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Center for Environmental
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Technology Transfer

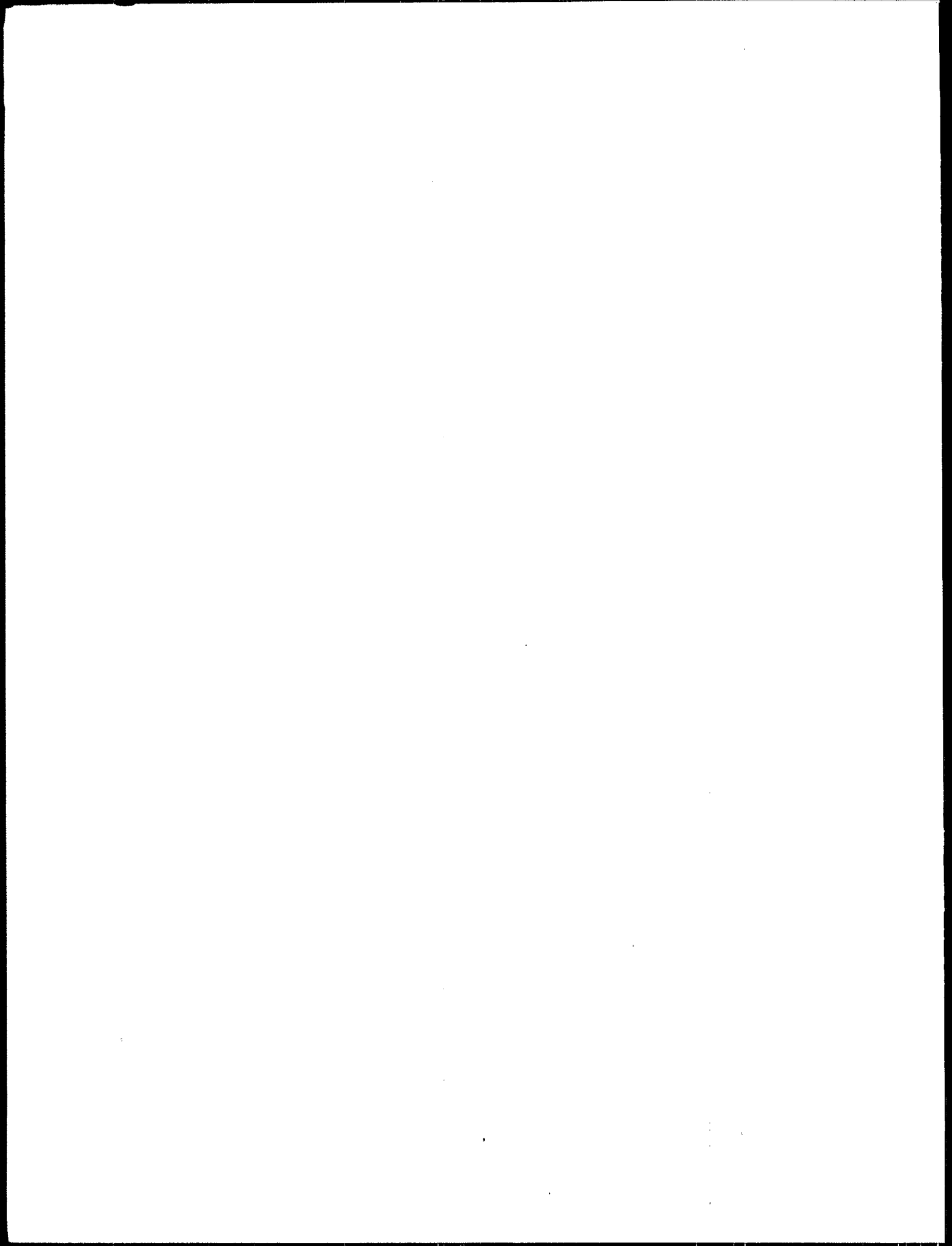
EPA/625/6-87/017



Handbook

Retrofitting POTWs for Phosphorus Removal in the Chesapeake Bay Drainage Basin





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Handbook

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U.S. Environmental Protection Agency
Office of Research and Development

