components incorporated into an IFAS system using plastic carrier media are similar to the components of the MBBR process described in Section 6.2.5.

6.4.5 Solids Separation for Integrated Biological Treatment Systems

As solids entering a secondary clarifier from an IBT system generally arrive with concentration and settling characteristics similar to that in a suspended growth system, the secondary clarifier design of IBT systems should follow the criteria in this chapter related to suspended growth clarifiers (see Section 6.3).

6.5 Wastewater Treatment Ponds

Wastewater treatment ponds, in which bacteria are used to stabilize wastewater before it is sent to a receiving water body, are capable of achieving secondary treatment. Types of pond systems include aerated facultative, flow-through, and controlled discharge.

6.5.1 Location

6.5.1.1 Location and Buffer Zones

Minimum distances to residences are provided in Section 4.1.1. Consider site topography as it relates to construction and the effects on wetlands. Hydrogeologic investigations should be conducted to determine the minimum buffer zones needed to protect groundwater quality.

6.5.1.2 Soil Exploration

Sufficient subsurface site investigation should be conducted to properly evaluate a site's geotechnical, geological, and hydrological characteristics.

Geotechnical: The site's soil must support the proposed facility. Consider the impact of construction of the facility at the site. Suitable soil must be available for embankment construction.

Geology: A minimum separation of 5 feet between the pond bottom and any bedrock formation is recommended; however, less separation may be acceptable when supported by appropriate hydrogeologic and engineering designs/investigations.

Hydrology: A minimum separation of 4 feet between the bottom of the pond and the maximum groundwater elevation should be maintained; however, lesser separation may be acceptable when supported by appropriate hydrogeologic and engineering designs/investigations.

6.5.2 Basis for Design

6.5.2.1 General

6.5.2.1.1 Preliminary Treatment

Screening and/or comminution should precede wastewater treatment ponds. Large facilities, and facilities with significant quantities of grit, should provide for grit removal.

6.5.2.1.2 Hydraulics and Site Piping

The piping and control arrangement should ensure that the individual cells may be operated in series or in parallel for flexibility of operation. The control arrangement should consider provisions to maintain a different water level in each cell when operated in series.

Where possible, the piping should provide for minimum velocities to ensure self-cleaning and head loss constraints. In addition, minimum frost depth, avoidance of crests and troughs in pipe grade, and other site piping design issues should be considered.

The hydraulic capacity for continuous discharge structures and piping should allow for a minimum of 250 percent of the facility’s design maximum daily flow. The hydraulic capacity for controlled discharge systems should permit transfer of water at a minimum rate of 6 inches of pond depth per day at the available head.

6.5.2.1.3 Multiple Ponds and Configuration

The wastewater pond cell should be shaped so as to preclude stagnant areas and short circuits. The shape of all cells should be such that no narrow or elongated portions exist. Typical length-to-width ratios for aerated facultative ponds range from 2:1 to 4:1. No islands, peninsulas, or coves should be permitted. Dikes should be rounded at corners to minimize the accumulation of floating materials. Common-wall dike construction should be used wherever possible.

At a minimum, a wastewater treatment pond system should consist of two cells designed to facilitate both series and parallel operations. The maximum size of a pond cell should be 40 acres.

All systems should have piping flexibility to permit isolation of any cell without affecting the transfer and discharge capabilities of the total system. Also, provide the ability to discharge the influent waste load to a minimum of two cells and/or all primary cells in the system.

6.5.2.1.4 Controlled Discharge

Controlled discharge is defined as limiting the discharge from a pond system when the effluent quality will satisfy discharge requirements. Hydrograph release, a variation of the controlled discharge ponds concept, was developed to optimize the dilution of pond effluent in receiving waters. In hydrographic release, effluent is discharged based on stream flow; the discharge varies (above a minimum discharge flow) with the actual flow in the receiving stream.

6.5.2.1.5 Cold Weather Considerations

Flexible membrane liners need to provide for anticipated ice loads and scour potential. Facilities that employ aeration systems that use floats to locate diffuser plates should consider the effects of ice. Surface mechanical aerators should be designed and operated to prevent freeze-up.

6.5.2.1.6 Operational Considerations

Safety floatation rings should be provided around the perimeter of all wastewater treatment ponds. In addition, life lines should be installed around the perimeter of ponds that have liners which are slippery at the water's surface.

Consider minimizing weed growth along embankments.

An all-weather access road should be provided to allow year-round maintenance of the facility.

The pond area should be enclosed with a fence to prevent large animals from entering and to discourage trespassing. Fencing should not obstruct maintenance vehicle traffic on top of dikes. The width of the vehicle access gate should accommodate mowing equipment. All gates should have locks.

Permanent signs should be provided along the fence, describing the nature of the facility and advising against trespassing. At least one sign should be provided on each side of the site, including one sign for every 200 feet of the site's perimeter.

6.5.2.1.7 Power Requirements

Energy consumption is a major factor in the operation of wastewater treatment ponds. Accordingly, energy is a major consideration when designing and planning facilities. Energy is needed for such operations as pumping building utilities, and aeration (where used), with aeration being the largest consumer of energy.

Consider pond aeration energy efficiency measures such as floating chain aerators, fine bubble diffused aeration, or variable-frequency drives for mechanical aerators or blowers.

6.5.2.1.8 Algae

Wastewater treatment ponds occasionally have a high concentration of suspended solids or algae in their effluent. Pond outlet facilities with adjustable draw-off levels should be provided. Some state regulatory agencies recommend series pond operation to promote algae sedimentation within cells; however, the efficiency of such sedimentation is limited by the inevitability of mixing and the inconsistency of the settling, due to various species of algae having different characteristics.

Where the problem is seasonal, controlled discharge ponds can control algae concentrations in pond effluent. The design of such ponds should facilitate discharge during periods of low levels of algae and suspended solids.

To promote settling, in-pond removal methods include the addition of coagulants such as alum or ferric chloride to the final cell. The pond design should incorporate facilities such as boat ramps to facilitate chemical addition, where needed.

6.5.2.1.9 Industrial Waste

Consider the type and effects of industrial wastes on the treatment process. In some cases, it may be necessary to pretreat industrial or other discharges. Industrial wastes should not be discharged to ponds without assessing the possible effects of such substances on the treatment process and sludge disposal. The adverse effects of industrial wastes should be considered when selecting the lagoon liner.

6.5.2.2 Aerated Facultative Lagoons

6.5.2.2.1 Sizing

The aerated facultative lagoon is a flow-through basin designed to provide an aerobic liquid phase, while allowing for internal sedimentation, retention, and digestion of solids.

Detention time is based on many variables such as waste strength, volume, temperature, nutrient balance, and intended removal efficiencies. With normal biological reaction rates and removal efficiencies, hydraulic detention time is generally in the range of 20 to 40 days.

For the development of final design parameters, actual experimental data should be developed. However, the aerated treatment pond design for minimum detention time may be estimated using the following formula applied separately to each aerated cell:

$$t = \frac{E}{k_e\,(100 - E)}$$

where:

t = detention time, days

E = percent of BOD to be removed in an aerated pond

k_e = reaction coefficient, aerated lagoon, base e. For normal domestic wastewater, the k_e value may be assumed to be 0.28 per day at 68 F (20°C) and 0.14 per day at 34°F (10°C). The design value of k_e should be evaluated on a case-by-case basis. The use of varying k_e in series cells should be considered. For a three-cell facility at 10°C, suggested values are as follows:

First Cell – 0.14

Second Cell – 0.06

Third Cell – 0.02

Typical organic loading rates are 10–20 lb/BOD/day/acre. The first cell in a series of cells should have loading limited to 36 lb/BOD/day/acre.

The reaction rate coefficient for domestic wastewater that includes some industrial wastes, other wastes, and partially treated wastewater must be determined experimentally. Conversion of the reaction rate coefficient to other temperatures should be based on experimental data.

Additional pond volume should be considered for sludge storage. In northern climates, it should also be considered for ice cover. An additional volume for sludge storage of approximately 10 percent is required. The volume occupied by ice is commonly estimated as 10 percent.

6.5.2.2.2 Aeration Systems

An aeration system provides the air needed to satisfy major oxygen demand. It also allows for sufficient mixing for suspended solids, and ensures uniform dissolved oxygen levels.

Oxygen requirements generally will depend on the design average BOD loading and the degree of treatment. In the design phase, provide sufficient aeration to satisfy oxygen demands exerted by carbonaceous and nitrogenous BOD, endogenous respiration, sludge digestion, and benthal demand. Evaluations of oxygen demand must be done on a case-by-case basis. Normal oxygen requirements are 2 lb O_2 per lb BOD applied, but the aeration system should be capable of transferring 3 lb O_2 per lb BOD applied.

Systems using diffused aeration should include adequate filtration of the inlet air to protect diffusers from premature fouling. Aeration piping from the blowers to the diffuser system should be constructed of stainless steel.

Aeration equipment should maintain a minimum dissolved oxygen level of 2 mg/L throughout the liquid depth of the ponds at all times.

Distribution of the design air supply is based on the degree of treatment (percent BOD reduction) occurring in each pond and is tapered throughout the plant. Typical air distribution for four equally sized lagoons operated in series is 50 percent, 25 percent, 16 percent, and 9 percent for lagoons one through four, respectively.

6.5.2.2.3 Recirculation Systems

Treated effluent should be recirculated to the primary pond. This seeds the influent, dilutes high-strength wastes, and improves chemical balance. Recirculation rates depend on the type and strength of waste to be treated. In domestic wastewater, recirculation rates of 10 percent of the design flow are adequate.

6.5.2.3 Stabilization Ponds

6.5.2.3.1 Flow-Through

The design average BOD loading for flow-through ponds may vary from 15 to 35 pounds per acre per day. The major design considerations for BOD loading should be directly related to climatic conditions.

Design variables such as pond depth, multiple units, detention time, and additional treatment units must be considered along with BOD, TSS, fecal coliform, dissolved oxygen, and pH.

A detention time of 90–120 days should be provided; however, this time must be properly related to other design considerations. A major factor is the duration of the cold weather period (water temperatures of less than 5°C).

6.5.2.3.2 Controlled Discharge

The design average BOD loading for controlled discharge ponds may range from 15 to 35 pounds per acre per day at the mean operating depth in the primary cells, with at least 180 days detention time between the 2-foot and maximum operating depth of the pond system. It is important to consider climatic conditions and effluent discharge limits when determining detention time and organic loading rates.

6.5.2.4 Storage Ponds

The design volume of storage ponds should be based upon the design year's wet weather maximum month flows, maximum month I/I, minimum evaporation, and maximum expected storage period. In addition, the volume of rainfall that enters the pond system should be included in the required volume.

Consider providing supplemental aeration, if required.

Floating draw-off platforms should be considered on large storage lagoons with variable draw-off points. An alternate method is to provide multiple valved draw-off points at different elevations.

6.5.2.5 Anaerobic Lagoons

Anaerobic lagoons are generally used for high-strength industrial wastes and are loaded to create anaerobic conditions. High BOD can be removed by anaerobic lagoons followed by aerobic lagoons. Facilities that use anaerobic lagoons need to be sited carefully so as not to create nuisance conditions for abutting property owners. Typical detention time is 20–50 days.

6.5.2.6 Aerated Treatment Ponds

Aerated treatment ponds are typically highly loaded, shorter detention time (7–20 days) lagoons that may be used in combination with facultative lagoons and/or settling.

6.5.3 Lagoon Construction

6.5.3.1 Embankments and Dikes

6.5.3.1.1 Maximum and Minimum Slopes

Maximum Slope: Inner and outer dike slopes should not be steeper than 1:2.5 (vertical to horizontal), although 1:3 is most common. A site's geotechnical properties and pond liner characteristics must be considered when calculating the appropriate slope.

Minimum Slope: Inner slopes should not be flatter than 1:4. Flatter slopes can be specified for large installations because of wave action, but it is important to consider that the addition of shallow areas promotes the growth of vegetation. For aerated lagoons, flatter side slopes also increase the unaerated area and increase the potential for short circuits.

In general, pond bottoms should be as level as possible at all points. Finished elevations should not be more than 3 inches from the average elevation of the bottom. Lagoons with bottom-mounted aeration should have bottom grades level to within 1.5 inches tolerance. Deeper, nonaerated seasonal storage ponds and polishing ponds may be constructed with sloped or stepped bottoms.

Outer slopes should be sufficient to prevent surface runoff from entering the ponds. All slopes on dikes should be protected from erosion.

6.5.3.1.2 Freeboard

Minimum freeboard should be 3 feet, except for small systems where 2 feet may be acceptable. Stabilization ponds should have a minimum freeboard of 2 feet.

6.5.3.1.3 Depths

Stabilization ponds should have a depth of at least 3 feet and no more than 5 feet. Greater depths in subsequent cells are permissible although supplemental aeration or mixing may be necessary.

Aerated facultative ponds should have depths of 10–20 feet. Greater depths should be discouraged to avoid a high ratio of aerobic-to-facultative volume, especially with surface aerators. The depth may be altered depending on the aeration equipment, waste strength, and climatic conditions.

The minimum operating depth should be sufficient to prevent growth of aquatic plants and damage to the dikes, pond bottom, control structures, aeration equipment, and other appurtenances. In no instances should pond depths be less than 2 feet.

6.5.3.1.4 Top Width

Dikes should be at least 12 feet wide to provide adequate width for use by maintenance equipment. Dike corners should be designed to allow maintenance equipment to have complete freedom of movement over all portions of the dikes.

6.5.3.1.5 Materials

Dikes should be constructed of impervious materials or lined with a suitable liner. Dikes constructed of impervious soil should be compacted to at least 95 percent Standard Proctor density to form a stable structure. Vegetation and other unsuitable materials should be removed from the embankment area.

Wave protection should be provided on lagoons with earthen interior side slopes, and should extend at least 1 foot below the minimum water level to at least 2 feet above the maximum water surface level.

6.5.3.1.6 Dewatering

To facilitate slope stability, relief seepage and toe drains should be part of the pond embankment design.

6.5.3.1.7 Groundwater

A system of wells or lysimeters may be required around the perimeter of the pond site to facilitate groundwater monitoring. Monitoring requirements should be determined on a case-by-case basis.

6.5.3.1.8 Allowable Leakage

Leakage from wastewater treatment ponds should be minimized. As a rule of thumb, leakage should be less than 500 gallons per day per acre. Design leakage rates should be based upon hydrogeologic analysis and environmental impacts. Leak detection systems should be used when warranted by hydrogeologic site conditions.

6.5.3.2 Liners

Ponds should be sealed so that seepage loss is as low as practicably possible, and so the allowable leakage limits (stated above) are met. Seals consisting of soils, bentonite, or synthetic liners may be considered, provided that permeability, durability, and integrity of the proposed material can be satisfactorily demonstrated.

6.5.4 Control Structures and Site Piping

6.5.4.1 Control Structures

Where possible, facilities should use multipurpose control structures to facilitate normal operating functions such as drawdown and flow distribution, flow and depth measurement, sampling, pump recirculation, chemical additions, and mixing.

Safety and Maintenance: Control structures should be accessible for maintenance and adjustment of controls; locked to discourage vandalism; capable of controlling water level and flow rate and complete shutoff; constructed of noncorrodable material; and located so as to minimize short circuits within a cell and prevent freezing and ice damage.

Regulating Valves: Valves, adjustable weir gates, slide tubes, or multiple slide gates may be used to regulate water levels. (Stoplogs should not be used.) Regulators should be preset to prevent the pond surface elevation from dropping below the desired operating level. Pond level gauges should be provided on each cell.

6.5.4.2 Manholes and Valve Pits

A manhole or clean-out structure should be installed before the entrance of the influent line into the primary cell, and should be located as close to the dike as topography permits.

6.5.4.3 Piping

All piping should be constructed of cement-lined ductile iron or other generally accepted materials for underground sewer construction. Restrained joints should be provided as required. In material selection, consider the characteristics of the wastes, exceptionally heavy external loadings, abrasion, soft foundations, and similar problems. Seepage collars should be provided around any pipes penetrating the dike, and should extend a minimum of 2 feet from the pipe.

6.5.4.4 Drains and Underdrains

Where possible, gravity drains should be considered on all lagoons. In addition, underdrains should be provided where needed to protect liners from uplift. Underdrain design should be based on hydrogeologic factors.

6.5.4.5 Flow Distribution

Flow distribution structures should effectively split hydraulic and organic loads equally among primary cells.

6.5.4.6 Influent and Discharge Points

Inlet Piping: Inlet piping should enter a pond at a point that is one-fifth to one-third of the total water depth above the lagoon bottom, but not less than 2 feet above the lagoon floor. In ponds with a width of 150 feet or more, multiple inlets should be used to enhance distribution of the influent flow.

Outlets: Outlets should provide multiple draw-off levels. Draw-off capability should be provided over as much of the operating depth as feasible.

Aerated Cells: All aerated cells should have influent lines that distribute the load within the mixing zone of the aeration equipment, minimizing short circuits. Influent lines should discharge horizontally onto a splash pad.

Deeper Ponds: For ponds that are deep enough to permit stratification of pond content, multiple takeoffs are recommended. A minimum of three withdrawal pipes at different elevations should be installed. Adequate structural support should be provided.

6.5.4.7 Surface Runoff

Adequate provisions must be made to divert stormwater runoff around ponds and protect pond embankments from erosion.

6.5.4.8 Erosion Control

A comprehensive erosion control plan should be incorporated into the design to protect both the lagoon embankments and adjacent water bodies. Riprap or another acceptable method of erosion control is required around all piping entrances and exits.

6.6 Other Biological Systems

Biological treatment processes not included in these guidelines may be considered in accordance with the guidance presented in Section 4.3.2.

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CHAPTER 7

PHYSICAL AND CHEMICAL PROCESSES FOR ADVANCED TREATMENT

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7.1 General Concepts

Physical and chemical processes used for advanced wastewater treatment may be used individually or in combination, and they may be employed after preliminary, primary, or (most commonly) secondary treatment. Whatever the configuration, the goal is to remove pollutants not adequately removed by conventional treatment processes. The pollutants that may be removed include suspended solids and the particulate fractions of phosphorus, nitrogen, and residual organics. Physical and chemical processes can also be used to increase dissolved oxygen concentrations and to adjust pH and alkalinity.

This chapter focuses on advanced processes that are commonly used in New England to treat domestic wastewaters or are rapidly emerging as means to meet regulatory limits. Filtration to achieve advanced suspended solids removal, chemical phosphorus removal, and total organic carbon removal are covered, as are technologies for effluent reoxygenation and pH/alkalinity adjustment. While this chapter provides guidelines for both established and innovative processes, it is important to note that technologies for advanced treatment are rapidly changing. The most current literature should be consulted to supplement the information presented here.

7.1.1 Energy and Life-Cycle Considerations

Advanced treatment systems commonly account for a significant percentage of a treatment plant's energy use, chemical usage, and personnel time. Therefore a careful analysis of energy consumption and overall life-cycle costs should be a part of any evaluation and design of facility improvements involving advanced treatment. Process and equipment selection for advanced treatment should include a detailed life-cycle cost evaluation that, at a minimum, takes into account capital cost, energy, chemical usage, equipment maintenance, and system operating time as well as indirect aspects such as greenhouse gas emissions.

7.2 Filtration

Physical treatment processes specifically designed to reduce secondary effluent suspended solids commonly include the following:

- Granular or synthetic media (depth) filtration
- Compressible media filtration
- Disc (surface) filtration
- Low pressure membrane processes including microfiltration and ultrafiltration specific to tertiary solids removal. (Guidance on these processes can be found in Section 7.3; information on membrane bioreactors (MBRs) is in Chapter 6, Section 6.3.8)

Note: Suspended solids may also be removed to advanced treatment levels with other processes, particularly those that use a granular or synthetic media bed as part of biological active filtration to achieve nitrification or denitrification. A description of these technologies is in Chapter 6, Section 6.2.5. Chemical coagulation and precipitation methodologies commonly used for the removal of phosphorus can also remove suspended solids to low concentrations and are described in Section 7.4.

7.2.1 Process Goals

Filtration is generally intended to remove residual total suspended solids (TSS) and reduce turbidity. Filtration may be used whenever treatment limits below typical secondary standards must be met, but it is used most frequently with limits of less than 10 mg/L effluent TSS or turbidity of less than 2 nephelometric turbidity units (NTU). Filtration is commonly employed to meet stringent limits for specific pollutants, such as nitrogen or phosphorus, that may occur as a portion of the effluent TSS. Effluent filtration may also be used as a means of pretreatment for effluent disinfection or other technologies required for effluent reuse.

7.2.2 Process Evaluation

Many criteria must be considered when determining the need for filtration and the type and configuration of filter process that is most appropriate for the application. These criteria should include the following:

- Filter influent characteristics.
- Filter effluent requirements.
- Compatibility with other processes (including pretreatment requirements).
- O&M requirements including level and capabilities of staffing.
- Sidestream and recycle impacts.
- Solids production.
- Operational and energy requirements.
- Space requirements.
- Health and safety considerations.
- Capital and operating costs.

7.2.3 Pretreatment

Upstream treatment processes should on average reduce suspended solids concentrations to less than 30 mg/L with peak concentrations no higher than 50 mg/L prior to filtration. Fats, oils, and grease (FOG) removal should also be provided before filtration. Effluent filtration systems may require or be greatly enhanced by pretreatment of the secondary effluent prior to suspended solids removal, using methods such as those described below.

7.2.3.1 Coagulant Feed System for Filtration

To ensure operating flexibility, good engineering practice typically dictates that a coagulant feed system be used with any advanced suspended solids removal process. Both organic and inorganic coagulants have been used successfully. Bench-scale testing may be conducted to determine optimum chemical selection, dosing, and performance. Special care should be taken when designing systems that may be susceptible to blinding due to coagulant addition. Chapter 4, Section 4.5 and Section 7.4 (below) include information related to chemical feed system design.

7.2.3.2 Clarifier Optimization

Additional pretreatment measures may be incorporated to improve secondary clarifier performance upstream of filters. These measures include hydraulic improvements or flocculating type clarifiers to maximize suspended solids removal prior to advanced treatment. Chapter 6, Section 6.3.5, provides additional design information related to secondary clarifiers.

7.2.3.3 Algae Removal from Lagoon Effluent

The presence of algae can greatly hinder the performance of suspended solids removal systems. To safeguard advanced treatment system performance, both physical and chemical control mechanisms should be provided to adequately control algae growth in lagoons and, when necessary, to remove algae from lagoon effluent.

7.2.4 Backwash Requirements

Filtration systems are backwashed intermittently or constantly, depending on the specific design configuration, and may use filtered effluent or a combination of filtered effluent and compressed air for backwash. The impacts of backwash flows and associated pollutant loads must be considered relative to the overall capacity and operation of the facility.

7.2.5 Hydraulic Requirements

Filter systems should be designed to accommodate peak hourly flows with one unit in backwash mode and to accommodate filters operating at design maximum headloss through filter media. The systems should include appropriate provisions for redundancy as covered in Section 7.2.10. Filters should also include provisions for automatic bypass in the event of filter media blinding as well as provisions for positive flow distribution.

Depending on the flow regime of the facility and filter configuration, equalization should be considered upstream of filtration.

7.2.6 Filter Process Monitoring and Controls and Appurtenances

Effluent filtration systems should include automatic control features to initiate backwash based on intervals of time or on high filter headloss. (This does not apply to systems employing manual slow sand filters.) Controls should have the flexibility to allow sequencing of backwash events in the installed units as well as adjustments to backwash duration.

At a minimum, filter systems should be provided with instrumentation to monitor headloss and turbidity of both filter influent and effluent, and to monitor for filter influent and backwash flows. Additional instrumentation to monitor TSS, nutrients, particle size distribution, and other parameters may be warranted, depending on site-specific conditions.

7.2.7 Enclosures

Effluent filtration systems should include provisions that protect the process, controls, and ancillary equipment from weather impacts, particularly moisture, precipitation, and freezing conditions. Filter enclosures should include appropriate features for personnel health and safety, and adequate space for equipment maintenance.

7.2.8 Redundancy

Redundancy requirements for effluent filtration systems depend on the type of filter and many site-specific conditions. Filter systems that require year-round operation to meet effluent requirements should provide full capacity at peak hourly flow with one unit out of service for maintenance and one filter backwashing. At facilities with less stringent effluent requirements, the appropriate level of redundancy should be determined by the designer and the involved regulatory agency. However, maximum filter capacity should always be reduced to reflect at least one filter in the system in backwash mode, with the portion of the system being backwashed not available for filtration. A reduction in capacity due to backwashing may not apply to systems that continuously backwash with no loss of filter operating capacity. However, in such a case, a redundant unit is still warranted when year-round filtration is required.

7.2.9 Cleaning

To control biological (bacteria and insect) activity in filter media, facilities for adding chlorine to filter influent and backwash water should be provided. Filters should have valving to allow isolation for filter cleaning and service. In some cases, disinfection may be accomplished using non-chlorine methods, which can be performed through the filter process. In cases where very little or no chlorine is allowed in the plant effluent, these alternative disinfection approaches can be used or care should be taken to dechlorinate or adequately backwash to prevent any discharge of chlorine.

7.2.10 Configurations

Effluent filtration may be implemented in a number of configurations. The alternatives are generally classified as depth filters—which utilize sand, synthetic granular media, or synthetic compressible media—or surface filtration, which uses permeable discs with media consisting of either cloth or metal. Filter capacity presented in this section reflects capacity with redundant units out of service and one unit in backwash mode.

7.2.10.1 Slow Sand (Intermittent) Filters

Slow sand filters following secondary treatment should meet the following minimum design criteria:

- Loading rates at peak hourly flow should not exceed 6.0 gallons per day per square foot (gpd/sf) of filter surface area.
- Filter underdrains should not be subject to flooding under any flow regime.
- Manually cleaned slow sand filter systems should be provided with sufficient redundant units to allow maintenance and cleaning.

7.2.10.2 Rapid Rate, Automatically Backwashed Granular Media Filters

Rapid rate, automatically backwashed (ABW) sand filters can be either deep bed, mono, or multimedia filters, or shallow bed, travelling bridge type filters.

The following minimum design criteria should be met when using any rapid rate ABW sand filter:

- Loading rates at peak hourly flow should not exceed 5.0 gallons per minute per square foot (gpm/sf) of filter surface area unless a specific media and filter configuration has demonstrated higher loading capacity.
- A minimum of two filter units should be provided.
- Filters should be designed and installed so that all components and areas of media surface can be accessed for inspection and maintenance.
- Equalization or surge tanks should be provided when necessary to protect filters or downstream operations.
- Each filter should have washwater troughs, surface wash capacity, and/or air scouring capability.

7.2.10.2.1 Deep Bed ABW Sand Filters

In addition to the criteria in Section 7.2.10.2 above, deep bed ABW sand filters should meet the following minimum design criteria:

- The underdrain system should be designed for uniform distribution of backwash water and air, if provided, without danger of clogging.
- Backwash systems must be able to fluidize and expand media based on the specific attributes of each type of filter and characteristics of the filter media. Filter backwash water should be returned to plant or primary clarifier influent.
- Clearwells should store, at minimum, enough water to conduct at least two complete backwashes. Where needed for efficient plant operation, mudwells should have, at minimum, enough volume to store water from at least one filter backwash, with provisions to gradually introduce the backwash into plant or primary clarifier influent. Where multiple units can backwash simultaneously, larger clearwell and mudwell capacities may be warranted.
- Filter backwash pumps should provide the required rate with the largest pump out of service. Systems that utilize air scour for backwashing should follow the same criteria for blowers.

7.2.10.2.2 Shallow Bed, Traveling Bridge ABW Sand Filters

Shallow bed, traveling bridge ABW sand filters must meet the minimum design criteria required for all ABW type filters (Section 7.2.10.2), but the following criteria also apply:

- Shallow bed ABW filters generally do not require mudwells, and clearwells required for these systems are typically included in vendor package sizing.
- Given their high sensitivity to chemical overdosing, shallow bed ABW filters should not be designed to operate with regular chemical addition.

Continuously washed, moving bed filters are generally proprietary systems; their size and features are typically defined by system manufacturers on a site-specific basis.

7.2.10.2.3 Continuous Backwash Filters

Design criteria for continuously backwashed filters should be based on manufacturer’s criteria and may warrant pilot testing.

7.2.10.3 Compressible Media Filters

A compressible media filter (CMF) is a semi-continuous operation depth filter that uses a fibrous compressible synthetic media in lieu of sand.

- CMFs are generally proprietary systems; their size and features are typically defined by system manufacturers on a site-specific basis.
- A minimum of two filter units should be provided.

7.2.10.4 Disc Filters

Disc filter systems are generally a continuous flow surface filtration process that, for a filter media, utilizes hollow discs which are covered in synthetic material (either cloth or metal). Disc filters typically do not require either clearwells or mudwells, and can operate in either a fully submerged or partially submerged mode, depending on manufacturer guidance. Disc filters should meet the following minimum design criteria:

- In cold climates, disc filters should be housed in heated and ventilated enclosures, due to the mechanical aspects of the systems.
- Loading rates at peak hourly flow should not exceed 6.5 gpm/sf of filter surface area.
- A minimum of two filter units should be provided.

7.3 Membrane Filtration

Membrane filtration can be incorporated as an advanced treatment process to remove suspended and/or dissolved particles, with the result being a highly polished effluent. The four membrane categories and typical pore size are:

- Microfiltration (MF): 0.1 to 10 microns
- Ultrafiltration (UF): 0.01 to 0.1 microns
- Nanofiltration (NF): 0.001 to 0.01 microns
- Reverse osmosis (RO): Less than 0.001 microns

Microfiltration and ultrafiltration generally operate at lower pressures and can be configured in pressure-driven or immersed, vacuum-driven applications. Nanofiltration and reverse osmosis are pressure-driven technologies, and operate at higher pressures commensurate with the energy required to pass flow through smaller pore sizes.

Typically membrane systems that remove suspended solids following secondary treatment utilize either microfiltration or, more commonly, ultrafiltration. Information related to immersed microfiltration as part of a membrane bioreactor (MBR) process is included in Chapter 6, Section 6.3.8. Use of reverse osmosis for total organic carbon removal is discussed later in this chapter (Section 7.6.2).

Regardless of the type and configuration of membrane filtration selected for a facility, the system design should be prepared holistically, taking into account the interrelationship between various aspects of the system. The design should be developed in close consultation with the system manufacturer.

7.3.1 Membrane Influent Characteristics

Membrane system influent characteristics can vary widely depending on the upstream processes (in use or proposed) and variations in system performance. Microfiltration or ultrafiltration can be used following either secondary or tertiary treatment systems, depending on overall process goals. Table 7-1 lists typical secondary effluent quality entering membrane systems used for solids removal.

Table 7-1 **Typical Feedwater (Secondary Effluent) Quality** (WEF, 2006)

Parameter	Units	Secondary Effluent	Reported Values for MF Feedwater
Biochemical oxygen demand	mg/L[b]	5–30	5–30
Total organic carbon	mg/L as C	5–30	5–30
Total Kjeldahl nitrogen	mg/L as N	10–20	5–30
Total phosphorus	mg/L as P	1–8	1–8
Iron	mg/L	0–1	0–1
Total suspended solids	mg/L	5–30	2–30
Turbidity	NTU	2–10	1–10
pH	s.u.	6–9	
Temperature	0C	8–30	
Total coliforms[a]	No./100 mL	50,000–2,000,000	
Fecal coliforms[a]	No./100 mL	10,000–1,600,000	
Viruses	PFU/100 mL	0.05–1,000	
Protozoan cysts	No./100 mL	5–10	
Total residual chlorine	mg/L	0–2	
Fats, oils, and grease	mg/L	0.1–10	

[a] Before disinfection
[b] mg/L = ppm

7.3.2 Typical Effluent Performance

Membranes are a physical barrier that captures all particulate matter larger than the pore size of the media and some percentage of matter smaller than the pore size. As such, a high percentage of pollutants that are particulate in nature will be removed as will some percentage of colloidal material. Soluble pollutants, particularly those of low molecular weight, will pass through membranes. Table 7-2 lists the range of effluent possible by microfiltration and ultrafiltration when treating secondary effluent. Significantly better performance can be expected by systems with membrane bioreactors or tertiary treatment upstream of membranes.

7.3.3 Pretreatment

The pretreatment processes required by a membrane filtration system depend on the specific requirements of the upstream treatment system and membrane system in use. However, pretreatment commonly consists of flow equalization, fine screening, straining, filtration, disinfection, pH adjustment, or chemical coagulation.

Solids removal for microfiltration and ultrafiltration systems typically requires 1–3 mm screening prior to immersed membrane filtration and 0.2 mm screening for pressure-driven membrane systems.

The level of pretreatment influences the rate of membrane fouling, frequency of backwash, and chemical cleaning requirements. Consideration should be given to providing the highest level of solids pretreatment possible upstream of membranes to reduce maintenance requirements and extend the operating life of the membranes.

Table 7-2 **Typical Filtrate Water Quality for MF and UF Treatment Facilities** (WEF, 2006)

Parameter	Units	Range of Values	Removal
Biochemical oxygen demand	mg/L[a]	<2–5	85–95%[b]
Total organic carbon	mg/L as C	5–25	5–60%[b]
Total Kjeldahl nitrogen	mg/L as N	5–30	6–8%b
Total phosphorus	mg/L as P	0.1–8	1.5–3%[b]
Iron	mg/L	0–0.2	0–20%[b]
Total suspended solids	mg/L	Below detection limits	>99%
Turbidity	NTU	<0.1	95 to >99%
Silt density index		<2–3	N/A[c]
Fecal coliforms	No./100 mL	<2–10	3 to >6 log
Virus	PFU/100 mL	<1–300	0.5 to 6 log
Protozoan Cysts	No./100 mL	0–1	3 to >6 log

[a] mg/L = ppm

b No removal can be expected in the absence of chemical treatments if the parameter exists only in soluble form; however, in secondary effluent, a significant fraction of this parameter is associated with suspended and colloidal solids.

[c] not applicable

7.3.4 Membrane System Components

Pressurized membrane systems typically consist of a series of units configured in parallel pressure vessels. Immersed systems are generally configured in cassette modules.

System redundancy should be provided to allow system backwashing and membrane replacement. All systems should be provided with at least one spare membrane unit or cassette for every three units required. All installations, regardless of size, should have at least one redundant unit or cassette. For each pumping system, feed, backwash, and waste pump capacity should be provided with the largest unit out of service. The required aeration should also be maintained with the largest unit out of service.

Membrane backwash and chemical cleaning systems are dependent on membrane materials and manufacturer configurations. Typical chemicals used for membrane cleaning are citric acid, sodium hydroxide, and detergents. Chlorine is used to a limited extent and with only certain membrane materials. Chemical handling requirements may be site-specific but in general, seven days of chemical storage should be provided at larger plants (>10 mgd) and 30 days of storage at smaller plants (<10 mgd); in both cases, dedicated metering pumps should be used. Backwash flows should have a surge tank to dissipate the hydraulic and solids impacts on downstream components.

Residuals captured by the membrane separation process can be directed to the preliminary or primary treatment system. Systems that generate a brine stream or that reject water high in total dissolved solids require specialized handling systems.

Note: See Section 7.6.2 for a discussion of membrane filtration relative to total organic carbon removal.

7.4 Chemical Treatment

Chemicals can be used in various ways to directly remove pollutants or alter water chemistry to enhance the performance of treatment processes. The discussion of chemical treatment in this section is limited to phosphorus removal and pH/alkalinity adjustment.

7.4.1 Phosphorus Removal

This section describes the use of chemical precipitation for phosphorus removal when conducted independent of conventional treatment systems or in combination with them. Selection of the appropriate chemical precipitation process should be based on:

- Chemical analysis of the influent wastewater.
- Treatment objectives.
- Capability of existing or proposed wastewater treatment processes in the facility, especially those for biological nitrogen and phosphorus removal.
- Overall costs of the alternatives: Economic evaluations should be conducted to assess the capital investment and operating expenditures associated with each phosphorus treatment system under consideration, including the costs of chemical storage and feed equipment, sludge handling and disposal, and chemical recovery and reuse.

In facilities that process significant quantities of sludge, special attention should be paid to nutrient recovery and sidestream treatment processes from recycle streams.

7.4.1.1 Forms of Phosphorus in Municipal Wastewater

Municipal wastewater contains phosphorus in orthophosphate, polyphosphate, and organically bound forms. The orthophosphates and polyphosphates are soluble compounds. The organically bound phosphorus can be present in either soluble organic compounds or particulate organic matter.

The orthophosphate form of phosphorus reacts with metal ions to form an insoluble precipitate that can be separated from treated wastewater. The polyphosphates and soluble organic phosphorus forms are biologically converted in the secondary treatment process into the orthophosphate form, which is then precipitated by adding metal salts. Particulate organic phosphorus is removed by settling or via incorporation into flocculant particles followed by physical separation, i.e., filtration.

7.4.1.2 Commonly Used Chemicals

The chemicals most commonly used for phosphorus precipitation are the salts of aluminum and iron. Lime (i.e., calcium hydroxide) is not commonly used because of problems associated with its handling, high chemical doses, high capital and operating costs, and the large volume of sludge generated.

Most aluminum and iron salts are acidic and will lower the pH of wastewater. The engineer should ensure that the influent wastewater has adequate alkalinity to neutralize the acidity caused by the metal salts. A pH adjustment system may be necessary in some cases. Certain metals, it should be noted, have raised concerns related to effluent toxicity and may be subject to limits that require compliance (see explanation below in Section 7.4.1.2.1).

7.4.1.2.1 Aluminum Salts

The three aluminum salts commonly used for the precipitation of phosphorus are aluminum sulfate (alum), sodium aluminate, and polyaluminum chloride

(PAC). Of these three, alum is the one most frequently used and is the least expensive. However, its reaction it generates an acid that consumes alkalinity. Recent actions by U.S. EPA indicate that metal compounds, particularly aluminum compounds, will need to be monitored in local rivers and will be subject to permitting.

7.4.1.2.2 Iron Salts

Iron salts such as ferric chloride, ferrous chloride, and ferrous sulfate are frequently used as precipitants. Since these compounds are also often used to thicken biosolids, using them to reduce phosphorus may allow a facility to use a single chemical handling facility for both purposes. Liquid solutions of these salts are highly corrosive. Iron salts may be available as inexpensive industrial by-products, but it is critical to be aware that, depending on the source, some of these by-products may contain many harmful contaminants. Iron salts also act as a mild acid and will consume alkalinity.

7.4.1.3 Chemical Application Points

Metal salts are commonly added to primary clarifier influent, secondary treatment facilities, tertiary treatment facilities, or combinations of these points simultaneously. The points of application should have adequate turbulence to ensure complete mixing of the metal salt with the wastewater. The application point should be followed by a physical process (clarifier, filter, etc.) for separating the precipitate from the wastewater. The chemical application points should be located downstream of the plant’s internal recycle streams, such as recycles from sludge treatment facilities. Separate chemical addition to sludge recycles should be considered.

7.4.1.3.1 Addition of Metal Salts to Primary Clarifier Influent

Common points of application when adding metal salts before primary clarifiers are aerated grit chambers, discharge piping of raw sewage pumps, aerated channels, and flow distribution structures. When metal salts are added to the primary clarifier influent, only the orthophosphate present in the raw wastewater will be removed by the precipitation reaction. Soluble polyphosphates and organic phosphorus will not be removed in the primary clarifiers. However, some amount of phosphorus bound in particulate organic matter will be removed in the primary clarifiers, depending on solids removal efficiencies (which typically increase with metal salt addition). If ferrous salts are added to primary clarifiers, the phosphorus removal efficiency will be lower than that expected with ferric salts because the ferrous ion needs to be oxidized to a ferric ion before it can form an insoluble precipitate with phosphorus. Ferrous salts added to the upstream portion of an aerobic zone allow for the oxidation of the ferrous ion to a ferric ion.

Addition of metal salts to the primary clarifiers will increase biochemical oxygen demand (BOD) and solids removal efficiencies, depending on wastewater characteristics, primary clarifier design features, and the type and quantity of chemical used. The higher BOD removal efficiency associated with metal salt addition should be a concern if the downstream secondary treatment process is designed for denitrification. The engineer should perform process modeling or a mass balance on BOD to determine if sufficient amounts of organic carbon are available in the primary effluent for denitrification. It may be inappropriate to use metal salt addition to the primary clarifier influent as the only means of phosphorus removal if a downstream BNR system is included.

Application of phosphorus precipitating chemicals to primary clarifiers can produce a final phosphorus effluent concentration in the range of 1 to 2 mg/L. If higher phosphorus removal efficiencies are required, the metal salts should be added to secondary treatment facilities or to both primary and secondary treatment facilities. Because of competing reactions, the amount of chemicals required for phosphorus precipitation in primary treatment is much greater than the amount required to achieve the same removal efficiency in secondary treatment. It is important that chemical addition throughout the plant does not cause a nutrient deficiency in a downstream biological treatment process.

7.4.1.3.2 Addition of Metal Salts to Secondary Treatment

Commonly used application points in secondary treatment facilities are aerated influent flow channels, influent flow distribution structures, the influent and/or effluent end of aeration basins, and between aeration basins and secondary clarifiers. Effluent phosphorus levels in the range of 0.5 to 1 mg/L can be achieved by adding metals salts to secondary treatment facilities. To achieve total phosphorus concentrations lower than 0.7 mg/L, however, often requires a tertiary treatment process. For a design that calls for secondary treatment facilities alone to achieve effluent phosphorus limits less than 0.7 mg/L, a detailed evaluation of the facilities should be performed to document the capability and expected performance of the proposed system.

The addition of metal salts to an activated sludge process will normally increase the inert fraction of the mixed liquor suspended solids (MLSS). The impact of metal salt addition on activated sludge solids should be determined by mass balances or process modeling.

7.4.1.3.3 Multipoint Chemical Addition of Metal Salts

The addition of metal salts to some combination of primary, secondary and/or tertiary treatment facilities is the most cost-effective means of phosphorus removal by chemical precipitation. It minimizes the total dose and offers maximum operating flexibility by minimizing sludge production, controlling the inert fraction of MLSS, and optimizing carbon use for denitrification in cabon-deficient wastewaters. Therefore, the design engineer should provide for flexibility in feeding metal salts to multiple locations throughout the liquid treatment train, and in some cases, to liquid recycles from solids processing.

7.4.1.4 Advanced Treatment

A number of technologies have the potential to meet effluent total phosphorus limits of 0.2 mg/L or lower either alone or in combination with downstream sand, disc, or membrane filtration. However, there are many factors that may influence the level of treatment and reliability possible from such systems. These factors include the potential for non-reactive phosphorus, the impacts of wet weather flows, and other stressed conditions that impact plant performance. With many of these advanced technologies, there are only a limited number of installed units; also, most of the technologies have aspects that are particular to them, or they are completely patented and proprietary. As a result, the reliability of these systems is not well documented, particularly with regard to their ability to meet monthly average effluent total phosphorus limits of 0.1 mg/L or lower. Further, little definitive design criteria exist for these processes and pilot testing is often warranted, especially when stringent effluent limits have been imposed.

Newly developed advanced processes and those in use as of the publication of this document are described below. Specific design criteria for each technology should be developed on a site-specific basis and with the benefit of pilot testing as appropriate.

7.4.1.4.1 Common Aspects

Most tertiary phosphorus removal systems use a number of the same unit operations, although there may be variations in the design criteria that system suppliers use for each operation. Typically, tertiary phosphorus removal configurations utilize a combination of the following:

Chemical Addition: Metal salts are added that react with soluble phosphorus and other compounds in the wastewater, resulting in the removal of phosphorus through direct chemical precipitation and via adsorption onto floc particles. The chemical dose is stoichiometric when less stringent limits are in place but the does increases substantially with limits below 1 mg/L. The appropriate metal salt dosing and its implications for the chemical system capability should be determined with jar or pilot testing, with an additional factor of safety applied. Many of the metal salts commonly used as precipitants are acidic and are also impacted by pH during the precipitation process. Therefore, pH control is generally required to provide optimal solids formation and phosphorus removal. When selecting and using chemicals, consider the impact on downstream plants as well as effluent disposal requirements.

Rapid mixing: Complete mixing is required to provide the maximum contact between metal salts and phosphorus. Typically metal salts are added immediately upstream or concurrent with rapid mixing.

Flocculation: Optimal solids flocculation is critical to achieving low effluent phosphorus concentrations because any fines that remain in the effluent will contain trace amounts of phosphorus that will limit performance. Chemical conditioning with polymer is often used to optimize flocculation.

Solids Separation: Achieving very low effluent phosphorus requires correspondingly low effluent solids. This high level of solids removal requires consistent operation or the addition of an additional solids removal process such as filtration.

Note: The processes that remove phosphorus to a high degree typically remove a high percentage of other pollutants. Through the removal of suspended and colloidal solids, other pollutants such as metals, organics, and even pathogens are often removed to trace levels. Improved disinfection efficiency is also seen, due to the improved solids removal and lower turbidity associated with advanced phosphorus removal systems.

7.4.1.4.2 Sand or Disc Filtration

Filtration using conventional sand, continuous backwash, or disc filters can be used to reduce phosphorus to low levels. This approach requires that effective coagulation and flocculation are provided upstream of filtration.

7.4.1.4.3 Membrane Filtration

Membranes can be used as the tertiary solids barrier for phosphorus removal following coagulation and flocculation. Due to the exceptional solids-removal capacity of membranes, systems using membranes require a lesser degree of solids flocculation than systems using other terminal solids barriers.

7.4.1.4.4 Actiflo

Actiflo, developed by Veolia Water, is a ballasted sedimentation process that uses chemical addition to precipitate phosphorus and microsand to enhance the settling rate. Flow enters the coagulation tank where the chemical is added and flash mixing occurs. The chemically treated wastewater passes to the injection tank where microsand is added to serve as the "seed" for flocculation and as a ballast to increase the settling rate. Flocculation occurs in both the injection tank and the downstream maturation tank, and polymer may be added to enhance solids formation in either of these locations. Solids separation is performed with gravity clarifiers aided by plate settlers. Solids removed from the clarifier are wasted to a hydrocyclone, where the sand is separated from the chemical solids. Chemical solids are conveyed to the sludge handling systems, and the microsand is returned to the injection tank. Virgin microsand is also added to the injection tank to replace the amount lost in the sludge or effluent. In applications where stringent effluent limits must be met, the Actiflo process is sometimes followed by filtration to improve effluent quality.

7.4.1.4.5 CoMag

Developed by Cambridge Water Technology, CoMag is a ballasted sedimentation process that uses chemical addition with flash mixing, solids recirculation, flocculation with magnetite, and polymer addition prior to conventional gravity sedimentation. Excess sludge is wasted from the process, and magnetite in the waste sludge is recovered via a combination of shearing, which liberates the magnetite from the sludge floc, and a magnetic drum, which captures the magnetite and allows the chemical solids to move to sludge processing systems. Magnetite recovered from the waste sludge and virgin magnetite are blended and continuously added to the process to serve as ballast for the chemical sludge. The addition of magnetite, with a specific gravity of 5.2, to the chemical sludge floc allows settling rates far in excess of that seen in typical primary or secondary clarifiers. In some applications, the CoMag process is followed by a magnetic drum filter to capture stray magnetite particles and improve effluent quality.

7.4.1.4.6 DensaDeg

Degremont Technologies' DensaDeg process is a high rate solids contact clarifier process that uses chemical addition with flash mixing, two forms of solid recirculation, flocculation with polymer addition, and settling with gravity clarifiers that incorporate tube settlers. Flocculation is enhanced via an intense internal recirculation that uses a draft tube arrangement and u-shaped internal flow pattern. Sludge is periodically wasted from the process to the sludge handling system. The DensaDeg process commonly employs effluent filtration when stringent effluent limits must be met.

7.4.1.4.7 AquaDAF

Degremont Technologies' AquaDAF process is a high rate chemical coagulation, flocculation, and dissolved air flotation system. Flow enters the system at the coagulation inlet where the chemical is added, and the flow then enters the flocculation zone. Flocculated solids enter the air-water dispersion zone where water that is supersaturated with air is added. As this mixture enters a depressurized area, micro-bubbles are released, agglomerating with the flocculated solids and lifting the mixture to the surface of the flotation zone. Clarified water exits the process through a perforated floor, and solids are removed mechanically from the surface and transported to the sludge handling system. The AquaDAF process commonly employs effluent filtration in situations involving stringent effluent limits.

7.4.1.4.8 Blue PRO

The Blue PRO system, developed by Blue Water Technologies, uses a combination of chemical addition and continuous backwash filtration with reactive media that captures phosphorus via adsorption. The reactive media contain a coating of ferric oxide that is continuously regenerated. Waste solids are removed in a continuous reject stream, and are directed to the sludge handling system.

7.4.2 Alkalinity and pH Adjustment

Control of pH and alkalinity is extremely important for the optimization of chemical and biological treatment processes. The formation of metal salt-phosphorus precipitates is pH dependent, and most metal salts used are acidic and consume alkalinity. Nitrification consumes alkalinity and denitrification restores alkalinity.

Addition of alkaline compounds increases both pH and alkalinity, although there is no definitive relationship between these parameters. Chemical addition to increase pH is dependent on specific wastewater characteristics, and titration curves are often developed to determine the quantity of chemical required. Acid addition is occasionally warranted to lower pH to optimize chemical phosphorus removal. In lieu of this approach, some facilities will overdose metals salts.

Alkalinity addition is often required at plants that remove nitrogen or phosphorus. It is good practice to provide the materials and equipment necessary to maintain the minimum level of alkalinity required in the effluent of biological treatment processes (preferably 75 mg/L of alkalinity). Table 7-3 lists the chemicals commonly used for alkalinity addition and the relationship between each chemical and increased alkalinity.

Table 7-3 **Alkalinity Equivalents for Common Alkaline Reagents**
(adapted from WEF, 2010)

Chemical	Formula	Alkalinity Equivalent mg Chemical /mg Alkalinity Added (expressed as $CaCO_3$)
Calcium carbonate	$CaCO_3$	1.0
Calcium oxide	CaO	0.560
Calcium hydroxide	$Ca(OH)_2$	0.740
Magnesium oxide	MgO	0.403
Magnesium hydroxide	$Mg(OH)_2$	0.583
Dolomitic quicklime	$[(CaO)_{0.6}(MgO)_{0.4}]$	0.497
Dolomitic hydrated lime	$[Ca(OH)_2]_{0.6}[Mg(OH)_2]_{0.4}$	0.677
Sodium hydroxide	NaOH	0.799
Sodium carbonate	Na_2CO_3	1.059
Sodium bicarbonate	$NaHCO_3$	1.680

7.4.3 Mechanical and Ancillary Equipment

7.4.3.1 Mixing

Mixers are used to provide rapid or flash mixing and to maintain solids in suspension. Rapid mixing equipment should provide a velocity gradient, G, in the range of 300 to 1,500 s^{-1}.

7.4.3.2 Chemical Storage

- Larger plants (>10 mgd) should require, and have the facilities for, storing the amount of a chemical necessary for, at minimum, 7 days of operation. Smaller plants should provide, at minimum, storage for 30 days demand. (For plants of all sizes, 30 days of storage is preferred, where possible.)
- Bag or drum storage should be located in close proximity, and with direct access, to solution makeup tanks.
- Bag or drum loaded hoppers should have a minimal storage of 8 hours at nominal maximum demand rates. At least 24 hours of storage should be provided at facilities manned less than 8 hours per day.
- Liquid chemical storage tanks and tank fill connections should be located within a containment structure having a capacity of no less than 125 percent of the total volume of the storage vessel(s), excluding the volume of the storage vessel above the elevation of the containment wall. Valves on the discharge lines should be located adjacent to the storage tank and within the containment structure. The containment area should slope to a sump area. No floor drains should be permitted in the containment area.
- Any auxiliary facilities, including pumps and pump controls located adjacent to the containment area, should be situated above the highest anticipated liquid level.
- Platforms, ladders, and railings should be provided as necessary for convenient and safe access to all connections, storage tank entries, and measuring devices.

- Reasonable access to storage tanks to facilitate cleaning should be provided.
- Adequate ventilation, and humidity and dust control facilities should be provided in areas where dry chemicals are stored.

7.4.3.3 Chemical Feed

- Chemical feed facilities should supply peak demand with the largest unit out of service.
- Chemical feed equipment should continue to function properly in the event of a storage tank or pipe failure.
- The lime feed system should be designed to minimize the length of slurry conduits. The conduits should also be accessible for cleaning.
- The configuration of the rubber hose for lime conduits must allow for scale removal by flexing or pounding on the hose material. Permanent flushing water attachments should be provided.
- Chemical overfeeding caused by induction siphoning must be prevented.
- Feed tanks should have drains for maintenance and above-bottom draw-offs to avoid the withdrawal of solids into chemical feed lines.
- Consider the accessibility of piping. Piping should be installed with plugged Ys, Ts, or crosses at changes in direction to facilitate cleaning.

7.4.3.4 Protective Measures

- Chemical feed equipment and storage facilities should be constructed of materials resistant to chemical attack.
- Prevention of freezing or crystallization should be addressed in the design.
- Any structural shelter for equipment should have adequate ventilation for protection of personnel and equipment.

7.5 Effluent Reoxygenation

Effluent reoxygenation is typically required to increase dissolved oxygen levels in plant effluents when permit limits require high dissolved oxygen levels prior to discharge to rivers and streams. There are several methods by which plant effluent may be reoxygenated; the two most common types are mechanical (mechanical aeration and diffused air) and gravity.