Water Engineering Research Laboratory
Cincinnati, OH 45268

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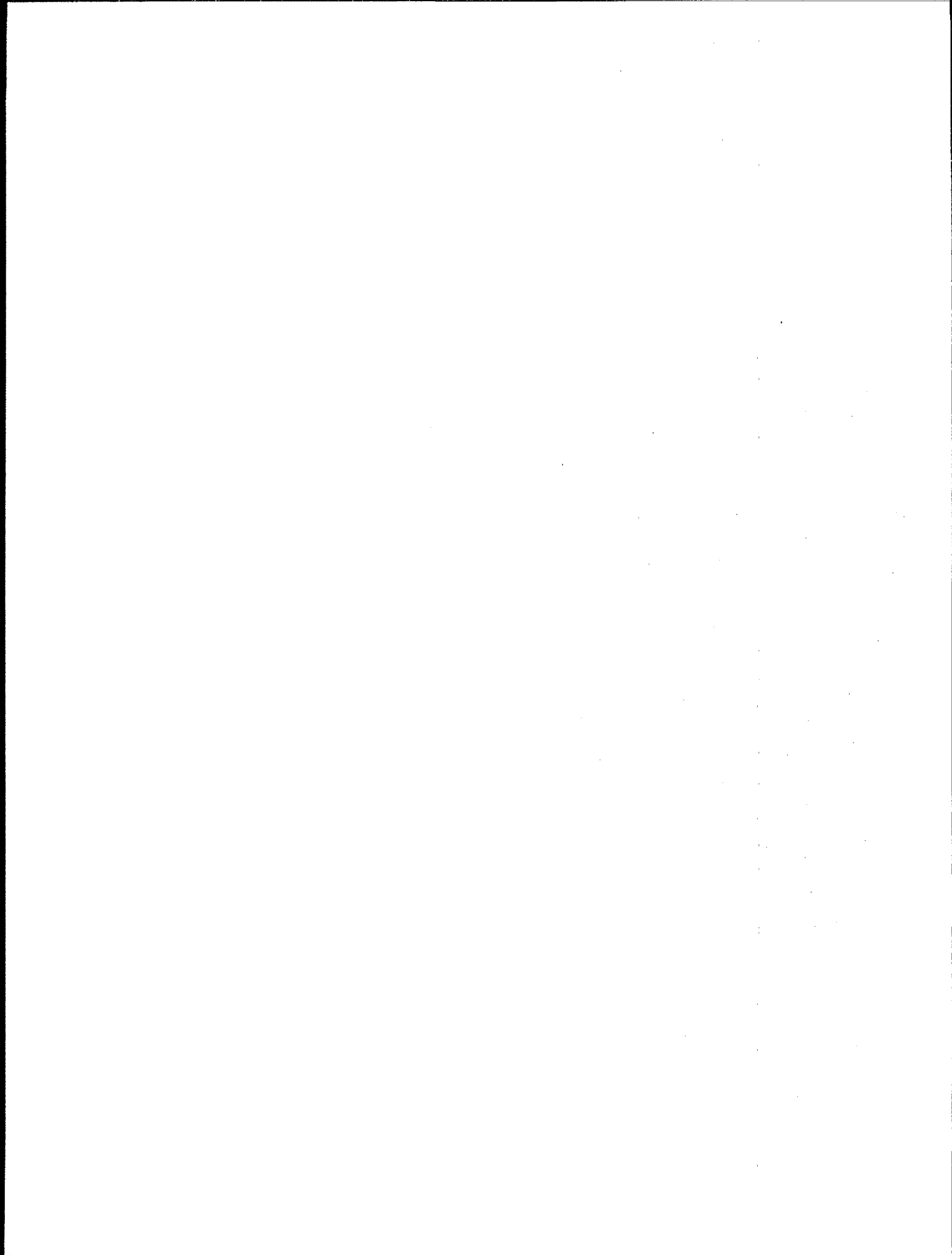
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Chapter 1

Introduction

1.1 Purpose

The states of Maryland, Pennsylvania, and Virginia have many wastewater treatment facilities that discharge into the Chesapeake Bay Drainage Basin (CBDB). For the protection of the ecology of the Chesapeake Bay, phosphorus removal has been implemented at selected treatment facilities and needs to be instituted at a greater number of sites.

This document assesses the technology, economics, and efficiency of phosphorus removal processes available for use in the CBDB to achieve required levels of protection. Since phosphorus removal requirements in the CBDB vary a great deal with geographical location, this assessment includes the feasibility of achieving effluent total phosphorus (TP) concentrations of 0.2, 0.5, 1, and 2 mg/l. Also addressed is the impact that a requirement for either nitrification or nitrogen removal has on phosphorus removal processes.

The information base for this document includes data collected from various municipal wastewater treatment facilities in the United States, particularly those located in the CBDB and the Great Lakes Drainage Basin, as well as from other sources.

This document is a reference manual for government officials, design engineers and plant operators in the CBDB to assist them in retrofitting existing treatment plants to remove phosphorus.