Regardless of the method used, the designer should be aware of the following:

- Wastewater temperature is an important design element to consider as dissolved oxygen saturation concentration is directly related to wastewater temperature.
- Typically, reoxygenation should be the final process before discharge to the receiving water body. If this is not the case, special consideration should be given to downstream processes and the potential negative impacts that highly oxygenated wastewater may have on these processes, including effluent filters.

7.5.1 Cascade Aeration

Cascade aeration, the oldest form of reoxygenation, can be accomplished at any number of locations where there is an air and water interface and the availability of hydraulic head; possible locations include weir overflows, flumes, and other similar structures. This type of reoxygenation is very effective but difficult to control. If the hydraulic head is already available, however, cascade aeration can be an inexpensive means of achieving high levels of dissolved oxygen.

WEF's MOP 8: *Design of Municipal Wastewater Treatment Plants* (2010) contains several methods for designing a cascade aeration system to ensure adequate DO entrainment.

7.5.2 Mechanical/ Diffused Aeration

There are many types of mechanically assisted aeration processes available for reoxygenation of wastewater. These systems include, but are not limited to, the following:

- Fixed or floating mechanical aerators
- Fine or coarse bubble aeration
- Jet aeration
- Pump agitators

All of these systems can be specially designed to deliver the precise amount of oxygen needed to enhance effluent wastewater. The use of mechanical aeration also provides facilities with an excellent opportunity to conserve energy through monitoring the concentration of oxygen in the wastewater and limiting over-aeration through a feedback loop.

7.6 Total Organic Carbon Removal

The need to treat municipal wastewater to meet low concentrations of total organic carbon (TOC) is an emerging requirement, particularly in the northeastern United States. As of the publication of this document, there is little experience in New England with pilot or full-scale municipal systems. Nationwide, TOC concentrations in treated water have typically been used as a bulk measure of organic contamination in reclaimed municipal water intended for reuse. In this sense, TOC concentrations are being used as a surrogate measurement for the presence of such contaminants of emerging concern (CECs) as endocrine disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs), and other organic compounds commonly found in treated water. However, TOC has long been targeted for removal from drinking water supplies due to its role in the formation of disinfection by-products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs), some of which are suspected human carcinogens. Drinking water regulations include both limitations on acceptable concentrations of DBPs in finished water as well as TOC removal objectives for source waters with elevated TOC concentrations. Much of the information related to TOC removal through unit treatment processes, therefore, has been developed in support of meeting regulations for drinking water and water reuse, particularly direct or indirect potable reuse.

It is important to understand the differences between TOC found in natural source waters and TOC in treated water. Organic matter found in treated water is typically higher in total concentration, lower in humic acid, more polar, and higher in nitrogen than organic matter found in natural source waters. In addition, higher concentrations of biologically-available organic matter are observed in treated water than in natural source waters. As a result, technologies used to remove TOC from natural source waters may perform differently when used to reduce TOC concentrations in treated water.

An important consideration in determining the most appropriate technology for removing TOC is its solubility. Dissolved organic carbon (DOC) is the portion of TOC that can pass through a 0.45 micrometer (µm) membrane filter. The DOC/TOC ratio can be used as a guide in determining the most effective approach to TOC removal. If the DOC/TOC ratio is low, indicating that a significant portion of the organics are in particulate form, then physical separation processes such as sedimentation and filtration would be expected to be effective in reducing TOC concentration. Conversely, if the DOC/TOC ratio is high, indicating that the organics are largely in solution, then coagulation, adsorption, and membrane filtration may be required to achieve significant TOC removal.

Several pilot and full-scale municipal installations in the United States have evaluated TOC removal techniques for their efficacy in removing organic carbon. Much of the data collected have focused on the ability of unit processes to selectively remove EDCs, PPCPs, and other CECs. The body of data regarding approaches to meeting TOC regulations for treated water continues to grow, and should be monitored when researching alternatives. Through wastewater characterization, the design engineer should also develop a good understanding of the total organic carbon that requires treatment. Depending on the levels of TOC that require treatment and the expected permit limitation, multiple technologies may be required to cost effectively remove TOC. Bench-scale studies and/or pilot studies are expected to be needed for proposed technologies until more extensive experience is gained with TOC removal alternatives.

The best available information on this topic may be found in individual technical papers such as those available from the Water Research Foundation and U.S. EPA. As of the writing of this document, reliable and proven TOC removal alternatives for wastewater applications include adsorption and membrane filtration, which are discussed below.

7.6.1 Activated Carbon

Activated carbon may be used to adsorb soluble organics including carbon and nitrogen compounds. Granular activated carbon (GAC), biological activated carbon (BAC), and powdered activated carbon (PAC) are commonly used adsorption technologies.

7.6.1.1 Granular Activated Carbon

The use of granular activated carbon is a well-tested method of TOC removal, traditionally used in drinking water applications. GAC can be used in downflow or upflow contactors. Downflow contactors are the simplest configuration, though upflow contactors have been successfully applied in cases with very long contact times and high concentrations of suspended solids. GAC systems typically require pretreatment—coagulation, filtration, or softening—to prevent filter clogging. In addition, GAC adsorption effectiveness decreases over time, with a corresponding increase in effluent TOC concentrations. Once the effluent concentration has reached a threshold limit, the GAC column must be taken offline to allow the GAC to be replaced. Spent GAC may be disposed of or regenerated either on- or off-site.

7.6.1.2 Biological Activated Carbon

An alternative to traditional GAC filtration is the use of biological activated carbon (BAC) filtration. In this process, instead of replacing or regenerating spent GAC, the GAC is allowed to become biologically active. Over time, microorganisms adhere to pores in the GAC media, essentially covering the media with a biofilm. TOC removal is achieved through biodegradation by miroorganisms in the biofilm, rather than through adsorption onto GAC.

BAC filtration processes are typically less effective than virgin GAC; however, operation and maintenance costs are significantly reduced, as carbon replacement frequency is reduced by an order of magnitude. BAC filtration efficacy can be significantly improved by adding an oxidation step prior to BAC filtration to cleave large organic molecules, making them more bioavailable. Because contact by a strong oxidant increases the bioavailability of organic molecules, GAC filters located downstream of a strong oxidation process tend to readily convert to BAC filtration processes.

7.6.1.3 Powdered Activated Carbon

Powdered activated carbon (PAC) is typically added in a rapid mix step, and settles out in the sedimentation stage. PAC capacity for TOC removal increases with contact time up to seven days; therefore, the contact time provided by typical settling basins is insufficient to produce effective removal. PAC is often used with membrane processes, and is frequently combined with microfiltration or ultrafiltration to improve performance by increasing organics removal and decreasing membrane fouling. This approach can also increase PAC detention time by recycling PAC through the membrane fibers.

7.6.1.4 Pilot testing

Although GAC is a reliable process for TOC removal, pilot testing is needed to determine how long the media will last. Other activated carbon systems also require some type of pilot testing.

7.6.2 Membrane Filtration

Membrane processes can remove TOC through filtration and adsorption. Organic molecules greater in size than the membrane pores are rejected based on size exclusion. Membranes may also remove TOC through surface adsorption, though this mechanism is undesirable as it has been shown to cause irreversible fouling.

As explained in detail in Section 7.3.1, pressure-driven membrane processes are typically grouped into the following categories (in order of decreasing pore size): microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). NF and RO have very small pore sizes, and are extremely effective at reducing TOC concentrations through size exclusion. MF and UF have shown limited efficacy in TOC removal due to their relatively large pore size. As a result, nanofiltration and reverse osmosis appear most promising, though it is important to consider that membrane treatment with RO and NF membranes is a relatively energy-intensive process.

Both RO and NF membranes reject a vast majority of contaminants, though precise rejection values vary by membrane manufacturer. However, RO membranes are typically more effective than NF membranes at rejecting compounds of lower molecular weight, including some forms of TOC and total dissolved solids (TDS). Because RO membranes typically reject a higher percentage of TDS than NF membranes, RO concentrate is expected to have a higher TDS concentration than NF reject. Reject water volumes and contaminant concentrations can be significant, and a proper disposal area must be identified; this can be a significant challenge for a municipality.

The water that passes through membrane systems can be quite aggressive, especially for RO systems. As a result, further treatment, i.e., conditioning, of the water may be needed prior to disposal. Determination of the proper conditioning system will likely require wastewater characterization testing.

7.6.2.1 Pilot Testing

Pilot testing of membrane filtration is needed to better understand performance and long term costs.

7.6.3 Other Alternatives

Other technologies or processes that appear to be able to remove TOC or seem to hold promise are listed below. All require at least bench-scale testing and possibly pilot testing to develop design criteria. Some may require the inclusion of activated carbon in the process or as a polishing step.

7.6.3.1 Coagulation and Filtration

TOC removal through coagulation and filtration involves altering the physical or chemical properties of suspended particles to increase their agglomeration, which creates larger flocs that are more readily separated from solution by sedimentation and/or filtration.

7.6.3.2 Ion Exchange

TOC can be removed through ion exchange, in which water comes into contact with a charged resin, and dissolved molecules from the source water replace resin molecules. Ion exchange produces reject water that needs to be disposed of outside of the treatment process.

7.6.3.3 Advanced Oxidation Processes

Advanced oxidation processes (AOPs) break down the chemical bonds in organic molecules that make them difficult to be degraded biologically. Once these bonds are broken, the organic compound is further metabolized by the biological or adsorption processes. AOPs are often used as a polishing step to destroy particularly recalcitrant organic compounds present in low initial concentrations.

7.6.3.4 Biological Processes

Biochemical oxygen demand (BOD) and TOC generally exist in a certain ratio, although this ratio may become nonlinear in plant effluents. As BOD is reduced, TOC also decreases. If a process can reliably reduce BOD levels to very low levels, TOC levels may likely follow. These processes may be enhanced by a process that conditions the TOC to make it more bioavailable.

References – Chapter 7

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CHAPTER 8

DISINFECTION

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8.1 General

All wastewater containing harmful pathogens must be disinfected before discharge from a treatment facility, regardless of the nature of the receiving point. These pathogens may be in the form of viruses, bacteria, protozoa, cysts, or parasites. Usually, disinfection must be performed year-round if the receiving water is used for drinking water by downstream communities or is home to shellfish and other forms of aquatic life consumed by humans. Seasonal disinfection may be allowed if uses of the receiving water are limited to bathing or other recreational activities. If waterways are considered significantly impaired, however, regulatory agencies may require year-round disinfection. Regulatory limits and disinfection system design are usually based on the one of the following indicator species: total coliform, fecal coliform, *E. coli* (Escherichia coli), or *Enterococci*.

Procedure: The disinfection procedure should not impair the natural aquatic habitat and biota of the receiving water. If chlorination is used, it may be necessary to dechlorinate wastewater before discharge if the residual chlorine would impair the receiving water. In individual cases, an approving authority will determine the acceptability of any disinfection system.

Method: The disinfection method should be selected after consideration of treated wastewater flow and quality, application, demand rates, and effects; mixing zone dynamics; pH of the wastewater; cost of equipment; availability; operations and maintenance costs as well as labor requirements for operability, reliability, and safety considerations.

Chlorination and UV radiation are the most commonly used methods for wastewater disinfection. Other disinfection methods, including ozone, peracetic acid, bromine and electron-beam irradiation, may be accepted by an approving authority in individual cases.

8.2 General Requirements

8.2.1 Federal and State Regulations

The basic criteria for establishing the need for wastewater disinfection is that the treated effluent affects the receiving water body and its subsequent downstream uses. A majority of regulatory agencies, commissions, boards, and other interested parties support these criteria. The existence of multiple regulations, policies, or standards as adopted by state water pollution control agencies, coupled with continual updates and revisions of water quality effluent standards, makes the documentation of specific regulations beyond the scope of this report.

8.2.2 Disclaimer

The information presented in this chapter is not intended to provide comprehensive design and safety guidance, and should not be interpreted as such by a designer or reviewing authority. For more in-depth design and safety guidance and other information, refer to resources such as Pamphlet 001, *Chlorine Basics,* published by the Chlorine Institute.

8.3 Disinfection Methods

8.3.1 Chlorination (Liquid/Gaseous Chlorine)

8.3.1.1 Capacity of System

Liquid/gaseous chlorination systems should be capable of providing a minimum chlorine dose at the point of disinfection at design average flow as indicated below:

Type of Upstream Treatment	Chlorine Dose
Trickling filter plant effluent	30 mg/L
Activated sludge and rotating biological contactor plant effluent	25 mg/L
Tertiary filtration effluent	20 mg/L
Nitrified effluent	20 mg/L

Systems should be designed to provide an adequate chlorine dose to meet disinfection limits under peak flow conditions, and should have the flexibility to provide proper dosage control during low flow periods. Systems should be able to increase or decrease dosage rapidly and effectively.

8.3.1.2 Equipment

Quantities of chlorine can be supplied in either 100- or 150-pound (45- or 68-kg) containers, 1-ton cylinders, or chlorine tank cars. The use of 1-ton containers should be considered where the average daily chlorine consumption is more than 150 pounds (68 kg). Cost, the potential for residential exposure to chlorine, and local building and fire codes should be considered when making a determination on the most appropriate method of chlorine supply.

Tank Cars: At large chlorination installations, consider the use of tank cars accompanied by vaporizers. Liquid chlorine lines from tank cars to vaporizers should be buried and installed in a conduit, and should not enter spaces below grade. Systems should have the shortest possible pipelines for transportation of liquid chlorine.

Chlorine Cylinders: When chlorine cylinders are used, two scales, preferably of the indication and recording type, are recommended for weighing the cylinders in use. Each scale should be sized to accommodate the maximum chlorine feeding rate. Adequate means for supporting cylinders on the scales should be provided. Scales should be of corrosion-resistant material.

Manifolds: Separate manifolds should be provided for the bank of cylinders in each scale. The manifolds should have valves that allow one bank of cylinders to be replaced while chlorine is being withdrawn from the other bank of cylinders.

Gas Chlorinators: Gas chlorinators should be of the solution-feed type. Where manifolds on several cylinders or ton containers will be required to supply sufficient chlorine gas, consider installing evaporators to produce the required quantity of gas.

8.3.1.3 Housing and Storage

Compliance with federal and state regulations on the storage and housing of chlorine and chlorination equipment is imperative. Safety requirements include the following:

- Gaseous chlorine and chlorination equipment rooms should be isolated from other sections of a building by partitions that are sealed against gas leaks.
- The chlorine storage room and chlorination equipment room should be separated.
- All means of egress from rooms that contain gas chlorination equipment and that are used for chlorine gas storage should open directly to the outside of buildings.
- All doors should be equipped with panic hardware and a viewing window.
- Multiple exits should be provided for each room in which chlorine gas is stored or used.
- Chlorination rooms should be heated to 70°F (21°C), with active ventilation provided so temperature is maintained at a level no higher than normal summer temperature.
- Rooms containing chlorine cylinders from which chlorine is being withdrawn should be heated to above 60°F (16°C), but never above the temperature of the equipment room.
- When chlorine containers are stored outdoors, the storage area should be provided with a canopy.
- Cylinders and containers stored outdoors must reach room temperature before being used.
- Floor drains from chlorine rooms should not be connected to floor drains from other rooms.
- Chlorine rooms should be at ground level, with all equipment easily accessible.
- Storage areas should be separated from feed areas. Chlorination equipment should be situated as close to the application point as reasonably possible.
- Non-sparking rubberized rollers should be installed at points where cylinders rest, allowing large cylinders to be easily moved when necessary to correctly align discharge valves.

8.3.1.4 Ventilation

With gas chlorination, both the chlorinator and chlorine storage room must have a mechanical ventilation system that meets the following requirements:

- The system should provide a minimum of one complete air change per minute or 1 cubic foot of air per minute per square foot of floor area.
- The system should include an inlet fan located near the ceiling for ventilation.
- Air exhaust vents must be located 12 inches off the floor.
- The ventilation fan switch must be located outside of the chlorine room and in an area that is not near any room ventilation exhausts.

- The chlorine gas detector should activate in the event of a chlorine leak.

Normally, ventilation from chlorine storage rooms is discharged to the atmosphere. When a chlorine leak occurs, ventilated air containing chlorine should be routed to a treatment system. Treatment systems should be used to process all exhaust ventilation. Treatment systems should reduce the maximum allowable discharge concentration of chlorine to one-half the IDLH (Immediately Dangerous to Life or Health) level. The IDLH for chlorine is 10 ppm. Facilities with four 150-pound cylinders or less do not require a contaminant (scrubbing) system as long as the storage room is fireproof.

8.3.1.5 Ancillary Systems

Water Supply: An ample supply of clean or solids-free water should be available for operating a chlorinator. Where a booster pump is required, duplicate equipment should be provided and standby power available. Potable water supplies should be protected with a backflow preventer. Air breaks or tanks are not suggested for these applications due to water's reaction with chlorine gas or liquid.

Other Equipment: All electrical fixtures and drainage conduits should be sealed to prevent the spread of chlorine gas in the event of a leak. Sealing material should be of a type that does not react with chlorine gas or liquid.

8.3.1.6 Piping and Material

A piping system should be as simple as possible—with a minimum number of joints—and specifically selected and manufactured for chlorine service. Piping should be well supported and protected against temperature extremes. Because minute traces of water added to chlorine can result in a corrosive attack, pressure piping materials such as silver, gold, platinum, or Hasteloy "C" should be used. Low-pressure lines made of hard rubber, polyethylene, polyvinyl chloride (PVC), or Uscolite materials, or lined with saran or rubber are satisfactory for wet chlorine or aqueous solutions of chlorine.

8.3.1.7 Reliability

The following equipment must be connected to an emergency power system:

- All chlorine feed, mixing, and control equipment
- Chlorine injector water pumps
- Chlorinator and chlorine cylinder room ventilation and treatment system
- Chlorine leak alarm
- Chlorine leak gas cleaning system

For gas chlorination systems, a minimum of two injector water pumps must be provided, each capable of providing the quantity and pressure of water necessary for the satisfactory operation of the chlorine injector. A potable water supply with an appropriate backflow prevention system can be used as a backup.

Duplicate feed pumps must be provided in systems that use liquid chlorine solutions for disinfection.

8.3.1.8 Residual Monitoring

Equipment should be provided for measuring chlorine residuals using accepted test procedures.

For treatment facilities with capacities above 1 million gallons per day, automatic effluent chlorine residual monitoring is required, with high- and low-chlorine residual alarms that sound at a place monitored 24 hours a day or that are tied into a discrete alarm in an auto-teledialer or manned SCADA system. When selecting residual monitoring equipment, it is vital to carefully consider instrument reliability and ongoing maintenance requirements.

Residual monitoring should be located so that, in the event of a cylinder or piping leak, the monitoring equipment is not compromised, thus enabling the system to rapidly return to operation.

8.3.1.9 Safety

All gas chlorination systems must be provided with the following safety-related equipment:

- At least two sets of respiratory air-pack protection equipment with a minimum capacity of 30 minutes (equipment must meet requirements of the National Institute for Occupational Safety and Health)
- An appropriate cylinder repair kit as approved by the Chlorine Institute
- Chlorine gas-leak detection system in both the chlorinator and chlorine storage rooms, with a local alarm and an alarm that signals at a place maintained 24 hours a day

Every facility using gaseous chlorine requires an emergency response plan (ERP). Other planning documents, such as OSHA Process Safety Management and EPA Risk Management plans, are generally applicable as well. Designers should determine if local authorities require additional plans specific to extreme weather or other such impacts a facility may experience in its location. Such procedures must be developed by a registered professional engineer, and should be provided as part of process design.

8.3.1.10 Contact Period

The minimum contact time required is impacted by the initial dose of chlorine, residual chlorine concentration at the discharge of the contact chamber, quality of effluent being disinfected, and discharge permit requirements. In the absence of site-specific studies to demonstrate a minimum contact period needed to achieve adequate disinfection, the minimum contact period for chlorine disinfection at peak flow rate should be 30 minutes unless specific testing can demonstrate the ability to achieve the discharge limit at lower contact times. The contact period provided by outfalls and pipelines may be credited only if the discharge point can be monitored or if a facility's discharge permit allows holding the chlorinated sample for a suitable time period to duplicate the detention time in the outfall.

When evaluating whether an expansion of contact tank volume is required, it is permissible to "grandfather" an existing chlorine contact chamber, providing less than 30 minutes of contact time at peak flow, if historical plant data justifies sufficient, reliable disinfection at lower contact times. If increased flow is anticipated, field testing should be performed to demonstrate how the existing chlorine contact tank will permit reliable disinfection at the expected peak flow.

8.3.1.11 Chlorine Contact Chamber

A minimum of two tanks, which operate independently, must be provided to facilitate cleaning while minimizing the reduction in contact time.

A method for removing tank solids from the bottom of the tanks should be provided. In most cases, a slightly sloped floor with sump in each tank is adequate. The sump should be able to pump out leaves that may accumulate on the bottom of tanks in the fall. (Leaves are fibrous and may cause problems in some pumps.) Some tank baffling designs require gated submerged ports between bays to allow for full drainage. The discharge should be such that flow is returned by installed piping to an acceptable process point in the treatment facility or have couplings that permit quick connections to piping and/or hoses.

To provide plug-flow characteristics and minimize hydraulic short-circuiting, the tank should have the following:

- An inlet baffle to dissipate inlet velocities and introduce flow across the entire cross section
- A minimum length-to-width ratio of 40-to-1
- A width-to-depth ratio of approximately 1-to-1
- A minimum number of turns, each provided with an “L” flow direction baffle
- A flow distribution chamber to equally distribute flow among all contact chambers
- A scum retention baffle and scum removal system at the tank effluent for each contact chamber

8.3.1.12 Point of Application

Chlorine should be applied to wastewater in an area of adequate mixing. Mechanical mixing is most commonly used, but hydraulic mixing can be effective.

Mixing systems should be designed so that:

- The chlorine diffuser is located at a maximum depth below the water surface.
- The mixing takes place in a dedicated tank isolated from the chlorine contact chamber.
- Diffusers and/mixing devices should be designed so they can easily be removed without requiring tank entry.

8.3.1.13 Control Equipment

All chlorination systems should have control flow pacing with chlorine residual control (compound loop control). Flow control should be from effluent flow meters or a flow value that equates to effluent discharge. The placement of sample pickup or probe placement should ensure proper “lag” time for residual analyzer control.

A system must provide for automatic gas cylinder or liquid chlorine tank changeovers. Individual backup power may be appropriate for some locations but should be designed to minimize the location of control components at the tanks themselves.

For treatment facilities with capacities above 1 million gallons per day, automatic residual monitoring of effluent chlorine is required. Monitoring equipment should have high- and low-chlorine residual alarms that sound at a location monitored 24 hours a day. An alarm should be provided to enable effective control if SCADA is not part of the facility system.

8.3.2 Chlorination (Sodium Hypochlorite)

Sodium hypochlorite can be purchased and delivered to a wastewater treatment plant for wastewater disinfection. Sodium hypochlorite may also be generated on-site at a POTW—that is, if the regulatory agencies involved accept the practice. Designers should consider that sodium hypochlorite generation will require additional considerations to ensure operability and reliability.

8.3.2.1 Capacity of System

See Section 8.3.1.1.

8.3.2.2 Equipment

Hypochlorinators: Except for large installations, sodium hypochlorite feeders should be of the positive displacement type. Chemical metering pumps or eductor piping systems may be used to withdraw disinfectant from storage tanks. Chemical metering pumps and pump accessories used with sodium hypochlorite should be designed to control off-gassing of the sodium hypochlorite. On-site generators should use electrolytic cells operating in direct electric current.

8.3.2.3 Housing and Storage

Storage vessels may be of high-density polyethylene or hypochlorite-resistant fiberglass-resin, or concrete or steel tanks with protective linings. Storage tanks should be located above ground and protected against light and heat, both of which will hasten deterioration of a sodium hypochlorite solution. (Sodium hypochlorite will deteriorate in strength over time.) Solution storage capacity should be based on quantity used and reliability of delivery. Storage of diluted sodium hypochlorite should be considered to reduce the speed of deterioration.

All storage tanks that contain chemical solutions of chlorine and are in a liquid state at atmospheric pressure must be enclosed by a secondary containment dike with a containment volume of 125 percent of the storage tank's volume.

Internal and/or external piping systems should allow for the replacement of short sections of pipe if the pipe systems are aging or if they are outdoors where sunlight may hasten pipe deterioration. Shutoffs should be strategically located as well as the ability to switch between multiple storage vessels.

8.3.2.4 Ventilation

Ventilation must follow normal industrial building requirements and maintain a room temperature no higher than 80°F (27°C).

Chemical storage tanks require dedicated venting to atmosphere.

8.3.2.5 Ancillary Systems

A supply of water is required for dilution. If treated effluent from the plant is used, filters that can be easily checked and removed for cleaning should be considered. Due to the possibility of spills, floor drains in the area should be made of hypochlorite-resistant material.

An adequate supply of electricity is required for on-site sodium hypochlorite generation.

8.3.2.6 Piping and Materials

PVC, saran-lined steel, or polyethylene piping may be used with sodium hypochlorite. Valves may be made of PVC or other hypochlorite-resistant materials. PVC or polyethylene piping must be supported with fixtures that are hypochlorite resistant and can be easily accessed. Sodium hypochlorite outgases as it decays, hence piping systems must not contain sealed areas that allow dead space with no way to vent the outgassing. Valves need to be of the special ported vent design to prevent piping ruptures and spills.

8.3.2.7 Reliability

The following equipment must be connected to an emergency power system:

- All sodium hypochlorite feed, mixing, and control equipment
- Carrier water pumps (if used)

A minimum of two chemical feed pumps must be provided in systems that use sodium hypochlorite for disinfection. Sizing should be considered carefully; pumps may need to be of different pumping capabilities to facilitate disinfection requirements.

8.3.2.8 Residual Monitoring

See Section 8.3.1.8.

8.3.2.9 Safety

Sodium hypochlorite is far less hazardous than chlorine or calcium hypochlorite. Care should be taken, however, because sodium hypochlorite is a skin irritant and is hazardous to eyes. Eyewash stations and overhead showers that utilize potable, tempered water should be provided in storage and metering areas. In some situations, it may be possible to locate eyewash stations and showers in an area adjacent to storage and metering areas, which provides the advantage of separating emergency care from the environment that created the emergency. However, this must be done in accordance with regulatory requirements, and cannot result in any lessening of a facility's ability to provide immediate emergency care.

Hydrogen gas produced from on-site generation of sodium hypochlorite must be vented to the atmosphere. Sodium hypochlorite generation involves many more safety design considerations than can possibly be described in this report; if such facilities are being considered, it is important to consult other available guidance on this topic.

8.3.2.10 Contact Period

See Section 8.3.1.10.

8.3.2.11 Chlorine Contact Chamber

See Section 8.3.1.11.

8.3.2.12 Point of Application

See Section 8.3.1.12.

8.3.2.13 Control Equipment

See Section 8.3.1.13.

8.3.3 Chlorination (Calcium Hypochlorite)

Calcium hypochlorite is available commercially as dry powder, granules, tablets, pellets, or a liquid. Use of calcium hypochlorite for disinfection may be applicable for small systems.

8.3.3.1 Capacity of System

See Section 8.3.1.1.

8.3.3.2 Equipment

Generally, calcium hypochlorite should be fed as a liquid, using positive-displacement feeders. Aqueous hypochlorite solutions are extremely corrosive, and should be prepared and stored in nonreactive containers. Provisions should be made for the cleaning of sludge from any liquid storage container.

8.3.3.3 Housing and Storage

These requirements are similar to those for sodium hypochlorite, described in Section 8.3.2.3. In addition, special consideration should be given to the storage of dry calcium hypochlorite, avoiding damp or warm conditions.

The design of facilities should provide for the possibility of reactions of calcium hypochlorite with certain organic compounds, which may result in fire or explosion, and the possibility of spontaneous combustion of dry calcium hypochlorite.

8.3.3.4 Ventilation

See Section 8.3.2.4.

8.3.3.5 Ancillary Systems

A supply of water is required for dilution.

8.3.3.6 Piping and Materials

See Section 8.3.2.6.

8.3.3.7 Reliability

Sludge deposits in liquid storage tanks and feed equipment reduce the reliability of calcium hypochlorite as a disinfectant.

8.3.3.8 Residual Monitoring

See Section 8.3.1.8.

8.3.3.9 Safety

See Section 8.3.2.9.

8.3.3.10 Contact Period

See Section 8.3.1.10.

8.3.3.11 Chlorine Contact Chamber

See Section 8.3.1.11.

8.3.3.12 Point of Application

See Section 8.3.1.12.

8.3.3.13 Control Equipment

See Section 8.3.1.13.

8.3.4 Ultraviolet (UV) Light Radiation

8.3.4.1 Capacity of System

UV systems should be capable of providing the minimum UV dose at the point of disinfection at design average and peak flows necessary to comply with a facility's effluent disinfection limit. The necessary design dose is a function of the process influent bacteria count, the target organisms and permit limit, process influent TSS concentration, particle size distribution, hardness, and transmittance (UVT). The site-specific variability of these parameters complicates the establishment of guideline design dosages that can be generally applied. The following table indicates typical ranges:

UVT (%)	TSS (mg/L)	Effluent Requirement (per 100 mL)	UV Dose (mJ/cm^2)
55	30	200 (fecal coliform)	35,000 – 40,000
55	10	200 (fecal coliform)	25,000 – 30,000
65	10	100 (total coliform)	40,000 – 50,000
65	10	2.2 (total coliform)	100,000 – 140,000

Project-specific design dosage should be established by use of a collimated beam test. Sample(s) used for the test should be representative of the effluent to be disinfected by the UV system. The system must maintain the minimum design dose as established by the collimated beam test under the following conditions:

- Inclusion of a lamp aging factor of 0.80
- Inclusion of a lamp fouling factor of 0.88 (based on clean sleeves)
- Peak hour flow

A UV system's ability to provide the design dosage must be established by an independent bioassay completed per the guidelines in U.S. EPA's *Design Manual for Municipal Wastewater Disinfection* (October, 1986).

8.3.4.2 Equipment

8.3.4.2.1 UV Lamps

When selecting UV lamps, consider the individual lamp wattage, efficiency in terms of emissions at 253.7 nanometer wavelength, and the total number of lamps required to provide a design dose. Careful attention should be paid during the design process to design a system that meets performance requirements in as energy-efficient a manner as possible through the full range of flows expected.

Provisions should be made for easy removal and inspection of UV lamps without draining the UV reactor. Electrical wiring should be contained in a cabinet that protects the wiring from dirt and accidental spray water.

8.3.4.2.2 UV Modules

UV lamps must be placed within modules that provide a uniform configuration, with all lamps in a module installed parallel to one another. The lamps should be evenly spaced in horizontal or vertical rows, with equal centerline spacing in both directions.

Each UV module should be equipped with safety interlocks to shut off electrical power to the lamps automatically when the access panel to the module is opened.

8.3.4.2.3 Lamp Cleaning Systems

UV modules should be equipped with a convenient method for cleaning the quartz sleeves. The cleaning system must be capable of removing a scale or grease buildup without disassembling the system. Automatic cleaning systems are strongly recommended. If an automatic cleaning system consists only of a mechanical cleaning component (i.e., wipers), a chemical cleaning tank (dip tank) should also be provided.

8.3.4.3 Housing and Storage

The UV modules installed within UV reactors and the vital electrical equipment that supports the UV modules (e.g., the ballast enclosures) should be designed for outdoor exposure; however, the UV module and electrical equipment area should be covered with a weather-protective canopy at a minimum, and full enclosure within a building should be considered.

8.3.4.4 Ancillary Systems

Open-channel UV systems require a means to maintain water level in the UV reactor within a tight tolerance over the entire range of flow. Outlet fixed weirs, motorized automatic level controllers, or hydraulic controls should be sized to maintain a nearly constant water level at the lamps, allowing maximum fluctuation from the control level within the specifications of the supplied UV system. Each UV reactor should also have a water level sensor and a safety interlock that automatically shuts off the UV lamps if a low-water level is measured.

A means of protecting the UV reactors and modules from flooding is required. This can be a bypass channel (if permissible by a facility's permit and the approving authority) or a flood-protective pumping system. It is also necessary to have a means of lifting UV modules out of the UV channels.

8.3.4.5 Materials

All metal components in contact with plant effluent must be Type 316L stainless steel. All metal components not in contact with plant effluent need to be Type 304L stainless steel. All materials exposed to UV light must be a suitable UV-resistant material.

8.3.4.6 Reliability

A UV system must be capable of delivering the design dose and disinfecting effluent at peak instantaneous flows with one bank of modules out of service. For systems that require continuous, uninterrupted disinfection, more than one UV reactor (channel) is required.

A UV system also requires a backup electrical supply capable of powering the entire system. The electrical supply must be designed to prevent common-mode failure of an electrical component from disabling the entire disinfection system.

8.3.4.7 Dosage Monitoring

Each UV module should be equipped with a UV intensity meter responding only to light between 2,525 and 2,550 angstroms. The sensing device for this meter should be fixed at the area of minimum expected intensity. The sensor should be installed within a quartz sleeve.

8.3.4.8 Safety

All electronic and electrical components in the disinfection system must be designed, constructed, and installed in accordance with the National Electrical Code. Proper lockout/tagout provisions should be provided.

UV module placement within reactors requires consideration of the dangers of UV overexposure on skin and eyes; measures should be implemented to prevent exposure. UV-protective safety glasses should be provided, and warning signs should be posted.

8.3.4.9 Contact Period

Sufficient contact time is required in a UV reactor to provide the established design dose at the delivered UV intensity under peak flow conditions.

8.3.4.10 UV Reactors

UV module(s) must be installed in the UV reactor(s) within open channels, and arranged in banks comprised of one or more modules. Channel width and depth must be specifically designed to suit the UV modules supplied. Channel length is determined by several factors. The length must suit the UV banks; there must be adequate length upstream of the first bank to establish an even flow regime within the reactor; adequate space is required between banks of modules for mixing; and downstream of the last module for access to the level control device.

In systems with more than one UV reactor, special attention must be directed to the design of an even flow split between the multiple reactors and the reactors' influent hydraulics. Uneven flow split between UV reactors results in overloading of individual units, and can compromise system performance.

The downstream end of a channel should be equipped with a sump to collect and facilitate removal of solids. This sump should be equipped with a drain valve to flush accumulated solids from the channel.

8.3.4.11 Control Equipment

To monitor the proper functioning of a UV disinfection process, the following should be incorporated into the system:

- Each UV module should activate a local and remote alarm signal when the UV intensity drops to 80 percent of original output.
- Each UV module should be equipped with a lamp monitoring system that tracks and displays the operating condition of each individual lamp within the module. A visual warning light should signal immediately after the failure of any single lamp. The display should immediately identify the failed lamp.
- An elapsed time indicator should be provided for each bank of UV lamps to maintain proper lamp replacement schedules.
- A spare PLC processor with a current program should be available.
- A variable-output UV system that can minimize energy consumption while also maintaining adequate disinfection should be considered. Such a system can vary output in response to an effluent flow signal or other signal generated by a plant SCADA system.

8.3.5 Other Disinfection Chemicals and Systems

The use of other disinfecting chemical agents and systems will be considered by approving agencies on a case-by-case basis. Cost, chemical handling hazards, toxicity to receiving waters, availability of chemical agents, and suitability of effluent for the selected chemical agent must be considered. Supporting information must be submitted to the reviewing agency for preliminary approval.

8.3.5.1 Ozonation

As an alternative to chlorination, disinfection using ozone may be considered. Ozone is a very strong oxidant, and is very effective in disinfection of wastewater treatment plant effluent. And by using ozonation, a facility can reduce the production of disinfection byproducts. Historically, however, ozonation has been more expensive than chlorination in terms of both capital and operating costs, so it has not been employed in widespread fashion in the United States. However, ozone frequently is used in conjunction with other units, such as UV or hydrogen peroxide, in an advanced oxidation process for both disinfection and removal of trace contaminants.

8.3.5.2 Peracetic Acid

Disinfection using peracetic acid has not been employed in full-scale facilities in the United States as yet, but research to date indicates that this strong oxidant may have significant advantages over chlorination. These advantages include a shorter contact time required for disinfection and an absence of disinfection byproducts.

8.4 Dechlorination

8.4.1 General Requirements

8.4.1.1 Capacity of System

Dechlorination systems should be capable of providing the following doses at average daily flow:

Dechlorination Chemical Used	Dose
Sulfur dioxide	6 ppm
Sodium metabisulfite	9 ppm
Sodium bisulfite	9 ppm
Sodium sulfite	12 ppm

The use of other dechlorination chemical agents and systems is considered by approving agencies on a case-by-case basis. Cost, chemical handling hazards, toxicity to receiving waters, availability of chemical agents, and suitability of effluent for the selected chemical agent must be considered. Supporting information must be submitted to the reviewing agency for preliminary approval of these methods.

Effluent should be re-aerated to meet effluent dissolved oxygen limits since some chemicals used for dechlorination may remove oxygen.

8.4.1.2 Equipment

See Sections 8.3.1.2 and 8.3.2.2.

Sulfur dioxide is more prone to reliquefaction than is chlorine. Therefore, the sulfur dioxide header should be heated.

Liquid storage tanks should be installed in a suitable containment area having a capacity of 125 percent of the storage volume. On-site storage should be provided for a minimum of 30 days. Storage vessels should be in heated enclosures if not located in buildings where heat can be maintained.

8.4.1.3 Housing and Storage

See Sections 8.3.1.3 and 8.3.3.3.

8.4.1.4 Ventilation

With gas dechlorination systems, both the sulfonator and sulfur dioxide gas storage rooms must have a mechanical ventilation system that meets the following requirements:

- The system should provide a minimum of one complete air change per minute or 1 cubic foot of air per minute per square foot of floor area.
- The system should include an inlet fan located near the ceiling for ventilation.
- Air exhaust vents must be located 12 inches off the floor.
- The ventilation fan switch must be located outside of the chlorine room and in an area that is not near any room ventilation exhausts.

Sodium bisulfite starts to freeze at 34°F (1°C) and, therefore, must be kept in a heated room.

To remove residual sulfur dioxide gas, sodium bisulfite storage tanks may need to be vented through an alkaline fume recovery system.

8.4.1.5 Ancillary Systems

See Sections 8.3.1.5 and 8.3.2.5.

8.4.1.6 Piping and Material

See Sections 8.3.1.6 and 8.3.2.6.

8.4.1.7 Reliability

The following equipment must be connected to an emergency power system:

- All dechlorination chemical feed equipment
- Sulfur dioxide injector water pumps
- Sulfonator and sulfur dioxide room ventilation system
- Sulfur dioxide leak alarm

For gas dechlorination systems, a minimum of two injector water pumps must be included, each capable of providing the quantity and pressure of water necessary for satisfactory operation of the sulfonator injector. A city water supply with an appropriate backflow prevention system can be used as a backup system.

8.4.1.8 Residual Monitoring

See Section 8.3.1.8.

8.4.1.9 Safety

All gas dechlorination systems must have a sulfur dioxide gas detection system in both the sulfonator and sulfur dioxide storage rooms.

Dechlorinating chemicals should not be stored in the same room as gaseous chlorine.

Chlorinators and sulfonators must be in separate rooms, with separate vents and separate drains.

8.4.1.10 Contact Period

A minimum of 2 minutes detention time at average flow should be provided.

8.4.1.11 Contact Chamber

The contact chamber should reduce short-circuiting of flow to a minimum.

8.4.1.12 Point of Application

Dechlorination chemicals should be applied to disinfected wastewater in an area that provides good mixing. Mechanical or hydraulic mixing is required.

Mixing systems must be designed so that:

- The dechlorination chemical diffuser is located below the water surface as far as possible.
- The mixing takes place in a dedicated tank isolated to some degree from the chlorine contact chamber.
- A minimum of 2 minutes detention time at average flow is provided in the mixing tank.

8.4.1.13 Control Equipment

All dechlorination systems should be controlled by flow pacing and chlorine or sulfur dioxide residual. Alternate control systems based on oxidation-reduction potential (ORP) may be considered. Effluent flow meters should control flow. Samples or probes in the effluent of the chlorine contact chamber and/or dechlorination chamber should control residuals.

A system must provide for automatic gas cylinder or liquid chlorine tank changeovers.

References – Chapter 8

U.S. EPA, *Design Manual for Municipal Wastewater Disinfection,* October 1986, EPA/625/1-86/021

CHAPTER 9

LAND TREATMENT, TREATED EFFLUENT DISPOSAL, AND TREATED EFFLUENT REUSE

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9.1 General

These guidelines pertain to land treatment, disposal, and reuse of domestic wastewater. As with all chapters in this document, this chapter is intended for community officials, planners, engineers, and regulators. The reader is encouraged to use the guidelines as an evaluation tool, not a sole source reference, with the understanding that specific federal, state, and local criteria will govern final design. Comprehensive design will require the use of multiple resources, many of which are listed at the end of this chapter. Because of the many complex hydrogeologic factors that must be evaluated in the design of land treatment and effluent disposal systems, a case-by-case review of each proposed system is recommended.

Land treatment systems use plants and soil to remove contaminants from wastewater. Land treatment can achieve removal levels comparable to advanced wastewater treatment technologies, with additional benefits. Crop production is just one example of how the recovery, reclamation, and beneficial reuse of wastewater and its nutrient resources allows land treatment systems to accomplish more than conventional treatment and discharge alternatives.

Because land treatment processes contribute to reclamation and recycling, they should be considered feasible wastewater management alternatives. While acceptance is not universal, the use of land treatment systems offers tangible benefits, including the potential for significant cost savings—no minor consideration for water pollution control programs.

When land application for effluent disposal includes credits for treatment in the soil, the system is considered land treatment. When land application is used only for effluent disposal, treatment must be provided by processes prior to land application. The level of treatment required to protect groundwater quality is determined through the regulatory framework. Disinfection may be required, particularly when effluent is applied to land where crops will be grown or where direct human contact may occur. The need for disinfection to minimize public health concerns should be evaluated on a case-by-case basis.

9.1.1 Groundwater Standards and Discharge Requirements

Consideration may be given to land treatment and effluent disposal systems as an alternative to surface water discharge. Discharge to groundwater can be achieved within the current federal and state regulatory framework, provided ambient groundwater standards are maintained within the receiving aquifer at the site boundary.

9.1.2 Discharges in Protected Drinking Water Supply Areas

Consult each state's regulatory agency for specific restrictions. See Section 9.6 for a partial list of NEIWPCC member states' regulations and guidance related to effluent reuse and disposal.

9.2 Planning Considerations

9.2.1 General

In the New England region, land treatment and land disposal are viable alternatives to new or expanded surface discharges. In addition to a cost-benefit analysis, a risk-benefit analysis comparing conventional treatment with land treatment should be performed. Land treatment may also be considered as a supplementary process where expansion or upgrade of an existing treatment system is required. Regardless of the level of use being considered, the environmental benefits of land treatment should always be weighed against legal restrictions, public health impacts, regulatory compliance, potential environmental impacts, and political ramifications.

9.2.2 Legal Aspects

In the United States, 18 states have regulations pertaining to land treatment, effluent disposal, and wastewater effluent reuse. Another 18 states have established some form of guidelines and minimum design standards. The remaining 14 states have no regulations pertaining to land treatment, effluent disposal, and wastewater effluent reuse. Currently, no federal regulations govern effluent reuse. See Section 9.6 for the names of NEIWPCC member state agencies and their statutory authority to regulate land application.

9.2.3 Identification of Potential Sites

During the planning phase, potential land treatment and effluent disposal sites should be evaluated with regard to physical characteristics, environmental impact, and future land use considerations.

9.2.3.1 Physical Site Characteristics

Site geology, soils, and hydrogeology should be researched to identify prevailing soil types, soil permeabilities, and root zone storage capacity. U.S. Geological Survey (USGS) topographic maps and Natural Resource Conservation Service (NRCS) soils maps should be reviewed for basic information before initiating site work. A preliminary review of site topography can be obtained from a USGS topographic map, while subsurface geology should be investigated using NRCS soils maps. The need for and location of any on-site storage impoundments should be identified. Consider existing topography that would lend itself to economical development of site access roads for long-term operation and management of the site. Potential locations of warning signs, natural barriers, access gates, and any buildings should also be evaluated at this stage.

9.2.3.2 Potential Environmental Impacts

Assess the potential environmental impacts of a land treatment or effluent disposal system using a risk-benefit analysis. Primary risks include:

- Contamination of groundwater or surface water.
- Public exposure to disease-causing organisms.
- Degradation of plant and animal life.
- Degradation of local air quality.

Potential benefits include:

- Groundwater aquifer recharge.
- Vegetative uptake of nutrients.
- Entrapment of trace metals in the soil.
- Natural elimination of pathogens within the soil root zone.

With land treatment or effluent disposal, the benefits listed above can be achieved with less capital outlay than would be required to achieve the same benefits through other existing advanced treatment technologies.

Proper planning can reduce potential risks by ensuring that a land treatment or effluent disposal program provides reliable pretreatment, limits access to the treatment/effluent disposal site, uses prevailing wind speed and direction to control air transport of odors and aerosols, and uses natural means to control vectors. (A vector is any insect or arthropod, rodent, or other animal of public health significance capable of harboring or transmitting the causative agents of human disease.)

9.2.3.3 Future Land Use

The size and location of the proposed site should be reviewed for its compatibility with the community's long-term land use plans. Within the site boundaries, ample room must be provided for perimeter buffer zones, short-term and seasonal storage, site access roads, and future system expansion. Ready access to monitoring stations must be provided, as well as access for operations and maintenance.

The total impact on the area may extend well beyond the physical boundaries of the site. A community must consider the social impact on its residents, the effect on adjacent property values, the yearly cost of maintaining the system, and the potential to affect future property development.

9.2.4 Potential Health Impacts

A thorough chemical analysis should be performed to identify the prevalent constituents in the waste stream. The presence of toxic or organic compounds and excessive nutrients may be considered in conjunction with area businesses and industries; such problems can be addressed through a state or federal pollution prevention program and/or a local industrial pretreatment program. Reductions of detrimental constituents in wastewater before it reaches the head end of a facility will greatly reduce the potential for a negative impact on groundwater.

On a local level, minimum guidelines must be adopted regarding public access to a land treatment site. High treatment reliability must be maintained to ensure regulatory compliance as well as public acceptance. A contingency plan should be developed in the event of component failure. An emergency response plan should be developed in the event of treatment system failure resulting in direct public exposure to the applied wastewater effluent.

Consider the proximity of dwellings, public buildings, businesses, and industries to the proposed application site. Disinfection may be required before land application to reduce the likelihood of public exposure to disease-causing organisms. (In Massachusetts, disinfection is required if using an open sand bed or if discharging into a water supply recharge area for a drinking water supply well.) Access to the site should be limited using obvious warning signs, vegetative barriers, and natural (i.e., topographic) physical barriers. Potential vectors should be identified and controlled to the extent possible. Prevailing wind direction during the application season(s) should be identified as wind has the capacity to transfer odors and possibly aerosols off-site.

9.2.5 Public Education Efforts

A series of public information meetings and media presentations are recommended. The information presented should include clear and simple cost-benefit and risk-benefit analyses of treatment and disposal options, and an impact summary of land treatment, effluent disposal, and reuse options. Community officials, planners, engineers, and regulators should be involved in the public education effort, which should include the abutters of the land application site as well as all community residents whose homes are connected to the wastewater facility's collection system. The public education program should keep residents informed of pertinent meetings, deadlines, funding status, construction schedules, and long-term operation and management plans for the system.

9.2.6 Expected Treatment Performance

Land treatment systems perform best when gross solids are removed prior to application. The design should allow for a minimum of primary treatment in accordance with applicable state regulations. Land application can achieve BOD_5, TSS, pathogen, nitrogen, and phosphorus reductions, often to concentrations of less than 10 parts per million (10 mg/L).

Consider future development within the community as it may affect wastewater composition. Projected changes in hydraulic, biological, and chemical loadings to the wastewater treatment facility should be conservatively estimated.

A strong commitment to the employment of certified wastewater treatment facility operators is essential. Budgeting for annual technical training, certification, and professional development of facility staff is strongly recommended. A properly trained staff is better able to deal with mechanical failures, changes in the waste stream, and potentially more stringent regulatory requirements in the future for testing and reporting.

9.3 Hydrogeological Site Analysis

9.3.1 Levels of Hydrogeological Studies

Different levels of hydrogeological review of a site are needed at different points in project planning and site development. In addition, the various land treatment and disposal options need different levels of studies. During the conceptual design phase, a review of published data (i.e., a desktop review) can be useful for identifying potential sites. As the project progresses to a feasibility phase or to a comparison of options that involves the development of cost information, it is essential to have field data to verify that any assumptions are accurate for determining land areas needed for each disposal option under consideration. This data can be confirmed with further field studies during the preliminary design and permitting phases. The following sections explain standard levels of hydrogeological studies for land application systems.

9.3.2 Desktop Review and Field Investigation

9.3.2.1 Desktop Review

A desktop review includes a review of available published data to identify sites for further investigation. Published data for a given site may include the following sources:

- Color orthophotos
- USGS topographic maps
- County soil maps
- Surficial geology mapping

- Water resource investigation reports
- Tax maps
- Maps showing locations of water supply wells or other sensitive areas
- Past reports or field evaluations

Town planning boards may have other applicable maps.

9.3.2.2 Visual Inspection

A visual inspection of a site should be done to assess the accuracy of the information from the desktop review and to identify other issues. The following should be assessed during the site inspection:

- Surface soils
  - Verify soils are as expected; consider collecting surface soil samples for sieve analysis and hydraulic conductivity tests.
- Site accessibility
- Steepness of site topography
- Buffer area to neighbors
- Distances to water supply wells/sensitive areas
- Wetlands/surface water

9.3.2.3 Initial Field Investigation

The initial field investigation should be planned and conducted by a hydrogeologist. The level of testing will vary with the type of treatment/disposal system planned. For a slow rate system (see Section 9.4.2), it may be acceptable to drill fewer borings and test wells or to make them less deep. The purpose of the initial field investigation is to verify the data from published sources and to compare several sites by determining each site's potential before doing costly, more comprehensive investigations. The extent of this investigation will vary by project needs, though it should include the following:

- Initial borings
  - Characterize soil types and depth/thickness of soil layers
  - Collect soil samples for sieve analysis
  - Collect soil samples for hydraulic conductivity analysis
  - Determine depth to bedrock
  - Determine depth to groundwater
- Monitoring wells
  - Establish monitoring of depth to groundwater over time (needed for hydraulic modeling if site is selected as land application site)
- Site map development
  - Property boundaries
  - Elevation contours/topography
  - Location of borings

  - Location of wetlands, surface water, and other features
- Historic data from nearby wells
  - Depth to groundwater over time/seasonal

9.3.2.4 Detailed Field Investigation

Once the best site has been identified based on the results of the initial field investigations, a more detailed field investigation of that site should be conducted. As with the earlier field investigations, the extent of the detailed field investigation will vary with the type of land application system planned. Additional testing should be planned by a hydrogeologist and, depending on the site, a geotechnical engineer.

The detailed field investigation may include the following:

- Comprehensive borings and test wells
  - Sufficient borings and test wells must be installed to adequately identify soil layers and to understand existing groundwater flow.
  - Collecting data over an entire year will provide the best understanding of the site's seasonal variations.
- Infiltrometer tests
- Load cell testing
  - Load cell testing is an in-situ test. A load cell is a box or cylindrical hole built into the ground that can be filled with water; the only exit for the water must be through the bottom. By pumping water continuously to the load cell, it is possible to determine the rate at which water enters the ground. Utilizing nearby monitoring wells, it is possible to see the extent of groundwater mounding and to evaluate the infiltration rate and in-situ hydraulic conductivity.
  - The data from a load cell test can be useful in calibrating a groundwater model.
- Groundwater modeling

9.3.2.5 Soil and Groundwater Considerations

Soil permeability is typically a limiting factor in the design of slow rate systems. Depending on the soil type, slope, depth to groundwater, and depth to an impermeable layer, application rates may vary from 0.5 to 4.0 inches per week (including precipitation). Chemical analysis of the soil is recommended to determine if the accumulation of nitrogen may limit system design. (Massachusetts's discharge to zone 2 regulations require total organic carbon (TOC) removal; see Chapter 7 for TOC removal technologies.) Minimum depth to an impervious layer (prior to application) varies among the seven NEIWPCC member states, and ranges from 1.0 to 5.0 feet.

Complete background sampling and analysis of existing groundwater quality is recommended. Check with the appropriate regulatory agency for specific minimum ambient groundwater quality standards. The minimum vertical separation from the ground surface to the actual water table during the period of effluent application ranges from 1.0 to 5.0 feet and varies among the seven NEIWPCC member states.

Pathogens, particularly viruses, are adsorbed to soil particles in the first 20 inches (0.5 m) under the infiltrative surface. In cool, moist conditions, pathogens can remain viable for more than a year, and may desorb under saturated conditions. Therefore, it is not desirable to allow seasonal high groundwater to inundate the treatment zone even if effluent application is not occurring at the time. High groundwater may not be an issue if the effluent to be applied is pretreated to at least secondary levels and is disinfected immediately prior to application.

9.3.3 Site Hydrogeological Information

To assess and develop sites for land treatment and disposal, hydrogeological information is needed. Different information is needed for different types of land treatment and disposal systems, with more detailed field tests required for faster rate systems than for slow rate systems. There are generally two hydrogeological issues that need to be assessed—the surface infiltration rate (i.e., the ability to get water into the ground) and the subsurface hydraulics—to determine where the water will go once it is in the ground and where and when it may come back to the surface.

9.3.3.1 Site Location

Proposed contours and physical site boundaries (i.e., property lines) should be identified and mapped. Preliminary site screening can be done using a 7.5-minute (preferred) or 15-minute series USGS topographic map. A site map should be prepared showing the following:

- Proposed wetted areas of the wastewater discharge
- Buffer zones
- Surrounding land uses
- Prevailing vegetative cover
- Sensitive areas such as floodplains, wells, water courses, reservoirs, and wetlands
- Storage tanks or lagoons

9.3.3.2 Site Location and Topography

A detailed field investigation should be undertaken to produce a topographic map with 2-foot contours. Assess proposed site topography by preparing a more detailed site plan indicating:

- Proposed slopes with a contour interval of 2 feet.
- Existing and proposed site drainage, including proposed retention/recapture zones.

9.3.3.3 Site Geology

Field verification of mapped structures should be performed to determine depth to bedrock, type(s) of bedrock, and type and location of geologic discontinuities.

9.3.3.4 Soil Characteristics

Soil chemical analysis is recommended to quantify soil pH, conductivity, and nutrient content. Review current NRCS soils maps. Perform an on-site soil survey to:

- Verify depth, type, and texture of soil (from in-field test pit logs).
- Identify distinct soil layers.
- Identify grain size.
- Measure in-situ soil density.
- Determine soil permeability.

- Determine chemical soil properties such as pH, nutrient levels, and cation exchange capacity.
- Determine root zone storage capacity.

9.3.3.5 Groundwater Hydrology

For rapid infiltration (RI) systems, groundwater mounding analysis should be performed to simulate the effects of repeated effluent application. Groundwater conditions to be evaluated include the following:

- Depth to groundwater, as confirmed by field investigations (i.e., piezometers or backhoe test pits) for various seasons, including data from the period of March through May
- Location of perched water tables
- Groundwater contours
- Direction of groundwater movement and flow
- Location of groundwater seeps or discharges

A background analysis of existing site groundwater quality and drinking water wells in the vicinity should be performed. Consult with state regulators to verify requirements for minimum radial distance to potable water supply wells and to determine the constituents for which the groundwater should be analyzed.

A complete description (i.e., depth and type) of all water supply wells in the area of the land treatment/disposal site should be developed.

9.3.3.6 Groundwater Monitoring

For all systems discharging to groundwater, a routine monitoring program must be developed. At a minimum:

- Provide the regulatory agency with a map showing proposed monitoring well locations.
- Install the recommended quantity and type of groundwater monitoring wells, according to the regulatory agency's guidelines.
- Establish a schedule reflecting sampling frequency, analysis requirements, and reporting requirements.
- Provide adequate protection from vandalism and contamination from outside sources.

9.3.3.7 Climate

Design of a land treatment system must consider the added effects of natural precipitation as it relates to soil saturation, and seasonal changes affecting both soil and groundwater characteristics. At a minimum:

- Evaluate yearly rainfall, seasonal rainfall variations, and total precipitation for each month (use the wettest year from the past 10 years).
- Determine the mean number of days per year with temperatures less than or equal to 32°F (0°C).
- Determine mean wind velocities and prevailing direction.
- Determine potential water loss through evapotranspiration.
- Evaluate plant growing seasons and periods of highest nutrient/water uptake.

9.3.3.8 Special Considerations for Effluent Disposal

When land application is used only for effluent disposal, treatment must be provided by processes prior to land application. To protect groundwater quality, the level of treatment before discharge is determined through the regulatory framework. Of particular concern is nitrogen because organic and ammonium nitrogen can nitrify in the soil and cause high levels of nitrate-nitrogen in groundwater.

Disinfection may be required, particularly when effluent is applied to land where crops will be grown. However, disinfection is generally not necessary; numerous studies have found that percolation through soil effectively reduces pathogenic bacteria.

The need for disinfection to minimize public health concerns should be evaluated on a case-by-case basis and should consider:

- The degree of public access.
- The feasibility of providing buffer zones.
- The climatic conditions affecting aerosol travel, potential for runoff, etc.
- The hydrogeologic connections to potable water supplies.

Storage may be required during periods when the amount of wastewater produced exceeds the design hydraulic loading rate, and when periods of freezing temperatures or snow cover limit application. When storage ponds are used, algal solids may be produced that can cause clogging of the soil surface and/or distribution piping and equipment. To help prevent this from occurring, consider prechlorinating effluent.

9.4 Design Guidelines for Land Treatment

9.4.1 General

Land treatment of wastewater may provide similar levels of treatment as conventional activated sludge processes but in a more economical manner. As of the writing of this document, eight methods of land treatment systems are commonly accepted: slow rate (SR), rapid infiltration (RI), freeze crystallization (FC), subsurface disposal (SD), overland flow (OF), constructed wetlands (CW), floating aquatic plants (FAP), and unlined leaching lagoons (UL). Five of these eight—SR, RI, FC, SD, and UL—are primarily used for effluent disposal. The other thre—OF, CW, and FAP—are primarily used for treatment but require additional design considerations before discharge to surface water or groundwater.

9.4.2 Slow Rate (SR) Systems

Slow rate systems apply wastewater on the surface or within the root zone to vegetated land, and the applied water is then consumed through evapotranspiration and percolation. Vegetative cover can consist of pasture crops, row crops, field crops, and forest cover.

SR systems provide treatment as the wastewater percolates through the soil. Primary treatment is the minimum preapplication treatment required by SR systems, and secondary treatment with disinfection is recommended where human contact is likely. The limiting design factor is most often soil permeability, but the application rate may be limited by a particular constituent in the wastewater.

Historically, the most common application method was spray irrigation. However, with spray irrigation, some of the applied wastewater is lost to evaporation, and if over-application occurs, surface runoff must be contained on-site. In recent years, drip irrigation technology has made significant strides and has become more widely used. The advantage of drip disposal over spray irrigation is that drip systems limit the possibility of human contact with partially treated wastewater. Spray irrigation, however, has the highest potential for pollutant removal because of lower application rates than other land application methods.

9.4.2.1 General Site Requirements

From the general list of site requirements in Section 9.2.3, special emphasis should be placed on field verification of soil characteristics (see Sections 9.3.2.3 and 9.3.2.4). When a detailed soil survey is not available, a high-intensity soil survey should be conducted by a qualified soil scientist. Even when published data is available, field confirmation and refinement of soil properties in the areas to be used are necessary. The soil profile should be evaluated in several areas using test pits, and hydraulic conductivity and/or soil permeability tests should be conducted. Also, verify depth to groundwater at several locations. Using the soil and groundwater information collected, perform a hydrogeologic evaluation to quantify the site's hydrogeologic capacity. A field survey of the existing topography should allow detailed mapping of natural surface drainage patterns.

Soil permeability should be midrange for SR infiltration. When soils are rapidly permeable, rapid infiltration basins are generally a better treatment choice. Typical soil permeabilities for SR systems used for effluent disposal are in the range of 0.2 to 2.0 inches per hour and are normally associated with loamy soils.

Crop/vegetative cover selection directly affects the level of preapplication treatment, type of distribution system, and hydraulic loading rate. Perennial forage grasses, turf grasses, some field crops, and tree species are suited to SR. It is important to select a crop with high nitrogen uptake capacity, a high evapotranspiration rate, and tolerance for moist soil. Periodic crop harvesting and removal from the site is recommended to minimize nutrient impacts to groundwater. The cultivated crop cannot be used for human consumption. When livestock forage crops are grown, consider indirect pathogen pathways. The type of vegetative cover will determine the period of expected transpiration and the duration of the application season.

9.4.2.2 Spray Irrigation

It is necessary to provide for cold season or wet weather storage for spay irrigation systems if the application site is restricted to the growing season. The need for and location of any on-site storage impoundments should be identified. Storage may be addressed on an operational and seasonal basis. The volume of storage required can be calculated from a monthly water balance, using an approach similar to that used to calculate the annual hydraulic loading rate. Typical operating constraints for spray irrigation systems that affect storage volume are as follows:

- Cannot land apply if greater than 0.5 inch of rain fell in previous 8-hour period
- Cannot land apply if frost is in the ground
- Cannot land apply if more than 1 inch of snow is on the ground
- Cannot land apply on snow if ground is frozen and a hard crust is on the snow
- Cannot land apply if high groundwater limits infiltration of effluent

Surface runoff from spray sites should not be allowed. During storm conditions, wastewater application should cease. Where intense storm events may lead to runoff from the spray site, consider the construction of retention basins. Sampling of retention basins for pathogens is advised.

Land area requirements include storage area, access roads, buffer zones, site drainage recapture zones, and wastewater application areas. The wastewater field application area can be calculated using the formula below:

$$A = \frac{Q \quad (\text{ft}^3/7.48 \text{ gal}) \quad (365 \text{ day/yr}) + \Delta V}{Lw \quad N \quad (\text{ft./12 in.}) \quad (43{,}560 \text{ ft}^2/\text{acre})}$$

Where: A = field area, in acres

Q = wastewater flow, in gallons per day

ΔV = net loss or gain in stored water volume because of precipitation and/or evaporation, in cubic feet per day

Lw = design hydraulic loading rate, in inches per day

N = number of days of operation, in days per year

9.4.2.3 Drip Disposal

9.4.2.3.1 History and Background

Systems incorporating modified irrigation tubing to disperse wastewater into the ground have been extensively used in the United States and Canada for more than 20 years. The technology was pioneered in states having large-scale agricultural production, but has since spread to New England and become well established.

Through scientific research and field applications, the technology has evolved from a simple use of irrigation tubing as a leaching device to the current state-of-the-art system, which includes timers, cleaning mechanisms, and filters. Aboveground and below-surface drip systems are allowed in some states, with stricter standards for aboveground drip due to the potential for human/vector exposure. Below-surface drip may be possible year-round.

9.4.2.3.2 General Design Considerations

The ability of a drip disposal system to handle effluent and disperse it through various zones and manifolds is based on the rules of fluid hydraulics, and effective designs are possible for almost any configuration. The most important variables in preparing a design are mostly related to site conditions. Specifically, special attention should be paid to the receiving soil's characteristics, regulatory constraints such as vertical and horizontal setbacks to the system, vegetative cover and site constraints that will promote or prevent plant uptake of effluent, and winter conditions that may require special attention in the design.

Soils: As with any type of wastewater dispersal system, it is important to consider the appropriate loading rate for the soil conditions expected to be encountered. Typically, drip dispersal tubing is placed in the upper soil horizons, so the condition of this soil's matrix is important to examine closely. The small dose volume and even distribution can allow for usage in soils with poor absorptive capabilities; usage in such soils may not be appropriate, however, for more traditional higher volume leaching systems.

Regulatory Environment: It is important to consider the ever evolving regulatory structure around water reuse and wastewater disposal when designing a system of this nature. Designers should contact state and local regulators early in the design process to ascertain the regulations that will govern a project.

Site Conditions: When attempting to maximize evapotranspiration, the location of the drip dispersal tubing should ideally be on a south-facing portion of the site. Plant species should be chosen based on their ability to achieve the desired uptake.

9.4.2.3.3 Components

A drip dispersal system is essentially a means of effluent disposal that utilizes timed doses to spread wastewater effluent into the environment in small applications throughout the course of a day. Dose volumes being discharged through each emitter are quite small (usually about pint per dose), which makes for a unique loading condition in the soil horizon. In addition to the irrigation tubing used to disperse the wastewater, there are several key components the designer must consider when choosing a drip dispersal system. The components are described below in general order of the flow cycle.

Pretreatment: Drip dispersal systems are not capable of handling raw sewage and must be preceded by appropriate levels of sewage settling and storage. Regulatory standards and the technology manufacturer will assist the designer in determining the amount of pretreatment required. Generally, it is advisable to seek a higher level of pretreatment with larger flow projects, with surface discharges, and with recharges used specifically for well replenishment. Most drip disposal systems are capable of accepting highly treated effluent as is typically generated in larger flow projects. Not all systems, however, will be suitable for use in dispersing septic tank effluent. The designer should carefully consider the application and planned use of the system in the preliminary design stage.

Dosing tank: A wet well or other storage system must be employed to accept effluent from the treatment system and to provide temporary storage before discharge to the drip system. The proper sizing of this component is critical, since effluent dispersal occurs on a timed-dose basis. Careful consideration should be given to peak day and peak hour flows to ensure that adequate attenuation of these peak flows is provided for in the system. This is particularly important with systems receiving only septic tank effluent, as a septic tank provides no flow attenuation. The required volume of storage is a function of any flow equalization preceding the pretreatment step, the anticipated peak flows, and specific regulatory requirements. Typically one-half to one day of storage is provided in the effluent disposal pump tank.

Control Systems: To maintain sufficient effluent in the dosing tank (and thereby allow proper pump function), a series of floats or liquid level controls should be employed to monitor and control the pump cycle.

Inline Filters and Field Zone Control: As drip dispersal systems use small diameter subsurface tubes with extremely small weep holes to distribute effluent to the ground, the filter and distribution mechanism is a key component. Inline filtering of effluent is critical for the protection of drip tubing, since septic tank upsets or other issues could cause solid material to migrate into the wet well, causing clogged drip tubes if filter protection is not in place. In addition to filtration, field zone control of the system is necessary to allow dosing to different zones of drip tubing within the effluent field. By dividing the drip field into different zones, a smaller pump can be used, and the existing landscape and profile of the site can be better preserved.

The zone configuration and manifold system also serves to provide periodic backwashing cycles for the drip tubing in some drip dispersal systems. Other systems, however, rely on anti-microbial properties embedded in the tubing to prevent bacterial growth and clogging. Before selecting a drip dispersal system, the designer should carefully weigh the pros and cons associated with each type of system and should, whenever possible, consult with system manufacturers. Site-specific constraints, such as a system's ability to collect and retreat backwash water, should be factored into the design.

Drip tubing: Effluent is released to the environment using flexible tubing with orifices, and emitters inside the orifices, at routine intervals. Typical spacing is 2 feet between each emitter, but many other configurations are available, depending on the end use and desired distribution pattern. Typical usage is with pressure compensating emitters so that uniform distribution can occur regardless of landscape position. Non-pressure compensating emitters are available and can be used for specific applications.

Manifold and air release valves: Providing for uniform distribution requires a manifold system to spread the effluent evenly to the different areas of tubing within a zone. These piping layouts are typically placed below the drip tubing with risers coming towards the ground surface at varied intervals. Another, less common configuration is a single riser at the high point, with feeders heading towards different sections of drip tubing. The high point of each drip zone should be provided with an air release valve to bleed off any air in the manifold system; this air release ensures better overall performance of the system.

Controls: The operational sequence of the different zones, pump cycle length and frequency, and reporting of any data occurs through a control panel that typically includes a programmable logic controller (PLC). Control panel types can range from a basic, solid-state, or digital timer configuration for standalone small systems to integrated remote monitoring and operation via PLCs and SCADA systems. For more information on control system options, see Chapter 13.

9.4.2.4 Expected Treatment Performance

SR systems can achieve greater than 90 percent BOD_5 removal from primary or secondary effluent, nearly complete pathogen reduction, and significant nitrogen and phosphorus reduction. BOD_5 removal is achieved by filtration, soil adsorption, and bacterial oxidation. These same three processes also remove pathogens, which are further reduced by radiation and exposure to adverse environmental conditions. Effluent disinfection immediately before SR application ensures pathogen reduction when the potential for human contact exists.

Phosphorus is removed by soil adsorption and chemical ion exchange. Nitrogen is removed through plant uptake, nitrification/denitrification, and storage in the soil. Without crop uptake, a conservative estimate of 15-25 percent should be used for denitrification. Even with crop uptake, a significant concentration of total nitrogen will remain. Metals are primarily removed by adsorption, chemical precipitation, and ion exchange. Trace organics are removed by photodecomposition, volatilization, sorption, and biological degradation.

9.4.2.5 Discharge Limitations

Hydraulic loading rate must be calculated on a site-specific basis using the water balance equation:

$$Lw = ET - P + Wp$$

Where:

Lw = wastewater hydraulic loading rate based on soil permeability, in depth per time

ET = design evapotranspiration rate based on the estimated average evapotranspiration of the crop, in depth per time

P = design precipitation rate based on total precipitation for the wettest year in a 10-year period, in depth per time

Wp = design percolation rate as measured in the field, in depth per time

In this formula, the precipitation rate should be the wettest year in the past 10 years. The percolation rate should be based on field measurements. If permeability varies across the site, determine the average minimum based on different soil types. The design percolation rate should not exceed 4–10 percent of the minimum soil permeability. Use the lower percentage for poorly defined soil conditions. A water balance should be calculated using the equation above for each of the 12 months of the year to determine the annual loading rate. Consideration must be given to the agronomic rate for the selected vegetative cover at the application site. Typical spray irrigation systems in New England use sprinklers for wastewater application and apply 3.5–6.5 feet per year.

Nitrogen may be a limiting factor at a given SR site. If this is the case, percolate nitrogen should be limited to a maximum of 10 mg/L total nitrogen.

9.4.2.6 Operation and Management

The type of distribution system used in SR systems will be a function of site topography, existing or selected crop/vegetative cover, and site soil characteristics. Both sprinkler systems and sub-surface (drip) irrigation systems can be automated to reduce the man-hours required to operate the system. The system should be operated by qualified, trained individuals with a strong wastewater background and a high degree of mechanical aptitude.

All distribution pipes and sprinkler heads should be able to be completely drained within a reasonable time. Main distribution headers should have flow measurement devices, pressure relief or vacuum relief valves, and pressure gauges. Any mechanical or electronically operated zone valves should have a manual override. Adequate grounding and placement of lightning arresters within the distribution system is recommended. Sufficient spare parts for all spray site components should be provided. Warning signs should be posted at regular intervals along the perimeter of the application site.

By controlling the hydraulic and nitrogen loading rates, long-term treatment at a site should be ensured. The rate of application of nutrients is ultimately determined by their retention and buildup in the soil and their concentration in groundwater. Site management requires routine groundwater monitoring and soils analysis with periodic evaluation of the generated data. Future additions to the waste stream, particularly from nondomestic sources, should be reviewed on a case-by-case basis.

9.4.3 Rapid Infiltration (RI) Systems

Rapid infiltration systems consist of spreading basins to which wastewater is intermittently applied. RI systems provide treatment as wastewater percolates through the soil. Primary treatment is the minimum preapplication treatment required by RI systems, although existing facilities often provide secondary treatment and, in some cases, tertiary treatment before rapid infiltration. When RI basins follow aerated lagoons, filtration for algae control is sometimes necessary to prevent surface clogging. The limiting design factor is most often soil permeability, but the application rate may also be limited by a particular constituent in the wastewater. Very little of the applied wastewater is lost to evaporation, and RI systems typically achieve a high level of treatment.

9.4.3.1 Design Factors

9.4.3.1.1 Hydraulic Loading Rate

The design average annual hydraulic loading rate is calculated as follows:

$$Lw = I \times (24\text{ hr/day}) \times N \times f$$

Where:

Lw = annual design loading rate, in inches per year
I = measured infiltration rate, in inches per hour
N = number of operating days per year
f = design application factor expressed as a decimal that ranges from 2 to 15 percent of the measured infiltration rate, depending on type of infiltration test conducted

Drying periods are required for RI systems to allow soil to aerate and recover between application periods. Because wastewater application is not continuous, the actual wastewater application rate is greater than the annual design loading rate. The actual application rate is calculated according to the following formula:

$$RA = \frac{Lw \times \text{operating cycle in days}}{365 \times \text{application period in days}}$$

Where:

RA = actual application rate, in inches per day
Lw = average annual design loading rate, in inches per year

Typical RI system design loading rates vary from 50 to 400 feet per year.

Basin bottom area requirements for rapid infiltration are calculated from the following formula:

$$A = \frac{Q\ (\text{gal/day}) \times (365\ \text{day/yr})}{(0.083\ \text{ft/in.}) \times Lw\ (\text{in./yr}) \times (7.48\ \text{gal/ft}^3) \times (43{,}560\ \text{ft}^2/\text{acre})}$$

Where:

A = basin bottom area in acres

Q = wastewater flow, in gallons per day

Lw = average annual design loading rate, in inches per year

This formula is applicable if flow equalization or storage is available. When equalization is not available, the daily wastewater flow should be adjusted to provide for the highest flow rate anticipated on a weekly, monthly, or seasonal basis. Additional basins can be provided to accommodate periods of high flow.

RI basins can operate year-round, so storage may not be necessary. However, it has been found useful to dose basins with a large flow from storage, particularly when daily flows are small. Small continuous flows are more susceptible to freezing than large doses of warmer wastewater. For winter operation, the formation of an ice cover is encouraged, as each dose of wastewater should float the ice to allow infiltration to occur under the ice surface. Storage may also be needed if soil permeability is relatively low and the water drains so slowly that freezing occurs.

9.4.3.1.2 Site Requirements

From the general list of site hydrogeological information in Section 9.3.3, special emphasis should be placed on site geology and field verification of soil characteristics (see Sections 9.3.2.2–9.3.2.4). RI basins generally require deep, permeable soils with percolation rates of 1 inch per hour or more. A complete hydrogeologic evaluation should be done to predict the range of the effluent plume and the point of breakout. Location and infiltration rate of the most restrictive soil layer in the profile should be determined using test pits and permeability tests. Site investigations should include depth of soil to groundwater or bedrock, topography, and groundwater movement. Verify depth to groundwater and bedrock at several locations during the field investigation.

Field verification of soil conditions and permeabilities is critical. Measurements of infiltration rates using flooding basin tests should be conducted whenever possible. Other methods of measuring can overestimate the infiltration rate. Adequate test pits or monitoring wells must be constructed to define the movement of groundwater. Soil conditions beyond the RI basin site should be verified to ensure that percolate will flow away from the site.

9.4.3.2 Expected Treatment Performance

RI systems can remove relatively high levels of BOD and TSS through filtration, soil adsorption, and bacterial decomposition.

Nitrogen removal does not always occur, but removal rates of 40–90 percent have been reported at some sites. However, for design purposes, a nitrogen removal rate of 15–25 percent should be used. Nitrogen removal is a function of biological denitrification and occurs through modified operating procedures that ensure an anoxic period.

Denitrification is affected by the BOD-to-nitrogen ratio (optimally 3:1), hydraulic loading rate, and ratio of flooding time to resting time (basin rest periods may range from 5 to 20 days).

Phosphorus removal occurs through soil adsorption and chemical ion exchange. Detention time in the percolate zone must be estimated, and considered in relation to the proximity of monitoring wells. Short-circuits may occur, yielding false high phosphorus content in the groundwater. Consult with the regulatory agency to determine recommended monitoring well locations.

RI is also effective at removing pathogens, metals, and trace organics.

9.4.3.3 Soil and Groundwater Considerations

Relatively deep, highly permeable soil is necessary for successful implementation of RI systems. Depending on the soil type, application rates may vary from 4 to 120 inches per week. Chemical analysis of the soil is recommended to determine if accumulation of phosphorus or nitrogen in the soil may limit design. Minimum depth to an impervious layer prior to application should be 10 feet. A groundwater mounding analysis should be conducted to predict the minimum unsaturated thickness below the disposal site and to identify any potential impacts of increased water table elevation in the site vicinity. The mounding analysis should be based on maximum monthly flows and seasonal high water table elevations. A computer simulation of groundwater flow beyond the site boundaries may be needed to predict the ultimate fate and impacts of effluent-impacted groundwater.

A complete background sampling and analysis of groundwater is recommended. Conservatively, a minimum distance from the application surface to groundwater should be 10 feet prior to application. Verify the unsaturated thickness requirements with the state’s regulatory program. After application, mounding should be no closer than 2 feet to the basin bottom.

9.4.3.4 Discharge Limitations

Design should include multiple dosing basins. Avoid overdosing individual basins. Allow sufficient drying time between doses on individual basins. At the very least, the surface of the basin should be dry prior to the next dosing. Conservatively, dosing patterns should be 4 doses per basin per day. Consult EPA guidance documents for recommended cyclical dosing patterns to maximize nitrogen removal.

Nitrogen and phosphorus may be limiting factors at a given RI site, particularly if groundwater in the aquifer approaches or exceeds state drinking water limits for these nutrients.

9.4.3.5 Operation and Management

By controlling the hydraulic and nitrogen loading rates, site management should ensure long-term treatment. Future additions to the waste stream, particularly from industrial contributors, should be reviewed on a case-by-case basis. Vegetation on basin slopes and bottom areas should be controlled by periodic cutting, and the cuttings should be removed. Exterior basin slopes and surrounding grounds should be cut regularly to discourage burrowing animals and tree roots from penetrating basin embankments.

9.4.4 Freeze Crystallization (FC) Process

In freeze crystallization, wastewater is stored in lagoons during warm weather and larger solids are allowed to settle. When the weather gets cold, the FC plant’s operations are initiated. The wastewater is atomized and projected over a prepared site from high towers using specialized nozzles and compressed air similar to snow-making equipment used at ski areas. The water droplets freeze as they fall to the ground and collect in snow piles.

The rapid freezing of the droplets causes two major reactions: the separation and precipitation of contaminants, and the killing of many of the bacteria and viruses in the wastewater. Throughout the winter, other reactions occur in the snow piles that cause most of the nitrogen to be released as ammonia and other contaminants to be rendered insoluble. Any bacteria that may have survived the original freezing will die from the damage caused by further freezing in winter or be eliminated by natural solar UV radiation.

When the snow melts in the spring, very clean water infiltrates the soils, and the insoluble contaminants form a nutrient residue on the surface of the ground. Although the dense snow pack melts very slowly and runoff is not usually a concern, consideration should be given to grading or berming to prevent runoff from leaving the site. The nutrient residue is a plant fertilizer and is consumed by grasses previously grown on the site. The grasses are harvested as hay and can be fed to farm animals or used as mulch.

Note: This is a brief discussion of a complex process. The appropriate state agency should be consulted for the feasibility of this option whenever it is considered.

9.4.5 Subsurface Disposal (SD) Systems

Data from the 2000 Census shows that approximately 32 percent of all Americans live in urban clusters or rural areas that are defined as cities or towns with populations of less than 50,000 inhabitants. Of that 32 percent, approximately 21 percent are served by onsite subsurface disposal systems, according to 2001 American Housing Survey data. In the Northeast, most cities and towns are comprised of populations of far fewer than 50,000 people and, therefore, the percentage of the populace relying solely on SD systems as a means of wastewater disposal may be far greater than the 21 percent observed nationally. In the Northeast, many people live in suburban and rural areas where large centralized treatment with surface water disposal is not available or is not cost-effective compared to onsite treatment. Furthermore, due to Clean Water Act revisions and to federal and state limitations placed on inter-basin transfers of water, most new developments and commercial properties built in non-urban centers can be expected to use some form of SD as a means of wastewater treatment.

SD systems generally consist of onsite tankage and some form of land-based effluent disposal. As the configurations of these systems can vary greatly from state to state, the designer of any project that requires a SD system should initially consult the appropriate state regulations. Since some systems may include basic forms of fixed film or suspended growth aerobic treatment to reduce the organic and nutrient loadings being imparted on the subsurface soil strata, the designer should also become familiar with the many proprietary SD technologies. Small-scale (often modular) treatment systems are now commonly used for decentralized treatment, and in some cases, allow a higher effluent loading rate.

SD system components, at a minimum, should include a precast concrete septic tank (of sufficient size to provide 24 hours of storage of the total volume of design wastewater flow) and a means of subsurface effluent disposal. The septic tank will provide primary and some amount of secondary treatment of the raw wastewater. Typically, septic tank effluent (STE) indicates a reduction of TSS and BOD by 75 percent and 49 percent respectively. It is important to note that recent research indicates septic tanks do not effectively remove an appreciable amount of wastewater nutrients such as nitrogen and phosphorus from wastewater (Lowe, 2007). If an SD system is planned in a nutrient-sensitive area, proper consideration to advanced nutrient removal via soil uptake or biological treatment should be considered.

All septic tanks must be equipped with inlet and outlet tees made of PVC pipe of the same diameter as the incoming sewer pipe. In addition, the outlet tee must be installed with a gas baffle to trap rising sludge in the tank. Effluent "tee" type filters are also recommended for SD systems. Where more than 2,000 gallons of storage is required in a septic tank, improved solids removal can be achieved by utilizing a two-compartment tank or by using more than one tank in a series.

Effluent disposal configurations typically are configured based upon either subsurface slow rate (SR) or rapid infiltration (RI) systems. Further discussion of these technologies is included in the related sections of this chapter.

The following are effluent disposal technologies considered acceptable for SD systems:

- Perforated PVC pipe and stone trenches
- Pressure distribution with effluent disposal beds
- Drip dispersal
- Leaching chambers
- Concrete leaching pits and chamber systems

The designer is encouraged to consult the work of the Massachusetts Alternative Septic System Test Center for guidance on other acceptable means of effluent disposal. Typically, large effluent disposal systems are pressure-dosed or fed via an effluent pump system. Therefore, an effluent dosing or pump chamber is often another critical component of an SD system. Pump chambers should be precast concrete with risers and access hatches to grade. The pump chambers should hold a minimum of 1,000 gallons but also have 24 hours of emergency storage as part of the working volume of the tank (if standby or emergency power is not provided). See Chapter 3 for further detail on pump systems. The appropriate state agency should always be consulted for specific requirements that apply to SD systems.

9.4.6 Overland Flow (OF) Systems

Overland flow (OF) systems treat wastewater in a thin film on a sloping ground surface. Runoff is collected at the base of the slope and disinfected prior to ultimate discharge to surface water or groundwater. Wastewater is applied to the upland slope by gravity flow through a perforated distribution header pipe or low-pressure dispersed spray. OF systems require a minimum of gross solids removal prior to dosing and aerated storage for odor control. With primary treatment prior to application, OF systems can achieve secondary effluent quality. Key design factors are application rate, slope length, slope gradient, and application period. Vegetative cover should consist of water-tolerant grasses such as reed-canary grass, tall fescue, perennial rye grass, and redtop. Unlike SR and RI systems, OF is not a zero-discharge option.

9.4.6.1 Site Requirements

From the general list of site requirements in Section 9.3.2, special emphasis should be placed on field verification of soil characteristics (see Sections 9.3.2.2–9.3.2.4). Evaluate the soil profile in several areas using test pits. Predominant soil types should be relatively impermeable. Construction of a uniform sloping ground surface will limit short circuits caused by channeling in the treatment area. Care should be taken to prevent extraneous surface runoff from entering the OF site.

For vegetative cover, select a crop with high nitrogen uptake capacity, high evapotranspiration rate, and a tolerance for moist soil.

9.4.6.2 Expected Treatment Performance

OF systems can remove up to 90 percent BOD_5 after gross solids are removed. A minimum of primary treatment is recommended prior to OF application. Substantial pathogen reduction, measurable nitrogen reduction, phosphorus removal ranging from 40 to 60 percent of applied phosphorus, and metals removal ranging from 60 to 90 percent of applied trace metals are possible.

9.4.6.3 Soil and Groundwater Considerations

Minimum depth to an impervious layer should be 2 feet. The reconstructed finished application surface should have a uniform slope in the range of 2 to 8 percent. The sloping ground surface should be planted with a water-tolerant stabilizing grass to mitigate slope erosion in the event of a distribution header failure. Consider constructing down-gradient curtain drains to intercept potentially blocked groundwater. These drains should tie into the collection trench at the base of the OF slope prior to the disinfection process.

Depth to groundwater is not typically a factor because of the slope requirements inherent in the design of OF systems.

9.4.6.4 Discharge Limitations

If the effluent discharge is subject to a phosphorus limit, pre-application or post-application phosphorus removal may be needed. When ultimate discharge of the effluent is to surface water, disinfection is usually required.

9.4.6.5 Operations and Management

OF systems typically consist of gravity flow or low-head distribution at the uphill end of the slope. The system should be checked regularly for clogs, leaks, and breaks. The system can be operated by entry-level wastewater personnel, though operation by staff with proper wastewater certification and licensing is strongly recommended.

The application site should be mowed regularly after adequate drying time. Cuttings should be completely removed from the slope. Occasional dethatching of the OF slope is advisable to encourage vigorous growth of vegetation.

9.4.7 Constructed Wetland (CW) Systems

Natural wetlands are areas consisting of poorly or very poorly drained soils supporting distinctly adapted vegetation existing in a saturated condition for all or most of the year. The use of natural wetlands to treat wastewater may not be desirable because of the current regulatory framework restricting activities within natural wetlands. Furthermore, while natural wetlands provide a high degree of polishing, it is unlikely that a natural wetland will respond well to frequent and significant fluctuations in organic and hydraulic loadings.

Constructed wetland treatment systems, however, have been used successfully to treat municipal and industrial wastewater. Land area requirements and system performance limit use of CW systems for treating raw wastewater or primary effluent. The use of CW systems as a polishing mechanism for secondary treated effluent may be an economically favorable alternative to more conventional advanced treatment methods. The engineer of a CW system should consult with the appropriate regulatory agency regarding the potential for regulatory jurisdiction as a wetland, which may restrict CW system operation and maintenance.

Rational design models are now available for sizing CW systems for removal of wastewater constituents. The reader is encouraged to obtain the latest edition of EPA’s design manual, *Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment*. For additional resources, see the references at the end of this chapter.

9.4.8 Floating Aquatic Plant (FAP) Systems

Floating aquatic plant treatment systems have been operated in the southern United States since the 1970s. These systems depend upon floating plants such as water hyacinth and duckweed to provide oxygen transfer and surface attachments for microbial action. Aquatic treatment systems may be costly in the Northeast because of the need for high wastewater temperatures (70–90°F for water hyacinths) and because plants die when ambient temperatures are at or below freezing for more than 48 hours. With influent wastewater temperatures below 50°F for much of the winter and extended periods of subfreezing temperatures, a means to heat and enclose an aquatic plant system would need to be developed to ensure treatment. The costs associated with such heating and enclosure likely prohibit extensive use of FAP systems in the Northeast.

9.5 Effluent Reuse Considerations

9.5.1 General

Adequate pretreatment may render wastewater effluent usable on a large commercial scale, turning a waste into a resource. However, this effect may be highly site-specific. Always consult state rules and regulations to determine allowable uses and specific restrictions.

Direct exposure of the public to reclaimed wastewater should be considered only on a case-by-case basis. The appropriate level of treatment and disinfection must be addressed in these instances.

Another major consideration when evaluating potential end users is the user's minimum water quality requirements. For example, an industry may not be able to directly use a reclaimed wastewater for manufacturing purposes, but may be able to use it for cooling or air conditioning.

Securing a long-term commitment from end users is critical for a successful reuse program. Reuse systems may be more cost-effective for new construction compared with retrofitting existing supply systems.

9.5.2 Evaluation of Potential Markets

As population growth puts even greater strain on existing potable water supplies, markets for reclaimed wastewater will invariably expand. Although this trend will not be as profound in the water-rich Northeast as in drier areas, such as the arid Southwest, it is anticipated that opportunities for effluent reuse will increase.

Nationally, large-scale uses fall into the following categories: industrial; agricultural, including for certain crops and silviculture; municipal and recreational, such as golf courses, parks, and fountains; and certain commercial applications. In New England, principal reuse opportunities are found in industries, agriculture (and silviculture in particular), habitat restoration and/or enhancement, and groundwater recharge. As of the writing of this document, in fact, effluent from some New England wastewater treatment plants is being used as cooling water for power generation, golf course and agricultural irrigation, and toilet flushing. Note that roughly 40 percent of total U.S. water demand comes from agriculture, with cooling water requirements at power generating facilities accounting for another 39 percent. Clearly, the potential exists for safe reuse of reclaimed wastewater effluent.

In assessing opportunities for effluent reuse, a first step is to evaluate the water needs and long-term stability of large water-consuming entities in a study area. Water quality and quantity needs must be considered. Demand requirements must be determined and compared with the availability of sufficient reclaimed water. Determine if the end users are prepared to further treat reclaimed water for their own use when higher quality is required.

Preliminary cost estimates should be prepared, with a focus on conveyance system construction and life cycle cost-effectiveness. Incremental costs associated with increased treatment requirements should be included. As the price of advanced treatment technologies becomes more affordable, tertiary filtration systems and membrane bioreactor (MBR) systems may offer cost-effective reuse options for consideration. Economic analyses should account for money saved by not expanding existing wastewater treatment facilities and by limiting the need to expand potable water delivery.

The capital cost of constructing new reclaimed water distribution lines must be considered when evaluating the potential for reuse. For example, a separate distribution system serving a multitude of smaller users may be cost-prohibitive, whereas constructing a short pipe to a single large industrial user may make a program viable. Such a limited approach may in fact be the only practical application for water reuse in the Northeast for the foreseeable future. When possible, establish long-term contracts with users to guarantee payback for capital costs associated with conveyance systems.

9.5.3 Estimation of Demand

In New England, the most likely end users of reclaimed water are agriculture and industry. As agriculture in the region is highly seasonal, industries and power plants may prove to be the most reliable continuous users.

Reasonable care should be given to developing water use estimates. Where possible, actual flow, consumption rates, and volumes should be recorded. From these data, required storage volumes should be calculated and the availability of storage space should be determined, particularly for seasonal installations. Storage may also be a consideration when diurnal variations in use and/or supply are an issue.

Check existing potable water supply records to establish actual trends in demand.

9.5.4 Reliability of Effluent Quality

Generally, the level of effluent quality will be proportional to end-use requirements, with the protection of public health of principal concern. Therefore, disinfection may be required. Treatment programs must be developed on a case-by-case basis. Retrofitting instrumentation may be appropriate. For example, in-line turbidimeters or TSS analyzers, pH meters, and chlorine residual and/or ORP analyzers are all available and are more reliable than in previous years.

If bacteriological integrity is important, the frequency of related analyses should be increased accordingly, as should analyses for other relevant effluent quality parameters. QA/QC programs should be developed to ensure consistency in sampling, analysis, and recordkeeping. Installation of filtration devices to ensure consistent quality may be appropriate.

Redundant (backup) unit processes should be made available to prevent effluent deterioration because of mechanical failure, flooding, peak flows, and other emergency conditions. Adequate emergency power generation should be provided. Comprehensive alarms and/or SCADA systems should be installed and maintained to ensure proper process control and effluent quality.

Unacceptable effluent should be diverted away from the end user. This task has been made easier by the reliability and accuracy of the latest process instrumentation, which may allow for automated on-line information that can redirect unacceptable water to discharge. Additionally, adequate pretreatment, pollution prevention, and sewer use programs are extremely important in maintaining treatable waters and minimizing upsets and contaminant pass-through. Because of the importance of disinfection, public health, and aesthetics, a minimum level of secondary treatment prior to effluent reuse is required in NEIWPCC's member states. Ultraviolet disinfection systems can provide reuse water free of disinfection chemical residuals, making the water well suited for irrigation.

9.5.5 Effluent Reuse Options

Effluent reuse may become more economically attractive as stricter regulatory requirements are placed on potable water use in the Northeast. Greater demand for potable water by a larger population base may accelerate reuse of disinfected secondary- or tertiary-treated wastewater effluent.

9.5.5.1 Industrial Reuse

Reuse of treated wastewater may be appropriate for those industries that do not require potable-quality water for their processes. Industries must be contacted to ascertain their water quality needs; how they use water will dictate the quality of effluent required.

Industrial cooling water requirements vary. Once-through cooling systems require vast quantities of water (as much as 650 mgd for a 1,000 megawatt fossil fuel power plant), which may limit opportunities for effluent reuse. Recirculating systems that use cooling towers or ponds require much less makeup water. While new water must continuously be added because of evaporation, aerosol drift, and blowdown requirements, recirculated cooling systems typically reuse the initial water volume between five and ten times prior to replenishment. If reuse is used, consider reduction of pathogens by disinfection, control of regrowth within the system, and the control of aerosols.

Industrial cooling systems are subject to a variety of problems, such as corrosion, biological growths, scaling, foaming, and fouling. To curb these problems, contaminants in cooling water must be controlled. Pretreatment for scaling, biological fouling, and corrosion control may be required and should be considered prior to reuse.

Reused wastewater effluent is unlikely to be a cost-effective alternative for boiler feed water, due to the relatively high quality of water required.

9.5.5.2 Agricultural Irrigation

Demand for irrigation water varies with crop, climate, and seasonal requirements. Adequate storage and/or supply should be available to meet the maximum crop demand. Demand is defined as the amount of water required to meet the needs of the crop and overcome system losses such as wind drift, runoff, percolation, and evaporation. A range of irrigation system efficiencies are as follows:

• Surface or flood irrigation	50 to 70 percent of demand
• Sprinkler irrigation	65 to 70 percent of demand
• Drip or trickle irrigation	85 to 90 percent of demand

If effluent supply is inadequate to meet demand, a supplemental irrigation source should be available.

Consider the sensitivity of crops to contaminants remaining in the reclaimed water—specifically, chlorides, sodium, metals, chlorine, nutrients, and other trace materials. The most critical parameter regarding reuse of wastewater for irrigation is salinity. It may be possible to control salinity impact on a crop by intentionally overapplying water to encourage leaching or downward movement of the water and salt away from plant root zones. Salinity is most detrimental during plant germination and early growth. Therefore, reuse may be more feasible during latter growth stages of certain crops. The effect of heavy metals on plant health should also be evaluated.

The pH of reclaimed water for agricultural use should consistently be above 6.0 at all times to prevent heavy metal migration, uptake, and potential toxic effects.

Adequate buffer zones around spraying sites must be addressed, as should control of surface runoff. Pathogen attenuation, vector pathways, and the human food chain must also be considered. Contact the appropriate state regulatory agency for specific groundwater monitoring requirements.

9.5.5.3 Municipal/Recreational Reuse

Because of the generally adequate supply of relatively clean water in the Northeast, municipal wastewater reuse opportunities that are cost-effective may be minimal; however, reuse is technically feasible in many applications. Specifically, wastewater may be reused in municipal parks and other recreational facilities, at cemeteries, on highway medians and roadsides, and for domestic landscape irrigation. For low-flow installations, such as schools and lifestyle centers, treated effluent may be used to irrigate landscaping and athletic fields. The reduction in water sent to the disposal field can increase the life of the field. The use of reclaimed water will also ease demand to the potable water supply during the high demand dry season, a potential savings. Advancements in treatment technologies also contribute to cost-effectiveness; MBR systems, for example, can reclaim up to 75 percent of incoming wastewater.

If adequate storage is available, the reuse of wastewater for fire protection may be promising. The use of reclaimed water may also occur in construction activities such as dust control, concrete mixing, and vehicle washing. If irrigation is to be considered, then setback requirements are appropriate. Nationwide, these setbacks range from 50 feet (i.e., to a property line) up to 1,000 feet (i.e., protective radius surrounding a community water supply well). The potential for pathogen attenuation, regrowth, and pathways via direct contact and aerosols must be evaluated for each project. Spraying during evening hours to minimize human contact may be appropriate.

Approximately half of the domestic water consumed in this country is for toilet flushing. Reused water may be appropriate for this function although it requires dual water supply piping. Disinfection and low solids content are desirable to prevent pathogen contact and aerosols. Use in private residences is not recommended. If reused water is used for toilet flushing, it is absolutely essential that cross connections be prevented. Appropriate measures such as backflow prevention and air gaps are required.

In coastal areas with sand/gravel substrata, water supply wells are subject to salt water intrusion if overpumped. If reclaimed water is available, overpumping may be controlled by groundwater injection. Similarly, groundwater supplies that are vulnerable to overuse may be recharged with high-quality reclaimed water. In sandy areas, soil and structural subsidence may also be controlled by groundwater replenishment using reclaimed water. Conditions appropriate for such use may exist on Cape Cod, Long Island, and the glacial moraine islands off southern New England.

Any reuse of wastewater effluent that entails direct human contact must be carefully considered. In states where reuse is practiced, the regulatory standards for water quality are quite stringent and may include the need for advanced treatment, primarily filtration. Stringent TSS and turbidity limits are often imposed, because at lower TSS concentrations and turbidity, thorough pathogen destruction can occur; at higher levels, microbes can survive in suspended solid particles and withstand disinfection efforts.

Recreational reuse options include the following:

- Artificial lakes and ponds
- Fish hatcheries
- Stream flow augmentation
- Wetlands enhancement or creation
- Park, athletic field, and golf course irrigation
- Snowmaking

Of these options, irrigation and snowmaking are typically the only two that can be considered with only secondary treatment and adequate disinfection. (The others would usually require tertiary treatment such as nutrient removal.) The reuse of treated wastewater for recreational irrigation purposes has been done successfully in New England, and the availability of nutrients in secondary effluent make it a prime candidate for irrigation. However, such irrigation may be better performed at night to limit possible direct human contact. Golf courses, for example, typically irrigate at night, which has the added benefit of minimizing the evapotranspiration and plant impact that occurs during daytime watering. In some cases, this form of wastewater disposal is used at second-home developments, where it appears to be an environmentally sound option.

The use of treated wastewater for snowmaking has been undertaken successfully in the Northeast, most notably at Waterville Valley, New Hampshire, where effluent from the community's advanced wastewater treatment facility was blended with river water and pumped to the ski area's snowmaking pond. Well-treated and disinfected secondary effluent has also been successfully used at other ski areas in the region. Subjecting wastewater to the snowmaking process can result in destruction of pathogens and a volatilization of ammonia.

It is important to note that the components of any reclaimed water system, including pumps, appurtenances, and piping, must be clearly marked. In the absence of a national color code standard, purple is recommended and is currently in use by most industries and many municipalities.

9.6 NEIWPCC Compact Member States Regulatory Summary

Each of NEIWPCC's compact member states—Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont—has rules pertaining to groundwater discharges. Many states' reuse programs are limited to beneficial use of biosolids in the form of land application, and composting. As of the writing of this document, none of the compact member states have full-scale municipal wastewater facilities using overland flow, or floating aquatic plants for treatment, disposal, or reuse. New York State has two facilities using constructed wetlands for treatment.

Table 9-1 identifies the specific laws, regulations, jurisdictions, and governing authorities in each of the NEIWPCC states as they relate to effluent reuse and disposal. To obtain the most current set of rules and regulations, contact the appropriate state agency program manager.

Table 9-1 **NEIWPCC States Regulatory Summary: Land Treatment, Effluent Disposal, and Reuse**

State	Agency	Program	Prevailing State Rule(s)	Type of Permit	Types of Systems Permitted and In Use
CT	DEEP	Solid Waste Management	CGSSection 22a-430 Parts 1-16	land application	no effluent reuse or disposal; only biosolids reuse and disposal
MA	DEP	Water/Solid Waste	314 CMR 5.00; 314 CMR 20.00; 310 CMR 32.00	groundwater discharge; reclaimed water	water reuse; drip irrigation; agricultural use
ME	DEP	Solid Waste Management	Chapter 419	land application	no effluent reuse or disposal; only biosolids reuse and disposal
NH	DES	Groundwater Protection	Env-Wq 400	groundwater discharge	rapid infiltration; slow rate infiltration; spray irrigation at golf courses
NY	DEC	Solid Waste Management Division of Water	Guidance – Sludge & Septage Land Application	land application SPDES Permit	biosolids reuse and disposal; effluent reuse
RI	DEM	Groundwater Protection	Regulation #12-190-008	land application	one effluent irrigation project, otherwise biosolids reuse and disposal
VT	DEC	Solid Waste Management	Guidance – Sludge Reuse	land application	no effluent reuse or disposal; only biosolids reuse and disposal

Table 9-2 lists some of the guidance documents, rules, and references used by NEIWPCC states in assessing effluent disposal and reuse projects. Again, the designer should contact the appropriate state agency program manager to verify the most current guidelines and references.

Table 9-2 **NEIWPCC States Design Guide and Reference Documents**

State	Agency	Type(s) of Document	Title of Design Guide or Reference Document
CT	DEEP	Guidance on Sludge Waste	Connecticut General Statutes, Section 22a-430,1-16
MA	DEP	Guidance - Land Treatment	Reclaimed Water Permit Program and Standards, 314 CMR 20.00 Land Application of Sludge and Septage, 310 CMR 32.00 Groundwater Discharge Permit Program, 314, CMR 5.00
ME	DEP	Guidance - Residuals Application	State of Maine, Department of Environmental Protection, Guidance for Municipalities, Regulation of Septage & Sludge Land Application by Municipalities, September 2002
NH	DES	Design Manuals	Land Treatment of Municipal Wastewater, U.S. EPA (EPA 625/1-81-013) Land Treatment of Municipal Wastewater - Supplement on Rapid Infiltration and Overland Flow, U.S. EPA (EPA 625/1-81-013a) Guidelines for Water Reuse - 2004 U.S. EPA (EPA/625/R-04/108)
NY	DEC	Guidance on Sludge & Septage Land Application Effluent Reuse	Department of Environmental Conservation, Solid Waste Management Facilities, Subparts 360-1-11, Land Application Facilities NYSDEC, Subpart 750-1.1 through 750-1.24, State Pollution Discharge Elimination System Regulations Process Design Manual - Land Application of Sewage Sludge and Domestic Septage (EPA 625/R-95/001), September 1995 Land Application of Sewage Sludge - A Guide for Land Appliers on the Requirements of Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503 (EPA/831-B-93-002b), December 1994 Biosolids Management in New York State, NYSDEC, October 1998 Potential Reuses of Greywater and Reclaimed Wastewater in New York State, NYSDEC, November 2010.
RI	DEM	Guidance - Effluent Reuse & Sludge Disposal	Department of Environmental Management, Guidance for Water Reuse Projects Rhode Island Groundwater Protection Act DEM Rules and Regulations for the Treatment, Disposal, Utilization, & Transport of Sewage Sludge, April 1997, Regulation #12-190-008
VT	DEC	Guidance - Sludge Reuse	State of Vermont, Solid Waste Management Guidelines for Beneficial Use of Sewage Sludges and Similar Wastes, September 2007

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Many academic studies have been published and are generally available in research and journals published by the National Onsite Wastewater Recycling Association (NOWRA), Water Reuse Foundation, American Society of Agricultural and Biological Engineers (ASABE), American Society of Civil Engineers (ASCE), and others.

CHAPTER 10

ODOR AND VOC CONTROL

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10.1 General

The most significant air contaminants released from wastewater treatment plants are odorous compounds and volatile organic compounds (VOC). Odorous compounds generally include reduced sulfur compounds such as hydrogen sulfide, mercaptans, dimethyl sulfide, and dimethyl disulfide, and nitrogen-based compounds such as ammonia and trimethyl amine. VOCs are precursors to the formation of ground-level ozone and include benzene, toluene, chloroform, and other chlorinated organics that are primarily of industrial origin. Many of these VOCs are toxic and subject to state air regulations. Other contaminants that result from combustion processes (e.g., NO_x and SO_x) must be addressed on a case-by-case basis, and are not discussed in this chapter.

Regulations that control the release of odorous compounds are primarily nuisance ordinances that do not define the compounds to control or specify the control levels. Discharges of VOCs, however, are regulated under the provisions of the federal Clean Air Act. Engineers should contact their state air quality agency to determine how and what federal or state regulations and air permits apply.

Unit processes that are major sources of odors at wastewater treatment plants can be significant sources of VOCs. Turbulent processes that release large amounts of odorous compounds and VOCs include aerated grit chambers, primary clarifier weirs, aeration basins, and sludge dewatering processes. Although many practitioners discount aeration basins as major sources of odors, the large turbulent surface area produced during aeration can result in a high odor emission rate even though odor levels are lower and less objectionable than from raw sewage or sludge handling processes.

10.2 Basis for Selection and Design of Odor/VOC Control Systems

10.2.1 Planning Considerations

Plant siting and buffer zones are important planning considerations. One of the most difficult engineering judgments in planning odor control systems is estimating the degree of odor control required. Different odor control technologies will yield different efficiencies in removing odors and VOCs. For example, addition of chemicals to wastewater or sludge may reduce odor emissions by only 30–50 percent, while covering of odorous processes followed by multistage scrubbing may reduce odor emissions by more than 95 percent. Use of dispersion models can assist the engineer in planning for odor control. By selecting, for example, a target odor level at the plant's fence line or nearest receptor, various odor control scenarios can be input into the model to determine if they achieve the desired result. Such models may require information on local meteorology (including wind speed and direction), odor emission rate, and the location of odor sources and downwind receptors.

10.2.2 Chemical Addition for Odor and Corrosion Control

Chemicals are effective in reducing the emissions of most odors from wastewater and sludge, although chemicals are unlikely to be effective in reducing emissions of VOCs. Chemicals are commonly used in collection systems to control odors and corrosion associated with hydrogen sulfide.

Chemical requirements for odor control can be estimated based on certain wastewater and sludge characteristics. Often, the concentration of dissolved sulfide is used to estimate chemical doses. Whenever possible, jar tests and/or pilot tests should be conducted to more accurately estimate quantities of chemicals necessary to achieve a desired result. These tests provide a basis for conducting a cost-effectiveness analysis. A summary of chemical control options is presented in Table 10-1.

10.2.3 Containment and Treatment

Covering of odorous processes, ventilation of enclosed space, and treatment of air are all very effective means of controlling odors and VOC emissions. The selection of a particular control technology depends largely on the characteristics of the airstream to be treated, site considerations, and the degree of odor/VOC reduction required. Airstream characterization can include gas chromatography-mass spectrometry (GC/MS) or other analytical techniques to identify specific constituents. Analytical techniques are particularly important for odor control applications where the odors are complex and consist of compounds other than hydrogen sulfide and reduced sulfur. Odor panel analysis can also be used as an analytical tool. Such tests, conducted in accordance with ASTM E-679, provide useful data on odor strength or detectability, which is defined as the number of dilutions required before half the odor panel can no longer detect the odor.