This document covers the following broad areas:

1. Chemical phosphorus removal information is tailored to reflect those factors specific to the CBDB, i.e., influent phosphorus, effluent phosphorus, and plant type.
2. Biological phosphorus removal technologies are a recent development and may be feasible at this time for retrofitting certain plants in the CBDB. Biological phosphorus removal discussions and data are also tailored to reflect conditions specific to the CBDB.
3. Several plants in the CBDB may require concurrent phosphorus and nitrogen removal. Information is presented to enable engineers to select appropriate phosphorus removal systems that will be compatible with current or future nitrogen removal requirements.
4. Data presented correspond to the sizes of plants and process types found in the CBDB. Influent TP concentration ranges of 6 to 10 mg/l and 3 to 6 mg/l and effluent TP limits of 2, 1, 0.5, and 0.2 mg/l are considered.

Based on data provided by Virginia, Maryland, and Pennsylvania environmental agencies, there are 526 municipal wastewater plants discharging to the CBDB from these three states (144 in Virginia, 219 in Maryland, and 163 in Pennsylvania). Ninety-nine of these plants are removing phosphorus (10 in Virginia, 28 in Maryland, and 61 in Pennsylvania). Seventy-eight plants are achieving nitrification. In addition, a number of extended aeration plants are known to nitrify seasonally. A matrix showing the design capacities and types of these plants is given in Table 1-1.

1.2 Handbook Organization

Table 1-2 presents a brief summary of each of the nine chapters that compose this document.