Airflow rate is also an important design parameter that may affect the cost-effectiveness of a particular technology. Ventilation rates of enclosed spaces are discussed in Section 10.5. NFPA 820 should also be consulted for fire prevention and hazardous material storage.

Technology selection and design is affected by performance requirements. Some technologies, for example, may be effective for removing odors but not VOCs. If high odor/VOC removal efficiencies are required, multiple stages or a combination of technologies may be necessary.

A summary of air treatment technologies is presented in Table 10-2.

10.3 Chemical Addition for Odor and Corrosion Control

10.3.1 Description

Liquid phase treatment entails the addition of chemicals to wastewater to control hydrogen sulfide. The control of sulfide generates important benefits:

- Control of corrosion in sewers, manholes, pump stations, etc.
- Reduction in odorous emissions downstream of the odor source.
- Potential for improved treatment at wastewater treatment plant or reduction of odor at headworks due to altering characteristics of wastewater in the collection system.

Table 10-1 Summary of Hydrogen Sulfide Control Techniques

Technique	Frequency of Use	Advantages	Disadvantages
I. OXIDATION			
Air injection	Low	Low cost, adds DO to wastewater to prevent sulfide generation	Applicable only to force mains; potential for air binding; limited rate of O_2 transfer
Oxygen injection	Low	5 times solubility of air; high DO possible; economical for force mains	Higher capital cost; requires on-site generation or purchase as liquid O_2
Hydrogen peroxide	Medium	Effective for sulfide control in gravity sewers or force mains; simple installation	Costs can be high to achieve low (<0.5 mg/L) sulfide; safety
Sodium hypochlorite	High	Applicable to gravity sewers or force mains; effective for broad range of odorants	Safety considerations; high chemical costs
Potassium permanganate	Medium	Effective, powerful oxidant; good for sludge handling applications	High cost; requires preparation of solution from crystals
Sodium chlorite	Medium	Purchased as a liquid in drums or totes; effective for sludge handling	High cost
II. PRECIPITATION			
Iron salts	High	Economical for sulfide control in gravity sewers or force mains	Does not control non-H2S odors; sulfide control to low levels may be difficult; increased sludge production
III. pH ELEVATION			
Sodium hydroxide (shock dosing)	Medium	Intermittent application; simple, minimal equipment required	Does not provide consistent control; safety considerations
Magnesium hydroxide	Medium	Maintains pH at 8–8.5; adds alkalinity; economical for high (>5 mg/L) sulfide levels; safe	Requires mixer to maintain slurry in suspension; requires freeze protection
IV. PREVENTION			
Nitrate formulations	High	Can be used to prevent sulfide generation or oxidize sulfide in gravity sewers and force mains; safe to handle	Dosages and operating costs vary depending on use: prevention vs. removal
Anthraquinones	Low	Prevents sulfide generation biochemically by disrupting sulfur cycle	Not well developed; results inconsistent and difficult to predict

Relying on chemical addition to control sulfide, however, can have drawbacks, such as high annual chemical costs and containment/storage of chemicals at remote locations.

Chemical addition for sulfide control in wastewater can be done in a number of ways, as listed below:

- Addition of oxidizers such as sodium hypochlorite or hydrogen peroxide
- Direct oxygen or air injection
- Addition of alternate oxygen source, such as nitrate
- Precipitation with iron salts
- pH adjustment

10.3.2 Oxidizers

Oxidizers are used to remove odorous compounds through oxidation-reduction reactions.

Table 10-2 **Summary of Odorous Air Treatment Alternatives**

Technique	Frequency of Use	Cost Factors	Advantages	Disadvantages
Packed tower wet scrubbers	High	Moderate capital cost, high O&M cost	Effective and reliable; long track record; small footprint	High chemical consumption, high O&M
Activated carbon adsorbers	High	Cost-effectiveness depends on carbon replacement frequency	Simple; few moving parts; effective; several media options	Applicable to relatively dilute air streams in order to ensure long carbon life
In-ground biofilters	High	Low to moderate capital; low O&M costs	Simple; low O&M; effective; no chemicals	Large footprint; design criteria varies; some failures due to short-circuiting, overloading
Pre-engineered biofilters	Medium	Moderate to high capital; low O&M	Low O&M, no chemicals; longer media life and smaller footprint than in-ground systems	Higher capital costs than in-ground biofilters
Bioscrubbers, Biotrickling filters	Medium	Moderate capital; low O&M	Smaller footprint than biofilters, high H_2S loadings possible; little or no chemicals	Reduced performance at low temperatures; not as effective for non-H2S odors.
Thermal oxidizers	Low	Very high capital and O&M (energy) costs	Effective for wide spectrum of odors and VOCs	Only economical for high-strength, difficult to treat air streams
Diffusion into activated sludge basins	Low	Economical if existing blowers or diffusers are used	Simple; low O&M; effective, reliable	Potential for corrosion of blower inlet components; add'l air filtration required
Odor counteractants	High	Operating cost dependent on chemical usage	Low capital cost	Limited odor removal efficiency (<40%); only applicable for dilute air streams

Hydrogen peroxide, chlorine, hypochlorite, and potassium permanganate are examples of oxidizers typically used in wastewater collection systems.

Hydrogen peroxide oxidizes hydrogen sulfide to elemental sulfur at neutral pH based on the following equation:

$$H_2S + H_2O_2 \rightarrow S + 2H_2O \text{ (at pH < 8.5)}$$

Theoretically, the dosage rate is 1 lb of hydrogen peroxide to 1 lb of hydrogen sulfide but hydrogen peroxide, like other oxidants, reacts with other organic material so the actual dosage rate is higher, roughly 1.5–3 times the theoretical dosage rate. Hydrogen peroxide reacts completely in 20–30 minutes, making it appropriate for treatment upstream of the source of a problem. But hydrogen peroxide is consumed rapidly, making it less effective for treatment in long reaches of a collection system. It is considered hazardous, requiring a secure site for storage and careful handling, and has a limited shelf life.

Chlorine is a strong oxidant that can be purchased in many forms—pure gas, hypochlorite solution, or tablets. Chlorine reacts with hydrogen sulfide along with numerous other compounds. The most common form of chlorine used for sulfide control is sodium hypochlorite solution. The main reaction with hydrogen sulfide is:

$$HS^- + 4Cl_2 + 4H_2O \rightarrow SO_4^- + 9H^+ + 8Cl^- \text{ (at acidic pH)}$$

Due to the side reactions with other compounds in wastewater, overfeeding of chlorine is needed to ensure complete oxidation of sulfide. Actual practice has shown that 10–15 parts by weight of chlorine are required to oxidize 1 part by weight of sulfide.

Potassium permanganate is another storage oxidizer that reacts with hydrogen sulfide. Actual dosage rate can vary between 6 to 14 parts of potassium permanganate per part sulfide. Potassium permanganate is normally purchased in crystalline form, and must be mixed as a solution prior to dosing. It is commonly used to reduce odors from sludge dewatering processes.

10.3.3 Oxygen Injection

The addition of pure oxygen or air directly into wastewater increases the amount of oxygen available to bacteria, preventing the generation of hydrogen sulfide. Oxygen is preferred as it is five times more soluble in water than air, requiring a smaller volume to achieve the same oxygen transfer. On-site oxygen generators are available for installation, or oxygen can be purchased in liquid form. Injection sites are typically force mains as the higher pressure ensures the oxygen stays in solution. Dosage rate is determined by the oxygen uptake rate in the force main and the wastewater detention time.

10.3.4 Nitrate Addition

Nitrate addition aids in hydrogen sulfide removal by two means: prevention of formation of sulfide, and biological oxidation of sulfide. Nitrate addition prevents the formation of sulfide by providing a substitute source of oxygen. When the dissolved oxygen in wastewater is depleted, bacteria will preferentially use nitrate, rather than sulfate, as a source of oxygen; hence, nitrogen gas and other nitrogenous compounds are produced instead of sulfide. Nitrate removes sulfide by providing oxygen to bacteria, which metabolizes the hydrogen sulfide.

In prevention mode, theoretical dosage rate is approximately 10 parts nitrate to one part sulfide on a mass basis. In removal mode, theoretical dosage rate is approximately 3 parts nitrate to one part sulfide on a mass basis. Actual dosage rates are higher. Reaction times for nitrates are typically 1–2 hours; therefore, locations upstream of odor or H_2S problem areas need to be identified. There are minimal hazards associated with storage and handling of nitrate salt solutions.

10.3.5 Iron Salts

Iron salts and some other metals combine with dissolved sulfide to form a relatively insoluble precipitate. The four most common types of iron salt solutions used for sulfide treatment are ferrous sulfate, ferrous chloride, ferric sulfate, and ferric chloride. Iron salts are fast-acting, but, unlike oxidizers, do not react with other organic material in wastewater, which means overdosing is possible without unnecessary or unwanted side reactions. Iron precipitate is typically added in gravity portions of a collection system, and will contribute to additional solids at a treatment plant. Typical dosage rates are 3.5–4 parts of iron salts per part of sulfide treated on a weight basis.

Iron salts have been combined with an oxidizer, typically hydrogen peroxide, for a more complete and cost-effective treatment of sulfide. In this process, iron is introduced upstream and reacts instantaneously; hydrogen peroxide is added downstream, after the iron has reacted with the sulfide and regenerates the iron, allowing for further reaction while oxidizing to elemental sulfur.

10.3.6 pH Adjustment

The pH of wastewater is a significant factor affecting the release of hydrogen sulfide gas. A change in pH of 0.5 units can have a considerable effect on the proportion of hydrogen sulfide available for release as a gas from wastewater. Magnesium hydroxide, a commonly used chemical for pH adjustment, is capable of holding dissolved sulfide in solution at a pH of approximately 8.5. Magnesium hydroxide is a non-hazardous slurry that must be kept mixed. Sodium hydroxide has also been used for sulfide control, mostly via “shock dosing” to achieve a high pH (>12.0), short-term (20 min) slug that inactivates a sulfide-producing slime layer. The dosing is repeated every 3–10 days.

10.4 Covers and Enclosures

10.4.1 Description

The objectives of odor containment are as follows:

- Prevent escape of odorous gas to the atmosphere
- Minimize volume of air to be treated
- Allow reasonable access to process for inspection and maintenance
- Ensure worker safety

Table 10-3 summarizes various types of containment alternatives applicable to wastewater treatment facilities. These range from simple flat plates to large geodesic domes. The objectives of odor containment cannot be satisfied with one type of containment option for all odor sources; an engineer must consider multiple factors when making a selection.

10.4.2 Design Basis

Materials Selection: Covers should be fabricated from materials that can withstand prolonged exposure to humid, corrosive atmospheres containing elevated levels of H_2S. Typical materials include aluminum, fiberglass-reinforced plastic (FRP), and stainless steel. Various synthetic fabrics and membranes have also been used. Table 10-4 summarizes the advantages and disadvantages of these materials.

Design Loadings: Design loadings will vary depending on the material selected, intended application, and geographical location. In general, design loadings should meet or exceed local and state building codes.

Table 10-3 **Summary of Containment Options**

Type	Applications	Advantages	Disadvantages
Flat plates	Channels, grit chambers, effluent launders	Minimizes air volume for treatment	Reduces access; may accelerate corrosion
Flat plates with integral or external reinforcement	Longer spans—e.g., aeration basins, primary clarifiers	Minimizes air volume for treatment	Reduces access; may accelerate corrosion
Full domes	Circular clarifiers, thickeners, holding tanks	Easily accessible by workers	Results in very high air volumes requiring treatment; high capital cost
Low-profile domes or arches	RBCs, clarifiers, sludge holding tanks, thickeners	Reduced air volumes	More limited access to process than full domes
Domes with suspended ceilings	Circular clarifiers, thickeners, holding tanks	Somewhat reduced air volumes; easily accessible by workers	High capital cost
Equipment enclosures	Sludge dewatering and conveyance equipment, screens, mixing tanks, etc.	Minimizes air volumes; improves working conditions	Access to equipment may be more difficult; may accelerate corrosion
Diffusion into activated sludge basins	Low	Economical if existing blowers or diffusers are used	Simple; low O&M; effective, reliable
Odor counteractants	High	Operating cost dependent on chemical usage	Low capital cost

Table 10-4 **Materials of Construction for WWTP Process Covers**

Material	Advantages	Disadvantages
Fiberglass-reinforced plastic (FRP)	Resistant to H_2S corrosion and chemical attack Lightweight Can be molded into many shapes	Must be protected against UV attack Proper specifications and good quality control essential for long life
Aluminum	Resistant to H_2S attack Lightweight Good structural strength	Limited variations in shape available Subject to attack by some chemicals
Stainless steel	Resistant to H_2S corrosion High structural strength	High cost Subject to attack by some chemicals
Polycarbonate	Clear polycarbonate allows visual inspection of process Useful for custom enclosures	Polycarbonate requires regular cleaning Subject to abrasion, hazing
Fabric or membrane	Lightweight Lower capital cost	Poor structural qualities Not well demonstrated for WWTP applications

Covers should support the weight of a worker, even in areas where worker access is not anticipated.

Corrosion Protection: Covering of channels and basins and the enclosure of equipment can greatly increase the potential for corrosion because of the presence of H_2S and water vapor. If H_2S levels in excess of 10 ppm are expected, corrosion control measures must be taken to protect both concrete and steel surfaces. Generally, control measures involve preparation of a surface followed by application of a protective lining or coating system. PVC linings, bonded to a prepared concrete surface, provide an effective barrier against sulfuric acid attack. Many coatings are available, and it is critical that a coating system withstand exposure to H_2S, sulfuric acid resulting from biochemical oxidation of H_2S, and high humidity. In general, high-build (i.e., greater than 50 mil) epoxy or epoxy mortar coatings have been relatively successful. Coal tars are not recommended. Proper surface preparation and coating application procedures are essential to ensure long-term protection.

10.4.3 Equipment Features

Covers should fit as tightly as possible to prevent the escape of odors. Elastomer gaskets are generally used to provide a good seal. Make-up air inlets are normally not necessary as make-up air typically enters through seams in a cover system.

Hatches and doors should allow for inspection and maintenance of processes and equipment.

10.4.4 Operating and Maintenance Considerations

The number and location of hatches and removable panels will depend on the type of process and the need for access for inspection, cleaning, and equipment maintenance. For example, primary clarifier or gravity thickener weirs may be cleaned daily so hinged covers are generally preferred. Equipment such as a belt press requires frequent inspection so clear panel doors may be appropriate in an enclosure. The need for periodic replacement of major equipment components such as grit collector chains and aeration basin diffusers must be considered. For this reason, large sections of the covers should be removable.

10.5 Ventilation of Enclosed Spaces

10.5.1 Description

Ventilation of enclosed spaces is recommended to prevent buildup of combustible vapors, minimize escape of odors, reduce potential for corrosion, and provide a safe working environment for employees. Ventilation rates may vary widely depending on characteristics of the odorous air, degree of conservatism in minimizing the escape of odors, and use and accessibility of the enclosed space.

10.5.2 Design Basis

Criteria for establishing ventilation rates for covered processes are:

- Maintenance of a minimum negative pressure (e.g., 0.05 inch water column) to prevent release of odors.
- Provision of a safe working environment (e.g., H_2S less than 10 ppm) if the enclosure is designed to be routinely entered.
- Control of the buildup of combustible gases such as methane.
- Control of H_2S levels to reduce corrosion.

Ventilation rates for enclosed areas are usually expressed by number of air changes per hour (AC/hr), which can be calculated as follows:

$$\text{AC/hr} = \frac{\text{Exhaust air flow (cfm)}}{\text{Enclosed volume (cu ft)}} \quad 60$$

Table 10-5 summarizes typical ventilation rates for various covered processes. For recommended ventilation rates, the source widely used within the industry is the latest edition of NFPA 820: *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*. Examples provided here are no more than examples and are not intended to supersede NFPA 820. NFPA considers these ventilation rates to be the minimum necessary to reduce the possibility of accumulation of combustible vapors.

For covered channels, grit chambers, and effluent launders that are not routinely entered, the most important criterion is minimizing the escape of odors. NFPA recommends a minimum negative pressure of 0.1 inch water column (25 Pa) under all operating conditions. Consider the opening of hatches and inspection ports as part of routine operating and maintenance practices. Sizing of fans should be conservative as cover seals may deteriorate over time and hatches may be left open by operations staff. The application of the negative pressure criteria may or may not be necessary depending on the strength of the odor and how much escape is acceptable. Maintaining a negative pressure under all operating conditions may result in high airflow rates and large odor control systems that are difficult to justify.

Covering of odorous processes without ventilation is normally not recommended. If the area to be enclosed is a source of odors, it is likely to contain H_2S, which is corrosive at low concentrations and toxic at high concentrations, and organic matter that upon decomposition can generate methane gas, which is explosive. Even processes or channels that normally treat or convey aerobic wastewater can accumulate gases when taken out of service and the wastewater allowed to become septic.

Table 10-5 **Typical Ventilation Rates**

Process	Type of Containment	Air Exchange Method (air changes per hour)	Surface Area Method (cfm/sq ft)
Grit chambers and channels	Flat plate	6 to 18	0.5 to 1
Primary clarifiers	Dome (routine entry)	12 to >20[1]	–
Primary clarifier feed wells, effluent launders	Flat plate	6 to 18	0.5 to 1
Aeration basins	Flat with reinforcing ribs or external support	4 to 6[2]	0.5 to 1 + process air
Gravity thickeners	Dome (routine entry)	12 to >20[1]	–
Belt presses, screens, DAF units, etc.	Custom enclosure	12 to 30	0.5 to 1
Belt presses, screens, DAF units, etc.	Custom enclosure	12 to 30	0.5 to 1
Belt presses, screens, DAF units, etc.	Custom enclosure	12 to 30	0.5 to 1

1 Depending on the application, high air exchange rates may be necessary to maintain H_2S concentrations below OSHA-recommended exposure levels (e.g., 10 ppm)

2 Applicable to mechanically aerated basins; for diffused air systems, exhaust rate must exceed peak aeration rate to maintain negative pressure.

10.6 Wet Scrubbers

10.6.1 Description

Wet scrubbing is a common term for liquid absorption. A liquid “scrubs” the air clean by transferring airborne pollutants into the liquid stream. In wastewater treatment, the scrubbant liquid is typically water and the process occurs in an enclosed vessel. These mass transfer vessels are called wet scrubbers. The primary advantage of wet scrubbing is that most odorants can be isolated and removed by selecting the proper scrubbing solution contact time. The degree of air-to-water mass transfer, often called the percent removal, is affected by two primary factors:

- Air-liquid contact area and time
- Absorptive capacity of the liquid

The absorptive capacity of the scrubbant solution is related to the solubility of air contaminants. Solubility can increase and decrease for different compounds based on the pH of the solution. For example, hydrogen sulfide absorption improves with higher pH, while ammonia absorption improves with lower pH. Acids and bases are often added to the scrubbant solution to adjust the pH and optimize removal of target pollutants. Solubility is also affected by the buildup of materials that have been absorbed. If a scrubbant solution reaches saturation, removal efficiency would drop to zero regardless of contact area or time. To minimize the effects of saturation, oxidants can be added to the scrubbing solution. These additives will oxidize odorants by converting them into other compounds and creating more space for further air contaminant absorption.

Wet scrubbers are typically “packed” with a media that, when coated with scrubbant, increases the air-to-liquid contact surface area. When wet scrubbers were first employed at wastewater treatment plants for odor control, plants commonly used either packed-tower scrubbers or fine mist scrubbers; the latter utilize high pressure nozzles to create fine droplets of water to increase contact surface area. Due to maintenance and performance concerns with fine mist scrubbers, packed bed scrubbers are preferred.

Packet-tower scrubbers can be arranged in many different configurations to best match removal needs. In a vertical tower, airflow and scrubbant flow are normally counter-current to one another. In a horizontal or cross-flow scrubber, airflow is horizontal and scrubbant flow is vertical. The packing can be very porous to reduce pressure drop, clogging, and/or operating costs, or very intricate to increase surface area and removal efficiency. The packing can be randomly dumped or structured, and can be constructed of ceramic, plastic, or metal. The system can be one stage or multiple stages. The scrubbant could be recirculated or flow once through the tower.

To reduce the number of potential design considerations, a number of manufacturers have developed packaged wet scrubbing systems designed for odor control at wastewater treatment facilities. These systems are configured for typical wastewater odor, and normally use coarse nozzles, caustic addition to control pH, sodium hypochlorite to oxidize dissolved sulfide, and appropriate controls.

10.6.2 Design Basis

a. *Gas and Liquid Loading:* Scrubbing loadings are typically presented as weight-per-time divided by cross-sectional-area. The typical range for gas loading is 1,500–2,500 lb/ft^2/hr and the typical liquid loading is 2,500–4,000 lb/ft^2/hr. Gas and liquid loadings are discussed together here because they are directly related. Sufficient liquid is necessary to maintain a coating of liquid on the packing, but should not flood the packing. Flooding is directly affected by gas loading, since more gas loading per square foot adds turbulence, and also requires more liquid for sufficient removal capacity.

b. *Packing Bed Depth:* Ultimately, the removal efficiency of a packed-tower scrubber is determined by adjusting the packing depth. Through calculations and field testing, packing manufacturers have developed curves to determine the height of a transfer unit (HTU) for standard velocity. The number of transfer units (NTU) can be predicted by a ratio of the inlet to outlet concentrations via the equation, NTU = $\ln (C_{in}/C_{out})$.The total theoretical bed depth is calculated by the equation, HTU   NTU.

For example, a packing type with an HTU of 1.5 feet for H_2S and an NTU of 7 for a given removal efficiency will have a theoretical bed depth of 1.5 feet x 7 = 10.5 feet. A safety factor of 1.2–1.5 is recommended to account for operating variables such as short circuiting and fouling of packing over time.

In addition to standard safety factors, it is important to analyze whether competing absorptions and reactions can also affect HTU. For example, the HTU of hydrogen sulfide rises significantly in the presence of ammonia in the parts per million range. Essentially, ammonia must be removed in its own stage prior to hydrogen sulfide removal, or hydrogen sulfide will be limited.

c. *Chemical Feed System:* The chemical feed system consists of chemical metering pumps, chemical probes, an analyzer/controller to generate a 4–20 mA control signal used to pace the metering pump, and chemical storage and containment. The pump may be an electronic solenoid-actuated diaphragm pump or, for larger chemical demand, a motor-driven piston-actuated diaphragm pump with variable-speed drive. Diaphragm pumps are used because they have no metallic parts that will come into contact with the aggressive chemicals that they handle. Peristaltic pumps are becoming more popular for metering hazardous chemicals.

The chemical metering system typically feeds pH adjusters and oxidants. In wastewater treatment odor control, pH adjusters are often sodium hydroxide for acidic odorants (e.g., H_2S) and acid (i.e., sulfuric acid) for basic odorants. Oxidants can be bleach, hydrogen peroxide, chlorine dioxide, dissolved oxygen, or any other compound that has available oxygen to oxidize reduced sulfurs and nitrogen compounds. Sodium hypochlorite is the oxidant most commonly used in wet scrubber systems.

d. *Chemical Storage Tanks:* Chemical feed systems require on-site chemical storage. Based on dosage rates, storage can be in 55-gallon drums, totes, or bulk storage tanks. Most of the chemicals are toxic or hazardous, so the key to chemical storage is safety. A chemical containment area is necessary to collect any spill, and the tanks must be made of a corrosion-resistant material. FRP is often used for larger vessels because they can be made with corrosion- and UV-resistant resins. In some plants, chemicals are centrally stored in bulk storage tanks, with the chemicals pumped to smaller, remote day tanks.

e. *Recirculation and Blowdown:* The scrubbing solution in a packed-tower wet scrubber can be used in a single pass, whereby the liquid comes in contact with the odorous airstream only once and then is discharged back to the plant for treatment. Typically, however, the liquid is recirculated to reduce chemical costs. The fraction of the liquid stream that continually overflows a sump is called the blowdown. The blowdown is required to eliminate the potential buildup of salts. Salts form from the cations in the chemicals and from hardness in the water. Over time, the scrubber may accumulate salts that can foul the packing, resulting in decreased removal efficiency. This buildup can also be detrimental to system components such as pump seals. To prevent such buildup, the sump water is slowly replenished with fresh makeup water. Typically 1–5 percent of the scrubbant recirculation rate is discharged in the blowdown.

f. *Controls:* A pH probe is used to meter the pH adjuster. Since absorption of acid and caustic odorants directly affects pH, this is considered direct chemical control. An oxidation-reduction potential (ORP) probe is often used to meter the oxidant. ORP is a measure of the ionic potential of the liquid stream, which is an indicator of the oxidative power of the scrubbant solution. ORP is not an ideal control parameter, since it is affected by pH.

10.6.3 Equipment Features

a. *Reactor Vessel:* The scrubber vessel is often constructed from fiberglass reinforced plastic (FRP), although PVC and HDPE are also used. FRP is extremely corrosion-resistant and very versatile. It can be formed into many different configurations, does not expand drastically with changes in temperature as HDPE does, and its UV inhibitors can prevent the type of damage from the sun seen with PVC. Scrubbers are still made of PVC and HDPE if they are shielded from temperature fluctuations and sunlight.

Scrubbers that recirculate liquid include a sump. The sump can be internal (at the bottom of the tower) or external (such as below grade in a tank), or in a building. The vessel will also include an air inlet, packing bed with supporting grid, spray system, mist eliminator, and outlet. For larger systems, manways should be included for access to the sump area, packing area, and spray manifold. For smaller systems, manways may not be necessary if the system can be readily disassembled for maintenance.

b. *Packing:* Two types of packing are mainly used in odor control scrubbers—random dump packing and layered (or structured) packing. The packing can be ceramic (for higher temperature requirements such as for sludge drying or incineration), polypropylene, PVC, or a variety of corrosion-resistant materials. The packing bed usually consists of a large volume of individual balls, saddles, etc. Each packing has its own benefits and drawbacks. The choice of packing often depends on a variety of characteristics such as HTU, potential clogging/cleaning requirements, longevity, durability, and static pressure drop.

c. *Mist Eliminator:* Contact between the scrubbant and the packing will create a fine mist that can carry over out of a tower. This carryover can have its own residual odor. The system can be one stage or multiple stages, depending on the type of concentration of pollutants. For example, an airstream containing both ammonia and hydrogen sulfide would require both an acid stage and a hypochlorite/caustic stage. In a multi-stage system, chemical carryover from one stage may create additional chemical demand in the next stage. To avoid these problems, a demister or mist eliminator is included before the scrubber outlet.

There are three main mist eliminator options. The first is simply a smaller packing. In some cases, a 1-inch diameter packing may provide sufficient removal. This is the least effective option, but often the easiest to maintain. The second alternative includes overlapping layers of mesh pads. The mesh pads can be a random wire or structured mesh configuration. These are often the most effective, but they require more energy to overcome the added pressure loss and can be difficult to clean because of the density of the packing. The third option is a chevron style demister, in which mist is removed by impaction based on particle size. Chevron style demisters are highly effective over certain size ranges and easy to maintain.

d. *Pumps and Piping:* The recirculation pump must be corrosion-resistant and sized to provide the required recirculation rate against a specific head plus the expected increase in pressure from the buildup of materials in the packing and piping. Vertical pumps without seals or horizontal centrifugal pumps are typically used. The latter incorporates a seal that requires flushing with fresh water; in some cases, plant water can be used. Precautions must be taken to prevent vortexes within the sump that would lead to pump cavitation. Piping must be corrosion-resistant and sized to provide the proper backpressure to the pump.

e. *Fan:* Most wet scrubber systems are positive pressure systems, with the fan located on the inlet side of the treatment vessel; as such, corrosion-resistance is important. The fan and motor must be of sufficient capacity and horsepower to deliver the required system airflow against the combined static pressure drop of the scrubber operating with liquid flowing and associated duct work; the fan and motor must also deliver the necessary airflow as pressure is lost over time due to scaling and clogging. The most common type of fan is a centrifugal non-overloading model with a backwardly inclined blade.

f. *System Controls and Instrumentation:* The three main concerns in automating an odor control system are airflow, liquid recirculation, and scrubbant solution chemistry. Different systems may offer varying degrees of complexity, but the overall intent is to provide the required air/liquid ratio through the packing bed at the proper pH and ORP. By design, the airflow and recirculation rate are easily set and therefore should remain relatively constant. A differential pressure gauge and/or switch monitors the difference in static pressure between the system inlet and outlet. A sudden decrease in differential pressure may indicate the fan is not operating properly. A gradual increase in static pressure indicates fouling of the packing bed. In these cases, media cleaning via acid washing or replacement may be necessary.

10.6.4 Operating and Maintenance Considerations

a. *Pumps:* A recirculation pump should have a routine maintenance schedule. Discharge pressure and flow rate must also be monitored as an indication of the condition of the liquid recirculation system. A low flow rate accompanied by a high discharge pressure may indicate clogged spray nozzles or an obstruction in discharge piping. A low discharge flow rate with a low discharge pressure may indicate pump cavitation or an obstruction before the pump inlet. The flow of seal flush water must be monitored to ensure against the seal running dry and rupturing.

b. *Fan:* The condition of belts should be checked frequently. Loud squealing when a fan is started is not uncommon and indicates loose belts. Continuous belt noise indicates worn belts.

c. *Packing:* Almost all packing requires periodic cleaning. A drastic increase in differential pressure across the system indicates fouled packing. It is important to remove scale before it completely fouls the packing. Once packing is fouled, it likely must be replaced. If caustic is used in the scrubbing solution, the packing should be acid-washed every 3–6 months. To acid-wash a system, the sump must first be drained and filled with fresh water. This is a very important step: If acid is added to the high pH sump, a runaway acid-base reaction could occur that would produce high quantities of heat that would damage system components. Acid washing typically uses a separate portable feed system that slowly drops the pH by the addition of acid. Once the pH drops and can be maintained below 2–3 with normal blowdown, the system should operate for 30–60 minutes, after which the sump should again be drained and filled with fresh water. The system will then be ready for normal operation.

d. *Control Systems:* Routine maintenance includes cleaning and calibration of sensors, checking for obstructions in tubes for airflow monitoring devices, etc.

e. *Performance Monitoring*: Monitoring of scrubber performance via “sniff tubes” is recommended. These sniff tubes can be used to monitor outlet concentrations of specific odorants of concern. After initial system startup, a comprehensive performance test is usually conducted that may include stack testing, monitoring of inlet and outlet contaminant concentrations, and collection of samples for odor panel analysis.

10.7 Activated Carbon Adsorbers

10.7.1 Description

Activated carbon adsorption is effective for removing low levels of odorous compounds such as hydrogen sulfide, reduced sulfur compounds, and VOCs from air emissions at municipal wastewater treatment facilities. Granular activated carbon (GAC) is an effective adsorbent because it possesses a high surface area per unit weight, an intricate pore structure, and a primarily hydrophobic surface. Bituminous coal and coconut shell are the most widely used sources for manufacturing GAC, because they create an activated carbon with good physical properties and excellent porosity. Activated carbon made from coconut shell is preferred for use in VOC removal because of the greater retentivity of the coconut shell carbons for small VOC molecules. Chemically-enhanced bituminous coal carbons are commonly used in odor control applications in municipal wastewater treatment plants to remove hydrogen sulfide and other reduced sulfur compounds. The chemical impregnant (e.g., MgO) increases the low adsorption capacity of hydrogen sulfide. Mixed beds of media (i.e., a layer of impregnated GAC and a layer of coconut shell-based GAC) have been used for applications requiring simultaneous hydrogen sulfide and VOC removal. A lignite-based carbon has also been shown to provide high H_2S capacity without chemical modification.

10.7.2 Design Basis

Some basic elements to be considered in the design of an odor/VOC capture system are the size of the carbon bed, linear flow velocity of vapor through the bed, resistance to airflow by the bed, type and concentration of constituents, and temperature and relative humidity of the inlet gas stream.

a. *Bed Size:* The size of the carbon bed determines the size of the container required to hold the carbon and the amount of carbon to be used in the system. Although custom-sized containers are readily available, modular (i.e., standard sizes) are usually the most economical choice. GAC bed depths of 36–48 inches are typically used in odor control applications in municipal wastewater treatment plants, representing a residence time of 2.0–8.0 seconds (i.e., empty bed contact time).

b. *Contact Velocity:* The cross-sectional area of the vessel should allow a linear gas velocity through the carbon bed of 30–60 feet per minute (fpm). This linear gas velocity, also known as contact velocity, allows sufficient time for establishing adsorption equilibrium.

c. *Pressure Drop:* The particle size of carbon in the bed affects the resistance to flow of bases through the bed. For gas-phase systems, 4 x 6 and 4 x 8 mesh GAC are preferred. Resistance to gas flow through the carbon bed should be minimized to reduce power consumption costs and to prevent gas channeling through the bed.

The gas inlet and outlet size of the adsorbent should minimize pressure losses. The proper size will allow an exhaust air velocity of 2,000–3,000 fpm. The inlet should ensure proper gas distribution to maximize the use of the GAC in the lower portions of the bed.

d. *VOC Type:* Carbon adsorption capacity is greatly influenced by the type of organic compounds to be treated. Halogenated and aromatic compounds have higher adsorption capacities than oxygenated compounds such as alcohols, ketones, and aldehydes.

e. *Temperature Effects:* Increased exhaust air temperatures reduce the adsorption capacity of activated carbon, because the adsorption process is exothermic. This effect appears to be more significant at lower concentrations.

f. *Relative Humidity Effects:* The most efficient use of GAC for adsorption of VOCs occurs when the relative humidity of the airstream is at or below 50 percent. For a saturated stream, this usually is accomplished by increasing the air temperature by 20°C. For carbon media designed for H_2S removal, humidity of the inlet air is less critical.

10.7.3 Equipment Features

a. *General:* Materials of construction should be carefully selected. Exhaust airstreams frequently contain contaminants exhibiting corrosive properties. The materials of construction and unit design must be suitable for the system pressure and meet building code requirements. The preferred material of construction for carbon adsorbers in municipal wastewater treatment plants is FRP, although other materials such as polyethylene are used.

b. *FRP Adsorber Vessels:* The carbon adsorber vessel should be fabricated in accordance with the following codes and standards:

- Uniform Building Code
- ASTM D-3299 *Filament Wound Glass Fiber Reinforced Polyester Chemical Resistant Tank*s
- ASTM D-833 *Definitions of Terms Relating to Plastics*
- ASTM D-2583 *Tests for Indentation, Hardness of Rigid Plastics by Means of Barcol Impressor*
- FRPI SP9000 *Laminating Process Certification* (vendor qualification)
- FRPI SP9100 *Laminate Certification* (product quality verification)

c. *Resin System:* The resin used in the corrosion liner and in the structural shell should be a premium BIS-A epoxy vinyl ester resin, with the brominated fire retardant in the structural portion (FRPI LS 601)

Each carbon adsorber vessel should include the following accessories:

- *Manometer*: A manometer should be provided to continuously monitor pressure drop across the carbon bed.
- *Sample Probes*: Each vessel should have three sample probes per bed that extend a minimum of 12 inches into the bed. The sample probes should provide suitable extraction of carbon samples from the carbon bed. The sample probes should extend outside the vessel wall, and should be blocked off with a ball valve constructed of CPVC.
- *Grounding Rod*: A stainless steel rod should be provided to adequately ground each carbon bed.

d. *FRP Centrifugal Fan:* The centrifugal blower should be the centrifugal, belt-driven type constructed of high-quality, corrosion-resistant FRP.

All parts of the fan should contact the airstream, including the rotor housing and inlet. The material should withstand attack from saturated hydrogen sulfide gas. All parts coming into contact with the gas should be spark-proof.

The fan should have the following standard features:

- *Wheel*: Use a backwardly inclined wheel of solid FRP.
- *Drive Assembly:* Belts should be oil-, heat-, and static-resistant, and oversized for continuous duty. Shafts should be turned, ground, and polished, and keyed at both ends.
- *Bearings:* Heavy-duty, self-aligning, pillow-block bearings are standard.
- *Shafts*: These should be constructed of heavy-duty 304 stainless steel and provided with a shaft sleeve constructed of FRP.
- *Shaft Seal:* A fiberglass and neoprene shaft seal must be placed where the shaft leaves the housing, along with a neoprene shaft slinger between the seal and wheel on the belt drive unit. This seal is not sealed against gas leaks.

- *Bases:* Heavy-gauge, hot-rolled steel (epoxy-coated) is preferred.

The fan should also have the following accessories:

- Flanged and drilled inlet and outlet
- Drain (heat trace if installed outdoors)
- Approved OSHA belt and shaft guard

The fan motor should be TEFC, energy-efficient, 1.15 service factor, and 230-460 V/3 Phase/60 Hz.

e. *FRP Ductwork:* The FRP ductwork should be fabricated in accordance with the following standards:

- ASTM D3982 *Contact Molded Fiberglass Duct and Hoods*
- ASME RTP-1 *Reinforced Thermoset Plastic Corrosion Resistant Equipment*
- FRPI SP9000 *Laminating Process Certification* (vendor qualification)
- FRPI SP9100 *Laminate Certification* (product quality verification)
- ASTM covers, cylinders, fittings, body flanges, and support spacing guidelines for ducting. ASME is a pressure vessel standard, which, for ducting, can be looked to for filament wound cylinder design (Parts 2 and 3) and drain or instrumentation nozzles construction with 150 pound dimensions (Article 4-400)

The resin should be a premium brominated fire-retardant epoxy vinyl ester resin. A paraffin wax coating with UV inhibitor should be applied on the outside. Specify FRPI Laminate Specification LS 600.

f. *Dampers:* Suitable sized dampers should be provided as follows:

- Balancing damper between the fan outlet and carbon adsorber inlet
- Isolation damper at the carbon adsorber inlet and outlet

The dampers should be flanged and drilled in accordance with ASTM standards and should withstand 10 inches of water column (w.c.) pressure. Fiberglass axles should extend for the full length of the blade and 6 inches beyond the frame. Dampers should be equipped with a full circumference blade seal to limit leaks to less than 3 cfm/sq. ft. at 10 inches w.c. Isolation dampers should be interlocked with fans to close upon fan shutdown or failure.

g. *Demister:* A demister/grease eliminator should be considered upstream of the carbon vessel to:

- Remove excess water vapor.
- Condense semi-volatiles such as grease aerosols that might otherwise foul the carbon.

10.7.4 Operating and Maintenance Considerations

a. *Carbon Replacement:* When replacement of spent carbon becomes necessary, carbon can be removed from a unit and replaced with fresh carbon. For some catalytic carbons, partial regeneration can sometimes be accomplished within the vessel. If the impregnated carbon is regenerated in situ with caustic, adequate safety provisions as outlined in the manufacturer's operation and maintenance manual must be followed. Accessibility to the carbon must be taken into consideration. When replacing spent carbon, container access must allow for removal according to the method adopted.

b. *Media Testing:* An analysis of the carbon bed should be conducted periodically to estimate the remaining life of the GAC. The following tests should be performed:

- Hydrogen sulfide breakthrough capacity
- Volatile matter (ASTM D-3175)
- Xylene moisture (ASTM D 2867)
- Sulfur content by extraction

10.8 Biofiltration

10.8.1 Description

Similar to dry media scrubbers, biofilters use a porous media bed to absorb/adsorb compounds from an airstream. However, biofilters rely on microbial degradation of the absorbed/adsorbed compounds to renew sorptive capacity rather than on frequent media replacement. The process for air distribution and support of the media can vary from custom engineered systems to packaged proprietary systems or components. Biofilters can be open to the environment, covered, or totally enclosed for a stack discharge. Biofilters are effective in removing the hydrogen sulfide and mercaptan odors most common in wastewater applications as well as a wide range of other contaminants. Biotrickling filters are a similar technology that is addressed in Section 10.9.

10.8.2 Design Basis

a. *Media Characteristics:*

Properties: The media must provide proper conditions for microbial growth, along with the necessary structural characteristics for maintaining porosity even under water-saturated conditions. Media with high moisture-holding capacity can be desirable in systems that experience drying conditions. However, during periods of net excess moisture, the media can saturate to the maximum level. If porosity is not maintained during saturated conditions, contaminant removal performance will be reduced and pressure drop will increase significantly. A large buffering capacity can be desirable to counteract the tendency for media to consume alkalinity during contaminant degradation, and to thereby maintain pH in the desired range. In cases where a very homogeneous gas stream is being treated, the media may need to be the source of essential nutrients.

Materials: The media for biofilters have evolved significantly, and are a critical consideration in the potential benefits of proprietary systems. Most custom engineered systems and many proprietary systems utilize a media with a wood-based structural component such as wood chips, hog wood (tub ground waste wood), or bark nuggets. The primary alternative is an inorganic structural matrix, which can include lava rock, Leca pellets, crushed stone, plastic packings, and other proprietary products.

Wood-based media are often mixed with compost, peat, or bark mulch. While compost, peat and bark mulch have been used extensively in the past, and can exhibit a high contaminant removal capacity, they can have problems with low porosity under moisture-saturated conditions. As a supplement to a wood-based structural matrix, compost has the most desirable characteristics, including typically a range of nutrients and microbial seeding. Consequently, the removal characteristics of wood-based structural components can be enhanced by adding compost at volumetric ratios of 5-to-1 to 10-to-1. However, many applications have been successful without any compost component. Softwoods are typically favored over hardwood sources, because hardwoods are subject to higher degradation, which leads to loss of porosity. However, softwoods have higher oil levels, which contribute to residual odor levels in the exhaust. Porosity of the media will typically decrease over time until replacement is required to restore removal performance and to reduce pressure drop. A useful life of no more than 2 to 4 years should be expected for wood-based media.

Media with an inorganic structural matrix will typically have the advantage of a longer expected life, but require careful consideration of moisture-holding capacity, nutrients, buffering capacity, and microbial seeding. Similar to wood-based media, supplementing the structural matrix with compost at volumetric ratios of 5-to-1 to 10-to-1 is typically desirable to address these concerns.

b. *Detention Time:* Contaminant removal is a function of media removal capacity and detention time. Detention times as low as 10 seconds can be adequate for dilute airstreams with high performance media, but concentrated airstreams can require detention times as high as 3–5 minutes with some media. Typical detention times are 20–60 seconds, and are highly dependent on the contaminant loading and the media. Temperature also plays an important role in the necessary detention time for typical wastewater applications involving hydrogen sulfide and mercaptan odors. Suppliers of proprietary systems should be expected to provide documentation of removal capacity versus detention time and temperature.

c. *Bed Depth:* The allowable bed depth depends in great part on the structural characteristics of the media. For media with high proportions of compost, a 3-foot bed depth is commonly used to limit pressure drop through the media. Bed depths of up to 6 feet are commonly used when the media has adequate structural characteristics and porosity.

d. *Gas Pretreatment:* The airstream into the biofilter may need to be treated to ensure proper temperature, relative humidity, particulate loading, and ammonia loading.

Temperature: Control of the airstream temperature will maintain the bed temperature in the range needed to sustain biological degradation of adsorbed contaminants. At lower temperatures, microbial activity is reduced, affecting the ability of a biofilter to renew sorptive capacity. At higher temperatures, microbial diversity may be reduced, affecting the ability of a biofilter to treat certain compounds. For hydrogen sulfide, optimum removal rates occur in the temperature range of 25°–50°C. At 10°C, the removal efficiency for hydrogen sulfide drops to 20 percent of the optimum level. Mercaptans follow a similar trend, since the degradation pathways typically lead to hydrogen sulfide as a by-product.

Relative Humidity: Moisture content of the media can be maintained by minimizing moisture loss and by direct water applications. In general, minimizing moisture loss should be the first priority, and should be achieved by humidifying the inlet airstream to near-saturated conditions.

Particulates: Particulates are present to some degree in all airstreams. Consequently, an air distribution system should be designed to allow removal of accumulated particulates. In cases where elevated particulate levels exist, a preliminary particulate removal system may be necessary before the biofilter.

Ammonia: Ammonia is an example of a specific compound that may need to be removed before a biofilter to ensure adequate performance. While microbial mechanisms exist to control ammonia in the biofilter at lower concentrations, applications such as composting can release elevated levels of ammonia, which can have a toxic effect on a biofilter. Wet scrubbing to remove ammonia should be considered when loading rates exceed 0.16 g N/kg dry media/day.

e. *Moisture Control:* The moisture content of the media can be maintained by direct water applications. Surface sprinklers or drip irrigation hoses buried in the media may be used for direct water addition to the media.

f. *Percolate Collection:* When water is applied to a biofilter, a portion is typically absorbed by the media and the remainder passes through, creating a percolate. Characteristics of the percolate will depend on the quality of the incoming air and the biofilter design. Monitoring of percolate has shown BOD levels of several thousand milligrams per liter. Systems with high sulfide loading can have low pH in the resulting percolate, while systems with ammonia loading will tend to have elevated levels of nitrogen. Containment of biofilters should be considered necessary unless it can be shown that the potential adverse effects of a system's percolate on groundwater are negligible.

g. *Enclosure:* Biofilters can be designed open to the environment, covered, or fully enclosed. Covering or complete enclosure of a biofilter eliminates the impacts of rainfall, which can create excessive pressure drops; covering or complete enclosure also eliminates the effect of temperature extremes such as heat spells, which can dry out media and reduce its efficiency. A cover has the advantage of providing greater flexibility when using heavy equipment for media replacement. A fully enclosed unit allows the entire exhaust stream to be sampled.

Table 10-6 summarizes biofilter design criteria.

Table 10-6 **Biofilter Design Criteria Summary**

Item	Range	Typical
Empty Bed Retention Time, sec	30 to 120	45 to 90
Media Moisture Content, %	45 to 65	50 to 60
Media Depth, ft	2 to 6	3
Media Temperature, °C	5 to 45	15 to 37
Influent Gas Humidity, %	>95	>98
Media Nutrient Content, %		
Total Nitrogen		0.2%
Ortho Phosphorus		0.2%
Potassium		0.2%
Media pH	6 to 9	7 to 8

10.8.3 Equipment Features

a. *Fan:* For pressure drops in typical biofilter applications (i.e., up to 10 inches w.c.), centrifugal fans are usually preferred. Materials of construction should be based on the corrosivity of the airstream to be treated. A biofilter will typically exhibit a variable pressure drop because of media consolidation, seasonal variations in moisture content, and particulate buildup in the air distribution system. The fan must be designed for the maximum backpressure, but the control system must also accommodate lower backpressure conditions. Pressure monitoring should track changes in backpressure.

b. *Air Distribution System:* For in-ground biofilters, a piping system in crushed stone is the most common form of air distribution. Materials of construction should be based on the corrosivity of the airstream to be treated. If interruption of biofilter performance cannot be tolerated, the air distribution system should be divided into cells with a positive means of isolating the airflow to allow for media replacement and other maintenance. The distribution system should have sufficient structural strength to allow heavy equipment traffic during media replacement.

c. *Containment:* Conventional geomembrane lining systems can be used to contain in-ground air distribution systems. Concrete retaining walls, and sometimes floors, are commonly used as well. However, corrosivity of the percolate needs to be carefully considered, especially in applications with high levels of hydrogen sulfide and mercaptans. Protective coatings or membranes should be used in most cases. For containerized biofilters, materials of construction can include fiberglass, plastics such as HDPE, and stainless steel. Careful consideration is required of the suitability of the actual materials based on the anticipated corrosivity of the percolate.

d. *Humidification and Moisture Control Systems:* Humidification is often carried out in a spray chamber. Frequently, spray nozzles are mounted directly in the air distribution piping. The application rate for effective humidification will depend on the mean droplet diameter of the spray nozzles. Higher application rates are needed as mean droplet size increases. If excess spray chamber liquid is reused, it may be necessary to remove particulate scrubbed from the airflow. A small biotrickling filter can also be used as a humidification chamber. Taps should be provided upstream and downstream of the humidification chamber to allow monitoring.

Water hydrants for surface sprinkling should be located adjacent to a biofilter. Surface water applications can be carried out using conventional sprinkler systems. Soaker hoses and drip irrigation hoses are also commonly used, and can be embedded below the surface of a biofilter for protection from freezing.

10.8.4 Operating and Maintenance Considerations

The following O&M considerations should be addressed during the design of a biofilter.

a. *Moisture:* The moisture content throughout the entire depth of the bed should be checked monthly. During periods of net moisture loss from a biofilter, daily monitoring may identify any areas of dryness.

b. *Media Nutrient Levels:* The media need to have sufficient nutrient levels to support the microbial population responsible for contaminant degradation. The use of compost as a supplement for the media will typically ensure adequate nutrient levels. If necessary, additional nitrogen, ortho-phosphorus, and potassium can be added by surface-applying conventional agricultural fertilizers or using water-soluble nutrients as a supplement to the water supply for the direct moisture addition system.

c. *Media pH:* The pH of the media will tend to drop with time as alkalinity is consumed during the degradation of contaminants, particularly hydrogen sulfide and mercaptans. Quarterly pH monitoring of the media should track pH drop. The pH can be raised back to the desired level through lime addition to the surface of the bed. It should be noted that low pH at the bottom of a bed is not necessarily problematic. Some hydrogen sulfide consuming bacteria prefer a low pH environment. However, degradation of mercaptans and other contaminants will be inhibited by low pH.

d. *Compaction:* As wood-based media degrades, the media will consolidate, reducing actual detention time and increasing pressure drop.

e. *Vegetation Control:* Plant growth on the surface of a biofilter contributes to the loss of moisture from the media because of transpiration. In most cases, this loss of moisture is undesirable. Tilling of the surface is commonly used to control plant growth and to restore the porosity of areas subject to water compaction at the surface.

f. *Performance Monitoring:* Outlet samples from open biofilters can be collected using a hood device over the surface of the bed. Multiple samples should be collected over the surface of the biofilter to ensure representative results. Velocity measurements from the outlet of the hood can determine the localized flow rate.

10.9 Biotrickling Filters

10.9.1 Description

As a form of biological odor scrubbing, biotrickling filters are similar to biofiltration. Both rely on a wetted porous media to absorb/adsorb compounds from an airstream, and the sorptive capacity is renewed through microbial degradation of the absorbed/adsorbed compounds. Biotrickling filters differ from biofilters primarily in that the media tends to have a lower moisture-holding capacity, and requires a more active moisture control system. Biotrickling filters are typically enclosed packaged systems, although it is possible to custom engineer a system. Biotrickling filters are effective in removing the hydrogen sulfide and mercaptan odors most common in wastewater applications as well as a wide range of other contaminants. Biotrickling filters are considered particularly effective in handling very high concentrations of hydrogen sulfide (up to 400 ppm) that can cause acidification of biofilter media. Biotrickling filters need a consistent food source to establish the desired microbial population for contaminant removal, and are not considered as effective in handling spikes in inlet air concentrations.

10.9.2 Design Basis

a. *Media Characteristics:* For biotrickling filter applications, the media are typically constructed from a non-degradable material. The media must provide a high surface area for microbial growth and high porosity to limit headloss even under water-saturated conditions. Unlike biofilter media, biotrickling filter media is not typically a source of nutrients or buffering capacity, which are addressed by a water addition system. A wide range of products have been used for biotrickling filter media including plastic packings, sponges of various materials, fiber mesh, lava rock, Leca pellets, and combinations of materials. One manufacturer uses rolls of a combination fiber mesh of varying sizes and sheet plastic.

b. *Detention Time:* Contaminant removal is a function of media removal capacity and detention time. Detention times as low as 10 seconds can be adequate for certain applications, but typically range from 20 to 40 seconds depending on contaminant loading. Higher removal rates can be achieved with greater detention time, but system cost may become prohibitive. Temperature also plays an important role in the necessary detention time for typical wastewater applications involving hydrogen sulfide and mercaptan odors. Suppliers of proprietary systems should provide documentation of removal capacity versus detention time and temperature.

c. *Bed Depth:* Allowable bed depth depends on the structural characteristics of the media. For plastic packings, individual stages of 10 feet or more are possible. For rolls of fiber mesh pads and sheet plastic, stages of 3.3 feet (1 meter) have been common. Manufacturers should be consulted for specific recommendations.

d. *Temperature:* Bed temperature is maintained by the airstream temperature, and needs to be in the range needed to sustain biological degradation of adsorbed contaminants. Loadings will typically be reduced during colder periods of the year, but the ability of a biotrickling filter to treat anticipated cold weather loadings needs to be carefully evaluated. For hydrogen sulfide, optimum removal rates occur in a temperature range of 25–50°C. At 20°C, the removal efficiency for hydrogen sulfide is about 90 percent of the optimum level, while at 10°C, the removal efficiency for hydrogen sulfide drops to about 30 percent of optimum. Mercaptans follow a similar trend, since the degradation pathways typically lead to hydrogen sulfide as a by-product.

e. *Moisture Control:* The method of wetting the media can be either a once-through water addition system or a recirculating system. For hydrogen sulfide and mercaptan applications with a vertical flow vessel, the once-through approach is generally favored. The inlet air is introduced to the bottom of the vessel, and the water is introduced to the top of the media. The water addition rate can be limited so the bottom layers of the media have low pH, which is favorable for hydrogen sulfide removal. The water addition rate should be selected to maintain the upper portion of the media at neutral pH, which is needed for degradation of mercaptans and other odorous compounds. By comparison, a recirculating water addition system requires the liquid pH be maintained at neutral for applications involving mercaptans and other compounds. The once-through approach will generally have lower power consumption. Some manufacturers utilize a recirculating mode during the initial start-up phase to help promote seeding before changing over to once-through for the long-term operation.

The preferred water source in wastewater applications is plant effluent, which provides the necessary nutrients for growth of the microbial populations responsible for contaminant degradation. When plant effluent is used, it is important that the chlorine residual is low and does not impact biological activity. It is also important that solids in the plant effluent are low and do not cause clogging in the water distribution system or media. When suitable quality plant effluent is not available, a nutrient addition system should be provided. This typically consists of a make-down system for a water-soluble fertilizer blend (N-P-K) and a simple water injection system.

f. *Wastewater Discharge:* For once-through systems in hydrogen sulfide applications, the pH of the wastewater will typically be low and may require neutralization before discharge. For recirculating systems, the pH typically must be maintained neutral either by adding make-up water or chemical addition; as a result, neutralization is not required at discharge.

g. *Enclosure*: Biotrickling filters are typically fully enclosed, and in a cold weather climate, full enclosure is highly desirable for freeze protection.

Table 10-7 summarizes biotrickling filter design criteria.

Table 10-7 **Biotrickling Filter Design Criteria Summary**

Item	Range	Typical
Empty Bed Retention Time, sec	10 to 90	20 to 40
Media Temperature, °C	5 to 45	15 to 37
Bed Depth, feet	3 to 10	3 to 10, in multiple stages if necessary
Pressure Drop, inches w.c.	1 to 6	2 to 4

10.9.3 Equipment Features

a. *Fan:* Centrifugal fans are usually preferred for the typical pressure drop with biotrickling filters of 2–4 inches of water column. Materials of construction should be based on the corrosivity of the airstream to be treated. Fiberglass reinforced polyester (FRP) is common in corrosive applications. Biotrickling filters will typically exhibit a steady pressure drop, so constant speed operation is possible. Pressure monitoring should be provided to track changes in backpressure.

b. *Enclosure:* Materials of construction can include fiberglass, plastics such as HDPE, and stainless steel. Careful consideration is required of the suitability of the actual materials based on the anticipated corrosivity of the airstream and percolate.

c. *Air Distribution System:* A grating system is typically used to support the media above an air distribution plenum in vertical systems.

d. *Moisture Control Systems:* Water addition for once-through systems is usually from a pressurized plant water or process water source to a set of nozzles that distribute the liquid to the top surface of the media. Water addition is usually controlled by a repeat timer. Recirculating systems utilize a pump drawing from a sump in the bottom of the biotrickling filter, similar to a chemical packed-bed scrubber.

10.9.4 Operating and Maintenance Considerations

The following O&M considerations should be addressed during the design of a biotrickling filter.

a. *Moisture:* The moisture content throughout the entire depth of the bed should be checked monthly. For once-through systems, moisture loss due to humidification of inlet air may be higher during warm weather periods and require higher water addition rates than during cold weather periods. This is usually accomplished by increasing the time that the water addition system operates each hour.

b. *Media Nutrient Levels:* The media need to have sufficient nutrient levels to support the microbial population responsible for contaminant degradation. When plant effluent is used as the water source, nutrients are not usually a concern. If necessary, additional nitrogen, ortho-phosphorus, and potassium can be added by using water-soluble nutrients as a supplement to the water supply for a direct moisture addition system; typically, this addition of nutrients needs to be done only once a week.

c. *Media pH:* As noted above, for typical wastewater applications, the pH of the media will tend to drop due to the formation of sulfuric acid as a byproduct of the degradation of hydrogen sulfide. The hydrogen sulfide-degrading bacteria have peak removal efficiency at a pH of about 3.2; above this pH, they maintain a relatively high removal rate, which is generally equal to or greater than 80 percent of the optimum rate. As the pH decreases below 3.2, however, removal efficiency drops rapidly, and at a pH of 2, it falls to about 20 percent of the optimum rate. The typical control strategy is to adjust the water addition rate to control the pH of the percolate to maintain the desired pH at the bottom of the bed. (This desired pH is typically in the range of 2.5 to 2.8.) As previously noted, for applications with significant loadings of mercaptans and other odorants, maintaining the upper portion of the bed at a neutral pH is critical to effective overall performance.

10.10 Activated Sludge Diffusion

10.10.1 Description

Odorous air can be effectively treated by diffusion of the air into the mixed liquor of activated sludge aeration basins. Odorants are removed through a combination of absorption, adsorption, and biological oxidation. Most facilities that have used this approach have done so using existing blowers and diffusers associated with the activated sludge process. Unfortunately, few design criteria are available for new facilities. For a diffusion system designed exclusively for odor control, energy costs can be high. Diffusion of odorous air into anything other than an activated sludge basin is not recommended, as a high active biomass is necessary for effective removal of odorous compounds.

10.10.2 Design Basis

Design considerations include air loading rate (i.e., cfm/sq. ft.), coarse-bubble versus fine-bubble diffusers, diffuser depth, and equipment selection. Given the lack of design criteria specific to odorous air diffusion, a system should be based on use parameters established for aeration systems, including diffuser spacing, flow rate per diffuser, and diffuser depth. Limited data suggest that fine-bubble diffusers perform better than coarse-bubble diffusers. Diffusers should be placed as deep as possible to maximize detention time of the bubbles and mass transfer of the odorants into solution. Wide spacing of diffusers would seem preferable to distribute the loading of odorous compounds over a large area.

10.10.3 Equipment Features

Blowers, piping, and diffusers should resist attack from H_2S. Blower manufacturers should be contacted to determine the need for special protection of blower components (e.g., ceramic coatings on blower lobes). Stainless steel is recommended for piping as carbon steel will be directly attacked by H_2S. Air filtration is recommended for removal of particulates and protection of the blower. A two-stage filter system consisting of a 2-inch thick pleated paper filter followed by a 12-inch thick deep bed filter has been found effective for particulates and grease aerosols. As with any aeration system, pressure gauges, temperature gauges, and air relief valves should be provided on the blower discharge piping.

10.10.4 Operating and Maintenance Considerations

Periodically inspect diffusers and internal blower components for corrosion damage. Other O&M provisions associated with conventional aeration systems also apply.

10.11 Thermal Oxidation Systems

10.11.1 Description

Thermal oxidation is a very effective means of destroying odors and VOCs that are primarily organic, because organic compounds are completely oxidized to carbon dioxide and water vapor. In general, thermal oxidation is not recommended for inorganic odors composed primarily of sulfur and nitrogen, such as H_2S, NH_3, and sulfides. The reason is twofold: First, combustion of sulfur- and nitrogen-based compounds will form sulfur dioxide and nitrogen oxides, which are odorous as well as criteria air pollutants. Second, SO_2 can form sulfuric acid, particularly in the final stages of heat recovery systems where the flue gas temperature is lowered, and condensation of acid gases may occur, causing severe corrosion. Low levels of sulfur- and nitrogen-based compounds can be incinerated provided concentrations of SO_2 and nitrogen oxides in the flue gases are low and adequately dispersed in the atmosphere so that ground-level concentrations of these compounds are below detection limits. Also, the combustion and heat recovery system should be designed so the chance for condensation of acid gases is minimal. The flaring of landfill gas is one example of an instance where oxidation of significant levels of H_2S is commonly performed.

The four types of thermal oxidation systems are:

- Direct flame or flare.
- Recuperative.
- Catalytic.
- Regenerative.

All four types have been used extensively in industrial applications. For wastewater treatment plant applications, regenerative thermal oxidizers (RTOs) have several advantages over the other types of oxidizers and are more commonly used. Because RTOs apply to wastewater treatment plant applications, Sections 10.11.2 to 10.11.4 pertain only to RTOs.

Direct Flame: Direct flame or flare units are the simplest to operate and have the lowest capital costs, but are the most costly to operate because no heat recovery is provided. Therefore, direct flame oxidizers are usually used on fume streams that are sufficiently concentrated to sustain autogenous combustion. For dilute airstreams, direct flame units are usually considered for only low-flow cases of less than 2,000 cfm.

Recuperative: Recuperative thermal oxidizers use heat exchange tubes to transfer thermal energy from hot combustion flue gases to the inlet airstream. Recuperative oxidizers are typically designed for operating temperatures of 1,500–1,600º F and residence times of at least 1–2 seconds. Present day units are capable of VOC destruction efficiencies of 95–98 percent, and can achieve thermal efficiencies of 75 to nearly 80 percent. Even with this relatively high thermal efficiency, the fuel cost of operating these units can be high if a large airflow is to be treated. The most important limiting factor with recuperative oxidizers is their metallic heat recovery tubes, which are susceptible to corrosion from condensation of acid gases. At wastewater treatment plants, most odorous airstreams contain H_2S or other reduced sulfur compounds, which would render the heat recovery sections susceptible to corrosion. Metal construction recommendations are as follows: For H_2S levels up to 10 ppm, Type 316 stainless steel should be considered. For H_2S levels greater than 30 ppm, use of a medium nickel alloy with 20–30 percent nickel should be considered. If, as a result of the combustion of chlorinated hydrocarbons, chlorides are present (even at low concentrations of a few ppm), then use of medium nickel alloy is warranted.

Catalytic: In catalytic oxidizers, the presence of a catalyst allows oxidation of an organic vapor or solvent to take place at a lower temperature (typically 800–1,100°F) and without a flame. Catalytic oxidizers are capable of high VOC destruction efficiencies of approximately 95 percent or more. The catalytic element is usually a ceramic fixed grid or honeycomb structure coated with platinum, palladium, or other rare earth metals. The use of catalytic units is generally limited to pure organic vapors and solvents with low residual ash content, which will not clog or coat the catalytic surface. Because of the presence of sulfur in most odorous airstreams at wastewater treatment plants, catalytic oxidizers are generally not recommended.

Regenerative: An RTO essentially consists of a combustion chamber with gas-fired burners and 2–3 heat recovery chambers filled with inert ceramic packing media or saddles. The RTO is equipped with inlet and exhaust manifolds with flow diverter valves that alternate the flow of cool inlet air and hot flue gas through the heat recovery chambers. Each chamber alternately absorbs heat from the flue gas and then releases this heat to the inlet airstream, preheating the inlet air. By switching the flow of flue gas and inlet air from chamber to chamber, a high degree of heat recovery can be attained. Overall thermal efficiencies of 90–95 percent are possible, which results in low fuel use. An RTO can achieve very high VOC destruction efficiencies of 95 to nearly 99 percent. RTOs can be used on odorous airstreams with moderate levels of H_2S and NH_3 since the ceramic saddles and refractory lining in the head recovery and combustion chambers are resistant to these compounds and their acids. Note that the inlet and outlet plenums and diverter valves on these units are susceptible to corrosion; the metal construction recommendations in the above recuperative section are applicable.

RTOs are now available in a variety of configurations with features such as different types of packing media (i.e., loose, structured, or gravel), purge air systems, and proprietary valve and manifold systems.

10.11.2 Design Basis

The primary criteria that determine the design of an RTO are airflow rate, thermal efficiency, VOC destruction efficiency, and particulate loading of the inlet air.

a. *Airflow Rate:* The inlet airflow or vapor rate determines the number and size (i.e., cross- sectional area) of the heat recovery chambers. Basically, the air velocity through the energy recovery chambers must be sufficient to provide turbulent flow as well as good mixing and contact of the airstream with the packing media. The RTO manufacturer will size the RTO based on certain air velocities for the particular size and type of packing media used. In general, RTOs have been designed and built for airflows from approximately 100 to 500,000 scfm.

b. *Thermal Efficiency:* The thermal efficiency of an oxidizer is a measure of the amount of thermal energy expressed as a percentage that is recovered from the combustion flue gases. A simplified formula for thermal efficiency is as follows:

$$\text{Thermal Efficiency} = \frac{T_c - T_{out}}{T_c - T_{in}}$$

Where: T_c = temperature of combustion chamber

T_{in} = temperature of inlet airstream

T_{out} = temperature of outlet or exhaust airstream

The greater the thermal efficiency of an RTO, the lower its fuel use. RTOs are typically designed with thermal efficiencies of 90–95 percent. The remaining 5–10 percent of the energy in the combustion flue gases must come from the combustible content of the inlet air or from auxiliary fuel firing, or from a combination of these two sources.

The thermal efficiency of an RTO is determined by the depth of packing media provided in the energy recovery chambers. The greater the depth of packing media, the higher the thermal efficiency. In general, with ceramic saddles, a thermal efficiency of 90 percent or greater requires a packing depth of approximately 8 feet. Thermal efficiency and packing depth do not vary linearly. To obtain a 2–4 percent increase in thermal efficiency at levels above 90 percent would require a significantly greater depth of packing. As packing depth increases, pressure drop through the RTO increases, and induced draft (ID) fan horsepower requirements increase. Thus, there is a tradeoff between maximizing thermal efficiency and keeping the ID fan horsepower requirements within a reasonable range. Fortunately, more efficient packing media (such as structured monolithic blocks) are now available, and thermal efficiencies of greater than 90 percent can be achieved with approximately 4 feet of packing. Thus, present-day units can achieve higher thermal efficiencies and require less horsepower to operate.

c. *VOC Destruction Efficiency:* An important feature of an RTO is that it can achieve VOC destruction efficiencies of 95 to nearly 99 percent. For many high-strength VOC sources, an RTO is the best available control technology (BACT) for VOCs. An RTO is usually required by its air permit to achieve a guaranteed VOC destruction efficiency. The VOC destruction efficiency of an RTO is determined by the following factors:

- Incinerator temperature and detention time in the combustion chamber, as well as the design of the chamber
- Amount of unoxidized fumes left in an energy recovery chamber when the chamber is switched to outlet mode, allowing the unoxidized fumes to flow into the exhaust duct and stack
- Amount of valve leakage at the flow diverter valves, which allows unoxidized fumes to leak from the inlet manifold to the exhaust manifold

An RTO combustion chamber typically minimizes short circuits and operates at 1,500°F with an average detention time of 1.5 seconds. Operation at higher temperatures does not significantly increase destruction efficiency.

Valve leakage is the one limiting factor that prevents RTOs from achieving greater than 99 percent VOC destruction efficiencies. Valve leakage is principally attributed to incomplete sealing of the valves. The valves are subject to approximately 20 to 25 inches w.c. negative pressure, and achieving complete sealing under these conditions is difficult. Recently, valves that seal more effectively have become available. However, even with these valves, the highest VOC destruction efficiency that can be consistently expected is 99 percent or fractionally higher (but less than 100 percent). It is recommended for permitting purposes that measures of VOC destruction efficiency be conservative. A VOC destruction efficiency of 98–99 percent should be considered a maximum. Odors are typically well controlled provided a combustion temperature of 1,400°F is achieved.

d. *Particulate Loading:* The particulate loading of inlet air should be considered in the design of an RTO installation. Because of the tight spacing of the packing media and the tortuous path of the airflow, the media essentially acts like a filter, collecting any dust or particulate matter in the inlet airstream. Continuous deposition of particulate matter over a long time period will eventually plug the media, causing the pressure drop across the chamber to increase to the point where the ID fan cannot draw the designed airflow through the unit; thermal efficiency of the unit will also be drastically reduced. Venturi scrubbers and wet electrostatic precipitators have been used successfully to remove particulate matter before it reaches an RTO. To avoid plugging problems, it is recommended that particulate matter in the inlet airstream be controlled to less than 0.01 grains per dry standard cubic foot.

10.11.3 Equipment Features

a. *Media:* Ceramic saddles randomly placed in the energy recovery chamber are the most common type of heat transfer media used in RTOs. Recently, 1/4–1/2 inch gravel has been used in smaller skid-mounted RTOs, which are available in standard sizes from 50 to 5,000 scfm. This gravel offers higher heat transfer rates, and results in more compact units than standard saddles. These units typically have a single bed with a flameless electric heating element in the middle of the bed. In general, gravel bed units are more prone to plugging, and are recommended only for clean air or pure solvent streams.

Structured ceramic packing in honeycomb grids is also now available. Benefits claimed for structured packing are lower pressure drop, less plugging, and easier installation and replacement.

b. *Refractory Lining:* The refractory lining in most RTOs is a lightweight modular ceramic fiber insulation that has very low thermal conductivity (i.e., high insulating value) and a maximum operating temperature of 2,400°F. For dirty applications where replacement of the media will eventually be necessary, more durable castable refractory linings are offered by some manufacturers.

c. *Valves and Manifolds:* Numerous types of valve and manifold design are offered by RTO manufacturers. Some systems use separate electric actuators at each flow diverter valve, while others use a single electric motor actuator connected by a drive shaft and links to each diverter valve. Diverter valves are butterfly valves constructed of cast iron or stainless steel, with integrated step seats to help minimize leaks. The valves should be installed on fully supported and level surfaces so that no uneven stresses, which might cause distortion, are transmitted to the valve or the valve seat. Manifolds are now designed with the diverter valves located above the inlet and outlet manifolds, so that the inlet airstream always flows upward through the valve. This arrangement allows moisture and condensation in the inlet stream to drop out before the valve seat, promoting a tight seal and minimizing maintenance of the valve. Recent RTO designs utilize double disk poppet valves, which minimize leakage and can achieve destruction efficiencies of 99 percent. Another innovation is the rotary unit that consists of a cylindrical vertical chamber with pie-shaped sections of structured packing. A single rotary valve at the bottom of the unit distributes airflow to the inlet and outlet heat recovery sections. These units are also capable of destruction efficiencies of 99 percent.

d. *ID Fan:* An RTO ID fan draws the process stream through the unit. A heavy-duty centrifugal fan is typically used. If significant levels of sulfur or chlorine are present in the inlet stream, consider constructing the fan housing out of 316 L stainless steel and the fan wheel out of Hastelloy C-276. Because of the relatively high pressure drop across an RTO (20–30 inches w.c.), fan horsepower requirements are high.

e. *Controls:* Flow diverter valves are automatically controlled by a programmable logic controller. Final adjustment of the sequencing is done by the manufacturer during initial startup testing. The temperature of the combustion chamber is controlled by thermocouples and temperature controllers that regulate the amount of fuel being fired by the combustion chamber burners. Airflow through an RTO is controlled by the ID fan, which is equipped with either an inlet vortex damper or a variable-frequency drive that regulates airflow through the unit by maintaining a slight preset negative pressure in the inlet duct to the RTO.

10.11.4 Operating and Maintenance Considerations

a. *Plugging of the Media:* The pressure drop across an RTO is a good indicator of the condition of the media, and must be continuously monitored. The pressure drop will gradually increase over time if deposition of particulate matters occurs. Some RTO manufacturers provide a bake-out feature that can raise the temperature of an energy recovery chamber to that of an incinerator to burn out any organic deposits. If the deposited material is inorganic, these systems will be of marginal valve in restoring a unit to its original pressure drop. Any upstream particulate control device should be operated and maintained in accordance with its original design criteria. For instance, operating an upstream Venturi scrubber at a lower pressure drop than its design criteria will subject an RTO to a high dust loading and greatly accelerate plugging of the media. At sludge dryer facilities, RTOs are typically used to control odors and VOCs in the dryer exhaust. At some of these installations, siloxanes volatilized from the sludge dryers have caused plugging problems in the RTOs. At one plant, these problems have been adequately addressed by monthly water washing of the ceramic media.

b. *Performance Monitoring:* Performance can best be monitored by checking the inlet and outlet VOC concentrations with a continuous emissions monitoring system (CEMS) or by periodic testing of VOC emissions. High VOC emissions likely indicate faulty operation of either the combustion chamber burners, temperature control system, purge system, or diverter valve control system. Alternatively, excessive valve leaks could be the problem. In time, valve sealing will tend to become less effective because of the buildup of impurities and scale on valve seats. Eventually, cleaning or resurfacing of the valve faces and seats will be required.

c. *Combustion and Energy Recovery Chambers:* The outer shell of the combustion chamber and energy recovery chambers should be monitored for hot spots (i.e., peeling paint and oxidized metal). Hot spots are an indication that the refractory lining on the inside has either fallen off its supports or that gaps have developed among the refractory modules. Burner tiles will typically need to be replaced in time. A complete internal inspection of an RTO should be conducted at least once a year.

d. *ID Fan*: On large RTO units, the ID fan should be equipped with vibration monitors and/or bearing temperature monitors to indicate an unbalanced condition of the fan. On small RTO units, periodic evaluation with a portable vibration monitor would be sufficient.

10.12 Dilution and Dispersion

10.12.1 Description

No odor control system is 100 percent efficient. Depending on the strength of the inlet odor and the odor removal efficiency of a treatment device, residual odor may need to be polished with another technology such as activated carbon adsorption, or the odor may be discharged up a stack for dispersion. Dilution may be accomplished by a mechanical fan designed to provide dilution of the exhaust or by using a high exhaust stack to improve atmospheric dispersion—or by implementing a combination of the two. The use of fans to provide dilution can significantly increase energy consumption and operating costs. In general, dilution and dispersion should be considered for exhausts from odor control systems, but should rarely be the principal means of odor mitigation.

It is important to consider the aerodynamic recirculation zones that exist around a building and nearby structures. Emissions should not be discharged into or trapped in these recirculation zones, because the zones minimize the dispersion and dilution effect. As a result, a stack is preferred over a roof exhaust fan. A horizontal-discharging exhaust fan is least desirable, and vertical up-blast exhaust fans are preferred. Sufficient emission exit velocity and temperature, which will improve the upward movement of a plume, are also desired. A rain cap or gooseneck design at the top of the stack will merely deflect the exhaust downward, and should be avoided. It is preferable to use a “no-loss” rain stack, which consists of a stack surrounded by an annular shell for drainage of water.

10.12.2 Design Basis

a. *Dilution Air Volume:* In some cases, fans are oversized to provide dilution of the exhaust with outside air. Dispersion modeling can be used to determine if the increased capital and operating costs of this approach are warranted.

b. *Stack Velocity:* The stack exit velocity should be kept between 2,000 and 3,000 fpm. This velocity will provide adequate plume rise, and will overcome the force of wind speed. This exit velocity should also prevent condensed moisture from draining down a stack, and prevent rain from entering a stack.

c. *Stack Height:* To avoid all aerodynamic recirculation zones of a building, a stack height that is 2.5 times greater than the building’s height is often recommended as good engineering practice (i.e., 1.5 times greater than building height above the roof). The plume rise because of upward momentum and temperature buoyancy can be considered part of the total effective stack height. Modeling can determine the optimum stack height.

References – Chapter 10

NFPA 820: *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*, 2008 Edition

WEF Manual of Practice No. 8, *Design of Municipal Wastewater Treatment Plants*, 5th Edition, 2010

CHAPTER 11

RESIDUALS TREATMENT AND MANAGEMENT

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11.1 General

11.1.1 Process Design

In selecting sludge treatment and disposal methods, the following elements should be considered:

- Overall capital and operating costs, including treatment and disposal costs
- Available methods of sludge disposal, including the use of sludge nutrients and sludge as fuel
- Control of odor and volatile organic compounds (see Chapter 10)
- Energy and chemical requirements
- Staffing requirements
- Complexity of equipment and process control
- Redundancy and standby requirements
- Toxic effects of heavy metals and refractory organics, if present, on sludge stabilization methods and on the environment
- Impact of recycle streams from thickening, conditioning, dewatering, stabilization, and other processes on the treatment plant
- Sludge storage requirements
- Environmental concerns related to air pollution, water pollution, traffic, and noise

11.1.2 Residuals Quantities

A sludge treatment system should accommodate the volume of sludge generated through the design period. Individual process sizing should account for sludge generation peaking factors appropriate for the size and type of facility, allowing for seasonal variations, industrial loads, and the type of collection system. As a general guide, domestic wastewater typically produces 1 dry ton of solids for every million gallons of wastewater treated. The rate of solids generation is typically lower at treatment plants using processes such as anaerobic digestion that destroy solids, while the rate is higher at plants using chemical addition.

Reserve capacity in the form of off-line storage or standby units, or the use of extended hours of operation should be considered. In small facilities, sludge processing should require less than 30 hours per week during normal operation. Sludge processing equipment must operate efficiently for the range of sludge characteristics expected from the preceding unit processes. The design engineer should supply the reviewing agency with copies of design sizing information, including the following:

- Average, minimum, and maximum sludge quantities
- Number and size of units
- Basic sizing parameters
- Hours of operation
- Expected capture efficiency
- Solids content of influent sludge
- Expected range of percent solids yield
- Chemical requirements

11.1.3 Residuals Sidestreams

The sludge system as well as the liquid handling system should consider BOD, suspended solids, nitrogen, phosphorus, and other contaminants that are controlled in a treatment facility from the solids processing units. The magnitude of such loads and resulting additional sludge will range from 5 to 30 percent of the influent load. Material balances must be calculated. At biological nutrient removal (BNR) facilities that dewater large quantities of sludge over a short period or store sludge for long periods, the BNR process may become overloaded if operational adjustments are not made when necessary or if the system is not designed to treat a wide range of nutrient loading.

Liquid sidestreams from sludge thickening, stabilization, and dewatering are typically recycled to the liquid treatment train upstream of the primary clarifiers. When recycling sidestreams, engineers must assess the impacts on the liquid treatment process, as the flows as awell as nutrient and solids loading from sidestreams may be significant. Table 11-1 summarizes sludge processing sidestream characteristics.

11.1.4 Residuals Storage

To reduce the need for designing the sludge process for maximum daily sludge production, provisions for sludge storage should be considered. Sludge storage will also provide operating flexibility during equipment outages. Storage options include in-process storage, storage tanks, and storage lagoons. Dried solids may be stored in silos or piles on-site or at the land application site. Temperature control for dried solids storage is critical, as the solids contain combustible organic matter.

11.1.4.1 Process Unit Storage

In-process storage is available in processes such as anaerobic digestion, aerobic digestion, and gravity thickening. To a limited extent, storage is available in primary and secondary clarifiers (by accumulating sludge) and in aeration systems (by increasing concentrations of mixed liquor suspended solids (MLSS)).

11.1.4.2 Equipment Design

A sludge storage system should be equipped with mixing devices to prevent separation

Table 11-1 **Sludge Processing Sidestream Characteristics**

Source	BOD_5, mg/L	TSS, mg/L	Ammonia, mg NH_3-N/L	Orthophosphorus, mg P/L
Thickening				
Gravity thickening supernatant	100–1 200	200–2 500	1–30	1–5 (higher if bio P)
Dissolved air flotation subnatant	50–1 200	100–2 500	1–30	1–5
Centrifuge centrate	170–3 000	500–3 000	1–30	1–5
Stabilization				
Aerobic digestion decant	100–2 000	100–10 000	1–50	2–200
Anaerobic digestion supernatant	100–2 000	100–10 000	300–2000 (higher end for retreated/ advanced processes)	50–200
Incineration Scrubber water	30–80	600–10 000	10–50	1–5
Dewatering				
Belt filter press filtrate	50–500	100–2 000	1–1 500	2–200
Centrifuge centrate	100–2 000	200–20 000	1–1 500	2–200
Sludge drying beds underdrain	20–500	20–500	1–1 500	2–200

Sidestreams in Wastewater Treatment Plants, U.S. EPA, 1987

of solids and to provide a more uniform feed-to-dewatering device. Provisions for adding lime, chlorine, or air to prevent septicity and resulting odors are desirable. Aeration may be required if the sludge is unstabilized. Decanting systems to provide thicker solids and flushing water to clean out tanks are necessary. Supernatant from the decanting system should be piped to the headworks of the plant. Depending on site considerations, covering and odor control devices may be required.

11.1.5 Federal and State Residuals Regulations

The design of selected residuals treatment and disposal methods should comply with applicable federal and state regulations. With regard to federal regulations, the Standards for the Use or Disposal of Sewage Sludge (Title 40 of the Code of Federal Regulations (CFR), Part 503) were published in the Federal Register in 1993. Part 503 establishes minimum requirements for pollutant limits (i.e., ceiling concentration, cumulative, or annual limits), management practices, operating standards (i.e., pathogen and vector attraction reduction requirements), and requirements for the frequency of monitoring, recordkeeping, and reporting for sewage sludge.

Part 503 establishes two sets of criteria for pathogen densities (Class A and Class B), two sets of criteria for heavy metals (pollutant concentration and pollutant ceiling concentration), and allows two approaches for reducing vector attraction (physical barriers or treating the solids). Municipal treatment plants typically use one of the following technologies to produce Class A or Class B solids: heat drying, composting, anaerobic or aerobic digestion, or alkaline stabilization.

Sewage sludge is:

- Applied to land to condition soil or fertilize crops or vegetation grown in the soil.
- Placed on a surface disposal site for final disposal.
- Fired in a sewage sludge incinerator.

Part 503 states that if sewage sludge is placed in a municipal solid waste landfill, the sewage sludge must meet the provisions of 40 CFR, Part 258.

Applicable state and local regulations may be more stringent than Part 503, may define sewage sludge differently, or may regulate some types of sewage sludge more stringently. For information on specific state sewage sludge regulations, consult the appropriate state sewage sludge permitting authorities.

11.2 Pumping and Conveying

11.2.1 Design Basis

11.2.1.1 Pump Capacity

Capacity should cover the full range of solids concentrations and sludge production. Variable-speed or other rate-control systems are desirable. The use of valve throttling for flow control is not considered desirable, except on thin and nonfibrous sludges. Operating pressures should be calculated to account for the high friction factor that occurs when pumping thick sludges (i.e., sludges with greater than 2–3 percent solids).

11.2.1.2 Duplicate Units

In cases where the failure of one unit would seriously hamper plant operations, duplicate units should be provided for redundancy. The interconnection of pump suction and discharge manifolds is recommended so that one pump discharge can be used to backflush other suction piping, but only if the pump can effectively perform this function without motor overload.

11.2.1.3 Minimum Head

Positive dynamic head should be provided at the suction side of all types of sludge pumps. For centrifugal pumps, the dynamic suction head should be equal to or greater than the top of the volume. For positive displacement pumps, suction lifts should not exceed 10 feet (3 m) when possible. Backflushing of suction lift piping should be performed with a flow rate at least equal to the pumping rate.

11.2.1.4 Piping Sizes

Sludge withdrawal piping should have a minimum diameter of 8 inches (20 cm) for gravity withdrawal and 6 inches (15 cm) for pump suction and discharge lines. For dilute sludges, available head should provide a velocity of at least 3 feet per second (0.92 m/s) at the design flow.

11.2.1.5 Piping Slopes

Gravity piping for free-surface flow should be on a uniform grade and alignment. The downward slope of gravity discharge lines should be 3 percent or greater.

11.2.2 Equipment Features

11.2.2.1 Pumps

Plunger pumps, peristaltic pumps, nonclog and recessed impeller or screw centrifugal pumps (for dilute sludges only, such as WAS and RAS), progressive cavity pumps, or other types of pumps with demonstrated solids handling capability should be provided for raw sludge. The abrasive nature of sludges, especially those containing grit, must be considered when selecting the pump type and the materials of construction. Based upon expected high wear rates, provide spare parts, including wear rings and pump stators, and other similar replaceable components, such as impellers. Provide pulsation dampeners on suction and discharge sides of plunger pumps.

11.2.2.2 Sludge Grinders and/or Screens

Sludge processing equipment is susceptible to rag and trash buildup or damage from debris, such as synthetic cloth belts used in thickening and dewatering systems. Sludge grinders and/or fine screens should be considered prior to process equipment such as centrifuges, heat exchangers, sludge mixing devices, or positive displacement pumps. Grinders are typically installed on the suction side of the pump to reduce clogging.

11.2.2.3 Valves

The piping system should be equipped with isolation valves for equipment or metering repairs. Check valves made for use with sludges (e.g., double-ball check valves) should be installed to prevent flow reversal through sludge pumps. Provide a cleanout or tee adjacent to any check valve.

11.2.2.4 Piping Layout

Provisions should be made for cleaning, draining, venting, and flushing sludge piping. Flanged tees, crosses, and cleanouts for rodding of the suction line and for backflushing with positive displacement pump discharge and/or plant water are desirable.

Provisions for cleaning using hot water, steam injection, or chemical degreasing should be considered in long or buried lines containing sludge or scum. When raising the operating temperature of a line beyond its normal temperature or ambient conditions, pipeline thermal expansion should be addressed. Any pumps used in the heating service should be designed and specified for the maximum heated service temperature expected.

11.2.3 Control Devices

11.2.3.1 Flow Meters

Flow meters suitable for use with sludge (e.g., magnetic flow meters) should be provided on all essential lines, including metering sufficient to permit plant personnel to establish a mass balance. Provisions should be made for equipment isolation, cleaning, and calibration.

11.2.3.2 Intermittent Withdrawal Service

Sludge pumps used on intermittent withdrawal service should be equipped with variable timer equipment.

11.2.3.3 Sampling Facilities

Unless sludge sampling facilities are provided, quick-closing sampling valves should be installed at the suction of each sludge pump. The valve and piping should have a diameter of at least 2 inches (5.2 cm). Provisions to purge and flush the sample lines with plant effluent are desirable.

11.2.3.4 Pressure Relief Valves

Pressure relief valves must be installed on the discharge side of all positive displacement sludge pumps.

11.3 Thickening

11.3.1 Gravity Thickeners

11.3.1.1 Design Basis

Typical gravity thickener design is a circular tank with a side water depth of 10–14 feet, a diameter of 60–80 feet and a slope between 2:12 to 3:12. Typical loading rates and the resulting solids concentration for gravity thickening are as follows:

Type of Sludge (underflow concentrations)	Solids Loading Rate lb/ft^2/day	kg/m^2 day	Percent Solids
Primary	20 to 30	98 to 146	5 to 10
Trickling Filter	8 to 10	39 to 49	3 to 6
Activated Sludge	4 to 8	20 to 39	2.5 to 3.0
Primary and Trickling Filter	10 to 12	49 to 59	5 to 9
Primary and Activated Sludge	6 to 10	29 to 49	3 to 6

For primary solids, hydraulic loading to produce overflow rates of 400–800 gpd/ft^2 (16–33 m^3/m^2 day) is desirable to prevent septicity. For secondary solids, the desired hydraulic loading is typically 100–200 gpd/ft^2 (4–8 m^3/m^2 day). Hydraulic loading can be controlled using dilution with water such as plant effluent provided that a measurable DO level in the plant effluent exists.

11.3.1.2 Equipment Features

Heavy-duty scrapers capable of withstanding extra heavy torque loads should be provided.

Consider adding chlorine solution to prevent septicity and to assist in the settling of activated sludges. The addition of polyelectrolytes might also help settle activated sludge and aid in solids capture.

Depending on adjacent land use, impacts from odor should be evaluated and covers and odor control systems should be considered.

11.3.1.3 Co-Settling

A form of gravity thickening is accomplished by returning trickling filter sludges or activated sludge to primary tanks for co-settling with primary sludge. If this method is used, peak overflow rates on the primary clarifier should be restricted to under 1,500 gpd/ft^2 (61 m^3/m^2 day). A minimum primary clarifier minimum sidewater depth of 12 feet (3.7 m) is desirable to provide sludge storage capacity.

11.3.2 Dissolved Air Flotation Thickeners

Dissolved air floatation (DAF) technology has generally been applied to the thickening of biological sludges. The thickening of combined primary and biological sludges has been successfully demonstrated in many installations. Typical loading rates and the resulting solids concentration are listed below. Similar performance using DAFs for combined sludges can reduce the solids loadings and/or the hydraulic loadings to not more than 75 percent of the respective tabulated values, unless demonstrated testing confirms higher loadings.

11.3.2.1 Design Basis

Typical loading rates and resulting solids concentration are as follows:

Solids Loading Rate

With Polymer	30 to 50 lb/ft^2/day (146 to 244 kg/m^2 day)
Without Polymer	20 to 30 lb/ft^2/day (98 to 146 kg/m^2 day)
Hydraulic Loading	0.5 to 2 gpm/ft^2 (30 to 120 m^3/m^2 day) (MOP 8, 23-23)
Percent Float Solids	3.5% to 5.0%

11.3.2.2 Equipment Features

When using dissolved air flotation technology, the design should incorporate the following considerations:

- Install duplicate units for flexibility and redundancy.
- Use equipment units with bottom scrapers to remove settled solids.
- Use either thickener underflow or secondary effluent for the pressurized recycle flow.
- Add polymers to increase unit capacity and capture efficiency. Typical polymer dosages range from 4 to 10 pounds of polymer per dry ton of solids (2–5 grams polymer/kg dry solids).

11.3.3 Centrifuge Thickeners

11.3.3.1 Design Basis

Solid bowl centrifuges are used to thicken waste activated sludge. Unit capacity is based on hydraulic loadings, solids loading, and manufacturer's recommendations. If possible, pilot testing should be used for design sizing. Designers must determine potential operating modes based on the treatment plant's thickening schedule. Centrifuge performance can be modified by adjusting several variables, including speed, polymer use, and flow rate. Centrifuges typically provide 70–95 percent solids capture and typically produce a thickened solids concentration of 4–9 percent.

11.3.3.2 Equipment Features

Solid bowl centrifuges should be used only where influent or primary sludge grit removal systems are available to minimize abrasion damage.

Equipment for polymer addition should be provided for thickening centrifuges that assist in solids capture.

11.3.4 Gravity Belt Thickeners

Gravity belt thickeners are typically used to thicken waste activated sludge, primary solids, blended solids, and digested solids that initially contain 0.4–0.8 percent solids. Hydraulic and solids loading rates, conditioning requirements, and performance should be based on pilot unit performance or operating results for similar sludges. If pilot performance data are not available, a conservative design value of 200 gpm per meter of effective belt width may be used. Gravity belt thickeners provide up to 95 percent solids capture with the use of polymers and typically produce a solids concentration of 8–10 percent for primary sludge and 4–6 percent for secondary sludge.

Multiple units are recommended unless storage capacity or alternate thickening methods are available to handle sludge during prolonged outages. Equipment features should be similar to the belt filter press dewatering requirements of Section 11.9.4. Belt washdown water should be provided for belt cleaning between thickening cycles.

11.3.5 Rotary Drum Strainers/Thickeners

Rotary drum thickeners are typically used to thicken WAS at small treatment plants because the largest unit has a capacity of 300 gpm. If rotary drum thickeners are the sole source for thickening, multiple rotary drum units should be installed for redundancy. Rotary drum units thickening WAS typically remove 90–98 percent of solids and produce a solids concentration of 4–6 percent.

In cases where rotary drums are used, clean-water washdown should be provided. Unit capacities must be confirmed with each manufacturer.

11.3.6 Membrane Thickening

Membrane thickening is typically used for in-loop thickening with aerobic digestion and is a relatively new technology. The process uses membranes suitable for high solids (i.e., flat plates) and may be fitted into existing basins to provide thickening and digestion at the same time. Designs include two, three or four basin configurations, in series or batch operations. Advantages of this process include thickening to 3–5 percent solids without polymer addition, reduced volume of digested sludge, increased capacity of existing basins, low TSS, and reduced nitrogen and phosphorus returns to the main treatment process.

11.4 Anaerobic Digestion

11.4.1 Design Basis

11.4.1.1 General

The anaerobic digestion system should provide for active digestion, supernatant separation, sludge concentration, and storage. Heating and gas collection systems are required. Primary digestion tank mixing systems are required, with enough mixing to ensure consistent temperatures throughout the digester. If secondary digesters are provided, secondary digestion tank mixing systems are recommended.

Although most anaerobic digesters are designed to operate at mesophilic temperatures (95–100°F, 35–37.8°C), they can also be designed to operate at thermophilic temperatures (122–135°F, 50–57.2°C).

The basic design criteria for mesophilic digesters include:

- Volatile solids (VS) loading rate: 0.12–0.16 pounds of VS per cubic foot per day. Thermophilic systems typically have much higher VS loading rates than mesophilic digesters, because the operating temperature is higher, increasing growth and metabolic rates.
- A minimum solids retention time in the digester of at least 15 days at maximum month conditions.
- Feed solids typically contain 4–6 percent solids.

11.4.1.2 Number of Units

Multiple units are recommended in all but the smallest facilities. If a single tank is used, alternate methods of sludge stabilization and emergency storage must be available.

11.4.1.3 Tank Capacity

The total digestion tank capacity should be calculated using factors such as the volume of sludge added, percent solids and character, temperature to be maintained in the digesters, degree or extent of mixing to be obtained, and degree of volatile solids reduction required. Calculations should be submitted to the reviewing authority in order to justify the basis of design. Additional tank volume may be added for grit accumulation in the bottom of the digester.

When calculations are not based on the above factors, the minimum digestion tank capacity outlined below will be required. Such requirements assume that a raw sludge is derived from ordinary domestic wastewater, digestion temperature is to be maintained in the range of 95–100°F (35–37.8°C), 40–50 percent volatile matter will be maintained in the digested sludge, and the digested sludge will be removed frequently from the system.

In order to satisfy EPA criteria, anaerobic digesters must provide a mean cell residence time and temperature between 15 days at 95–131°F (35–55°C) and 60 days at 20°C.

Completely Mixed Systems: Completely mixed systems should prevent stratification to ensure homogeneity of digester content. The system may be loaded at a rate from 120 pounds to 160 pounds of volatile solids per 1,000 cubic feet of volume per day (1.92 kg/ m^3•day) in the active digestion units. When grit removal facilities are not provided, a reduction in digester volume because of grit accumulation should be considered. (Complete mixing can be accomplished only with substantial energy input.)

Moderately Mixed Systems: For digestion systems where mixing is accomplished only by circulating sludge through an external heat exchanger, the system may be loaded at a rate up to 40 pounds of volatile solids per 1,000 cubic feet of volume per day (0.64 kg/ m^3•day) in the active digestion units. This loading may be modified depending upon the degree of mixing provided. Completely mixed systems are preferred and recommended over moderately mixed digester systems.

11.4.1.4 Depth

For those units that serve as supernatant separation tanks, the depth should allow for the formation of a reasonable amount of supernatant liquor. A minimum sidewater depth of 20 feet (6.1 m) is recommended.

11.4.2 Equipment Features

11.4.2.1 Tank Covers

Digestion tanks should be covered. Primary tanks may be equipped with fixed steel or fixed concrete covers, submerged fixed covers, or floating steel covers sealed against gas leaks by extended rims. Secondary covers may be fixed, floating steel, or flexible membrane, including gas storage units. Gas membrane covers may also be used on primary digesters for biogas storage, but this is less common. Floating covers should be equipped with a guiderail system to prevent tipping, lower landing ridges, and cover restraints.

11.4.2.2 Sludge Inlets and Outlets

Multiple recirculation withdrawal and return points should be provided to enhance flexible operation and effective mixing. The returns should discharge above the liquid level and be located near the center of the tank in order to assist in scum breakup.

Raw sludge should be discharged to the digester through the sludge heater and recirculation return piping. Avoid discharge of raw sludge directly to the digester. Frequent and consistent sludge feeding to the digesters is recommended to maintain optimal digestion conditions; avoid slug feeding.

Sludge should be withdrawn for disposal from multiple levels, including the bottom of the tank. This pipe should be interconnected with the recirculation piping to increase versatility in mixing.

11.4.2.3 Supernatant Withdrawal

11.4.2.3.1 Piping

In systems where supernatant is withdrawn from the digester, supernatant piping should not be less than 6 inches (15 cm) in diameter.

Piping should be arranged so sludge can be withdrawn from three or more levels in the digester. A positive unvalved vented overflow should be provided.

If a supernatant selector is provided, provisions should be made for at least one other drawoff level located in the supernatant zone of the tank in addition to the unvalved emergency supernatant drawoff pipe. High-pressure backwash facilities should be provided.

11.4.2.3.2 Sampling

Provisions should be made for sampling at each supernatant drawoff level. Sampling pipes should be at least 2 inches (5.1 cm) in diameter, and should terminate at a suitably sized sampling sink or basin.

11.4.2.3.3 Conditioning

Where appropriate, consider supernatant conditioning in relationship to plant performance and effluent quality.

11.4.2.4 Sampling

Sampling hatches should be provided in all tank covers with water-sealed tubes beneath the liquid surface.

11.4.3 Gas Collection, Piping, and Appurtenances

11.4.3.1 General

All portions of the gas system, including the space above the tank liquor, storage facilities, and piping, should be designed so that under all normal operating conditions, the gas will be maintained under positive pressure. All enclosed areas where gas leaks might occur should be ventilated. Review local, state and national requirements for gas piping, including National Fire Protection Association 820: *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*.

11.4.3.2 Safety Equipment

The following safety provisions should be made in designing gas collections, piping, and appurtenances:

- Include all necessary safety facilities where gas is produced.
- Pressure and vacuum relief valves and flame traps should be provided together with automatic safety shut-off valves.

- Methane sensors should be provided with an alarm panel located at the digester building entrance.
- Water-sealed equipment should not be installed.
- Gas safety equipment and gas compressors should be housed in a separate room with an exterior entrance.

11.4.3.3 Gas Piping and Condensate

Gas piping should be of an adequate diameter for a system's gas flow rate, and should slope to condensate and sediment traps at low points. A slope of 1–2 percent is recommended. Manually operated drip traps should be used in indoor installations. Automatic, float controlled drip traps require maintenance to prevent the valves from sticking, and should be considered only for outside installations. The velocity of digester gas in piping should be less than 12 feet per second.

11.4.3.4 Gas Utilization Equipment

Digester gas is often used in boilers to heat the digesters and in cogenerations systems to produce heat and power. Most cogeneration systems utilize internal combustion engines, microturbines, or gas turbines. When designing a cogeneration system, design parameters include:

- Volume of gas produced by the digesters (average day, peak hour, maximum month and minimum).
- Digester biogas energy value (typically between 500 and 650 British thermal units (BTUs) per ft^3).
- Gas composition (i.e., methane, carbon dioxide, hydrogen sulfide, siloxanes).
- Gas storage capabilities.

Gas treatment requirements should be considered when designing a cogeneration system. Biogas samples should be tested to determine the composition of the biogas. Hydrogen sulfide removal may be required to reduce corrosion in engines and boilers or to meet air permitting requirements. A common method for hydrogen sulfide removal is scrubbing with an iron impregnated media. As an alternative to scrubbing, some facilities add iron salts directly to the digester.

To prevent the formation of silicon dioxide deposits in boilers and engines, it may be necessary to remove siloxanes from biogas. Activated carbon media is typically used to remove siloxanes; other technologies include water scrubbing and refrigeration.

Gas-fired boilers for heating digesters should be in a separate room not connected to the digester gallery. This room would not ordinarily be classified as a hazardous location. Gas lines to these units should have suitable flame traps, pressure relief valves, and other gas safety equipment.

Consider dual fuel engines on major pumps or blowers for gas use, with possible recovery of exhaust and jacket cooling heat for heating digesters or building spaces.

11.4.3.5 Electrical Fixtures

Electrical fixtures and controls in enclosed places where hazardous gases may accumulate or in any other designated hazardous area should comply with the National Electrical Code (NEC) for Class I, Division I, Group D locations. Digester galleries should be isolated from normal operating areas.

11.4.3.6 Waste Gas

Waste gas burners should be accessible and should be located at least 25 feet (7.6 m) away from any plant structure when placed at ground level. The burners may be located on the roof of a control building if they are removed from the tank and high enough off the roof to ensure that flames will not be blown within 10 feet of the roof surface.

All waste gas burners should be equipped with automatic ignition, such as a pilot light or a device using a photoelectric cell sensor. Consider using natural or propane gas to ensure reliability of the pilot light. Biogas may also be used for the pilot.

11.4.3.7 Ventilation

Underground enclosures that are connected with digestion tanks or that contain sludge or gas piping or equipment should be provided with forced ventilation. The piping gallery for digesters should not be connected to other passages.

11.4.3.8 Metering

Gas meters with bypasses should be provided to measure total biogas production. Consider installing meters upstream of boilers, flares, and cogeneration equipment to track biogas utilization. Flow meters used in biogas applications include thermal dispersion mass flow meters, vortex meters, and positive displacement meters.

11.4.4 Digestion Tank Heating

11.4.4.1 Insulation

Digestion tanks should be located above groundwater level and insulated to minimize heat loss. Digester heat needs vary throughout the year so temperature variations and local weather conditions should be taken into account. When calculating digester heat needs, the two main factors are 1) the energy needed to heat the raw sludge entering the digester system and 2) the heat loss from the digester tanks to the environment.

11.4.4.2 Heating Facilities

Sludge may be heated by circulating it through external heaters or by heating units located inside the digestion tank.

External Heating: Piping should provide for preheating of feed sludge before introduction to digesters. The layout of piping and valving should facilitate cleaning of these lines. Heat exchanger sludge piping should be sized for heat transfer requirements.

Other Heating Methods: Other types of heating facilities should also be considered.

11.4.4.3 Heating Capacity

Heating capacity should be sufficient to maintain the design sludge temperature consistently. Where digester biogas is used for sludge heating, an auxiliary fuel supply such as natural gas is required. In cogeneration systems, heat is typically reclaimed in the form of hot water to heat the digesters.

11.4.4.4 Hot Water Internal Heating Controls

An automatic mixing valve should be provided to temper boiler water with return water so inlet water to the heat jacket can be kept below the temperature at which caking will be accentuated. Bypass valves should also provide manual control.

The boiler should have automatic controls to maintain the boiler temperature at approximately 180°F (82.2°C) to minimize corrosion, and to shut off the main gas supply in the event of pilot burner or electrical failure, low boiler water level, or excessive temperatures.

Thermometers should show temperatures of the sludge, hot water feed, hot water return, and boiler water.

11.4.5 Mixing Systems

Sludge mixing systems should be gas recirculation, draft tube mixing, or pump recirculation types. Adequate mixing is essential to digester performance and foam control.

11.4.6 Operating Considerations

The following guidelines should be followed in the actual operation of anaerobic digestion units:

- Where two-stage digestion is practiced, the secondary digester should be fed and heated. Mix secondary units.
- Pump secondary sludge to primary units for reseeding and extending sludge detention.
- When digested sludge is pumped to the dewatering unit, the layout of piping should prevent uncontrolled gravity flow.
- Adjust pH and alkalinity by chemical addition.
- Consider the addition of iron-containing compounds (e.g., ferrous chloride) for the control of hydrogen sulfide. Ferrous chloride may be added to the influent sludge entering the digester.
  - An unvalved emergency overflow should convey digester overflow to the plant headworks, the aeration process, or a liquid sludge storage facility. Flow should be monitored so that if an overflow occurs, an alarm sounds and the pump systems used to fill the digester are automatically shut down.
  - Anaerobic digestion produces a strong ammonia sidestream. The effects this sidestream may have on the liquid treatment process must be considered.

11.4.7 Maintenance Provisions

To facilitate draining, cleaning, and maintenance, the following features are desirable.

11.4.7.1 Slope

The tank bottom should slope toward the withdrawal pipe for drainage. For tanks equipped with a suction mechanism for withdrawal of sludge, a bottom slope of 1:12 or greater is recommended. Where the sludge is to be removed by gravity alone, a 1:4 or 1:6 slope is recommended.

11.4.7.2 Access Manholes

At least two 36-inch (91 cm) diameter access manholes should be provided in the top of the tank in addition to the gas dome. Stairways should reach the access manholes. A separate side wall manhole should be provided. The opening should be large enough for the use of mechanical equipment to remove grit and sand. Consider a manhole on the side of the tank to facilitate inspection and cleaning.

11.4.7.3 Safety

Provide nonsparking tools, safety lights, rubber-soled shoes, safety harnesses, gas detectors for inflammable and toxic gases, and at least two self-contained breathing units for emergency use.

11.4.7.4 Foam Considerations

Digester foaming is caused by several factors, including intermittent or slug feeding, filamentous bacteria in activated sludge feed, high volatile suspended solids loading rate, insufficient blending of primary and secondary sludges, insufficient mixing, and excessive grease or scum in the digester feed. Filaments can be controlled in the activated sludge system by selectors or chlorine dosing. Nozzles spraying recirculated sludge may be installed in the digester head space to entrain foam back into the sludge. Consider the use of foam separators to remove any foam from the digester gas piping.

11.4.8 Co-Digestion

To increase biogas production, fats, oils, and grease (FOG); food wastes; or organic liquid wastes may be added to the digester. Outside waste for co-digestion should be carefully evaluated for compatibility with the existing anaerobic digestion process, including sludge pumping systems, heating systems, digester mixing system, and biogas piping and utilization systems.

11.4.9 Pre-Digestion Processes

Pre-pasteurization processes are in compliance with 40 CFR, Part 503 regulations for Class A pathogen standards when solids are maintained at 65°C (149°F) for approximately one hour. Thermal hydrolysis treats solids in a batch reactor at elevated temperature and pressure to improve the digestibility of the solids. Thermal hydrolysis systems typically operate between 150–170°C (302–338°F) for 30 minutes. Sidestreams from the return liquor will contribute organic nitrogen and COD to the main treatment process, and must be considered.

Solids disintegration technologies applied to waste activated sludge, including ultrasonic and pulsed electric field technologies, may be considered to increase the volume of biogas produced during the digestion process.

11.5 Aerobic Digestion

11.5.1 Design Basis

Aerobic digestion can stabilize primary sludge, secondary sludge, or a combination of the two solids from membrane bioreactors and extended air facilities. Aerobic digestion is most effective when used to stabilize waste activated sludge. Digestion is accomplished in single or multiple tanks designed to provide effective air mixing, reduction of organic matter, supernatant separation, and sludge concentrations under controlled conditions.