Table 1-1. CBDB Plant Matrix

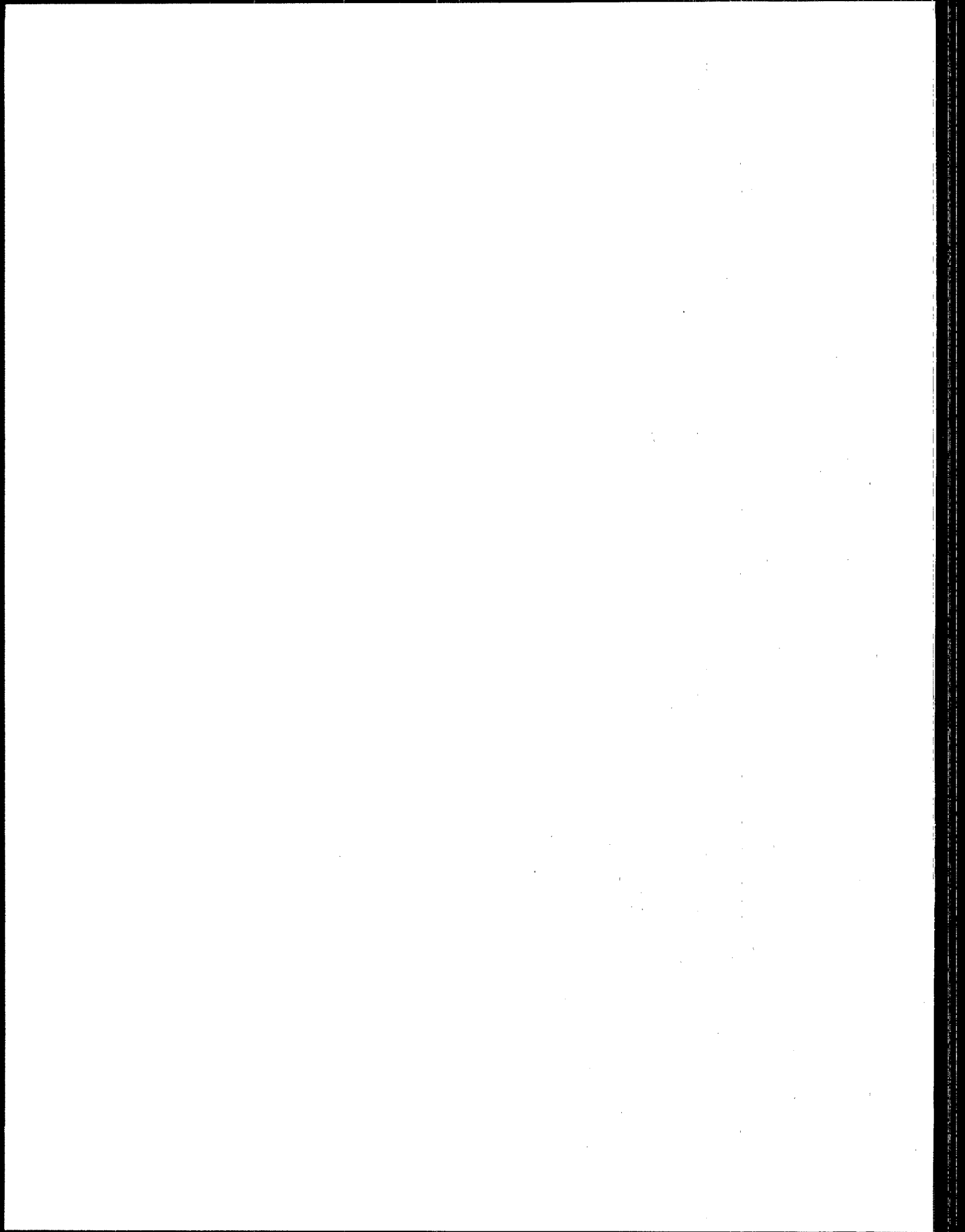
| Plant Type | State | Design Flow (mgd) ¹ | | | | | Total by State ¹ | Grand Total ¹ |
|--|-------|--------------------------------|----------|---------|---------|---------|-----------------------------|--------------------------|
| | | < 0.1 | 0.1 - 1 | 1 - 5 | 5 - 10 | > 10 | | |
| Activated Sludge - Plug Flow | VA | - | - | - | 2 (0) | 3 (0) | 5 (0) | 53 (19) |
| | MD | - | - | - | - | - | - | |
| | PA | 2 (1) | 18 (4) | 21 (10) | 4 (3) | 3 (1) | 48 (19) | |
| Activated Sludge - Complete Mix | VA | - | - | 5 (0) | 3 (0) | 5 (1) | 13 (1) | 85 (17) |
| | MD | 46 (0) | 13 (5) | 5 (4) | 2 (1) | 4 (4) | 70 (15) | |
| | PA | - | - | 1 (0) | 1 (1) | - | 2 (1) | |
| Activated Sludge - Contact Stabilization | VA | - | 3 (0) | 4 (2) | - | - | 7 (2) | 29 (14) |
| | MD | - | - | - | - | - | - | |
| | PA | - | 8 (4) | 10 (5) | 2 (2) | 2 (1) | 22 (12) | |
| Activated Sludge - Pure Oxygen | VA | - | - | - | - | 5 (0) | 5 (0) | 11 (5) |
| | MD | - | - | - | 1 (0) | 2 (2) | 3 (3) | |
| | PA | - | - | - | 1 (0) | 2 (2) | 3 (2) | |
| Activated Sludge - Step Aeration | VA | - | - | - | - | 2 (1) | 2 (1) | 2 (1) |
| | MD | - | - | - | - | - | - | |
| | PA | - | - | - | - | - | - | |
| Activated Sludge - Extended Aeration | VA | 12 (0) | 14 (0) | 2 (0) | - | 1 (1) | 29 (1) | 190 (20) |
| | MD | 74 (0) | 17 (2) | 5 (2) | 1 (1) | 3 (1) | 100 (6) | |
| | PA | 9 (1) | 46 (11) | 5 (1) | 1 (0) | - | 61 (13) | |
| Trickling Filter - High Rate | VA | - | 1 (0) | 6 (0) | 1 (1) | - | 8 (1) | 35 (2) |
| | MD | 9 (0) | 10 (0) | 6 (0) | 2 (1) | - | 27 (1) | |
| | PA | - | - | - | - | - | - | |
| Trickling Filter - Standard Rate | VA | 3 (0) | 6 (0) | - | - | - | 9 (0) | 40 (10) |
| | MD | 6 (0) | 1 (0) | - | - | 1 (0) | 8 (0) | |
| | PA | 2 (0) | 12 (3) | 7 (6) | 1 (1) | 1 (0) | 23 (10) | |
| Rotating Biological Contactors | VA | 1 (0) | 3 (0) | 1 (0) | - | 1 (1) | 6 (1) | 17 (4) |
| | MD | 3 (0) | 7 (2) | 1 (1) | - | - | 11 (3) | |
| | PA | - | - | - | - | - | - | |
| Combined Trickling Filter-Activated Sludge | VA | - | 1 (0) | 1 (1) | - | - | 2 (1) | 5 (4) |
| | MD | - | - | - | - | - | - | |
| | PA | - | 2 (2) | - | 1 (1) | - | 3 (3) | |
| Others ² | VA | 16 (0) | 34 (0) | 5 (1) | - | 3 (1) | 58 (2) | 59 (3) |
| | MD | - | - | - | - | - | - | |
| | PA | 1 (1) | - | - | - | - | 1 (1) | |
| Total | VA | 32 (0) | 62 (0) | 24 (4) | 6 (1) | 20 (5) | 144 (10) | 526 (99) |
| | MD | 138 (0) | 48 (9) | 17 (7) | 6 (5) | 10 (7) | 219 (28) | |
| | PA | 14 (3) | 86 (24) | 44 (22) | 11 (8) | 8 (4) | 163 (61) | |
| Grand Total | | 184 (3) | 196 (33) | 85 (33) | 23 (14) | 38 (16) | 526 (99) | |

¹ Plants already removing phosphorus are indicated in parentheses.