Normally, aerobic digestion is carried out in the mesophilic temperature range (i.e., 10–42°C, 50–107.6°F) with normal operating temperatures between 10–20°C (50–68°F). Aerobic digestion may also be accomplished in the thermophilic temperature range (i.e., above 42°C, 107.6°F) at normal operating temperatures between 55–65°C (131–149°F). Aerobic digestion typically reduces volatile solids by 35–50 percent.

11.5.2 Tank Capacity

Tank capacities should be based on calculations, including quantity of sludge produced and sludge characteristics, such as concentration, time of aeration, and sludge temperature.

11.5.2.1 Volatile Solids Loading

Volatile suspended solids loading should not exceed 300 pounds per 1,000 cubic feet of volume per day (1.60 kg/m^3•day) in the digestion units. Lower loading rates may be necessary depending on temperature, type of sludge, and other factors.

11.5.2.2 Solids Retention Time

Required minimum solids retention times for stabilization of biological sludges vary depending on the type of sludge. Coverings to prevent heat loss should be considered. Federal regulations specify that conventional aerobic digestion processes have a mean cell residence time of between 40 days at 20°C (68°F) and 60 days at 15°C (59°F) to qualify as a process to significantly reduce pathogens (PSRP).

If aerobic digestion is used for stabilization and does not meet the regulations that stipulate 40 days at 20°C (68°F) or 60 days at 15°C (59°F), then fecal coliforms must be monitored. In both cases, the aerobic digestion system must demonstrate that vector attraction reduction has been achieved by a 38 percent reduction in volatile solids, an oxygen uptake rate of less than 1.5 mg of oxygen per gram of total solids per hour, or a volatile solids reduction of less than 15 percent on further testing after 30 days of more digestion.

Thermophilic aerobic digestion systems qualify as a PFRP when a mean cell residence time of 10 days is maintained at temperatures between 55 and 60°C (131–149°F). If supernatant separation is performed in the digestion tank, additional volume is required to allow for decanting time. This added volume should not be included in the determination of mean cell residence or solids retention times.

11.5.3 Multiple Units

Multiple tanks are recommended. A single sludge digestion tank may be used in situations where an alternative method of solids handling exists or where storage is available when the single tank is not in service. When multiple units are provided, the ability to use them in both series and parallel operation is recommended. Where digestion tanks must function in series, more than one train is recommended unless alternative methods of solids handling or disposal are provided.

11.5.4 Mixing and Aeration Systems

The requirements for adequate mixing and oxygen transfer should be calculated separately with the larger of the two requirements governing overall system design. Aerobic sludge digestion systems should have sufficient aeration and effective mixing equipment. Aeration should maintain dissolved oxygen at 1–2 mg/L. The minimum quantity of oxygen provided should be based on 2.1 pounds of oxygen per pound of volatile solids destroyed in conventional systems, or on 1.5 pounds of oxygen per pound of solids destroyed in thermophilic systems.

Typically, a minimum mixing and oxygen requirement of 15–20 cfm per 1,000 cubic feet of tank volume (0.25-0.33 L/m^3•s) for WAS and 25–30 cfm per 1,000 cubic feet (0.40-0.50 L/m^3•s) for blended primary and WAS should be provided with the largest blower out of service. Influent solids concentration should be considered, since thicker sludges increase a system's oxygen requirements. Thicker sludges, however, also result in less digester volume, longer solid retention time (SRT), and less decanting. If diffusers are used, the nonclog type is recommended, and they should permit continuity of service. If mechanical aerators are used, a minimum of 1.0 horsepower per thousand cubic feet (26.3 W/m^3) should be provided. Aerobic digesters can add significantly to energy costs, so designers should design the most efficient aeration and mixing system possible. (More information on aeration and mixing can be found in Chapter 6, Biological Treatment.)

Additionally, if mechanical aerators are used, it is desirable to employ submerged turbine units or floating surface aerators, allowing for liquid level variation. Engineers should consult with equipment manufacturers to determine mixing requirements. Where freezing conditions are expected, mechanical aerators are not recommended.

11.5.5 Equipment Features

11.5.5.1 Supernatant Separation

Facilities for effective separation and withdrawal of supernatant and for effective collection and removal of scum and grease should be provided. The use of separate facilities for supernatant removal is recommended.

Where accomplished in the digestion tank, multiple decant withdrawal levels are recommended.

11.5.5.2 Foam Control

It is important to manage foam effectively to ensure effective oxygen transfer and optimal biological activity. Foam spray water piping and nozzles or mechanical foam control devices are recommended.

11.5.5.3 Scum and Grease Removal

Facilities should be provided for effective collection of scum and grease from the aerobic digestion system in order to prevent them from being recycled back into plant processes.

11.5.5.4 Emergency Overflow

An unvalved emergency overflow should be provided that will convey digester overflow to either the plant headworks, the aeration process, or a liquid sludge storage facility. Provisions should be made to monitor overflows by sounding an alarm and automatically shutting down systems used to fill the digester if and when they occur.

11.5.5.5 Insulation

Thermophilic digestion systems should be covered and fully insulated to ensure operation within design temperature ranges during the coldest temperatures. All exposed piping and valves should be insulated to ensure that solids remain at design temperatures throughout the digestion process.

11.5.5.6 Temperature Measurement and Control

The temperature at key locations within thermophilic aerobic digesters should be continuously monitored and recorded.

11.6 Alkaline Stabilization

11.6.1 Lime Stabilization

11.6.1.1 General

Alkaline material may be added to liquid primary or secondary sludges for sludge stabilization in lieu of digestion facilities, for supplementation of existing digestion facilities, or for interim sludge handling. The high pH stabilization process cannot directly reduce organic matter or sludge solids. An increase in the mass of dry sludge solids will occur.

Without supplemental dewatering, additional volumes of sludge will be generated. The design should account for storage, handling, transportation, and disposal for the increased sludge quantities and associated costs. Alkaline stabilization methods have been developed that use materials other than lime, including fly ash, cement kiln dust, and Portland cement.

Alkaline-stabilized sludge can be beneficially reused, depending on the particular quality requirements and associated standards. Traditional lime stabilization is classified by EPA as a Class B product, while many advanced alkaline stabilization technologies meet EPA's definition of a Class A product.

The two predominant types of lime are quicklime (calcium oxide) and calcium hydroxide. The type of lime used for stabilization should be selected based on cost and material handling considerations. Lime doses typically range from 0.12 to 0.30 pounds of calcium hydroxide per pound of dry solids, depending on the type of sludge involved.

11.6.1.2 Operational Criteria

Alkaline material should be added to liquid sludge to produce a homogeneous mixture with a minimum pH of 12 after 2 hours of mixing. Facilities for adding supplemental alkaline material should be provided to maintain the pH of the sludge during interim sludge storage periods. To meet Class B requirements, the pH of the sludge/lime mixture must be elevated to a pH greater than 12 for 2 hours and then maintained at a pH above 11.5 for another 22 hours. To produce a Class A product, the elevated pH is combined with elevated temperatures.

11.6.1.3 Odor Control and Ventilation

Odor control facilities should be provided for sludge mixing and treated sludge storage tanks. The reviewing authority should be contacted for design and air pollution control objectives for various types of air scrubber units. Ventilation is required for indoor sludge mixing, storage, and processing facilities.

11.6.2 Lime Stabilization with Supplemental Heating

Lime stabilization with supplemental heating is a proprietary process capable of achieving a Class A stabilized product.

11.6.2.1 Process Overview

The process includes mixing and pasteurization in a reactor.

Mixing: Dewatered sludge is mixed with quicklime and water to achieve a temperature of 70°C (158°F).

Pasteurization: The mixture is fed to a heated and insulated reactor where the contents are held for a minimum of 30 minutes.

11.6.2.2 Design Basis

Doses: The proportion of admixtures for sludge depends on the solids content of the sludge cake and the intended use of the stabilized product. Actual doses should be based on pilot testing or experience with similar sludges.

Equipment: Provisions for storage and metering of lime should be provided. Lime mixing facilities should be enclosed to prevent lime dust from escaping. The mixing unit and pasteurization unit should be equipped with variable-speed drives.

11.6.3 Alkaline Stabilization with Subsequent Drying

Alkaline stabilization with subsequent drying is a proprietary alternative sludge stabilization technology that provides beneficial reuse of sludge and alkaline by-products. There are several variations of this process, including the use of windrows or rotary drums to dry the solids, the use of electric heat to supplement the heat generated by quicklime, and the addition of acid to supplement heat produced by quicklime.

11.6.3.1 Process Overview

The process includes mixing and drying.

11.6.3.1.1 Mixing

Dewatered sludge is mixed with alkaline by-products to attain 40–50 percent solids and raise the temperature to 52–62°C (125.6–143.6°F). Alkaline materials mixed with sludge kills sludge pathogens by raising the pH of the mixture to 12 or greater and releasing ammonia from the sludge, and by raising the temperature of the material.

Cement kiln dust (CKD) is a fine powder with a highly variable chemical composition, containing up to 35 percent lime. Additional lime is required with the CKD if the material does not contain enough free lime to raise the temperature and pH. Other admixtures can substitute or supplement CKD, including lime, fly ash, and calcium sulfate (gypsum).

11.6.3.1.2 Drying

Three drying processes are possible:

Alternative 1: The mixture is air-dried while the pH remains above 12 and ambient air temperature is above 5°C (41°F) for at least 7 days. The mixture must be held for at least 30 days until solids content is at least 65 percent by weight.

Alternative 2: The mixture is self-heated while the pH exceeds 12 and the temperature exceeds 52°C (125.6°F) for a period of 12 hours. Following this heat pulse phase, the mixture is air-dried by windrowing until the solids content is greater than 50 percent by weight. The pH must remain above 12 for at least 3 days.

Alternative 3: The mixture is self-heated as in Alternative 2 during the heat pulse phase. Subsequent drying is accomplished during a 12-hour period in a rotary drum dryer.

11.6.3.2 Design Basis

Doses: The proportion of admixtures for sludge depends on the solids content of the sludge cake and the intended use of the stabilized product. Actual doses should be based on pilot testing or experience with similar sludges. Typical dosages are 35–70 percent by wet weight.

Equipment: The granularity and plasticity of the product is influenced by the polymer used for conditioning the sludge, the types of admixtures used, the mixer/proportioner, and the windrow machine. As a rule, the product must be compatible with the equipment in which it will be used. Care should be taken to select equipment that matches product needs.

Facilities: Equipment for mixing is usually enclosed in a building. Enclosure of the windrow area (if used) is an odor control issue and depends on whether residences or workplaces are nearby. Many existing windrow facilities are in open-sided buildings with translucent roofs to aid drying.

If the product is exposed to wet weather, it should be stored in conical-shaped piles to allow precipitation to drain off. A crust forms on piles, which does not allow rainwater to penetrate. When piles have not been shaped properly, odor problems develop, and the material must be reprocessed.

Odor and Dust Control: Odor control is needed for high ammonia levels in mixing areas and when windrows are turned. Odor and dust controls are highly site-specific, and should be considered carefully during facility design.

Odor control is achieved by:

- Siting with a sufficient buffer area.
- Installing an odor control system.
- Not turning all windrows in a short time period.
- Suspending operation under adverse weather conditions such as low wind velocity and low pressure.
- Using a rotary drum dryer with separate odor control.

For control of hydrogen sulfide and ammonia odors, systems include ventilation; the addition of ferric chloride, ferric sulfate, lime or other admixtures; and caustic and acid (often sulfuric acid) scrubbers.

It is essential to control dust generated by truck and front-end loader traffic among building, windrow, and stockpile areas, as well as dust generated from dispensing and mixing alkaline materials. Methods of controlling dust include sweeping, mopping, and hosing down dusty areas; installing baghouses on silos or air filtration units; and covering augers.

11.7 Other Stabilization Methods

11.7.1 Pasteurization

The main reason to use a pasteurization process is to disinfect solids, as pasteurization is not reported to significantly enhance volatile solids reduction. Sludge pasteurization systems should raise the temperature of the sludge to above 70°C (158°F) for a minimum of 30 minutes to effectively destroy pathogenic organisms. Part 503 regulations specify that the pasteurization process must precede the vector attraction reduction process (i.e., mesophilic or thermophilic anaerobic digestion).

Heat recovery should be considered when designing a pasteurization process. Also, a sludge storage facility should be provided for pasteurized sludge to avoid reinoculation of pasteurized sludge by raw products.

An odor control system is essential both for the pasteurization process and for the raw product storage facility.

11.8 Chemical Feed Systems

11.8.1 General

No chemicals should be used in the handling of sludge that are detrimental to the final use or disposal of the product.

11.8.1.1 Plans, Specifications, and Operating Manuals

The following information should be included in plans, specifications, or operating manuals:

- Descriptions of feed equipment, including maximum and minimum feed ranges
- Location of feeders, piping layout, and points of application
- Storage and handling facilities
- Specifications for chemicals to be used, including strength and shelf life
- Operating and control procedures, including proposed application rates
- Descriptions of testing equipment and procedures

11.8.1.2 Chemical Application

Chemicals should be applied to sludge at such points and by such means as to:

- Ensure the product material is environmentally compatible with its intended use or disposal method.
- Provide maximum safety to operators.
- Ensure maximum efficiency of treatment.
- Ensure satisfactory mixing of chemicals with the sludge.
- Provide maximum flexibility of operation through various points of application.
- Prevent backflow or back siphoning among multiple points of feed through common manifolds.

Note: General equipment design, types of chemicals, operator safety concerns, and descriptions of specific chemicals are presented in Chapter 4.

11.9 Dewatering

11.9.1 Operational Considerations

Housing: All equipment, including filters, sludge conveyors, and sludge hoppers, should be protected from inclement weather and freezing. Adequate heating and lighting should be provided.

Ventilation: Facilities should be provided for ventilation of the dewatering area. The exhaust air should be properly conditioned to avoid nuisance odors.

Floors: Floors should be pitched and drained for cleaning purposes and should be slip-proof. Walls should be constructed of easily cleaned materials. Provisions for effluent flushing or plant service water for cleanup should be made.

Chemical Handling: Material handling equipment should minimize manual lifting. Corrosive chemical tanks should be enclosed with spill contaminant walls. Emergency showers and eye washes should be near chemical handling and sludge dewatering areas.

Electrical Equipment: Electrical equipment provided within the room should be rated for wet environments. Consider housing motor control centers in separate dry areas.

11.9.2 Centrifuges

11.9.2.1 Design Basis

Where digested sludge is to be centrifuged, duplicate installations may not be required if adequate capacity is provided in a single unit on the basis of 30 hours of operation per week under design load.

Period of Operation: The period of centrifuge operation should be considered in choosing the size of the units. At small plants, the centrifuge operation period should not exceed 30 hours per week, which allows time for conditioning, cleanup, and delays. At large plants, centrifuges may need to operate for as much as 20 hours per day. Standby units should be provided to handle maximum sludge production after allowances are made for storage.

Feed Rate: Machine size, sludge conditioning requirements, and performance should be based on pilot unit performance or operating data on similar sludges.

Duplicate Units: Where undigested or partially digested sludge is to be centrifuged, duplicate centrifuges should be provided unless nuisance-free storage of sludge is provided. Duplicate installation involves duplicate conditioning equipment, feeders, and other appurtenances, as well as centrifuges.

11.9.2.2 Equipment Features

Sludge Storage Tanks: Sludge storage or blending tanks preceding the centrifuges should be provided. Also necessary are a means for feeding chemical conditioners, and sufficient aeration or mechanical agitation to prevent development of anaerobic conditions and associated odors. Aeration and agitation ensure a homogeneous feed to centrifuges.

Sludge Grinders or Fine Screens: Provisions for supplying sludge grinders or fine screens prior to sludge feed pumps are recommended.

Feed Pumps: Each centrifuge should be fed by a separate variable-speed pump.

Conditioning Chemicals: Storage, makeup, dilution, and feed equipment for polymers should be provided.

Centrifuges: Centrifuges should be provided for variations of scroll speed, torque control, and pool depth. Centrifuges should also be equipped with a vibration switch to shut down the unit in cases of high vibration. Depending on the application, centrifuges may produce dewatered cake with a solids content of 15 to more than 30 percent (using high torque centrifuges).

Crane Service: A crane or monorail should be provided for disassembling machines during maintenance.

Centrate: Centrate should be returned to raw or settled waste. Provisions should be made for sampling centrate from each unit.

Conveyors and Meters: Means for measuring the quantity of sludge processed should be provided. Provisions should be made for sampling the solids cake from each unit.

Flushing: It is recommended that flushing water be provided to flush the scroll of solids after shutdown of a unit.

Cooling: Provisions for cooling the oil lubrication system with either service or protected water is recommended.

Diverting Flow: Provisions for diverting flow discharged from the solids chute during startup of the centrifuge to the centrate discharge are recommended.

Ferric Chloride: When dewatering anaerobically digested sludge, consider providing ferric chloride for struvite control.

11.9.2.3 Operating Considerations

Housing, ventilation, and cleanup provisions are described in Section 11.9.1.

Noise Levels: Special consideration should be given to providing acoustical treatments within the room in which the centrifuges are housed to reduce noise levels during operation.

11.9.3 Pressure Filter Presses or Recessed Chamber Filter Presses

11.9.3.1 Design Basis

The following should be considered in designing pressure filter presses or recessed chamber filter presses:

- Unit sizing is a function of the number of chambers, chamber volume, and operating cycle.
- Expected performance, conditioning requirements, and cycle times should be based on pilot data or reliable operating results from similar sludges.
- Multiple units are recommended unless sludge storage capacity is available for prolonged storage.
- In small plants, the operating period should not usually exceed 30 hours, which allows time for chemical makeup, cleanup, and delays. A batch basis of operation will affect the available hours for operation. In large facilities, especially those with incineration facilities, operating up to 20 hours per day may be necessary.

11.9.3.2 Equipment Features

The following equipment should be provided:

- A chemical conditioning system; chemical requirements may include use of lime, ferric chloride, ash, or polymers. A holding tank should be provided to condition sludge prior to its being pumped to the press.
- Filter press feed pumps should be capable of a combination of initial high-flow, low-pressure filling followed by sustained periods of operation at 100–225 psi (690–1,550 kN/m). A minimum of one spare feed pump is required.
- Provisions for cake breaking, with particle reduction to under 1 inch (2.5 cm) being desirable with incineration.
- Crane or monorail services capable of removing plates.
- A minimum of one spare set of filter cloths.
- Provisions for high-pressure water and acid wash systems to clean cloths.
- Unless sludge cake is discharged directly into a disposal vehicle, storage provisions to dampen out batch loads onto conveyors is recommended.

11.9.3.3 Operating Considerations

Housing ventilation and cleanup provisions are described in Section 11.9.1.

11.9.4 Belt Filter Press

11.9.4.1 Design Basis

The following are guidelines for the design of belt filter presses:

- Hydraulic and solids loading rates, conditioning requirements, and performance should be based on pilot unit performance or operating results on similar sludges.
- Multiple units are recommended unless storage capacity or alternate dewatering methods are available to handle sludge during a prolonged outage.
- In small plants, the operating period should not usually exceed 30 hours per week, which allows one-shift operation with time for chemical makeup, cleanup, and delays. In large installations, the operating period may approach 24 hours per day.
- Depending on the type of sludge being dewatered, cake solids typically range from 15 to 25 percent.

11.9.4.2 Equipment Features

- A chemical conditioning system, chemical and sludge feed equipment, belt wash water, filtrate return, and a means for sludge cake conveying are needed.
- Belt alignment and tensioning should be regulated.
- If a single unit is used, standby equipment should be provided for the sludge feed pump, belt wash, and chemical feed.
- A minimum of one spare set of belts should be furnished.
- Provide for ease of access to grease fittings.

11.9.4.3 Operational Considerations

Housing, ventilation, and cleanup provisions are described in Section 11.9.1.

Other operational considerations are as follows:

- Provisions should be made to permit observation of floc formation on the top gravity section of the belt press.
- Belt presses should be provided with emergency pull cords to stop the press in an emergency.

11.9.5 Drying Beds

11.9.5.1 Design Basis

In determining the area of sludge drying beds, consider climatic conditions, the character and volume of the sludge to be dewatered, the method and schedule of sludge removal, and other methods of sludge disposal. In northern areas of the country, the drying season is only 6 months out of the year. In general, the sizing of the drying bed may be estimated on the basis of 2.0 ft^2/person (0.19 m^2/person) when the drying bed is the primary method of dewatering, and 1.0 ft^2/person (0.09 m^2/person) if it is to be used as a backup dewatering unit. An increase in bed area of 25 percent is recommended for paved beds. Sludge storage or alternative dewatering methods must be provided during winter weather.

11.9.5.2 Design Features

The following are guidelines for the design of drying beds:

Gravel: The lower course of gravel around the underdrains should be properly graded and should be 12 inches (30.5 cm) in depth, extending at least 6 inches (15.2 cm) above the top of the underdrains. Place gravel in two or more layers. The top layer should be at least 3 inches (7.6 cm) thick and should consist of gravel 1/8 to 1/4 inch (3.18 to 6.35 mm) in size.

Sand: The top course should consist of at least 6–9 inches (15.2–22.9 cm) of clean coarse sand. The finished sand surface should be level.

Underdrains: Underdrains should be vitrified PVC perforated pipe or concrete drain tile at least 4 inches (10.2 cm) in diameter. Underdrains should be spaced not more than 20 feet (6.1 m) apart. Underdrainage should be returned to raw or settled sewage. Line the bottom of the bed with an impermeable liner.

Partially Paved Type: A partially paved drying bed should include adequate space to operate mechanical equipment for removing dried sludge.

Walls: Walls should be sealed against water leaks and extend 15–18 inches (38–46 cm) above and at least 6 inches (15 cm) below the surface. Outer walls should be curbed to prevent soil from washing onto the beds.

Sludge Removal: No less than two beds should be provided, and they should be arranged to facilitate sludge removal. Concrete truck tracks should be provided for all percolation-type sludge beds.

Sludge Influent: The sludge pipe to drying beds should terminate at least 12 inches (30.5 cm) above the surface and be arranged so that it will drain. Concrete splash plates should be provided at sludge discharge points.

Protective Enclosure: A protective enclosure should be provided if winter operation is required. Consider implementing odor control measures.

11.9.6 Reed Beds

11.9.6.1 Design Basis

Bed Sizing: At a minimum, beds should accommodate approximately 45–60 gal/sf/yr, although other application rates may be appropriate based on site-specific factors, experiences with similar sludges, and/or pilot testing. Additional bed area should be provided for incomplete reed growth, variations in sludge wasting rates, and seasonal variations in sludge loading cycles. Beds should be planted with one reed plant (phragmites) per square foot of area. The regulatory agency should be consulted regarding acceptable reed types.

Sludge Loading Cycle: Each load will apply several inches of sludge to the bed. In warm months, loading once every 1 to 2 weeks is typical; once every 2 weeks is preferred. In winter, typical loading cycles are once every 3 to 4 weeks, although some facilities cease loading operations entirely in colder months. Winter applications should be minimized to reduce organic loadings to young plants from thawing sludge in spring. Sludge storage or alternate dewatering methods may be necessary in winter months.

Sludge Characteristics: Volatile solids contents of less than 70 percent are required for successful reed bed operations.

11.9.6.2 Design Features

The following are guidelines for the design of reed beds:

Gravel: The lower course of gravel around the underdrains should be properly graded and should be 12 inches (30.5 cm) in depth, extending at least 6 inches (15.2 cm) above the top of the underdrains. Place this gravel in two or more layers. The top layer of gravel should be at least 3 inches thick (7.6 cm) and should consist of washed gravel 1/8 inch to 1/4 inch (3.18 to 6.35 mm) in size.

Sand: The top course should consist of at least 6 to 9 inches (15.2–22.9 cm) of clean, coarse sand. The finished sand surface should be level.

Underdrains: Underdrains should be concrete drain tile or perforated PVC pipe at least 4 inches (10.2 cm) in diameter with open joints. Underdrains should be spaced not more than 20 feet (6.1 m) apart. Underdrainage should be returned to the wastewater treatment facility.

Liquid Sludge Distribution: A piping network is recommended to evenly distribute sludge in the bed.

Sidewalls: Walls should be sealed against water leaks, and provide at least 5 feet (1.52 m) of freeboard, and extend at least 6 inches (15.2 cm) below the surface of the sand. Outer walls should be curbed to prevent soil from washing onto the beds.

11.9.6.3 Operational Considerations

Sludge pH: A sludge pH of 7 is desired to promote reed growth. Sludge liming may be necessary to avoid stunting reed growth.

Startup Operations: After the initial reed planting, the beds should be watered or flooded to develop a dense growth. During this period, little or no sludge should be applied. Application, at designed rates, should not be attempted until 1 to preferably 2 years from initial planting.

Annual Harvesting: Reeds should be harvested annually, after they become dormant but before they shed their leaves, and preferably during frozen conditions. All dead leaves should be removed from the bed to avoid interference with liquid sludge distribution. Harvested reeds may be composted or landfilled.

Sludge Removal: Sludge accumulation rates vary, but are typically about 3–4 inches per year, or 3 feet over a 10-year period. When full bed depth is reached, the bed should be allowed to rest for about 1 year, after which the sludge and top layer of sand should be removed.

Sludge Disposal/Utilization: Depending upon its quality, removed sludge can potentially be applied to land or landfilled. The sludge must be tested for metals and pathogens before land application or other beneficial uses. Regulatory agencies may require testing prior to sludge disposal/reuse.

Pest Control: Aphids have been a problem at some facilities. Operating plans should include provisions for the application of ladybugs at a rate of 0.5 gallons per week for 3–4 weeks during aphid outbreaks.

Odor Control: Provisions for odor management should be included. The highest potential for odor exists during the spring thaw, but odor problems are also possible during sludge loading and removal operations.

11.9.7 Rotary Presses

Rotary presses are a relatively new technology that can achieve cake solids with solids capture performance similar to belt filter presses and centrifuges. Rotary presses typically use less energy than belt filter presses or centrifuges, but are more dependent on polymer for solids capture.

The hydraulic loading rate is a function of the number of channels in a unit. A rotary press unit is modular, and the hydraulic loading rate of a single drive unit ranges from 5 to 250 gpm, with a maximum loading rate of 50 gpm per channel. Solids loading rates vary with hydraulic loading rates, and the engineer should work with an experienced manufacturer to determine the applicable rates. Solids capture typically exceeds 95 percent.

11.9.7.1 Design Basis

The following are guidelines for the design of rotary presses:

- Hydraulic and solids loading rates, conditioning requirements, and performance should be based on pilot unit performance or operating results on similar sludges.
- Multiple units are recommended unless storage capacity or alternate dewatering methods are available to handle sludge during a prolonged outage.
- In small plants, the operating period should not usually exceed 30 hours per week, which allows one-shift operation with time for chemical makeup, cleanup, and delays.

11.9.7.2 Equipment Features

The following equipment should be provided:

- A chemical conditioning system, chemical and sludge feed equipment, filtrate return, and sludge cake conveying; polymer is required to achieve design performance.
- A wash water system that typically runs for 5-10 minutes at the end of each day to flush all equipment; high pressure water is not required.

11.9.7.3 Operational Considerations

Housing, ventilation, and cleanup provisions are described in Section 11.9.1.

11.9.8 Screw Press

Screw press design is determined by solids characteristics, chemical conditioning, and hydraulic and solids loads, which affect the speed of the screw. Chemical conditioning is an important factor affecting the hydraulic loading rate, because a screw press can only attain maximum capacity with the proper polymer type and application.

Screw presses can operate under a wide range of load rates by adjusting the screw speed. Typical hydraulic loading rates for a horizontal screw press range from 1 to 550 gpm (3.8 to 2,081 L/min). Typical hydraulic loading rates for an inclined screw press are between 5 and 60 gpm (18.9 and 227 L/min).

The solids loading rate for screw press dewatering varies, depending on solids characteristics, screw size, and rotational speed. The solids loading rate capacity for a horizontal screw press ranges from 2 to 1,550 pounds per hour (0.91–703 kg/h) while the typical solids loading rate for an inclined screw press is 50–650 pounds per hour (22.7–295 kg/h)

11.9.8.1 Design Basis

The following are guidelines for the design of screw presses:

- Hydraulic and solids loading rates, conditioning requirements, and performance should be based on pilot unit performance or operating results on similar sludges.
- Multiple units are recommended unless several days' worth of storage capacity is available or alternate dewatering methods are available to handle sludge during a prolonged outage.
- Screw presses are typically designed for continuous operation, 5-7 days per week.

11.9.8.2 Equipment Features

The following equipment should be provided:

- A chemical conditioning system, chemical and sludge feed equipment, and sludge cake conveying; polymer is required to achieve design performance. Polymer dosages typically range from 10 to 20 lbs/dry ton of solids (5–10 g/kg).
- Horizontal press systems include automatic wash water cycles that typically operate 1 minute every hour; an inclined press wash cycle runs intermittently, typically 1 minute every 10–15 minutes.

11.9.8.3 Operational Considerations

Housing, ventilation, and cleanup provisions are described in Section 11.9.1.

11.10 Composting

11.10.1 Methods and Design Basis

Composting Methods: Sludge composting by aerated static pile, windrow, or in-vessel methods may be used. Composting should be accomplished using PFRP. The in-vessel composting or aerated static pile methods are preferred, provided the temperature of the sewage sludge is maintained at 55°C (131°F) or higher for three days.

For the windrow method, the temperature should be maintained at 55°C (131°F) or higher for 15 days or longer with a minimum of five turnings of the windrow during that period.

To optimize the composting process, several variables are controlled: temperature, carbon to nitrogen (C:N) ratio, solids content, and aerobic conditions.

Time Periods: Typical total active composting periods are 18–21 days for aerated static pile and in-vessel methods, and 36–42 days for the windrow method.

Curing: In addition, a further curing period should be provided prior to distribution or end use. The curing period should be based on the required degree of stability for the compost product. Curing periods of 30 days are typically required.

11.10.2 Operational Considerations

Operational considerations for composting are as follows:

- Sludge should be dewatered to 15–30 percent solids and then mixed with bulking agents such as wood chips, bark mulch, sawdust, paper waste, or other materials to achieve a moisture content of less than 60 percent (typically 40–45 percent solids).
- Typically, the ideal C:N ratio is between 25:1 and 35:1. Municipal solids usually have a C:N ration between 5:1 and 20:1. Amendments are added to increase the carbon content.

- Provisions should be made for bulking agent storage. Also, provide processing equipment to ensure bulking agent uniformity and quality.
- Include provisions for runoff, and leachate control and treatment.
- Provisions should be made to contain any potential point sources or mass emissions of odor during the composting process. Achieve odor control through the use of biofilters, multistage wet chemical scrubbers, or other methods.

11.10.3 Monitoring and Marketing Considerations

Monitoring for moisture content, oxygen, temperature, carbon-to-nitrogen ratio, and stability of compost mixtures should be conducted and used in process control.

Monitoring, recordkeeping, and reporting should be conducted for a period in accordance with federal and state requirements.

Compost for bulk or retail use should be distributed in accordance with an approved compost distribution plan. Information on proper product use should be disseminated, and bagged products labeled appropriately.

11.11 Thermal Drying

11.11.1 Design Basis

Heat drying of sludge is used to produce organic fertilizer and soil amendment pellets, biofuels, or a drier sludge feed for incineration. If used as a fertilizer, sludge must be dried to at least 90 percent solids and be heated to 180°F (82°C), in accordance with 40 CFR, Part 503. All sludge drying processes release volatiles and particulates. These emissions must be captured and treated prior to discharge. Thermal drying systems produce sidestreams that must be considered during the design of a system. Refer to MOP 8 as well as NFPA 820 and NFPA 499 for design and safety guidance.

11.11.2 Convection Dryers

In flash drying systems, wet sludge cake and dried sludge are mixed in a cage mill, and hot combustion gases are added to dry the sludge. Gas and dried sludge are separated in a cyclone with a portion recycled to the cage mill. Flash drying technology is typically not utilized due to safety concerns and high energy and operation and maintenance costs. Rotary drum dryers are typically used for sludge drying. In rotary drum units, sludge may be dried in rotary kiln units directly fired by gas or oil, or heated by combustion gases.

11.11.3 Conduction Dryers

Conduction (or indirect) dryers are usually used at small- to medium-sized wastewater treatment facilities. Dewatered sludge is typically dried using one of three technologies: pressure filter dryer, tray dryer, or hollow flight dryer.

11.11.4 Safety Considerations

The end product may be combustible if moisture content exceeds 10 percent. Special precautions must be taken when storing the final product. For example, if the product is stored in a silo, the interior of the silo should have temperature monitors, continuous ventilation, etc. Refer to MOP 8 and NFPA 820 and NFPA 499 for additional information.

11.12 Use and Disposal of Residuals

For sludge use and disposal, refer to EPA regulations, and individual state and local regulations and/or guidance information. In the United States, each state is responsible for regulating sludge use within its borders. However, as stated earlier in this chapter, the federal government has issued minimum guidelines that all states must follow: the Federal Standards for the Use or Disposal of Sewage Sludge (40 CFR, Part 503), which apply to most publicly owned treatment works (POTWs). The regulations, which became effective on March 22, 1993, also apply to operators of sludge-only landfills, land application sites, and incinerators.

Sludge that is disposed of in landfills with municipal solid waste is regulated under 40 CFR, Part 258, while sludge containing toxic contaminants is regulated under the Resource Conservation and Recovery Act (RCRA) regulations (40 CFR, Parts 261–268). Sludge containing 50 mg/kg dry weight or more of polychlorinated biphenyls (PCBs) must be disposed of in accordance with 40 CFR, Part 761. POTWs with sludge handling practices falling into one of these categories are not affected by the federal sludge disposal regulations. Owners of such facilities should consider an industrial waste pretreatment management program or improvements to existing programs to improve sludge quality and reduce disposal costs.

The federal pollutant limits for sludge use and disposal are summarized in Table 11-2.

Many states and local regulators have developed or are developing and promulgating new regulations, some of which are more stringent than 40 CFR, Part 503. These state and local regulations may have a direct impact on the options available to a community and must be followed closely. An increasing number of states require permitting for land application sites and require nutrient management and conservation planning.

11.12.1 Sludge Application to Land

Land spreading of sludge must be evaluated as an integral system that includes stabilization, storage, transportation, application, soils, crops, and groundwater. The following guidelines provide criteria for municipal sludge disposal on land. Sewage sludge is useful for crops and soil by providing tilth, nutrients, and organic matter. However, some sewage sludge contains heavy metals and other substances that could affect soil productivity and crop quality.

Sludge and sludge-derived products meeting the pollutant concentration limits in 40 CFR, Part 503 (summarized in Table 11-2) are considered to be of exceptional quality if they also meet the Class A pathogen reduction and vector attraction criteria discussed below. Exceptional-quality sludges can be used and applied to a land application site without further regulation, but the sludges must be monitored, records must be kept, and reports made to the permitting authority.

11.12.1.1 Sludge Application on Forest and Farmland

Heavy metal loading to land should be limited in order to avoid reduction of soil productivity. The rate of sludge application should be based on agronomic limits. State regulatory agency and EPA regulations must be followed for specific limits. Local requirements may also apply.

11.12.2 General Design Criteria

Stabilized Sludge: Only stabilized sludge should be applied to farmlands or pastures. Stabilized sludge is defined as processed sludge in which organic and bacterial contents are reduced to levels deemed necessary by federal and state regulatory agencies to prevent nuisance odors and public health hazards. Any process that produces sludge equivalent to the above in terms of public health risk and odor potential may be accepted. At the federal level, accepted sludge refers to sludge that

Table 11-2 Pollutant Limits for Sludge Use and Disposal

Method	Land Application (1)					Surface Disposal (2)							Incineration
		Ceiling Concentration Limits	Cumulative Loading Rates (CPLR)	Pollutant Concentration Limits	Annual Pollutant Loading Rates (APLR)	Unit Boundary to Property Line, Meters							
	Chemical Symbol					0-<25	25<50	50<75	75<100	100<125	125<150	150	
Pollutant		mg/kg	kg/Ha	mg/kg	kg/Ha	mg/kg							g/24 hr
Arsenic	As	75	41	41	2	30	34	39	46	53	62	73	(3)
Beryllium	Be	–	–	–	–	–	–	–	–	–	–	–	10
Cadmium	Cd	85	39	39	1.9	–	–	–	–	–	–	–	(3)
Chromium	Cr	3,000	3,000	1,200	150	200	220	260	300	360	450	600	(3)
Copper	Cu	4,300	1,500	1,500	75	–	–	–	–	–	–	–	–
Lead	Pb	840	300	300	15	–	–	–	–	–	–	–	(3)
Mercury	Hg	57	17	17	0.85	–	–	–	–	–	–	–	3200
Molybdenum(4)	Mo	75	–	–	–	–	–	–	–	–	–	–	–
Nickel	Ni	420	420	420	21	210	240	270	320	390	420	420	(3)
Selenium	Se	100	100	100	5	–	–	–	–	–	–	–	–
Zinc	Zn	7,500	2,800	2,800	140	–	–	–	–	–	–	–	–
Total Hydrocarbons (5)		–	–	–	–	–	–	–	–	–	–	–	100 ppm

(1) Concentrations on dry weight basis unless noted.
(2) At sites that do not have a liner or leachate collection.
(3) Allowable concentration in sludge determined for each incinerator through testing and emission dispersion modeling.
(4) Limit Currently Remanded
(5) Carbon monoxide may be monitored as an alternative.

Conversions: 1 mg/kg = 0.002 lbs/ton   1 kg/Ha = 0.892 lbs/Ac meets the minimum Class B pathogen reduction requirements, pollutant concentrations, and one of the vector attraction reduction requirements.

Table 11-3 lists the six alternatives cited by EPA for meeting Class A pathogen reduction requirements. These alternatives are similar to the PFRP requirements of the 1979 40 CFR, Part 257 rule. Table 11-4 also lists the pathogen indicator or direct pathogen testing requirements required for Class A designation.

Table 11-5 shows the three methods for meeting Class B pathogen reduction requirements. These methods are similar to the PSRP rules of the 1979 EPA regulations. For land application of Class B biosolids, EPA also imposes site restrictions, which are summarized in Table 11-6.

Table 11-7 summarizes options for meeting vector attraction reduction requirements that apply to all land application programs. For additional information on pathogen and vector attraction reduction requirements, methodologies, monitoring, and testing, see the U.S. EPA document Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge.

Persistent Organic Chemicals: As of the writing of this document, there was insufficient information to establish criteria for sludge spreading with regard to persistent organic chemicals. However, if a known source in a sewer system service area discharges these materials or discharged such chemicals in the past, the sludge should be analyzed for such chemicals and the regulatory agency should be consulted for recommendations concerning sludge application. Per federal requirements, sludges with greater than 50 mg/kg of PCBs cannot be applied to land.

11.12.3 Site Selection

Proper selection of a sludge application site should minimize the nuisance potential and public health hazards. The regulatory agency should be consulted for specific limits, but in general, the following items should be considered:

- Land use plan
- Land ownership information
- Location of dwellings, roads, and public access
- Road weight restrictions
- Slope of land surface
- Groundwater table and bedrock location
- Soil characteristics
- Location of wells, springs, creeks, streams, wetlands, conservation land, and floodplains
- Climatological information and periods of ground freezing

11.12.4 Hauling Equipment

Sludge hauling equipment should prevent spills, odors, and other public nuisances. Where hauling equipment will be operated directly on forest or farmland, the vehicle should be equipped with high flotation tires that will minimize soil compaction.

For liquid sludge application, the spreading tank truck should have a control allowing the discharge valve to be opened and closed by the driver while the vehicle is in motion. The spreading valve should be of the fail-safe type (i.e., self-closing) or an additional manual standby valve should be used to prevent uncontrolled spreading or spills. Similar requirements apply where the application vehicle is connected to the sludge storage facility by flexible hose or other means.

Table 11-3 Summary of the Six Alternatives for Meeting Class A Pathogen Requirements

Alternative 1: Thermally Treated Biosolids

Biosolids must be subjected to one of four time–temperature regimes.

Alternative 2: Biosolids Treatment in a High pH–High Temperature Process

Biosolids must meet specific pH, temperature, and air-drying requirements.

Alternative 3: Biosolids Treated in Other Processes

Demonstrate that the process can reduce enteric viruses and viable helminth ova. Maintain operating conditions used in the demonstration after pathogen reduction demonstration is completed.

Alternative 4: Biosolids Treated in Unknown Processes

Biosolids must be tested for pathogens—*Salmonella* sp. or fecal coliform bacteria, enteric viruses, and viable helminth ova—at the time the biosolids are used or disposed, or, in certain situations, prepared for sale or given away.

Alternative 5: Biosolids Treated in a PFRP

Biosolids must be treated in one of the Processes to Further Reduce Pathogens (PFRP).

Alternative 6: Biosolids Treated in a Process Equivalent to a PFRP

Biosolids must be treated in a process equivalent to one of the PFRPs, as determined by the permitting authority.

Table 11-4 Pathogen Requirements for All Class A Alternatives

The following requirements must be met for all six Class A pathogen alternatives.

Either:

> The density of fecal coliform in the biosolids must be less than 1,000 most probable number (MPN) per gram total solids (dry-weight basis),
>
> or
>
> The density of *Salmonella* sp. bacteria in the biosolids must be less than 3 MPN per 4 grams of total solids (dry-weight basis).

Either of these requirements must be met at one of the following times:

- When the biosolids are used or disposed;
- When the biosolids are prepared for sale or given away in a bag or other container for land application; or
- When the biosolids or derived materials are prepared to meet the requirements for EQ biosolids.

Pathogen reduction must take place before or at the same time as vector attraction reduction, except when the pH adjustment, percent solids vector attraction, injection, or incorporation options are met.

Table 11-5 Summary of the Three Alternatives for Meeting Class B Pathogen Requirements

Alternative 1: The Monitoring of Indicator Organisms

Test for fecal coliform density as an indicator for all pathogens. The geometric mean of seven samples shall be less than 2 million MPN per gram per total solids or less than 2 million CFUs per gram of total solids at the time of use or disposal.

Alternative 2: Biosolids Treated in a PSRP

Biosolids must be treated in one of the Processes to Significantly Reduce Pathogens (PSRP).

Alternative 3: Biosolids Treated in a Process Equivalent to a PSRP

Biosolids must be treated in a process equivalent to one of the PSRPs, as determined by the permitting authority.

Table 11-6 Pathogen Requirements for All Class A Alternatives

Food Crops with Harvested Parts That Touch the Biosolids/Soil Mixture

Food crops with harvested parts that touch the biosolids/soil mixture and are totally above the land surface shall not be harvested for 14 months after application of biosolids.

Food Crops with Harvested Parts Below the Land Surface

Food crops with harvested parts below the surface of the land shall not be harvested for 20 months after application of biosolids when the biosolids remain on the land surface for 4 months or longer prior to incorporation into the soil.

Food crops with harvested parts below the surface of the land shall not be harvested for 38 months after application of biosolids when the biosolids remain on the land surface for less than 4 months prior to incorporation into the soil.

Food Crops with Harvested Parts That Do Not Touch the Biosolids/Soil Mixture, Feed Crops, and Fiber Crops

Food crops, feed crops, and fiber crops with harvested parts that do not touch the biosolids/soil mixture shall not be harvested for 30 days after application of biosolids.

Animal Grazing

Animals shall not be grazed on the land for 30 days after application of biosolids.

Turf Growing

Turf grown on land where biosolids are applied shall not be harvested for 1 year after application of the biosolids when the harvested turf is placed on either land with a high potential for public exposure or a lawn, unless otherwise specified by the permitting authority.

Public Access

Public access to land with a high potential for public exposure shall be restricted for 1 year after application of biosolids.

Public access to land with a low potential for public exposure shall be restricted for 30 days after application of biosolids.

Table 11-7 **Summary of Options for Meeting Vector Attraction Reduction**

Option 1:	Meet 38 percent reduction in volatile solids content.
Option 2:	Demonstrate vector attraction reduction with additional anaerobic digestion in a bench-scale unit.
Option 3:	Demonstrate vector attraction reduction with additional aerobic digestion in a bench-scale unit.
Option 4:	Meet a specific oxygen uptake rate for aerobically digested biosolids.
Option 5:	Use aerobic processes at greater than 40°C for 14 days or longer.
Option 6:	Use alkali addition under specified conditions to raise the pH.
Option 7:	Dry biosolids with no unstablized solids to at least 75 percent solids.
Option 8:	Dry biosolids with unstablized solids to at least 90 percent solids.
Option 9:	Inject biosolids beneath the soil surface.
Option 10:	Incorporate biosolids into the soil within 6 hours of application to, or placement on, the land.
Option 11:	Cover biosolids placed on a surface disposal site with soil or other material at the end of each operating day. *(Note: Only for surface disposal.)*
Option 12:	Use alkaline treatment of domestic septage to pH 12 or above for 30 minutes without adding more alkaline material.

11.12.5 Site Management

Sludge Storage: Sufficient capacity should be provided for periods of inclement weather and equipment failure. The storage facilities should be designed, located, and operated so as to avoid nuisance conditions and runoff to surface waters.

Spreading Methods: The selection of spreading methods depends on the sludge characteristics, environment, and other factors. When control of nuisance odors and runoff is required, immediate incorporation of sludge after spreading or subsurface injection should be considered. When such a method is used, an adjustment in the rate of ammonia loss into the atmosphere should be considered for the nitrogen balance.

Sewage sludge should be spread uniformly over the surface when tank truck spreading, ridge and furrow irrigation, or other methods are used. Application of dewatered sludge cake by manure spreaders may be used.

Proposals for subsurface application of sludge should include a description of the equipment and program for application.

Only downward-directed spray systems should be used.

Boundary Demarcation: The boundaries of a site should be marked (e.g., with stakes at corners and signs) to avoid confusion regarding the location of the site during sludge application. The markers should be maintained until the end of the growing season.

Where Class B sludge products are used, public access to the site must be controlled by either positive barriers or the location of the site. A sign should be posted at the site entrance specifying public access restrictions.

11.12.6 Surface Disposal and Landfilling

There are two types of landfill sites that typically accept solids. One is a monofill, a landfill that accepts only stabilized or unstabilized municipal wastewater solids and is regulated by 40 CFR, Part 503. The other is a co-disposal landfill, which accepts both residuals and municipal solid waste, and is regulated by 40 CFR, Part 258.

According to federal regulations, pollutant limits for sludges placed at surface disposal sites, such as sludge-only landfills, are based on the distance from the sludge application to the site boundary, as shown in Table 11-2. However, the stipulated pollutant limits may be site-specific, if allowed by the permitting authority. Also, if sludge is placed on a site with a liner and a leachate collection system, the sludge is not subject to any of the pollutant limits in 40 CFR, Part 503. Additional limits on surface disposal include the following:

- Sites must be managed to prevent environmental contamination.
- Public access to the site must be restricted.
- Groundwater under the site must be monitored, or a qualified groundwater scientist must certify that the sewage sludge will not contaminate an aquifer.
- Sites must be located in geologically stable areas.
- Grazing or production of food must be avoided unless it is allowed by the permitting authority.
- In the federal regulations, a two-year time limit is specified for on-site storage before a facility will be classified as a surface disposal site.
- In sanitary landfills, sludges and ash may be disposed of separately or in combination with municipal solid waste.
- Sludge dewatering systems should minimize free water in the sludge and reduce the volume of sludge sent to a landfill.
- When sludge is landfilled separately, it may be necessary to mix it with well-graded bank gravel to provide structural strength for equipment access.
- Sludge trenching techniques may be considered.
- Leachate and surface runoff should be controlled by use of daily cover, grading, and top sealing. Sludge should not be deposited close to seasonal high groundwater elevations (generally 4–6 feet; check state regulations).
- Groundwater quality control measures, including impervious liners and underdrains with leachate treatment, may be needed in specific instances, in accordance with regulatory requirements.
- Leachate, surface runoff, and stormwater runoff (25 years, 24 hours) should be collected and disposed of in accordance with a NPDES permit. Sludge should not be deposited within 200 feet (60 m) of an active fault line, in a wetland (unless a NPDES permit is obtained), or in an area where adverse impacts to a threatened or endangered species may occur.
- Provisions should be made for groundwater quality monitoring for heavy metals, persistent organics, nitrates, and pathogens in accordance with regulatory agency requirements. A groundwater monitoring program should clarify that sludge placed in a surface disposal site is not contaminating an aquifer.
- The concentration of methane gas should not exceed 25 percent of the low explosive limit (LEL) in any on-site structure when the final cover is installed.
- Closure and post-closure plans are required 6 months before closure of a surface disposal site.

11.12.7 Incineration Ash Landfilling or Reuse

Incinerator ash should be disposed of in accordance with applicable landfill regulations. Regulations vary from state to state, and designers should check local, state, and federal regulations before determining whether to use or dispose of incinerator ash. Some landfills require a pH test or a toxicity characteristic leaching potential (TCLP) test before accepting ash.

Beneficial reuse of incineration sludge ash includes uses such as landfill cover material, asphalt additive, soil amendment, lightweight glass aggregate, and excavation fill material.

11.12.8 Monitoring, Recordkeeping, and Reporting

The monitoring, recordkeeping, and reporting requirements of 40 CFR, Part 503 are contained within each subsection. Annual reports must be made to the permitting authority, and records must be kept for 5 years. The minimum sludge monitoring frequency for arsenic, cadmium, chromium, lead, and nickel are as follows:

Sludge Quantity Monitoring

Metric Tons/Yr, Dry Solids	Frequency
Less than 290	Once per year
290 to 1,500	Once per quarter (4 times per year)
1,500 to 15,000	Once per 60 days (6 times per year)
Greater than 15,000	Once per month (12 times per year)

After monitoring for 2 years, frequency of monitoring for amounts greater than 290 metric tons/yr may be reduced to once per year with the approval of the permitting authority. In addition, state requirements must be followed.

11.12.9 Permitting

Sludge management practices will be included under the NPDES permit for each treatment plant. State and local regulations should also be reviewed for additional requirements.

11.12.10 Value-Added Product

With land application of Class B solids becoming more difficult to permit, and with transportation of Class B solids to distant land application sites becoming more costly, many municipalities are evaluating technologies that can generate Class A products, which can be marketed and distributed locally to the public. Marketed solids must meet 40 CFR, 503 criteria, as well as state and local regulations.

Value-added products are marketed and distributed to various agricultural, landscape, horticulture, and residential markets. Value-added products include heat-dried solids, compost, advanced alkaline-stabilized solids, and ash-derived products. The markets for each value-added product typically have a set of benchmarking criteria that a product must meet before the market will be interested, including pH, salinity, nitrogen, phosphorus and potassium content (N-P-K), water-holding capacity, growth screening tests, bulk density, moisture content, organic matter content, particle size, and stability.

11.13 Incineration

Sludge combustion to ash and exhaust gases is most typically carried out in multiple hearth or fluid bed incinerators.

11.13.1 Design Basis

Unit size is based on the quantity and quality of sludge to be incinerated, its moisture content, and the heat value of the sludge. An analysis of the combustible fraction of the sludge should serve as the theoretical basis for combustion.

Autogenous combustion (i.e., combustion without the use of auxiliary fuel) may be achieved at a solids concentration of 25–50 percent, depending on volatile solids percentage and control of excess air.

Where single units are used, storage or alternative methods of stabilization and disposal must be available.

11.13.2 Equipment Features

Air pollution control facilities should be provided to meet state and local regulations.

Auxiliary fuel burners should be provided to handle the range of sludges expected.

Variable speed combustion or fluidizing air blowers are recommended.

Waste heat recovery or air preheating is recommended for large units.

Provide continuous emissions monitoring in accordance with 40 CFR, Part 503.

Provide incinerator and air pollution control systems monitoring in accordance with 40 CFR, Part 60.

11.13.3 Operating Considerations

The design should minimize startup fuel costs by allowing for as near-continuous operation as possible.

The incinerator and auxiliary equipment should allow operation and maintenance during inclement weather.

11.13.4 Multiple Hearth Incinerators

Wet sludge loadings for multiple hearth incinerators will range from 5 to 15 lb/ft^2/hr (24.4–73.2 kg/m^2/hr) of hearth area, with typical values of 8–10 lb/ft^2/hr (39–49 kg/m^2/hr). The higher sludge loadings are associated with a higher percentage of solids and/or combustibles.

Provide a minimum capacity of 100 percent air in excess of theoretical requirements using variable-speed drives that allow efficient adjustment of air flow rates.

Raise the temperature of exhaust gas to 1,200–1,400°F (650–760°C) for deodorization and destruction of hydrocarbons. To raise the temperature, use a furnace or an external afterburner.

11.13.5 Fluid Bed Incinerators

Wet sludge loadings will range from 75 to 175 lb/ft^2/hr of bed area (73.2–170.8 kg/m^2/hr). The higher sludge loadings are associated with a higher percentage of solids and/or combustibles.

Provide a minimum capacity of 50 percent air in excess of theoretical requirements using variable-speed drives to allow for efficient adjustment of air flow rates.

Design freeboard to provide sufficient temperatures and durations to fully destroy volatiles and eliminate odors.

References – Chapter 11

NFPA 70: *National Electrical Code*, 2011 Edition

NFPA 820: *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*, 2008 Edition

U.S. EPA, *Environmental Regulations and Technology, Control of Pathogens and Vector Attraction in Sewage Sludge*, July 2003, EPA/625/R-92/013

WEF Manual of Practice No. 8, *Design of Municipal Wastewater Treatment Plants*, 5th Edition, 2010

CHAPTER 12

RECEIVING HAULED WASTES

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12.1 General

Publicly owned treatment works (POTWs) receive wastewater from a variety of domestic and nondomestic sources (commercial businesses and industries). However, wastes may also be transported by truck or rail to POTWs by waste haulers. Such hauled waste may include domestic septage, chemical toilet waste, grease and sand trap waste, non-hazardous commercial and industrial waste, hazardous waste, groundwater remediation site waste, and landfill leachate.

Because pollutants are usually more concentrated in hauled waste, and because hauled waste may not be equalized when discharged, hauled waste may cause adverse impacts at treatment plants. These adverse impacts may include pass-through to receiving waters, interference to treatment plant processes and operations, sludge (i.e., biosolids) contamination, and hazards to POTW personnel.

Under 40 CFR 403.5(b)(8), the discharge of trucked or hauled pollutants is prohibited except at points designated by the POTW. This chapter will focus on design, management, and operational considerations associated with accepting hauled waste.

12.2 Materials Received by Truck or Rail

12.2.1 Septage

Septage is a general term for the contents removed from septic tanks, portable vault toilets, privy vaults, holding tanks, very small wastewater treatment plants, or semi-public facilities (e.g., schools, motels, mobile home parks, campgrounds, small commercial endeavors) receiving wastewater from domestic sources.

The physical characteristics of septage make it difficult and objectionable to handle and treat. High levels of grease, grit, hair, and large solids in septage can clog pipes and pumps, and the parasites, viruses, and bacteria that septage normally contains can cause disease. The anaerobic nature of septage results in the presence of odorous compounds (e.g., hydrogen sulfide, mercaptans, and other organic sulfur compounds), which are released with greater frequency when septage is exposed to the turbulent conditions that can occur at a POTW. Foaming can also be a problem when air is blown into septage. Table 12-1 contains typical septage characteristics.

Table 12-1 **Septage Characteristics – Conventional Parameters**

	Concentration: mg/L (milligrams per liter)		
Parameter	**Average**	**Minimum**	**Maximum**
Total Solids	34,106	1,132	130,475
Total Volatile Solids	23,100	353	71,402
Total Suspended Solids	12,862	310	93,378
Volatile Suspended Solids	9,027	95	51,500
BOD	6,480	440	78,600
COD	31,900	1,500	703,000
Total Kjeldahl Nitrogen	588	66	1,060
Ammonia Nitrogen	97	3	116
Total Phosphorous	210	20	760
Alkalinity	970	522	4,190
Grease	5,600	208	23,368
pH	—	1.5	12.6

Source: Table 2-2: Guide to Septage Treatment and Disposal. EPA, 1994.

12.2.2 Fats, Oils, and Grease

Fats, oils, and grease (FOG) collected from grease traps are sometimes hauled to POTWs. FOG, which may be of animal or vegetable origin, can be solid or viscous at ambient temperatures, and can cause blockages in pipes, clogging of pumps, and coating and clogging of monitoring probes. In addition, oils and grease from grease traps may have a pH less than 5.

If FOG wastes are not kept well mixed and heated, solid scum layers can form and cause blockages in pipes. Because of the potential problems caused by receiving FOG wastes, some POTWs prohibit or place restrictions on its discharge, both through the collection system and as a hauled waste. Other POTWs, which possess the ability to accept and treat FOG wastes, have established procedures for accepting these materials. When determining whether to accept FOG wastes, POTWs should consider the potential for the waste to cause pass-through and interference. At a minimum, POTWs must prohibit the discharge of FOG waste in amounts that would cause pass-through and interference.

12.2.3 Portable/Chemical Toilet Waste

Wastes from portable toilets, Type III marine sanitation devices, and chemical toilets may be hauled to treatment plants for disposal. These wastes may be incompatible with POTW operations due to antibacterial and disinfecting agents used in the chemical toilets. A POTW should require haulers to submit information on the volume and concentrations of bacterial growth inhibitors in hauled waste; a facility must also evaluate how much of this material it can safely handle.

12.2.4 Non-Hazardous Commercial/Industrial Waste

Non-hazardous commercial/industrial waste is waste generated by non-domestic sources that is not regulated as hazardous waste under 40 CFR Part 264. These wastes may include process waste, cooling water, and boiler blowdown.

The National Pretreatment Program establishes categorical pretreatment standards to regulate the level of pollutants in wastes discharged to POTWs by specific industries. Industrial and commercial wastes that are not regulated by a categorical pretreatment standard may also be incompatible with treatment plant operations. The pollutant concentrations in these materials can often be controlled through the development and application of local limits.

12.2.5 Groundwater Remediation Site Waste

Wastes from groundwater remediation sites have frequently been pretreated and contain only trace amounts of toxics, which typically can be accepted at a POTW without causing a problem. Nonetheless, a POTW should require remediation site operators to provide information on the volume, pollutants, and pollutant concentrations of the waste they propose to deliver.

12.2.6 Landfill Leachate

Landfill leachate is liquid that passes through or emerges from solid waste. Pollutant concentrations vary widely. Factors that can affect leachate quality include:

- Type and composition of waste.
- Age of waste.
- Climate and moisture composition of waste.
- Waste processing, compaction, and other landfill operational aspects.
- Temperature, pH, and redox condition in a landfill.
- Presence of large quantities of municipal sewage sludge or industrial sludge or wastes.

12.3 Receiving Station Design Considerations

Many of the materials listed above are considered treatable at a POTW. However, unless proper engineering and design is provided, these materials may represent a shock load to a facility or have other adverse impacts on plant processes and effluent quality. It is essential that an adequate engineering evaluation be made of a facility and the anticipated loading before receiving any such material. The appropriate regulatory agencies must also be contacted to obtain appropriate approval before initial material acceptance. For proposed plant expansions and upgrades, the engineering report and facility plan must include anticipated loading rates when addressing treatment plant sizing and process selection.

Listed below are general points to be considered as part of an engineering and design analysis:

- Capacity of a treatment plant relative to the amount and rate of materials directed to the facility.
- Unused plant capacity available (above current sewer collection system loadings) to treat hauled wastes.
- Sensitivity of treatment plant process to daily fluctuations in loadings resulting from the addition of hauled wastes.
- Slug loadings of BOD, ammonia nitrogen, or phosphorous that may cause process upset, odor nuisance, aeration tank/aerated digester foaming, or pass-through to effluent.
- The point of introduction of hauled waste into a treatment plant’s processes. Alternative points of feed to treatment units, including feeding to solids processing units, should be evaluated for feasibility, with particular focus on whether the unit function would be adversely affected.
- Ability to control feed rates to a plant so materials are introduced during off-peak loading periods.

- Volume and concentrations of bacterial growth inhibitors in materials from portable vault toilets and recreational vehicle dump station holding tanks.
- Impact on permitted plant-effluent regulatory limits from each of the controlled parameters.

Under federal regulations [40 CFR Part 403.5(b)(8)], a POTW must prohibit the discharge of any trucked or hauled pollutants except at discharge sites designated by the facility. Therefore, POTWs accepting hauled waste must designate a specific discharge point or receiving station. Factors to consider when selecting the location of a discharge site include sensitivity of the treatment plant to pollutant loadings from hauled waste discharged directly to the plant's headworks, accessibility to the discharge site, and visibility of the site to POTW personnel (i.e., ease of surveillance).

Listed below are general factors that should be considered in designating/locating a receiving station:

- *Speed limits on POTW roads:* Speeds should be posted clearly to ensure the safety of haulers and POTW personnel.
- *Sight lines:* Blind curves and corners should be avoided.
- *Wear on roads:* Constant wear from trucks may increase maintenance costs if access roads are not properly designed.
- *Vehicle access:* If a station is not a pull-through station, adequate space should be provided for trucks to back up. Providing access and explicit instructions for recreational vehicles should also be considered, if these types of vehicles are expected to use the station.

The following sections address design considerations for the acceptance of septage and FOG wastes, individually. Any unique design considerations associated with the other materials listed in 12.2 is considered beyond the scope of this report.

12.3.1 Septage Receiving Station Design Considerations

Generally, there are three options for septage receiving at a POTW: Add septage to the liquid treatment system, to the sludge handling train, or to a combination of both. Table 12-2 summarizes these options.

Septage received at municipal wastewater treatment facilities should be treated before being incorporated into either liquid or solid stream unit processes. The method of incorporating septage into a facility depends on a number of factors, including the septage loading in comparison with the POTW's current and design loadings, type of wastewater treatment process, and funds available for septage equalization and process improvements. Incorporating septage into the liquid and solid stream unit processes will be discussed in greater detail separately below.

12.3.1.1 Incorporation Into Liquid Stream Unit Processes

As of the writing of this document, the majority of wastewater treatment facilities that accept septage do so either at the headworks of the facility or at a manhole just upstream of the headworks. To minimize the potential for short-term overloading of downstream unit processes, a number of wastewater treatment facilities have incorporated receiving facilities and equalization. These facilities allow septage to be incorporated into the liquid stream process at a relatively constant and controlled rate.

12.3.1.1.1 Station Design

The characteristics of septage entering a wastewater treatment facility can vary greatly. Older, decaying septage systems often contribute a great deal of grit to wastewater treatment facilities. A properly designed receiving station is

Table 12-2 **Summary of Options for Handling Septage at POTWs**

Method	Description	Advantages	Disadvantages
Septage addition to upstream sewer manhole	Septage is added to a sewer line upstream of POTW	• Simple and economical due to very simple design • May provide substantial dilution of septage prior to reaching POTW	• Odor potential near manhole • Difficult to control access • Potential for accumulation of grit and debris in sewer • Only feasible with large sewers
Septage addition to plant headworks	Septage is added to sewage immediately upstream of screening and grit removal processes	• Simple and economical due to very simple design • Allows control of septage discharge by POTW staff	• May affect POTW processes if septage addition is uncontrolled or treatment plant is too small • Increase odor potential at POTW
Septage addition to sludge treatment process	Septage is handled as a sludge and processed with POTW sludge, after pretreatment in receiving station	• Reduces loading to liquid stream process • Reduces potential for affecting effluent quality	• May have adverse effects on sludge treatment processes, such as dewatering • May cause clogging of pipes and increase wear on pumps if septage is not screened and degritted in receiving station
Septage addition to both the liquid stream and sludge treatment process	Septage is pretreated to separate liquid and solid fractions, which are then processed accordingly	• Provides more concentrated sludge for processing • Reduces organic loading to liquid stream processes and hydraulic loading to sludge processes • Increases flexibility of subsequent processing steps	• Requires increased operations for septage pretreatment at receiving stations • Expensive, due to receiving station costs

Source: Table 2-6: Guide to Septage Treatment and Disposal. EPA, 1994.

a vital component of a successful septage management system. A receiving station should include:

- Hard surface unloading ramp sloped to a drain to allow cleaning of spillage.
- Quick disconnect fittings for vehicles delivering septage.
- Screening capabilities (both course and fine).
- Grit removal capabilities.
- Flow monitoring.
- Level sensor with alarm and indicator light.
- Flow equalization.
- Provisions for odor control.

Unloading Process: In addition, the area must collect and contain any septage spilled during unloading. Equipment and space for washdown must be provided, including water with ample pressure, hose, and spray nozzle. A facility must be able to serve tanks that discharge by pump or by gravity. A receiving station should be capable of receiving liquids at levels appropriate to completely drain tanks mounted on trucks.

Septage Screening: Septage course screening can be performed with manual or mechanical bar racks. Some vendors provide mechanical screening devices that also include septage degritting. One advantage of these devices is their ability to dewater and wash screenings and grit prior to discharge. The screened and degritted material is then introduced into a wastewater treatment facility's unit processes. Since discharge of septage at a receiving station will allow the release of odors into the immediate area, a receiving facility should provide for the containment, collection, and treatment of odors.

12.3.1.1.2 Impact on Reserve Capacity

Septage is a significant source of solid and organic loadings at wastewater treatment facilities. Septage can be either a high-strength wastewater or a relatively dilute solid. If the septage is to be introduced into the liquid stream, it must be considered a high-strength wastewater. To determine the amount of septage that a facility can successfully process (assuming septage was not included in the original design), the reserve capacity of each of the unit processes within the facility must be determined.

Evaluating Reserve Capacity: When evaluating the reserve capacity of unit processes, it is recommended that, at a minimum, three years of operating data be summarized and reviewed. The amount of operating data needed may increase if recent modifications have occurred at a facility or if new sources of organic or hydraulic loads have been introduced. Current loadings at a facility must be compared with design criteria to estimate reserve capacity.

Factors in Evaluating Facility Capacity: Each of a facility's unit processes must be evaluated to determine the facility's limits. Hydraulic and organic loadings are considered in the evaluation. The addition of septage to the liquid stream process typically has a greater effect on the organic capacity of a facility than on the hydraulic capacity. Introducing septage into the solid stream unit processes of a wastewater treatment facility often has a greater effect on the hydraulic capacity. If a plant's reserve capacity is found to be insufficient for the anticipated amount of septage, one option is to store septage received during the day and treat it at night when flows are lower. Research has shown, however, that constant loading is the optimal method for WWTP operation.

12.3.1.1.3 Impact on Solids Generation

The treatment of septage at a wastewater treatment facility will increase the amount of solids generated by that facility. The impact will depend on the type of treatment process used and the location at which septage is introduced to the facility. Typically, septage treatment will increase primary and secondary solids generation, providing an additional loading to any downstream solids handling unit processes and increasing the sidestreams resulting from those unit processes.

12.3.1.1.4 Methods to Estimate Septage Treatment Costs

The costs to treat septage include the costs associated with a reduction of reserve capacity, along with an increase in operation and maintenance. A number of facilities have allocated a certain portion of their reserve capacity for septage treatment. The value of this reserve capacity should be determined and incorporated into any calculations regarding the fee structure for septage treatment. When calculating the reserve capacity cost, which is similar to evaluating the impact on reserve capacity, both the required organic capacity and required hydraulic capacity should be considered.

Receipt and treatment of septage will increase the costs of operation and maintenance at a wastewater treatment facility. Additional labor is necessary, and some facilities report an increase in pump wear when septage is introduced. These costs must be included when determining the fee for septage treatment.

12.3.1.2 Incorporation Into Solid Stream Unit Processes

The majority of items discussed in Section 12.3.1.1 also apply when septage is to be incorporated into solid stream unit processes. However, all screening and degritting must be performed before the material is introduced into solid stream unit processes. When introduced into the liquid stream, septage typically receives preliminary treatment as part of the wastewater treatment process. When septage is incorporated into solid stream unit processes, no further preliminary treatment is available.

To minimize wear on downstream equipment, a thorough preliminary treatment process should be conducted before septage is introduced into solid stream unit processes. Preliminary treatment should include screening, degritting, and flow equalization. When septage is to be incorporated into the solid stream, it is necessary to pump the material to the unit processes.

12.3.1.2.1 Points of Incorporation

Septage can be incorporated into solid stream unit processes at a number of locations. The locations chosen will depend upon a wastewater treatment facility and its mode of operation. Typically, receipt of septage would be conducted ahead of thickening, digestion, or denaturing processes. Thickening and dewatering are volume reduction steps, which serve to concentrate septage solids. Introducing septage into the digestion process provides stabilization and solids reduction before treatment in subsequent unit processes.

12.3.1.2.2 Impact on Sidestream Loads

Introducing septage into solid stream unit processes will increase the impact of sidestreams on liquid stream processes at a facility. When evaluating the impact of these sidestreams on liquid stream unit processes, the impact of introducing septage directly into unit stream processes should be considered. Digestion followed by dewatering of septage will reduce the loading to a liquid stream by a factor of approximately 10 compared with introducing septage directly into unit stream processes.

12.3.1.2.3 Methods for Estimating Septage Treatment Costs

Treatment of septage in the solid stream will impact reserve capacity and increase the operation and maintenance costs of solid stream unit processes. It is important to consider both reserve capacity and the increase in O&M costs when determining the fee for septage treatment.

12.3.2 FOG Receiving Station Design Considerations

It is not advisable to receive FOG waste into liquid stream unit processes. If introduced at a facility's headworks, FOG waste has a tendency to float, along with an adhering effect that will trap other solids and form grease balls. Grease balls can blind screens and may need to be removed manually. FOG that passes through preliminary treatment would next be removed in primary clarifiers through a scum collection system. Grease in scum/primary sludge has a tendency to coat primary sludge lines, resulting in higher head loss.

FOG wastes can also coat and clog other plant piping, resulting in more frequent maintenance of sludge pumps and piping to remove FOG plated on equipment. The number of joints, bends, and elevation changes of lines conveying FOG can also lead to greater FOG accumulation. Odors can also be a major consideration. Odors will be especially problematic during FOG cleaning operations, because the lines and equipment are usually in buildings that require proper ventilation.

As is the case with lines vulnerable to sludge buildup, glass-lined steel or ductile iron piping has proven to be the most resistant to FOG accumulation. Making individual pieces of pipe as long as possible to reduce joints can reduce the number of sites where grease may get caught. Reducing the distance between incorporation point and treatment process will also reduce the possibility of FOG plating. Providing dedicated steam lines for cleaning is advisable, and placing cleanouts in places that are easily accessible will facilitate more efficient maintenance.

For facilities with anaerobic digesters, it can be beneficial—in terms of enhanced methane production and reduced sludge generation—to introduce FOG wastes into the digestion process after some preliminary pretreatment. The pretreatment components or processes to consider include:

- Coarse screening.
- Grit removal.
- Heated sludge blending tanks.

See Chapter 11 for more information on anaerobic digestion.

12.4 Elements of a Hauled Waste Management Program

The specific elements of a waste hauler control program may vary for each POTW, depending on treatment plant capacity, flows and pollutant loading, sensitivity of plant processes, types and amounts of hauled wastes accepted, funding, and local issues and requirements. The information provided below should be tailored, as necessary, for applicability to an individual POTW.

12.4.1 General Legal Authority to Impose Controls

The legal authority of a POTW or other local authority to administer controls on hauled waste or to implement a hauled waste permit program is derived from state laws and local ordinances. If adequate legal authority to control hauled waste is not present, local ordinances should be modified. A local ordinance must describe controls in sufficient detail so waste haulers and POTW personnel understand all procedures, expectations, and liabilities associated with a program. A POTW should request legal review by an attorney to ensure the local ordinance provides adequate authority and that the ordinance does not create unnecessary procedural or institutional obstacles that might hinder the discharge control program. If a POTW accepts non-domestic hauled waste from outside its jurisdiction, the facility should ensure it has authority to regulate generators outside its jurisdiction.

The legal authority required for an effective waste hauler control program is similar to those for regulating sources connected to a POTW; however, there are additional provisions that should be included in a POTW's sewer use ordinance. In particular, an ordinance should contain the following provisions:

- Discharging hauled waste is prohibited, except at points designated by the POTW.
- No load may be discharged without prior consent of the POTW.
- Hauled waste must meet applicable federal, state, and local pretreatment standards and requirements.
- The POTW may collect samples of each hauled waste load to ensure compliance with applicable standards.
- The POTW may require a hauler to provide a waste analysis of any load prior to discharge.
- The POTW may require commercial, industrial, and/or residential waste haulers to obtain a permit.
- Violating an ordinance or permit will result in penalties.
- Waste haulers are required to use a manifest system.

12.4.2 Access and Hours of Operation

Controlling access to a discharge site can greatly reduce the possibility of facility disruption due to illegal or incompatible discharges. At a minimum, manual locking gates should be installed at a discharge site entrance, and ideally, a system of electronic access control should be utilized. In such a system, permitted haulers are given an electronic access card that serves as a key to the facility, and that may also be used for waste hauler tracking and billing. A potential drawback to such a system is that cards may be "lent" to unpermitted haulers.

When determining hours of operation and discharge time limits, POTWs should consider times when POTW personnel are available and times when peak and low flows occur in the collection system and treatment plant. This is especially true for smaller POTWs where peak and low flows may be of particular concern. Twenty-four hour access is an option that may be appropriate for some facilities (e.g., facilities that are staffed at all times). Such around-the-clock access may increase the period of time between discharges and increase flexibility for septage haulers.

12.4.3 Permits

A permit system is the most direct and efficient method of regulating waste haulers that discharge to a POTW. Implementing a permit system provides the opportunity to monitor and regulate haulers based on a treatment works' operating conditions. If a POTW accepts hauled industrial waste, including wastes regulated by categorical pretreatment standards, it should consider permitting waste generators as well as waste haulers.

All waste haulers within a POTW's service area should be considered potential dischargers to the POTW system and should be notified of the permit system requirements, including the prohibition against discharge of hauled waste except at designated areas. Notification could be provided individually to each waste hauler that potentially could discharge to the POTW, or notification could be accomplished through general procedures such as publishing notices in newspapers or trade papers. It is important to be aware that if a POTW's local sewer use ordinance prohibits the discharge of hauled waste without a permit, any hauler that discharges without a permit is in violation and subject to all liability whether or not they received notification of permit requirements.

Each waste hauler should be required to complete a questionnaire or permit application. The permit application form should be designed to provide a POTW with all information necessary to identify, track, communicate with, and control waste haulers.

The following is a list of conditions a POTW should consider including in a discharge permit issued to waste haulers:

- *Right of refusal to accept waste:* The POTW should maintain the right to refuse any hauled waste loads.
- *Non-domestic loads:* Waste haulers should be limited to discharging only domestic waste if the POTW is not capable of treating hauled nondomestic wastes.
- *Prohibited discharges:* Waste haulers must be prohibited from discharging wastes that would violate prohibited discharge standards of the General Pretreatment Regulations or local ordinances.
- *National categorical pretreatment standards:* If waste haulers are allowed to discharge nondomestic wastes to the POTW, a determination must be made regarding whether the sources of these wastes are regulated by national categorical pretreatment standards. If a hauler discharges categorical process wastewater, the permit must require compliance with applicable categorical standards.
- *Local limits:* The permit should require compliance with local limits established by the POTW, including specific limits applicable to hauled non-domestic waste.
- *Designated disposal site:* The permit should clearly designate the disposal site and state all facility rules for discharging, such as cleanup requirements.
- *Number of loads:* If a POTW is susceptible to hydraulic or organic overloading, the facility may wish to consider placing a limit on the maximum number of loads a waste hauler can discharge over a given period of time.
- *Time limitations:* Specific days and/or hours that waste haulers are allowed to discharge should be stated in the permit conditions.
- *Waste tracking/manifest system:* The permit should contain a condition that requires waste haulers to provide documentation on the nature, origin, and volume of wastes being discharged.
- *Notification of waste type:* The POTW may want to require that any waste be approved prior to being hauled. The permit should require a hauler to notify and receive approval from the POTW when hauling waste from new customers as well as when there are changes in the nature of wastewater from existing customers.
- *Standard conditions:* Many standard conditions placed in other industrial user permits—such as modification of conditions, non-transferability, revocation of permit, and penalties/fines—should also be contained in waste hauler permits. The POTW may also consider requiring waste haulers to post performance bonds.

12.4.4 Monitoring Program

Monitoring is necessary to gather information about the characteristics of hauled waste that is discharged to the treatment plant, and to determine if waste should be rejected because of potential negative impacts to the facility. Monitoring is necessary to ensure that discharges conform to standards and regulations, and can provide vital information when hauled waste interferes with plant operations; through monitoring, a POTW can determine which load and what pollutants and concentrations caused the problems. A monitoring program demonstrates to waste haulers that a POTW is serious about enforcing the standards and requirements of its hauled waste control program. For these reasons, POTWs should seriously consider including monitoring as part of their waste hauler control programs, particularly if nondomestic wastes are accepted.

A POTW should consider a number of issues when establishing the sampling procedures associated with a monitoring program, including:

- Sampling frequency necessary to obtain data representative of the nature and volume of hauled waste.
- Sampling frequency required to deter unscrupulous haulers from delivering and discharging incompatible wastes.
- Actual (and potential) impacts of hauled waste on the operation of the treatment plant, receiving water body, and sludge/biosolids disposal practices.
- The hauled waste source and the types and concentrations of pollutants contained in the waste.
- Regulatory requirements of any permits, local ordinances, POTW policies, and federal and state regulations.
- Seasonal variations in the volume and makeup of hauled waste.
- Availability of POTW staff.
- Trends in delivery times.
- Compliance history of waste haulers.
- The costs of sampling and analysis borne by waste haulers and the POTW, and the resources—labor, materials, and equipment—available to conduct an effective monitoring program.

A POTW should establish a base sampling frequency and increase or decrease the frequency on a case-by-case basis (while considering the factors described above).

12.4.5 Waste Tracking – Manifest System

A manifest system, similar to those used for hazardous waste, is an efficient means of recording information on hauled waste. This type of control, which can be employed independent of a permit system, requires waste haulers to enter information on a waste manifest form for each load received. The manifest form should include information such as:

- Name, address, and telephone number of hauler and each waste generator.
- Types of wastes collected from each generator.
- Approximate volume(s) received by the hauler.
- Known or suspected pollutants, as identified by the generator.
- Certification by the generator that the waste is not hazardous and the waste is not generated from any process defined as a categorical process wastewater.
- Results of testing performed on the waste.

Before each discharge, a POTW should require a completed manifest form from the waste hauler. Each manifest sheet should be completed in triplicate—one copy for the waste hauler, one copy for the treatment plant operator, and one copy for the POTW's administrative/billing purposes. POTWs should supply blank manifest forms to each waste hauler. Treatment plant operators should periodically verify information provided on manifest forms by contacting the sources on the manifest.

12.4.6 Communication With Other POTWs

To effectively control hauled waste, all POTWs within a geographic region should readily share information they receive on hauled waste. When a POTW rejects a load, the operator should consider contacting nearby facilities where the waste may be delivered, and inform the facilities of the reason(s) for rejection. If a waste load is rejected, the POTW could also request the hauler to provide information on when and where the rejected load was ultimately discharged. POTWs should also communicate with one another to identify frequent violators. A list of haulers with frequent violations, including type of violation, can be distributed among a region's POTWs.

12.5 Operational Considerations

Table 12-3 contains a brief summary of operation and maintenance activities associated with hauled waste receiving facilities.

Table 12-3 **O&M Issues for Receiving Stations**

Task	Responsibility	Recommended Frequency
Collect and store sample, inspect waste for odor and appearance	Operator	Every load
Wash down pad	Hauler	Every load
Rake screenings from bar rack – if present	Hauler	Every load
Remove screenings and grit	Operator	Dictated by design
Lubricate mechanical screens, use grit removal equipment – if present	Operator	Per manufacturer's recommendations
Rotate use of transfer pumps	Operator	Typically monthly
Repack pump seals and conduct preventive maintenance	Operator	Per manufacturer's recommendations
Wash down walls of holding tank	Operator	Daily
Check oil levels in pumps and blowers	Operator	Per manufacturer's recommendations
Conduct preventive maintenance on blowers and diffusers	Operator	Per manufacturer's recommendations

Source: Table 8-1: Guide to Septage Treatment and Disposal. EPA, 1994.

12.6 Independent Septage Treatment

Facilities developed exclusively for the treatment and management of septage are becoming increasingly popular. Independent facilities treat septage as either a strong wastewater or a dilute solid. Some facilities process septage as a dilute solid and discharge effluents and any sidestream flows to municipal wastewater treatment facilities. Other facilities provide complete treatment of septage and treat primary effluents and any sidestreams. These facilities operate within the limitations of their National Pollutant Discharge Elimination System (NPDES) permit.

12.6.1 Receiving Station Design

The proper design and function of a receiving station at an independent septage treatment facility is crucial to the facility's success. The station must be able to receive septage in a timely fashion while providing preliminary treatment to protect downstream unit processes. It is not uncommon for independent facilities to use multiple truck bays. The considerations described in Section 12.3 also apply to independent facilities.

Receiving stations must also provide an effective means of septage screening and grit removal. Grease removal is an additional step that is conducted at some facilities. The preliminary processes contained within a receiving station are the only means of providing adequate protection to downstream unit processes.

12.6.2 Equalization

Flow equalization is an important component of an independent treatment process. Equalization allows septage to be received during normal working hours while maintaining a relatively constant influent flow to downstream unit processes. The volume required for equalization can be determined in the same manner as sizes for typical wastewater equalization basins—that is, by using an influent mass diagram on which cumulative inflow volume is plotted against time of day. The average daily flow rate, also plotted on the same diagram, would be a straight line drawn from the origin of a diagram to the end point. Equalization volume is equal to the vertical distance from the point of tangency to the straight line representing the average daily flow rate.

In addition to equalization, septage storage should be considered when determining the overall volume required. Some facilities may not receive septage during weekends and holidays. The storage volume provided must be sufficient to allow operation of downstream unit processes when septage is not entering the facility. The amount of storage required will depend upon the type of treatment process in use. Some independent processes in which septage is treated as a dilute solid are operated in a batch mode. Facilities that treat septage as a strong wastewater require continuous flow to maintain optimum performance.

12.6.3 Primary Solids Separation

Gravity thickening or chemically assisted primary settling prior to dewatering or biological treatment warrants consideration. The volume reduction obtained by solids concentration is beneficial to subsequent dewatering processes, reducing the required capacity and the amount of energy consumed. Thickening of septage can be accomplished in a circular tank similar to gravity thickeners at wastewater treatment facilities. Septage can also be chemically conditioned to improve its settling characteristics. Independent systems that process septage as a dilute solid can perform settling and decanting in a batch mode. The most commonly used chemicals for septage conditioning include lime, ferric chloride, alum, and polymers.

12.6.4 Treatment of Liquid Fraction

The effluent from primary clarification/gravity thickening can be treated using a number of liquid stream unit processes. Variability in effluent strength and characteristics may present operational problems for activated sludge processes with a low solids retention time. Extended aeration processes are more capable of handling such conditions. Fixed-growth biological systems operated at low loading rates are also well suited to septage treatment. Average organic loading rates of 5–10 pounds of BOD per day per 1,000 cubic feet have been used successfully in oxidation ditch systems. Rotating biological contactors have been operated with soluble BOD loading rates of 100–200 lbs/day per 1,000 sq ft. The impact of upstream chemical conditioning of septage as part of the clarification/thickening process must be taken into account when considering biological treatment.

Nitrification and Denitrification: A number of septage treatment facilities have been located in regions with extremely sensitive environments and stringent effluent limits. These effluent limits often require removal of nitrogen and phosphorus before discharge. As with wastewater treatment, nitrogen removal can be accomplished through nitrification and, if necessary, denitrification. The volumetric loading to achieve nitrification must be reduced and the solids retention time increased. Phosphorus removal can be achieved biologically or by adding chemicals ahead of secondary clarification.

Secondary Clarification: Following biological treatment, the wastewater will pass through secondary clarification to remove solids before discharge or subsequent treatment. The secondary solids can be transferred directly to the solids handling stream for further processing or introduced into primary clarifiers for co-thickening. Instead of installing secondary thickening units, some facilities have incorporated co-thickening of secondary solids within a primary clarifier.

12.6.5 Treatment of Solids Fractions

Some facilities treat septage as a dilute solid. These facilities thicken and dewater septage, then treat or discharge the primary effluent/thickener supernatant and filtrate (or centrate) generated during the dewatering process.

12.6.5.1 Thickening Processes

A number of thickening processes are available. These include gravity thickening, dissolved air flotation, gravity belt thickening, and rotary drum thickening. The selection of a thickening process will affect the size and operating requirements of any downstream dewatering processes. As of the writing of this report, the majority of facilities perform gravity thickening or chemically assisted settling prior to dewatering.

Historically, dissolved air flotation units have been used in thickening secondary solids generated during wastewater treatment. However, dissolved air floatation has become less popular with the advent of new technology and concerns regarding operating costs.

Mechanical thickening using gravity belt thickeners and rotary drum thickeners is a common method of thickening secondary wastewater treatment solids. These systems can also be used to thicken septage solids. When evaluating these mechanical systems, weigh the impact on downstream unit processes versus the cost of implementation.

12.6.5.2 Dewatering Processes

Methods of dewatering that warrant consideration in an independent septage treatment facility include belt filter presses, centrifuge, plate and frame, membrane or recessed chamber filter presses, and screw presses. An effective dewatering system should accomplish the following:

- Minimize adverse impacts of conditioning agents on subsequent biological treatment.
- Provide a high solids capture rate to reduce organic loading to subsequent biological treatment.
- Minimize washwater requirements to reduce hydraulic loading to subsequent biological treatment.
- Dewater to a minimum of 18 percent solids to reduce the capital investment and operating costs associated with a facility's handling of solids.
- Minimize septage exposure to agitation to reduce and contain odors.
- Provide cost-effective dewatering.

Belt filter presses, centrifuges, and recessed chamber presses have been used successfully in dewatering septage. Centrifuge and recessed chamber applications have, on occasion, used lime and ferric chloride as conditioning agents. However, conditioning agents have been the cause of difficulty in treating filtrate and centrate generated from dewatering. Screw presses have also been used on a pilot basis for septage dewatering.

Belt Filter Presses: Belt filter presses (BFP) are widely used for cost-effective dewatering of primary and secondary solids from municipal wastewater treatment facilities. Facilities with a filter press, however, have complained about excess amounts of grease, which can cause the filter press to blind. These facilities may want to ensure grease is not comingled with septage in excess amounts. Typical performance with mixtures of primary and secondary solids ranges from 18–25 percent solids with a capture rate of 85–95 percent. A BFP using a polymer as a conditioning agent at a rate of approximately 10 pounds per dry ton of septage has achieved cake solids up to 26 percent. Washwater requirements of BFPs are typically 60 gallons per minute per meter of belt width.

Centrifuge: Typical performance of centrifuge dewatering mixtures of primary and secondary solids ranges from 18–25 percent total solids with a capture rate of 90–95 percent. Centrifuges dewatering septage using a polymer as a conditioning agent have routinely achieved solids concentrations of 25 percent. Cooling water requirements are minimal.

Filter Presses: Two common types of filter presses in use today are recessed chamber and membrane presses. Recessed chamber presses rely on pumping pressure to force liquid septage through a filter membrane. Membrane presses rely on air or water pressure to force liquid through a filter medium. (The term “plate and frame press” refers to older units that consisted of separate filter plates and support frames rather than one recessed chamber.) Cake solids of conditioned municipal primary and secondary solids often exceed 40 percent and solids capture rates are as high as 99 percent. Filter presses for dewatering raw septage routinely achieve cake solids of approximately 30 percent. These systems typically use ferric chloride and lime as conditioning agents; one particular system averages a 7 percent ferric chloride dose and a 32 percent lime dose. While lime and ferric chloride are the most popular conditioning agents, organic polymers can be used to condition septage solids before dewatering. The use of polymers reduces adverse chemical impacts on subsequent biological treatment units.

Screw Presses: Screw presses can also be utilized for either municipal solids or septage dewatering. The septage is introduced to the bottom of a vertical screw auger that transports the liquid and solids upward within a screen barrel. Free liquid discharges through the screen openings, dewatering solids as they travel toward the discharge chute at the top of the unit. The performance of a screw press monitored during a pilot septage dewatering operation ranged from 13–25 percent total solids. Solids capture rates of approximately 80 percent were achieved, with polymer consumption in a range of 8–18 pounds per dry ton of septage dewatered.

Filtrate/Supernatant Pretreatment: The filtrate and supernatant from thickening and dewatering must be treated. Some facilities provide full biological treatment, and have obtained discharge permits for release of their effluent to the environment. A number of independent systems that manage septage as a dilute solid discharge their filtrate and supernatant to municipal waste treatment facilities. Processing provided at an independent facility greatly reduces the septage-derived organic load to a municipal system.

12.7 Land Application of Septage

Another management option for septage that some states allow is land application. In states where land application is allowed, it may be a cost-effective means of septage management. If implementation of a septage land application program is being considered, it is critical to consult the many federal and state publications outlining the controlling regulations. A description of all that is involved in operating a successful septage land application program is beyond the scope of this document.

References – Chapter 12

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CHAPTER 13

INSTRUMENTATION, CONTROLS, AND REPORTING

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13.1 General

This chapter provides guidelines for designing a modern instrumentation and control (I&C) system. The term “I&C” used in this chapter generally refers to hardware and software designed to:

- Measure important process variables such as liquid and gas flow rates, chemical residual, and dissolved oxygen concentrations.
- Control process equipment and flow-regulating devices in response to changes in monitored process variables.
- Indicate and/or record measured process variables, the on/off status of process equipment, and flow-regulating devices.
- Annunciate and/or log alarm conditions such as excursions from the desired range of monitored process variables, malfunctioning equipment, and the development of hazardous conditions in confined spaces.

The degree to which instrumentation, automation, and process control are used in wastewater treatment facilities greatly influences the design of the entire system. The configuration and size of tanks, channels, pipes, and mechanical equipment will be affected substantially by good instrumentation and control practices. Therefore, I&C decisions must be made early in the conceptual phase of a project.

Remote control (automation) and automatic process control can improve operation and reliability, decrease manpower requirements, provide energy savings, and reduce chemical usage. These savings may be partially offset by the cost of instrumentation maintenance. I&C should always support operations goals.

Some wastewater facilities use a supervisory control and data acquisition (SCADA) system, which includes a computer system, associated software, microprocessor-based (computer) controls, and wired or wireless communication to monitor, control, and collect data from wastewater processes that are local or remote. These systems can be designed for large complex facilities or very small facilities.

The type of instrumentation and control systems in wastewater treatment facilities depends upon numerous factors, including size of the facility, hours of manned operation, complexity of processes, reliability requirements, and availability of maintenance personnel. Ultimately, the decision regarding the extent and type of I&C depends on the costs versus the benefits, with careful consideration given to the specifics of each situation. All monitoring equipment should be manually checked periodically due to the harsh working environment and the need to maintain accuracy at the highest degree possible.

13.1.1 Instrumentation and Controls Design

13.1.1.1 Elements of Good Design

A good I&C design must show a clear scope of the work. For treatment facilities, it is desirable to have a design that consists of all or some of the following:

- Process and instrumentation diagram (P&IDs)
- Control system architecture drawing
- Control panel drawings or specification
- Instrumentation specification, lists, and mounting detail as required
- Input/output (I/O) list
- I&C specifications, including product description and methods of execution
- Control narrative to describe system logic for programming or wiring

Most major components of I&C systems are microprocessor-based and require configuration or programming. These devices are more desirable than previous electromechanical devices because of enhanced reliability and features.

13.1.1.2 Instrumentation and Sensors

Instruments used to measure parameters such as chlorine residual, dissolved oxygen, ORP, flow, level, and pressure provide vital inputs to control systems. It is important that these devices are properly placed in a process so the desired operations will occur. The design for these instruments should provide easy access for maintenance and calibration.

Discrete sensors such as float switches, level switches, pressure switches, and temperature switches are also important for control systems. These sensors must be carefully placed in a process to ensure a proper control result and to provide ease of maintenance.

Microprocessor-based control systems are programmed to react to instrumentation and sensor inputs. If the instruments and sensors are not properly designed and maintained, it will result in imprecise control of a process.

13.1.1.3 Controls and Communication

Most control systems in the wastewater industry consist of microprocessor-based controls, with the most popular type being programmable logic controllers (PLCs). Some very simple control systems still use electromechanical relays, but this is becoming less common. Some very large systems use distributed control systems (DCSs), though these too are becoming less popular and are giving way to PLCs. It is important to choose the right controller technology to fit the need. PLCs come in all sizes and price ranges, and can be fitted to all wastewater applications.

There are various methods used for a wastewater facility's internal and external communications. Controllers are generally networked together using a manufacturer's proprietary communications protocol or a standard protocol. The means of communication can be wireless, cellular, wired, fiber-optic, Internet-based, or telephone; most wastewater facilities use a combination of some of these means. It is important during the design phase that a plan is developed to ensure reliable communication at the plant and with remote sites. A communication system that is not well planned, and a plan that is not well executed, is costly to operations.

13.1.1.4 Operator Interface Hardware and Software

Before the advent of computers, interface between an operator and a process came in the form of lights, switches, indicators, alarm annunciator panels, mechanical timers, chart recorders, and thumbwheel switches. Although some of these devices are still used, they are much less common in modern control systems, which increasingly rely on operator interface terminals. OITs are panel-mounted displays that provide a graphical interface used to display graphics and animation, and to send data to and from a PLC by using a keypad or touch screen. These devices replace dozens if not hundreds of punch buttons, lights, etc. OITs are generally designed to be placed near the process with which they are associated.

13.2 Instrumentation and Sensors

13.2.1 Flow Measurement Equipment

Flow measurement is needed for both liquid flow and gas flow.

13.2.1.1 Liquid Flow Meters

Liquid flow meters can be either open channel flow meters or pipe flow meters.

- **Open Channel Flow Meters**

  Open channel meters are typically used for influent flows and flows between unit processes, because, among other considerations, they can handle measuring large variations in flow rates.

  Parshall Flume

  Although numerous types of flumes are available for measuring wastewater flows, the Parshall flume (Figure 13-1) is the most common. Advantages of the Parshall flume are its relatively low head loss and low potential for fouling, blockages, and accumulation of solids. A properly sized Parshall flume can measure a wide range of flows (i.e., 0.01 to 3,000 cfs) and has at least a 20:1 turndown ratio.

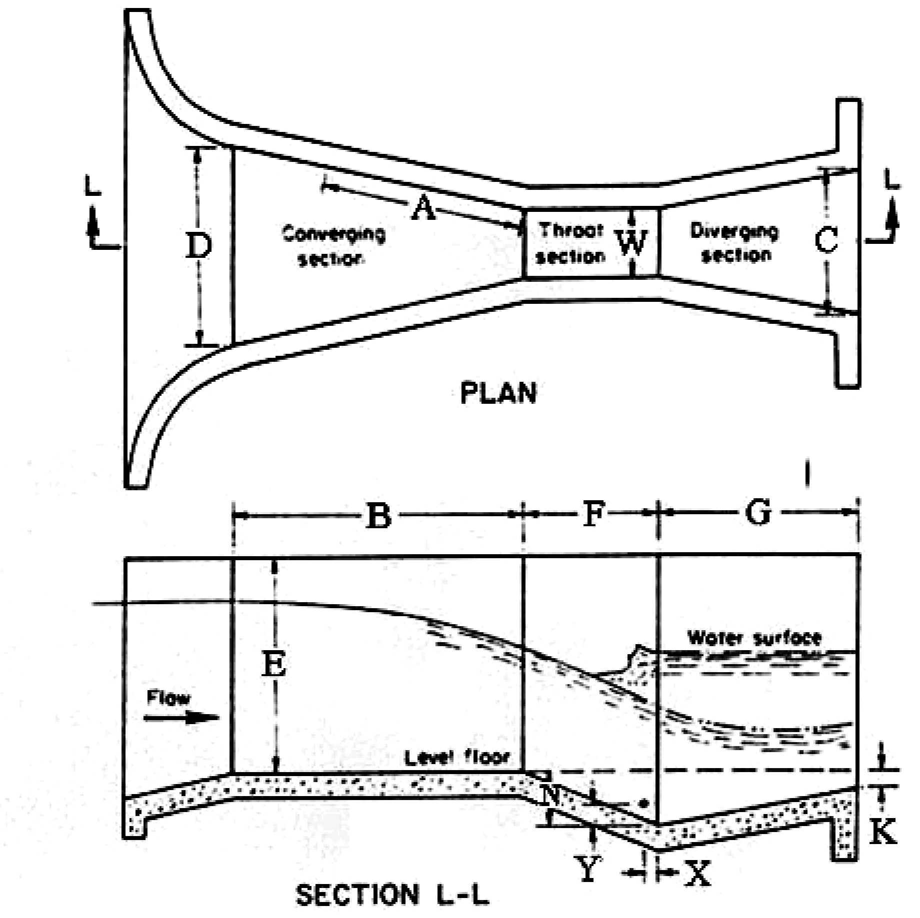
  The engineer should verify that the following conditions are met during design and construction:

  - The flume should be set with the convergence section as level as possible in both transverse and longitudinal directions. The floor elevation established for the convergence section must provide for an empty flume under no-flow conditions, and must ensure that the maximum discharge submergence for the flume is not exceeded. The effect of backwater produced by downstream restrictions at peak flow conditions must be thoroughly considered.
  - Hydraulic approach conditions should be as free as possible of changes in direction, and should be parallel to the center line of the flume. A rule of thumb is to provide, upstream of the flume inlet, a straight, unobstructed run that is at least 10 times the width of the flume's throat.
  - The smallest practical throat width capable of accommodating the full range of flows (i.e., initial minimum to design-year maximum) should be selected. At minimum flow, try to maintain a water depth of at least 0.1 foot. A smaller flume nested

in a larger flume should be considered where initial flows are below or near the lower limit of the range measured by the larger flume.

The flow level in a flume is typically measured with an ultrasonic transducer. Static pressure measurement is also a possibility.

Figure 13-1 **Plan and Sectional Views of a Parshall Flume**



Weirs

Weirs are commonly used for measuring flows at wastewater treatment facilities. Advantages of weirs are their relatively low initial cost and ease of installation. Weirs are generally considered to be more accurate than flumes. However, weirs consume more available head than flumes and are more sensitive to upstream turbulence and variations in approach velocities. Furthermore, flows containing substantial amounts of screenings, grease, and settled solids are not well suited to measurement by weirs. Screenings and grease can collect on the edges of a weir plate, altering crest elevation and introducing error. Settled solids can collect in the pool of water behind the weir structure, altering approach velocities.

The engineer should verify the following conditions during design and construction:

- To promote a favorable approach-velocity profile, the channel section upstream of the weir should be straight and have a uniform cross section of a distance equal to or greater than 15 times the maximum head on the weir.

- For accurate flow measurement, the distance between the secondary device (e.g., ultrasonic transducer) and the weir crest should be at least 4 times the maximum head expected over the weir.
- The maximum head over a rectangular weir should be less than one-half of the crest length of the weir. The minimum head as measured by a secondary device over a rectangular weir should be 0.2 foot or more.
- The minimum and maximum head over a V-notch weir should be 0.2 and 2.0 feet, respectively.

Area Velocity Flow Measurement

In channels where flumes or weirs are not practical, or where reverse flows may occur, a combination of depth measurement (pressure or level measurement) and measurement of the average velocity of the flow stream, typically using Doppler technology, will provide an accurate measurement of total flow.

- **Closed Pipe Flow Meters**

Closed pipe flow meters measure flow rates within a pipe or a completely enclosed and filled cross section.

Magnetic Flow Meters

Magnetic flow meters (also known as electromagnetic flow meters or mag meters) are used for metering water, solutions, slurries, or liquid sludge, provided that the fluid is conductive. The liquid can be corrosive, abrasive, or at a high temperature, as long as the proper construction materials are selected.

At the location of the meter, the pipeline must always be full for proper operation; air bubbles should be avoided because they can cause erroneously high readings. In vertical installations, the flow should always be upward.

The accuracy of wafer or flange type magnetic flow meters can be as low as 0.3–0.5 percent of the measured value. Insertion type magnetic flow meters offer 0.5–1.0 percent accuracy. The low end of the meter range may not be as accurate, particularly when velocity across the electrodes is low. In-line flow meters should be installed with 5 to 10 pipe diameters of straight, unobstructed pipe upstream of the meter, and 1 to 2 pipe diameters downstream.

A magnetic flow meter must be designed so the meter can be taken out of service for calibration or service without disruption of the process. If the process pipeline cannot be shut down for extended periods of time, bypass piping is recommended. Select a meter location that permits ease of calibration, meter removal, or in-place maintenance.

Magnetic flow meters must be properly grounded. Stainless steel grounding rings and grounding straps should be provided by the manufacturer.

- **Ultrasonic Flow Meters**

Ultrasonic flow meters fall into two basic categories: reflective or Doppler type, and transmission or transit-time type. Both methods are suitable for conductive and nonconductive liquids, but Doppler types require reflective elements (bubbles or suspended solids) in the stream. Sensors with multiple beams average out flow aberrations and increase accuracy. Ultrasonic flow meters come in clamp-on, insertion, and in-line versions.

Clamp-on sensors are easy to install and can achieve accuracies of up to 1 percent of measured value, but they are very sensitive to a pipe's acoustic properties. Because of this sensitivity, accuracy can be reduced to 20 percent. Typically, clamp-on sensors do not function at all with lined pipe. Therefore, it is important to the check manufacturer's specifications.

The major advantages of ultrasonic flow meters are low capital cost and minimal head loss.

- **Coriolis Mass Flow Meter**

  Coriolis mass flow meters are suitable for slurries and have superior accuracy over a wide range of conditions, but they are more expensive than other flow meter types, and therefore do not find application in wastewater treatment plants.

- **Other Liquid Flow Meter Types**

  Other liquid flow meters that are on the market but limited to clean water or very low suspended solids applications are:

  - Variable area flow meters (commonly known as Rota meters).
  - Differential pressure (venturi or orifice plate) flow meters.
  - Propeller or turbine flow meters.

13.2.1.2 Gas and Air Flow Meters

Gas and air flow is measured in closed pipes and can be expressed as volume per unit time (cubic feet per minute or cfm) or mass flow (typically expressed as standard cubic feet per minute or scfm). Mass flow is required for most control applications.

- **Thermal Mass Flow Meters**

  Thermal mass flow meters measure the cooling effect of air or gas moving over a heated element. They typically come as an insertion unit, but in-line versions are available for smaller pipe sizes. Because they measure mass flow, conversion to standard conditions (scfm) is not required.

  Installation is simple, but correct installation is important to achieve the stated accuracy of 0.75 percent for readings or 0.5 percent of full scale. Flow elements must be installed 15 to 40 pipe diameters downstream of an obstruction (depending on the nature of the obstruction) and 5 pipe diameters upstream of the nearest obstruction. Correctly applied flow straighteners can reduce the upstream requirement.

- **Differential Pressure Flow Meters**

  Venturi and orifice plate type differential pressure flow meters are still used for measuring airflow in wastewater treatment plants. The venturi type is preferred because it causes lower pressure loss (10–15 percent of inlet pressure) and is less sensitive to upstream obstructions. This results in less straight pipe needed for installation. Differential pressure transmitters are simple and robust, but venturi tubes are costly, particularly for larger pipe diameters. The systems also require precise calibration to achieve accurate readings.

- **Variable Area Flow Meters**

  Variable area flow meters (a.k.a. Rota meters) are primarily for lower gas flow rates (from 0 up to about 2,000 scfm). Versions are available with both visual and electronic readouts, and they can be intrinsically safe. They need to be installed vertically, but can be located near elbows or obstructions. Variable area flow meters are inexpensive, reliable, and practically maintenance free. They are typically used with process gases.

13.2.2 Liquid Level Measurement Equipment

Liquid level measurement can be divided into single point measurement and continuous measurement.

13.2.2.1 Single Point Level Measurement

Single point measurement refers to systems that recognize when a specific liquid level in a tank, well, or other containment has been reached. Single point measurement is normally used for switches and alarms.

- **Float Switches**

  Float switches are the most common level-sensing elements. These devices have a fixed setpoint, but are easily adjusted by manually arranging the float switch cable to which they are attached.

  Construction: Float switches should be constructed of a material that resists corrosion, and should include a chemical-resistant S/0-type rubber suspension cable with a weight at the bottom.

  Mounting: Float switches can be mounted vertically on pipes or suspended from a weighted cable via a cable support rack. Vertical pipe mounting is recommended for most applications because less space is required. With suspended cables, sufficient spaces between float switches must be provided, requiring more horizontal area.

  Installation: Correct installation of float switches is critical for proper operation. They should be located away from the invert location and the incoming flow.

  Spacing and Location: Vertically mounted float switches should be arranged so the switches are staggered on the pipe. Also, in most cases, the float portion of the switch should be tied to the pipe by a cable that allows the switch portion of the float to rise and fall by 90 degrees. Suspended cables allow for easier adjustment of float switches, but debris can cause the suspended cables to rise and malfunction. In either case, the float switch setpoints may be adjusted to within 4 inches (100 mm) based on the allowable limit of travel of the float switches.

  The type of area in which float switches are to be installed must be addressed. Typically, wet well areas are classified as Class I, Division I hazardous locations. Therefore, all float switch circuits and installations within wet well areas should use intrinsically safe relays.

  Cleaning: Grease, oil, scum, fats, and other debris can cause float switches to jam, so periodic cleaning of the switches is required. Flushing with clean water is recommended.

- **Conductance Switches**

  Conductance switches sense the change in conductance from air to liquid. Because they are easy to install and have no moving parts, they have very low maintenance requirements; they are also intrinsically safe. A single probe can have up to 10 sensors for 10 different levels, so multiple functions can be controlled by one probe.

- **Capacitance Switches**

  Capacitance switches function similarly to conductance switches, but measure change in capacitance.

- **Vibration Sensors**

  A vibration sensor is in the form of a tuning fork that is piezoelectrically excited at its resonant frequency. The oscillating frequency or the amplitude changes as the fork enters the medium. The change is recognized and converted into a switching signal. The sensor does not need calibration and maintenance, and works for all liquids and in conditions of build-up, turbulence, or air bubbles. A vibration sensor is unaffected by the electrical properties of the medium.

13.2.2.2 Continuous Level Measurement

Continuous level measurement is accomplished with non-contact or contact sensors.

- **Non-Contact Sensors**

  There are several non-contact level sensors. The main categories are ultrasonic and radar.

  Ultrasonic Sensors

  Ultrasonic sensors are located above the surface of a liquid and emit ultrasonic waves to the surface. The time it takes for the sound to reflect off the surface and return to the sensor is a measure of the level. The sensor needs to be located according to manufacturer's instructions to avoid echo interference. Measurement range can be up to about 65 feet, and accuracy is up to 0.2 percent of measurement range.

  The acoustic signal can be distorted by condensate (e.g., steam) or foam, which can lead to false readings. Systems with high powered acoustic pulses have greater range (up to 200 feet) and higher resolution, and can provide more accurate readings under difficult conditions.

  Radar Sensors

  Radar sensors use a radio frequency pulse that is reflected from the surface of the liquid. Radar has better penetration properties than acoustic waves so it is less sensitive to foam, vapors, and condensates. Measurement range is as high as 200 feet or more. Different manufacturers define accuracy differently, but it is typically around 0.1 percent of range or ± 0.4 inches.

- **Contact Sensors**

  Level sensors that contact the liquid include guided radar, capacitance probes, and hydrostatic pressure probes.

  Guided Radar

  In guided radar (guided wave radar, time domain reflectometry), high-frequency radar pulses are guided down a probe (rod or rope) inserted in a liquid. As the pulses impact the medium surface, the characteristic impedance changes and part of the emitted pulse is reflected. The time between pulse launching and receiving is measured and analyzed by the instrument and constitutes a direct measure of the distance between the process connection and the product surface. The measurement is insensitive to foam or turbulence, and accuracy is typically better than 0.005 percent over a range of up to 20 feet or more. Guided radar can also be used to measure the interface between two distinct liquids.

Capacitance Probes

Capacitance probes (RF admittance) measure the change in capacitance of a capacitor-like probe immersed in a conductive fluid. They are suited for depths up to about 10 feet and accuracy is better than 1 percent.

Hydrostatic Pressure Probes

Hydrostatic pressure probes measure the column of fluid above them and thus directly measure the depth (as long as the density is known). The probes are robust and have very good accuracy (0.2 percent) and linearity (0.1 percent of range). They are largely insensitive to clogging or contamination. Sensors can be protected by a cage in particularly hostile and abrasive environments.

Other Systems

Bubbler systems were used in the past, but they are costly to operate and maintenance intensive, so have largely been replaced by other systems. In most current guidance materials, bubbler systems are no longer specified as viable alternatives for continuous level measurement.

13.2.3 Pressure Measurement

Pressure measurement is ubiquitous at wastewater treatment facilities, because it is often a surrogate for another measurement (e.g., flow rate or liquid level). The specific type of pressure measurement involved can be characterized by numerous terms, including absolute pressure, gauge pressure or differential pressure, gas or liquid, and continuous measurement or pressure switching. Pressure measurements can be relayed via remote transmission, and can be viewed on analog or digital displays.

Pressure is normally measured by the force on a surface area. The surface can be a diaphragm, and the pressure is equivalent to the displacement of the diaphragm against a known spring force. For differential pressure measurement, the two pressure regions are applied to either side of the diaphragm and the deflection measured. The diaphragm can be replaced by a ceramic, metal or solid state sensor, and pressure can be measured as a change in the electrical or physical properties of the sensor.

Knowledge of the environment in which the pressure sensor will have to function (e.g., corrosive, abrasive or explosive environments; temperature range; etc.) is important when selecting equipment.

13.2.4 Gas Detection

There are two possible objectives of gas detection in wastewater treatment plants: detection of combustible gases and detection of toxic gases.

13.2.4.1 Gas Detection Equipment

In structures where combustible or toxic gases may accumulate, fixed gas detection systems must be installed. Portable units should be used by individuals when entering confined spaces that may contain gases, such as manholes, pump stations, tanks, and wet wells.

Gas detectors need to be calibrated. Calibration schedules depend on the type of instrument, use of the instrument, and the environment in which the instrument is used. Calibration frequency should be high initially, and slowly reduced if it becomes apparent that calibration adjustments are not needed.

13.2.4.2 Combustible Gas Detection

In wastewater treatment, the primary combustible gases that may require detection are methane and other hydrocarbons. Methane is encountered in and near anaerobic digesters, biogas piping and storage, and anywhere that anaerobic conditions could exist, such as pumping stations, wet wells, and composting facilities. Other hydrocarbons are encountered near storage facilities for fuels, methanol, and ethanol. Detection of combustible gases is regulated by NFPA 820: *Standard for Fire Protection in Wastewater Treatment and Collection Facilities*.

When selecting a location to install a gas detector, it is important to know whether the target gas is lighter or heavier than air. For example, methane is lighter than air, so detectors should be near the ceiling of an enclosed space, whereas ethanol vapor and propane are heavier than air, so detectors should be near the low point of a space.

Combustible gases can be detected using infrared (IR) or catalytic detectors. IR detectors are immune to poisoning, less sensitive to interfering gases, and have a self-check mode that reduces calibration requirements and improves reliability. Catalytic gas detectors are less susceptible to dust, dirt, and humidity; and can detect hydrogen, which is invisible to IR. The limitations of catalytic detectors are that they are sensitive to oxygen levels (low oxygen levels compromise sensor accuracy); can be poisoned by silicones, chlorine, or sulfur compounds; and can be contaminated by halogen compounds as well as oils and grease.

13.2.4.3 Toxic Gas Detection

Toxic gases encountered in a WWTP are typically chlorine, hydrogen sulfide, carbon monoxide, sulfur dioxide, and ammonia. Technically, carbon dioxide is not toxic, but it is heavier than air so it can displace oxygen in enclosed spaces and cause asphyxiation. Toxic gases can be detected by electrochemical and solid state systems.

- **Electrochemical Cell Sensors**

  Electrochemical cell devices are suited for detection of toxic gases such as carbon monoxide, hydrogen sulfide, and hydrogen chloride. They can also be used to detect oxygen deficiency. Electrochemical cell devices respond to the presence of gases by generating a current. They are accurate and respond quickly, but only function at or near atmospheric pressure. Electrochemical cell devices are not fail-safe and should be checked regularly.

- **Solid State Gas Sensors**

  Solid state gas sensors consist of a metal oxide layer deposited on a ceramic substrate. The sensor layer is heated to a temperature specific to a particular gas, and a resistance change is measured. Solid state sensors are robust, have a long operating life (2–10 years), and are insensitive to extreme ambient conditions and corrosive environments. However, they have high power consumption, have poor selectivity for certain specific gases, and can be cross-sensitive to other gases.

13.2.5 Sludge Instrumentation

Sludge blanket evaluation can be conducted with manual measurements or automatic systems. Manual sludge blanket measurement can be done with a clear plastic tube with a check valve at the end. The tube essentially takes a core sample that can be visually evaluated and measured with a tape measure.

Automatic systems use optical sensors or sonar. Optical systems use a turbidity or TSS sensor that is lowered on a cable until the turbidity changes; the level of the sludge blanket is measured by the movement of the cable. These systems can provide a complete turbidity profile of a clarifier or sludge thickener.

Sonar or ultrasonic systems use a submerged sensor to send and receive an ultrasonic signal. Changes in the liquid distort the return signal and the analyzer can generate a profile of the liquid showing the separation zone(s) and the sludge blanket. The sensor can be fitted with a pump for self-cleaning.

13.2.6 Analytical Instrumentation

On-line instruments of the type described below typically consist of a sensor (or probe) and an analyzer. The sensor is in constant contact with wastewater and sends a signal to the analyzer. The analyzer is rail-mounted near the sensor, and processes the signal both for local display and for transmission for further processing by a SCADA system, another controller, datalogger, or other such devices. Signal transmission is typically either analog (4–20 mA) or digital (e.g., Modbus or RS-422). Analyzers can process one or more signals.

13.2.6.1 Dissolved Oxygen Measurement

Dissolved oxygen (DO) probes measure the concentration of dissolved oxygen in wastewater, typically in the secondary treatment (aeration basin) phase. Measurements are in mg/L or ppm, and the range is from 0 to no more than 10 mg/L (saturation), although probe ranges typically extend to 20 or 60 mg/L.

Two basic technologies for measuring DO are available as of the writing of this report. The newer optical systems are becoming the standard for new installations. Optical probes work on the principle of fluorescence (or luminescence) quenching. They are essentially maintenance free, other than weekly cleaning of the probe, and do not require calibration. Some probes are available with air or water jets to keep the optical element free of fouling. They are insensitive to hydrogen sulfide, air bubbles, or other interferences. Manufacturers state that the sensor cap needs to be replaced every two years; however, replacement periods as short as one year are possible, depending on operating conditions and regular maintenance. The probe output is a digital signal.

Membrane (or electrochemical) technology is an older means of measuring DO. The probes have a semi-permeable membrane that allows oxygen to pass, and the cell generates a current proportional to the partial pressure of the oxygen. Membrane-type systems are less expensive than optical systems, but the membrane needs to be kept free of fouling, and the membrane and electrolyte need to be replaced regularly. The probe output is an analog signal.

13.2.6.2 Ammonium Measurement

Ammonium can be measured directly in wastewater using ion-selective electrodes (ISEs). The probes can be installed in secondary treatment or final effluent. Because the probes require regular cleaning, an automatic air cleaning option is recommended. In addition, the probes drift over time and require regular calibration. They also need to be adjusted for potassium interference. Probe life is typically 3–18 months, depending on chemistry of the wastewater. Accuracy is in the range of 5 percent (± 0.2 mg/L). On-line ammonium analyzers can be used for trending and for process control, but they are not certified for reporting purposes.

Ammonium can also be measured optically by analyzers that pump a filtered sample to a central analyzer (see Section 13.2.6.10).

13.2.6.3 Nitrate Measurement

Like ammonium, nitrate can be measured using ISE technology. The requirements listed above for ammonium apply also to nitrate measurement, with the exception that potassium compensation is not necessary.

Nitrate can also be measured in mixed liquor using UV spectrometry. The probes are robust and do not require calibration, but the sensor does require cleaning, either with an air or water jet, or with a wiper. Because the probes measure and compensate for TSS, a secondary TSS signal is normally an option. The accuracy is similar to that of a properly calibrated ISE probe. UV nitrate probes are more expensive than ISE probes, but require less maintenance.

13.2.6.4 Phosphate Measurement

On-line phosphate measurement in wastewater uses a calorimetric method, either the "blue method" for low phosphate concentrations (approx. 0.05–3 mg/L) or the "yellow method" for a larger measurement range (approx. 0.3–100 mg/L). Both methods require the addition of chemicals (consumables) to a sample for photometric measurement. Analyzers can be self-cleaning and self-calibrating.

Only dissolved phosphate can be measured in mixed liquor because pumping and filtering of the sample is required; final effluent samples, however, can be measured for total phosphate (including suspended and particulate phosphates). Accuracy is in the range of 3 percent ($\pm$ 0.05 mg/L).

13.2.6.5 Total Suspended Solids (TSS) Measurement

Optical systems are used for measuring total suspended solids (or turbidity) in mixed liquor. Measurement is conducted via light absorption or light reflection ("backscatter"), or a combination of both, depending on the level of TSS. Because contamination of the optical sensor may occur, such systems should have a cleaning option, such as an air scour, wiper, or ultrasonic cleaning mechanism. Even with such a cleaning device, manual cleaning at regular intervals is still necessary.

Dedicated TSS analyzers are available, but a TSS output is usually available as an option on any other optical instruments used in a plant (e.g., DO, UV-nitrate), since these devices need to compensate for turbidity and are already measuring TSS.

13.2.6.6 pH Measurement

Sensors that measure pH (i.e., the acidity or alkalinity of a solution) typically consist of a glass tube containing two electrodes and a polymer gel. The electrodes generate a voltage proportional to the concentration of hydrogen ions in a solution. The sensors are robust but need to be protected against breakage. They also need to be regularly cleaned, and occasionally calibrated or replaced.

13.2.6.7 Oxidation-Reduction Potential (ORP) Measurement

ORP sensors measure the level of oxygen available for a chemical reaction in a solution, so they can be used to detect the transition from anoxic to anaerobic conditions. ORP sensors are functionally identical to pH sensors.

13.2.6.8 Chlorine Measurement

Free chlorine is the sum of hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). The ratio of hypochlorous acid to hypochlorite ion is a function of pH and temperature. Because free chlorine sensors only respond to hypochlorite ion, they need to compensate for pH (internally or with a pH probe), and the analyzer needs to calculate total free chlorine.

Total chlorine is the sum of chloramines, sometimes called combined chlorine, and free chlorine. Some systems require sample conditioning through the addition of potassium iodide; others have internal compensation.

13.2.6.9 Temperature Measurement

The two widely employed devices for measuring in-process temperatures are thermocouples and resistive temperature devices (also called RTDs or thermistors). Both require signal conditioning to turn a sensor reading into a temperature. Also in use are miniaturized solid-state devices, which feature an integrated analog-to-digital converter and provide a direct digital signal for temperature.

Temperature measurement is often a by-product of other measurements, and is thus an optional analyzer output from DO probes, ammonia/nitrate analyzers, and similar devices.

13.2.6.10 Process Analyzers

Process analyzers can measure multiple parameters from multiple sample points with a single analyzer unit. Measured parameters include, but are not limited to: ammonia, nitrate, nitrite, phosphate, chlorine, monochloramine, and pH. A process analyzer contains a sample pump and filter; the filtered sample is pumped to a central unit consisting of a sample conditioning system and a photometric or UV-spectrometer cell for measurement.

In mixed liquor applications, regular maintenance of the filters is important.

13.2.7 Power Monitoring

Power monitoring in its simplest form consists of regular readings of a kWh meter. This practice provides a precise measure of average power (total electrical energy/time) used by all consumers on a circuit in the interval between readings. This information is important mainly for establishing a baseline for energy reduction programs and for verifying the results of a program.

Power monitors are available for monitoring frequency, voltage, current, and power in electrical control panels or motor control centers. Power monitors can provide additional, calculated information such as power factor, total harmonic distortion, and total energy usage for the monitored unit, which can be a single consumer or a bank of consumers, such as a group of pumps or blowers; these monitors have datalogging and remote communications capabilities.

Power monitoring of individual consumers is usually done by measuring the current to the unit. This is typically done with a shunt ammeter in a permanent installation or with a clamp-on ammeter for temporary measurements. Power monitoring of individual units may be done simply for remote confirmation that a machine is operating, or it may be done for precise machine controls, such as surge protection of a blower.

13.3 Controls and Communications

13.3.1 Electromechanical Controls

Electromechanical control systems consist of discrete components including, but not limited to: relays, timers, counters, selector switches, pushbuttons, pilot lights, and analog alarms. These components are arranged and wired to implement a Boolean logic or what is known in the industry as relay ladder logic. This logic is used to control equipment, perform functions, control processes, and provide alarming.

Electromechanical systems typically use pilot lights or text-based annunciators for alarm notification, numerical/bar graphs for data display, and proportional-integral-derivative (PID) controllers for process control (refer to Section 13.3.3). Because the systems require relay ladder logic changes that are difficult and time consuming due to required wiring modifications, electromechanical systems are not as flexible as programmable logic controllers (see Section 13.3.2).

Although still in use, electromechanical control systems are recommended for smaller, simpler systems where it is not cost-effective to use a programmable logic controller.

13.3.2 Programmable Logic Controllers (PLCs) and Input/Output (I/O)

13.3.2.1 General

Programmable logic controllers were developed to be a direct replacement for electromechanical control systems, where direct wiring of discrete components was required to implement the desired Boolean logic. PLCs were designed to handle a large amount of discrete inputs and implement a programmed logic to perform desired functions to energize discrete outputs. As PLC computer processing became more powerful, capabilities increased to include complex math, comparative, and data handling functions, along with ratio and PID functions, which has made the PLC the primary controller in the wastewater industry.

13.3.2.2 PLC Components

Typical components of a PLC system include, but are not limited to: power supply, chassis, central processing unit (CPU), communication/gateway modules, input/output (I/O) modules, and expansion racks.

13.3.2.2 PLC I/O Modules

Typical PLC I/O modules accommodate a variety of industry standard options such as +24VDC or 120VAC discrete input/output modules, relay output modules, 4–20mA input/output modules, 1–5VDC input/output modules, RTD modules, and thermocouple modules.

13.3.2.3 Remote I/O (RIO)

Typical control system architectures have multiple PLCs on a single communication network distributed throughout a wastewater treatment facility. For facilities in more remote areas, consideration should be given to utilizing remote I/O racks that use the plant communication network to interface with remote CPUs that implement control algorithms.

13.3.2.4 Redundant PLCs

For mission critical processes, consideration should be given to hot-standby redundant CPU/communication modules linked to remote I/O racks.

13.3.3 Control System Communications

Wastewater treatment facilities typically have a control system architecture that requires both a medium for communications and an associated communication protocol. Some communication protocols are open to multiple PLC manufacturers whereas proprietary protocols are specific to a single PLC manufacturer.

Communication mediums include wireless, wired, and fiber-optic.

13.4 Operator Interface Hardware and Software

13.4.1 Legacy Components

13.4.1.1 Indicating Lights, Switches, Annunciators, Panel Meters

As recently as the 1980s, indicating lights, switches, and pushbuttons were the dominant methods of controlling processes. Most large and small control panels had multiple devices to control equipment functions and settings, with each device requiring time and labor to mount, and needing wires and terminations to operate—thus each device was a potential point of failure. The industry is seeing less use of these devices and more use of operator interface terminals (OITs) and computer-based SCADA software to interface with a process.

Most modern control systems, for example, no longer include annunciator panels to indicate the status of an alarm condition in a process; instead, an OIT or SCADA system performs this function. The embrace of modern technology has also led to a decline in the panel meter and indicators in control panels. Computer-based systems allow for the display of many parameters on different screens on the same device.

13.4.1.2 Chart Recorders

Single and multi-pen chart recorders were once used to record process variables on round charts or strip charts. More recently, digital chart recorders became available. These devices are largely being replaced by human machine interface (HMI) computers for long-term trending of data and OITs for short-term trending of data. It is important to consider, however, that this technology, with all its merits, is also limited in its function, costly per parameter, and takes up panel or wall space.

13.4.1.3 Loop or Process Controllers

Controlling process variables such as flow, level, DO, chlorine residual, ORP, and pressure was traditionally done with single- or multi-look controllers. A process that had many variables to control required many of these devices, which were costly and consumed valuable panel space. Such process variables are now largely controlled by PLCs, even the smallest of which can control dozens of PID algorithm loops. A PID loop controller calculates an error value as the difference between a measured process variable, such as flow rate, and a desired setpoint. The loop controller attempts to minimize the error by adjusting the process control inputs. PLCs perform this function with software programming.

13.4.2 Microprocessor-Based Components and Software (SCADA)

13.4.2.1 Personal Computers

Most applications in the controls industry run on personal computers running Windows-based operating systems. When PCs are loaded with SCADA software, they are called HMIs or human machine interfaces, and they negate the need for the legacy components mentioned in Section 13.4.1. Most facilities have multiple PCs serving as HMIs in a single control room or in multiple control rooms. There should always be redundancy at the computer level so the loss of one PC does not inhibit control of a process or lead to a loss of data. PCs can be stand-alone desktops, panel-mounted, or, for larger control rooms, built into consoles.

13.4.2.2 Human Machine Interface Software (SCADA)

There are several SCADA software vendors that serve the industrial controls market, offering packages that must be configured for a particular project. Graphic displays must be designed to mimic the process involved, and a tag database developed to communicate with PLCs.

SCADA software performs the following functions:

- Displays graphically and alphanumerically what is happening in a process in real time
- Displays alarms and keeps a historical record of alarms
- Collects and stores data for trending process variables such as flow, level, and DO
- Allows supervisory control of a process by allowing an operator to change setpoints and other process parameters
- Allows an operator to view alarm and event logs

13.4.2.3 Operator Interface Terminals (OITs)

OITs are generally mounted to local control panel doors and allow an operator to monitor and control a machine or local process. These devices feature liquid crystal displays (LCDs), ranging in size from 3 inches to 15 inches. OITs replace pushbuttons, selector switches, and panel meters; they communicate directly to a PLC or to several PLCs on a network.

13.4.2.4 PLC Programming Software

A PLC's logic is programmed using specific software that runs on a PC. In a typical scenario, an engineer writes a control narrative on how a machine or process is to work. A PLC programmer then takes that narrative and, using the aforementioned software, develops the appropriate PLC code, which is uploaded to the PLC. The PLC executes the program and controls the process. The software is also used to maintain and troubleshoot the PLC.

13.4.2.5 Alarm Notification Hardware and Software

There are several ways in which a control system can annunciate alarms when a control room or plant is unattended:

- An auto-dialer features alarm contacts that are hand-wired to it or otherwise communicated; it will have anywhere from 4 to 96 alarm channels. Upon an alarm condition, the dialer will annunciate the alarm via voice or text communications. Auto-dialers are most appropriate for very small facilities such as pump stations.
- With cellular/Web-based alarm notification devices, status, alarm contact, and process variable signals can be wired directly, and this data is transmitted via cellular modem to a central processing station. The status, alarm, and data are displayed on a website, and alarms are voice annunciated, texted, or e-mailed to an operator. These devices are most appropriate for pump stations and other small facilities.
- Alarm notification software combines software and a telephone modem to annunciate alarms for an entire system. The alarm notification software is joined to a facility's SCADA software, allowing the alarm system to annunciate every alarm the SCADA software can alarm. This is helpful because more detailed information about an alarm condition can be obtained.

13.4.2.6 Reporting and Data Management

Reporting and data management is extremely important in the operation of wastewater facilities. Reporting software can be mated to SCADA software and can produce reports that include any desired data from the SCADA system. Analytical data from a laboratory can be added to these reports, allowing a complete report to be generated for regulatory compliance. The complexity of reporting software varies from very simplistic to extremely sophisticated; the level of complexity that a facility requires should be driven by an analysis of its needs.

13.4.2.7 Remote Access and the Internet

Utilities wishing to provide remote access to a SCADA system can do so via the Internet or telephone lines. Telephone access is relatively simple, requiring only the appropriate software for the SCADA PC and a modem. However, having the SCADA system accessible via the Internet is more desirable because it allows operations and management staff to monitor status and make changes to a process anytime and from any place that has Internet access. Internet access is complicated, though, because of security concerns over exposing the SCADA system to online security threats and viruses. It is important that Internet access be designed and configured by a specialist on Internet security.

13.5 Wastewater Pumping Stations and Flow Monitoring

13.5.1 Flow, Flow Totalization, and Trending

13.5.1.1 Flow

Wastewater pumping station flow can be measured by any of the instruments detailed in Section 13.2.1. Flow meters listed here are magnetic flow meters, venturi tubes, and open-channel Parshall flume flow meters. Flow meters are selected based on a number of criteria including area classification, potential submergence, flow range relative to turn-down (low flow range) of the instrument, accuracy, pumping station configuration, maintenance, and cost.

In more complex pumping systems, flow measurement can be utilized for on-off pumps of varying capacity to handle different ranges of station flow. Using station flow rate as a factor in pump selection can result in energy savings by allowing for the selection of pumps with no more than the horsepower required to handle the pumping duty.

13.5.1.2 Flow Totalization and Trending

Flow totalization can be displayed and provided as a signal from a flow meter, or flow can be totalized by a wastewater treatment facility's SCADA system (refer to Sections 13.4.2 and 13.5.9). In addition, flow trending can be determined from local chart recorders (refer to Section 13.4.1.2) as well as by a plant's SCADA system.

Trending data can be used for determining pump wear; this is done by reviewing pump runtime vs. flow rate and pump speed. Trending data can also be used to determine inflow and infiltration rates, which can indicate a need for influent pipe repair.

13.5.2 Level Measurement and Control

Reliable measurement of level is crucial in the operation of wastewater pumping stations. The level signal is used to determine multiple pump operation, provide alarms that protect pumping equipment, prevent sanitary sewer overflows, as well as produce a reasonably steady process flow of sanitary sewage to wastewater treatment plants.

13.5.2.1 Bubbler Systems

Bubbler systems are an older method of measuring liquid level in a wastewater pumping station.

13.5.2.1.1 System Components

A bubbler system consists of a small air compressor, receiver tank, pressure gauges, pressure switches, a pressure transducer (optional for continuous measurement), and devices for airflow measurement and control. This equipment is used to produce an airflow that runs down a small diameter (typically 3/8" to 1/2") tube installed within a wet well. The tube is typically run to within 3" to 6" of the bottom of the wet well. The pressure need to push air through the tube is directly proportional to the water level (inches of water column) within the wet well. To avoid measurement inaccuracies, the bubbler tube should not be installed on the bottom slope of a wet well or near any of the pump inlets.

13.5.2.1.2 Operational Benefits

A major benefit of bubbler systems is that they do not have electrical components or instruments that must be installed in wet wells, which are classified as a Class I, Division 1 hazardous area, per NFPA 820. Since the components used in a bubbler system are not installed in a wet well, they are not required to be rated for hazardous areas. Furthermore, the components are commonly found and fairly inexpensive.

13.5.2.1.3 Operational Issues

Bubbler systems pose a number of challenges. They require calibration of multiple pressure switches (and optional transmitter) and maintenance of the compressor. They are vulnerable to leaky fittings, possible freezing of condensation in the bubbler tube, blocking of the bubbler tube due to fouling and sediment, as well as compressor failure. It is therefore recommended that bubbler systems be designed with redundant compressors.

13.5.2.1.4 Control

The pressure switches are calibrated to switch at a particular level corresponding to levels associated with pump equipment protection, level alarms, and multiple pump level control start/stop setpoints. Where wet well level is calibrated in inches of water column to a 4–20mA signal, a pressure transducer can be utilized by a PLC to display a continuous level signal and provide similar functionality as the pressure switches mentioned above.

13.5.2.2 Ultrasonic Level Measurement

Ultrasonic level measurement is a relatively new technology that utilizes the emission of ultrasonic waves (20kHz–200kHz); the system measures the time of reflection off a water surface to determine a continuous wet well level.

13.5.2.2.1 System Components

Typical system components consist of a hazardous-rated (Class I, Division 1) level sensor mounted in a wet well. Level sensors are typically potted or sealed and provided with an encapsulated vendor cable wired to a junction box for easy replacement of the sensor should it become damaged. From the junction box, the sensor cable is wired to a level-indicating transmitter located in the non-hazardous area. The level-indicating transmitter is a "four wire" device that requires 120VAC power and converts the ultrasonic level sensor signal (typically in millivolts) to a 4–20mA signal proportional to the wet well level.

13.5.2.2.2 Installation Considerations

Ultrasonic level sensors are mounted on top of tanks or wet wells, typically through slabs or on pipe on slab mounting configurations. Additionally, the maximum level in the wet well should not exceed the blanking distance or dead-band area from the sensor head in which measurements are not valid (typically 12–24"). A submergence shield should be specified if the sensor is in danger of temporary submergence. In many cases, level sensors are available with a NEMA 6 (temporary submergence at a specified depth and duration) rating. The submergence shield will allow the transmitter to display and transmit a maximum level instead of the invalid level that would be transmitted without a shield in place. The sensor should also be located directly above the bottom of the tank or wet well. Also, to avoid producing false level signals, the sensor's 3db sensing cone (area of sensing) should not impinge on the side wall of the tank or wet well or above the sloped surface. The sensor mounting configuration and electrical connection should be made with an awareness of the need for easy accessibility and removal for maintenance and cleaning.

13.5.2.2.3 Operational Considerations

Measurement errors are introduced if excessive moisture or condensation accumulates on a sensor face. Some manufacturers recommend mounting the sensor face at a 1 degree angle (relative to the horizontal) to allow condensation to drip off the sensor face. Temperature is also a consideration, and manufacturers with integral sensor heaters should be considered for applications where excessively cold weather is a possibility. The sensor is also subject to measurement error if the atmosphere has a high level of carbon dioxide or if excessive foaming exists on the water surface.

13.5.2.2.4 Control

Ultrasonic level transmitters are complex in that they can be programmed to display and transmit not only level but (with appropriate geometry) tank volumes as well. The level-indicating transmitter can also be specified with programmable relay outputs for alarming and pump control. This provides an important means of secondary control; the systems can be used for hard-wired backup control of pumps and alarms in the event of primary PLC control failure.

13.5.3 Gas Detection, Alarming, and HVAC

13.5.3.1 General

Some wastewater pumping stations have open influent channels where debris is screened and removed by screening and washing equipment. The influent channels are typically located at the lowest level of a pumping station. NFPA 820 classifies this influent screening area as hazardous Class I, Division 1. Operational staff may need to occasionally enter this lower level to perform operation, maintenance, and troubleshooting.

Typically, there are two gases found in wastewater pumping stations that can accumulate in sufficient quantities to pose a risk to personal safety: methane (CH_4) and hydrogen sulfide (H_2S). To protect against fire and explosions and to protect plant operations staff, NFPA 820 calls for gas detection, a supervised means of reporting to the local authority of jurisdiction, and increased ventilation by HVAC systems.

13.5.3.2 Gas Detection Instrumentation and Installation

Both methane and hydrogen sulfide gas detection sensors and indicating transmitters are hazardous-rated for a Class I, Division 1 area. Methane-indicating transmitters are typically scaled between 0–100 percent lower explosive limit (LEL) while hydrogen sulfide-indicating transmitters are typically scaled between 0–50 parts per million (ppm). The indicating transmitters are typically +24VDC, 3–wire powered with 4–20mA signal output, and may be specified with both alarm contacts and programmable contacts.

Due to different densities of the gases, gas detection sensors for each gas are installed at different elevations, in accordance with manufacturer recommendations. Hydrogen sulfide sensors are typically installed 6" above finished floor (AFF) while methane sensors are installed 6" below finished ceiling. Sensors typically come with vendor cables wired to the indicating transmitters, which are installed between 5 and 6 feet AFF. Maintenance, calibration and troubleshooting are of primary importance given the critical nature of gas detection. Therefore, calibration ports, valving, and stainless steel tubing should be installed to facilitate the calibration process.

13.5.3.3 Gas Detection—Alarming and HVAC

Methane and hydrogen sulfide gas indicating transmitters have a +24VDC, 3-wire output where the 4–20mA transmitter is usually connected to a plant's SCADA system for display and trending. Alarms can not only be generated by SCADA but also by the programmable relay alarm contacts directly out of the indicating transmitter. For example, a high LEL percentage would be issued by the transmitter, and displayed on SCADA as a warning. Should methane gas levels in the area continue to increase, the indicating transmitter would issue the appropriate alarm and trigger any of the following potential functions: illuminate an alarm beacon located outside the hazardous area to warn operational staff not to enter the space, issue an alarm to the local automatic temperature control (ATC) panel in order to comply with NFPA 820 requirements, and increase the ventilation in the space from 6 to 12 air changes per hour and/or increase the percentage of outside air circulated in the hazardous area. Additionally, this same high LEL alarm contact should connect, via telephone dial-out, to the local fire alarm control panel (FACP) for reporting to the authority under local jurisdiction.

Additional programmable contacts may include a "transmitter failure" alarm issued to SCADA to inform operational staff of a faulty gas detection transmitter.

13.5.4 Intrusion and Fire Reporting

To protect property against vandalism and destruction by fire, various intrusion and fire detection sensors should be installed in strategic locations throughout a pumping station. These sensors activate a centralized alarm system to notify, via telemetry, the authority of local jurisdiction, prompting an appropriate response. This threat of reporting intrusion to police acts a deterrent to vandalism. In the event of a fire, prompt reporting to the local fire department can minimize fire damage.

13.5.4.1 Intrusion Reporting

Consideration should be given to intrusion detection of both the pumping station perimeter and interior. Typical sensors include door sensors, window sensors, glass breakage sensors, and motion detectors. These sensors should be connected to a UL listed security or alarm system.

To gain entry to a pumping station, operational staff would unlock the main door and enter a security code on the alarm system's keypad. If the code is incorrect or not entered within the allotted time, the alarm system would issue an alarm. The alarm system would also issue an alarm if a perimeter sensor or motion detector was tripped and the countdown of allotted time exceeded. The alarm system would activate a station alarm horn and alarm beacon as well as contact the local police department via telephone or other means of notification; see Telemetry, Section 13.5.9.

13.5.4.2 Fire Reporting

A UL listed fire alarm control panel monitors various sensors (typically heat and smoke detection) installed in a pumping station. Upon detection, an alarm is generated, alarm horns and strobe lights activated, HVAC systems shut down, and the fire reported to the local fire department.

13.5.5 Station Alarms

Station alarms are alarms that are not process related, but related to the pumping station itself. Typical station alarms include low building temperature; high building temperature (optional); flood; intrusion and fire (see Section 13.5.4); and utility, generator, low fuel, or automatic transfer switch failure (see Section 13.5.8).

13.5.6 Grinder Systems

Grinder systems typically include a grinder pump with an associated control panel that includes forward and reverse motor starters, and a motor current sensing device with programmable alarm outputs. The grinder pump grinds up solids in a pump station influent wastewater stream, allowing smaller debris to pass into a wet well. Depending on density, the small debris will likely get sucked into the pumping station pumps, and pumped to the wastewater treatment plant. Grinder systems prevent debris buildup in wet wells and, by creating smaller debris for pumps to pass, prevent potential damage to the pumps.

When debris gets lodged in a grinder pump, the result is a jam in the system and a high motor-current condition. The motor current sensor will detect this condition and trip the starter before the motor starter goes into overload. Since the default grinder pump direction is forward, a high current alarm would stop the forward direction and send the pump into reverse in an attempt to dislodge the debris. The grinder pump would then run again in the forward direction, hopefully passing the debris. If not, the process repeats (typically three times) before a grinder pump fault is issued.

13.5.7 Pump Control, Status, Data, and Alarms

13.5.7.1 Pump Control

Depending on the station flow rates, wastewater pumping stations usually require pumps driven by high-horsepower motors. To reduce motor starting current, the pumps should be driven by reduced voltage solid state (RVSS) starters or variable frequency drives (VFDs). To meet process flow and redundancy requirements, multiple lag/standby pumps are typically provided.

Wastewater pumping stations utilize level control methods to maintain wet well levels between a minimum and maximum level in order to safely deliver wastewater to a treatment plant. The pump controller can be any of the controllers listed in Section 13.3. The controller would compare a continuous wet well level signal (see Section 13.5.2) and compare it to predetermined pump control on/off setpoints and alarms. Setpoints (from lowest level to highest level), include, but are not limited to: low-low level alarm, low level alarm, lead off, lead on, lag1 off, lag1 on, lag2 off, lag2 on, high level alarm, and high-high level alarm. Any of these setpoints can be replaced by discrete level floats mounted at predetermined elevations. Consideration should be given to station flow and wet well volume relative to setpoint selection and/or float elevations, so as not to excessively and unnecessarily cycle pumps on and off.

If a pump should fail, its subsequent lag pump or standby pump may be prompted to start and assume pumping duties for the failed pump. Sequence control can be manually selected by the operator at the pump controller, automatically alternate on lead pump shutdown, or automatically alternate based on time of day.

Pumps controlled by RVSS starters ramp to full speed at pre-programmed rates in order to minimize startup motor current. In the case of VFDs, starting at reduced pump speed provides a means of minimizing startup current. Additionally, VFD speed can be modulated to efficiently maintain a level setpoint within a wet well and to provide better control of flow to the treatment plant.

Consideration should be given to the possibility of pump controller failure. To address this possibility, hardware interlock control is implemented in parallel operation with the pump controller. Level floats or a level-indicating transmitter (with programmable pump control and alarm outputs) can be implemented for this purpose.

13.5.7.2 Status, Data, and Alarms

13.5.7.2.1 RVSS

Signals may include start/stop, ready, running, at speed, and starter fault.

13.5.7.2.2 VFD

Signals may include start/stop, speed command, ready, running, VFD fault, and speed feedback. Motor current or KW may be provided as an option.

13.5.7.2.3 Pump/Motor

Signals may include high motor temperature, moisture (in the case of submersible pumps), and seal water.

13.5.7.2.4 Wet Well

Signals may include low-low, low, high, and high-high level alarms.

13.5.8 Utility/Generator Power Monitoring and Status

Wastewater pumping stations should be provided with standby power to prevent potential sanitary sewer overflows due to loss of utility power. Gas or diesel fuel generators are typically provided, depending on locally available fuels and associated fuel costs. An automatic transfer switch (ATS) continuously monitors utility power. Upon loss of power, the ATS commands a generator to start. Once the generator is running and providing the necessary voltage, the ATS switches from utility power to generator power.

Signals monitored may include, but are not limited to: generator running, generator fault, low fuel (or loss of gas pressure), utility power (ATS), generator power (ATS), and switch fault (ATS).

The pump controller should monitor these conditions and remove the pump start command upon power loss so as not to generate an unnecessary "fail to start" fault. It should also be noted that a running VFD will go into an "overcurrent" fault upon loss of power; consideration should be given to setting up an automatic reset of this fault following power transitions.

13.5.9 Telemetry

Telemetry is defined as any technology that allows remote measurement and reporting of information between a remote and centralized location—or to be specific to this case, between a pumping station and its associated wastewater treatment plant.

Methods of communication for telemetry systems include, but are not limited to: radio (licensed/unlicensed), cellular, dial-up or leased telephone lines, DSL lines, T1 lines, or fiber-optic cable. Initial cost vs. long-term cost, reliability, expandability, vulnerability, and data bandwidth must be taken into account in the design of telemetry systems. In addition, the telemetry system must work in conjunction with the treatment plant's control system architecture communication protocol (communication language). In many cases, communications cards, protocol converters, and communication drivers must be added and configured to accommodate the telemetry system's control and communication equipment.

A wastewater pumping station is designed as a stand-alone operation and requires no remote intervention to perform its intended design function. Telemetry, however, allows for the remote monitoring of pumping station equipment status and alarms, station alarms (intrusion and fire), wet well process conditions, level and flow, pumping control system, generator, and ATS; this monitoring is conducted through the treatment plant's SCADA system (refer to Section 13.4.2), which would notify operational staff of a problem. Depending on the fault, staff may be required to visit the pump station to investigate the condition.

13.5.10 Ancillary Equipment: Odor Control/Aeration

Odor control systems are typically employed with pumping stations that have low flow conditions for long periods of time. The wastewater sits in the wet well, becomes septic, and emits hydrogen sulfide, which is perceived as a foul odor. This is a major concern with pumping stations located in residential areas.

Odor control systems may include nitrate and/or oxygen chemical addition systems that create an environment in which certain naturally occurring bacteria thrive. The bacteria break down waste and reduce hydrogen sulfide emissions.

In addition, compressor systems with interval timer control and distribution piping may be used to introduce air into wet well water. The compressed air provides mixing to keep wastewater more homogeneous for better distribution of bacteria and suspended solids. More importantly, aeration is provided to support the aerobic bacteria as they break down waste and reduce hydrogen sulfide emissions.

The remaining hydrogen sulfide above the wastewater can be evacuated by a small blower that pushes the air through an activated carbon filter, which removes the hydrogen sulfide.

13.6 Wastewater Treatment Facilities

13.6.1 Influent and Effluent Flow Measurement

Accurate flow measurement is a critical component of wastewater treatment and regulatory reporting. Typically wastewater flow data is used in recordkeeping, compliance and permit monitoring, process control, process pump, chemical feed, and pacing of automatic sampling. All facilities should have at least one flow meter to record total treated flow. This meter is typically located on the effluent end of a facility. Medium to large facilities should incorporate both influent and effluent flow monitoring.

When selecting a flow meter and determining its placement at a plant, it is important to be mindful of numerous factors, including side stream effects, proper hydraulics, type of flow (i.e., influent or effluent), required accuracy, and costs for installation, operation and maintenance. The flow regime of the facility should also be considered when selecting a flow meter. To determine whether a meter of a particular type and size provides the necessary range and accuracy, consider the facility's anticipated peak hourly, daily, and annual flow variations. This is a critical step, since during low or high flow conditions, some meter types may have operational and/or accuracy issues. As the flow signal is often used for pacing of process and chemical feed pumps, meter accuracy over the entire range of the anticipated flow profile is vital. For details on the strengths and weaknesses of various types and configurations of flow meters, see Section 13.2.1.

13.6.2 Headworks (Pretreatment)

As headworks facilities are typically considered combustible and hazardous areas, any treatment facility with an enclosed headworks environment should have hazardous gas detection equipment. Applicable laws, standards, and practices should be consulted and followed when specifying and designing headworks instrumentation systems. Typically, any electrical equipment installed in the headworks should be rated for an explosion- proof area. Monitoring for combustible gas, hydrogen sulfide, oxygen, and methane should be considered. For headworks areas that are frequently manned, fixed gas detection systems should be utilized with alarm notification outside the area; this notification alerts personnel entering the headworks of potentially hazardous conditions in the area.

In addition to safety instrumentation, the headworks area will require some process control instrumentation. Typically, all grit removal and screening equipment should be provided with status, failure, and alarm switches. The alarm switches should provide both local and remote notification of the alarm condition. In addition to equipment status monitoring, the instrumentation needs include a high level alarm float or level sensor in the influent channel to indicate a backup condition.

For large facilities equipped with SCADA systems, equipment status (i.e., run, speed, water level, etc.) telemetry should be incorporated into a dedicated headworks screen within the SCADA system. PLC-based control of grit and screening removal equipment is highly recommended when SCADA systems are employed.

13.6.3 Primary Treatment

Primary treatment typically consists of primary clarifiers or clari-thickeners. Process control for these systems generally consists of status monitoring of the clarifier drive systems as well as control and monitoring of the clarifier's sludge removal system. Usually, the clarifier drive motor includes overload protection and alarm functions that are both locally and remotely monitored.

Sludge removal from primary treatment should be based on a set flow rate or on timers. For larger facilities, a flow rate setting for waste activated sludge (WAS) pump discharge is recommended.

With regard to monitoring the WAS flow rate, special attention should be paid to the flow meter's type and configuration, as certain meters are not effective in measuring wastewater with a high solids content.

In addition to discharge flow monitoring, it may be advantageous to consider sludge blanket level monitors on larger primary clarifiers; these monitors can provide alarm notification as well as trend data for sludge levels at a facility. For progressive cavity or diaphragm type pumps, stroke counters may be used. All pump systems must also have overload and failure alarms that are both locally and remotely triggered in the event of a pump failure. Standby pumping is recommended for larger facilities; the control systems should be designed so that if a pump fails to start or no discharge flow is being recorded when the pump is on, the standby pump is automatically started.

For large facilities equipped with PLCs and SCADA systems, equipment status (i.e., run, WAS flow, sludge level, etc.) telemetry should incorporated into a dedicated primary treatment screen within the SCADA system. PLC-based control of the clarifier and WAS removal pump system is highly recommended when SCADA systems are employed.

13.6.4 Chemical Feed Systems

Typical controls for chemical feed systems include manual flow control, wastewater flow pacing, concentration-based flow control, and compound loop control (i.e., both flow and concentration based control). Usually, plant staff use bench level testing to determine the typical chemical concentration necessary to treat a specific volume of wastewater. Upon determining this ratio, the chemical feed system is manually set to a constant flow or is paced based upon the wastewater flow as recorded by an influent or effluent flow meter.

With the advent of many affordable in-line chemical analyzers, larger facilities would typically benefit from the constant loop control that these types of analyzers can provide. However, location, cost, reliability, accuracy, ease-of-use, and frequency of calibration should all be considerations. Typical functions of such analyzers are alkalinity adjustment, disinfection chemical addition, supplemental carbon feed for denitrification, and metal salt chemical addition for phosphorus removal.

In addition to the control systems, all chemical feed systems require a failure, spill, and/or hazardous gas monitoring system, which in the event of a problem, triggers a local and remote alarm. In larger facilities, standby or backup chemical feed pumps must be provided, and a control system must automatically start the standby pump when an in-service pump fails. For hazardous chemicals such as potassium hydroxide (KOH), methanol and chlorine, permanent detection and alarm systems should be provided in the chemical feed area to warn operators of a hazardous condition caused by a spill or leak.

13.6.5 Secondary Biological Treatment

Typical controls for secondary biological treatment include dissolved oxygen (DO) monitoring and control as well as return sludge flow control. Some large facilities may incorporate pH or MLSS concentration (and to a lesser extent ORP) monitoring into their daily process control monitoring. Smaller decentralized facilities will typically use portable DO and pH meters to periodically monitor treatment and make necessary adjustments. Larger facilities should incorporate real-time continuous monitoring of DO and pH, and should consider MLSS concentration monitoring.

When real-time DO monitoring is conducted, PLC control loop systems should be employed to vary the amount of oxygen delivered to the aerobic zone; this helps to automatically maintain a specific dissolved oxygen concentration. For large facilities with multiple aerobic basins and zones, both blower speed and automated distribution valves should be considered. Each basin should be equipped with a dedicated DO analyzer, and the air distribution piping valves should be controlled to ensure adequate DO is maintained in all basins simultaneously while using the minimum amount of energy required to maintain those levels. It is also highly recommended that variable speed blowers and/or drives (VFDs) be provided to automatically adjust blower output based on DO concentrations in the wastewater. The blowers should be provided with inlet and outlet air pressure and temperature monitoring via gauges and (in larger facilities) relays that will provide this information to the plant's PLC and/or SCADA system.

As part of the secondary treatment system, the sludge removal system, typically clarifiers, must be equipped with a flow-paced control system to ensure proper return of the biological solids necessary to perform aerobic secondary treatment. Secondary clarifiers and their return activated sludge (RAS) pumps require alarm, overload, failure, and status controls.

In addition, flow-paced RAS control or RAS flow based on MLSS concentrations must be provided at larger facilities. Smaller facilities may consider timer-based controls, which return sludge on an hourly timed-cycle basis. To promote energy efficiency, VFDs should be considered by larger facilities; VFDs allow return pumps to run only as fast as necessary to provide the required flow. Lastly, consideration should be given to the type, configuration, and location of the RAS flow meter, since the percentage of solids in return activated sludge is significantly higher than the percentage in untreated wastewater or treated effluent.

13.6.6 Residuals Treatment and Management

Since most small- to medium-sized facilities no longer process residuals on-site, treatment and management is typically related to storage for off-site processing. However, some larger facilities still process and digest solids on-site and therefore need to be equipped to control and monitor these processes. At facilities that store and dispose of solids off-site, proper level and gas monitoring for storage tanks should be provided. High level and/or gas detection alarms are critical to alert operations staff if a tank is not functioning properly and requires attention.

Generally, residuals treatment consists of sludge digestion, thickening, dewatering, and disposal, or some combination thereof. Control for these systems is specific to the equipment utilized and should be given ample consideration during the evaluation and design process. At a minimum, all equipment failure alarms and control status points (i.e., running, etc.) should be incorporated into the PLC and/or SCADA system if present. For facilities without plantwide control and monitoring, local and remote alarm telemetry is recommended. Hazardous conditions and gases may be created during the treatment of residuals and therefore proper safety monitoring and gas detection equipment should be provided.

13.6.7 Disinfection

Disinfection systems typically fall into two categories, ultraviolet light systems and chlorine-based chemical disinfection. Their process and control systems, which are very different from each other, should be factored into the evaluation of which type of disinfection is most appropriate for a facility.

Chemical-based disinfection controls and monitoring should be implemented as detailed in Section 13.6.4. In addition, chlorine residual analyzers should be included in larger automated facilities to provide operations staff with real-time feedback on the effectiveness of disinfection dosing, as well as to prevent overdosing of chemicals that can enter the natural environment.

Ultraviolet (UV) disinfection systems do not require chemical addition to wastewater, but rather use electricity to generate UV light that acts as a disinfectant against microorganisms in wastewater. As the disinfection process is only as effective as the ability of the light to reach the targeted microorganisms, UV transmission through the wastewater is a key component to monitor. Since the process is electrical, monitoring of power supply is also important.

UV systems should include transmissivity monitoring equipment as well as power and failure alarms. Small- and medium-sized facilities typically have UV units that are either on or off, with banks of UV lights delivering a constant UV dose. Operational controls for these systems are minimal. Larger facilities, however, can save energy by using PLC-based flow-paced control systems, which are controlled in the same manner as flow-paced chemical addition. Essentially a PLC uses a control algorithm to determine the amount of UV light required to disinfect a specific volume of water going through the UV reactor. Most UV manufacturers include such control and operation systems with their units.

Care must be taken during the design to ensure that the PLC and control system provided with a UV unit is compatible with a facility's existing PLC and SCADA system. In addition to receiving and processing a flow signal from the plant's main flow meter, the UV system controls must record and monitor power, transmissivity, and UV bulb life. This information must also be recorded at the SCADA system for use in the overall operation of the UV system.

13.6.8 Advanced Wastewater Treatment

Advanced wastewater treatment typically consists of biological nutrient removal (BNR) and physical/chemical nutrient and metals removal, which are covered in detail in Chapter 6 and 7 of this report. The monitoring and control components of these advanced systems are critical to consistent and efficient performance and treatment. The advent of PLCs has made advanced treatment possible with very low flows and at facilities that are operated only part-time. The use of PLCs and SCADA has also provided designers and operators with the ability to perform the regular, automated adjustments in flow, chemical feed, airflow, mixing, and process times necessary to achieve advanced treatment and nutrient removal.

Generally, both process control and alarm monitoring are required for advanced treatment processes. Many aspects of the control systems described for chemical feed systems and secondary treatment systems are used with advanced treatment. Chemical feed systems for metal salts, coagulants, supplemental carbon, and alkalinity adjustment are typically employed and should be designed as detailed in Section 13.6.4.

In addition to chemical feed, process control for maintaining anaerobic, anoxic, or aerobic conditions in the various process zones of a BNR reactor is critical. Typically a BNR system requires a DO analyzer system that provides real-time feedback to aeration or mixing equipment to achieve and maintain desired DO levels. PLCs should be employed for all facilities, with larger facilities incorporating PLCs and SCADA systems to operate and monitor the process from a central location. Typical monitoring and control points include tank level, DO concentration, mixer speed, blower status, and air temperature and pressure, as well as chemical feed system status and dosage volume.

Advanced physical/chemical treatment processes, such as phosphorus and metals precipitation and filtration, rely on many of the same control and monitoring systems found elsewhere in a wastewater treatment facility. Typically, chemicals are added to precipitate nutrients and metals, which are then physically removed from the wastewater via a clarifier or filtration system. For process control of these systems, it is necessary to perform bench scale testing to determine the typical pollutant loads that need removal. Upon determining chemical dosing rates, flow-paced chemical addition is typically employed. Larger facilities, in an effort to control energy and chemical costs, should consider the use of in-line phosphorus or metals monitoring analyzers, which can be added to the PLC control loop for chemical feed pump control. Real-time monitoring also provides the benefit of data acquisition and trending to help operators identify diurnal or seasonal variations in wastewater composition.

Alarm and control setpoints for these systems are similar to those employed in disinfection chemical addition, as described in Section 13.6.4.

13.6.9 Odor Control

Odor control systems for wastewater treatment facilities are typically stand-alone packages that come equipped with control and alarm systems. Typically, odor breakthrough and failure of blowers and/or scrubbers are the main issues that require process monitoring and control. Local and remote alarms for blower function, air pressure, and air temperature should be included.

Larger facilities with SCADA systems should ensure the odor control system manufacturer incorporates PLCs in the system that allow communications over the SCADA network; the status of the equipment can then be monitored directly at a remote location.

13.6.10 Septage Receiving

Septage receiving should be done via packaged septage receiving units whenever possible. These units can be specified to include their own PLC-based control, billing, and alarm systems. Typically, system status and failure of the unit are the main issues that require process monitoring and control. Local and remote alarms for the function of the system should be included. The system should be designed so a septage hauler can activate the system via keycard or code, then offload the septage and complete the transaction without plant operator oversight or intervention. These systems typically require flow meters, channel level monitoring, grit and/or screening system status and control, as well as general alarms and, if located in an enclosed area, gas detection and safety alarms.

Larger facilities with SCADA systems should ensure the septage receiving unit manufacturer incorporates PLCs in the unit that allow communications over the SCADA network; the status of the equipment and alarms can then be monitored directly at a remote location. In addition, as described in Section 13.6.11, septage off-loading information (e.g., volumes discharged and time to off-load) should be recorded within the SCADA system for processing so billing can be automatically generated for customers.

13.6.11 Septage Management and Billing

For any facility that accepts septage, proper accounting of the volumes received is critical for control of the treatment process. Proper accounting ensures regulatory compliance and accurate billing (i.e., the appropriate party is billed correctly for the volume discharged). Many manufacturers of packaged septage receiving units provide management and billing software that can be used with their products' control systems and treatment facility SCADA systems.

In a septage management system, each user is required to set up an account and PIN number before using the system. The billing software maintains this information and locks out users who have accounts that are not in good standing as defined in the municipality's septage receiving and disposal regulations. For each discharge, the management system should, at a minimum, record:

- Total volume discharged as measured by a flow meter.
- Day, date, and time of discharge.
- Driver's keycard information.
- Driver's account number.

All transaction data should be stored on-site automatically on a removable flash memory card as well as printed on a receipt that the driver takes after completing the transaction. The transaction data must also be communicated, via the PLC and SCADA system, to the billing software provided with the unit and installed on the SCADA management terminal.

The software package should be integrated into the SCADA system and have a dedicated screen for an operator to manage the septage receiving unit and associated accounting. Generally, the software must be able to use recorded flow data for each account to calculate billing on a monthly basis (or some other operator-adjustable time period). The software must allow an operator to generate, without manual calculations, invoices for mailing.

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APPENDIX 1

TR-16: 2011 (REVISED 2016) REVIEWERS

The project of revising this work to reflect recent experience and thinking in preparing for storm surge and extreme weather events began with NEIWPCC's governing Commission in 2014 and grew to involve the Commission's staff and many at EPA, state environmental agencies, and private consulting firms. NEIWPCC is grateful to the below individuals who contributed to or guided the revision of the 2011 edition in 2015 and 2016.

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