² Oxidation ditches, lagoons, activated sludge nitrification, Griffith system, overland flow, primary treatment, combined trickling filter-rotating biological contactors.

Table 1-2. Summary of Handbook Contents

| Chapter | Description |
|---|---|
| 1. Introduction | Introduction and guide for using handbook. |
| 2. Description of Retrofit Phosphorus Removal Technologies | General engineering considerations for retrofitting plants to remove phosphorus by chemical addition or biological uptake. |
| 3. Summary of Existing Phosphorus Removal Performance Data | Tabulation of performance and costs data from selected plants in the United States and Canada. |
| 4. Process Design Considerations for Retrofitting Chemical Phosphorus Removal | Process design synopsis sheets for chemical addition retrofit for each process type, plant size, influent phosphorus range, and effluent phosphorus limit. |
| 5. Hardware Design and O&M Considerations for Chemical Phosphorus Removal in Small to Medium Plants [$< 0.44 \text{ m}^3/\text{s}$ (10 mgd)] | Information on chemical characteristics, suppliers, and costs; chemical storage and feeding; typical chemical feed system layouts; safety considerations; and laboratory and safety requirements. |
| 6. Process and Hardware Design Considerations for Retrofitting Activated Sludge Plants with Biological Phosphorus Removal | Detailed analysis and comparison of the A/O and Phostrip biological phosphorus removal processes. |
| 7. Compatibility of Chemical and Biological Phosphorus Removal with Nitrogen Control | The effects of combined phosphorus and nitrogen control on the engineering requirements for retrofitting plants by chemical addition or biological uptake. |
| 8. Cost Estimates for Chemical Phosphorus Removal in the CBDB | Estimated capital, annual chemical, and annual chemical plus amortized chemical system capital cost graphs for retrofitting plants to chemical phosphorus removal in the CBDB. |
| 9. Potential Effects of Various Implementation Factors on Phosphorus Planning in the CBDB | Broad factors in implementing phosphorus removal in the CBDB, including total area-wide costs for retrofitting (at different influent phosphorus levels and different effluent phosphorus limits), a comparison of key factors affecting chemical and biological retrofit systems, impact of license fees, difficulty of process operation, additional staffing required, degree of maintenance difficulty, implementation schedules, and operator training requirements. |



Chapter 2

Description of Retrofit Phosphorus Removal Technologies

2.1 Introduction

A variety of wastewater treatment processes exist in the CBDB. These facilities range in design complexity from lagoon systems to various modifications of the activated sludge process.

Experience gained at numerous treatment plants in the Great Lakes Drainage Basin between the late 1960s and early 1980s has shown that some degree of phosphorus removal can be retrofitted into almost any existing facility. In a specific retrofit situation, the degree of compliance with a required effluent TP limit is related to process configuration, organic and hydraulic loadings, and operator dedication.

This chapter presents a simplified explanation of phosphorus removal chemistry and discusses general engineering considerations for retrofitting existing plants to control effluent phosphorus using either chemical addition or biological uptake technology. In some cases where very stringent effluent TP limits are imposed, it may be cost-effective to utilize a combination of biological and chemical phosphorus removal retrofit alternatives. Later in this chapter, a series of flow diagrams (Figures 2-3 through 2-10) is given that represents the complete array of existing suspended growth and fixed film processes in the CBDB. These figures are schematics that indicate the location of retrofitted equipment and chemical dosing points and provide general engineering guidance related to chemical dosing and clarification requirements to meet specific effluent TP limits. Retrofit requirements for each type of treatment process installed in the CBDB (refer to Chapter 1 for list of processes) will be addressed in detail later in this manual. However, several items are common to most of the engineering decisions necessary for retrofitting and are discussed in this chapter. Table 9-5 compares key factors affecting chemical and biological retrofit systems.

2.2 Items Common to Most Retrofitting Situations

Successful phosphorus control depends on insolubilization of phosphorus compounds, either by chemical or biological reactions. Conditioning of the

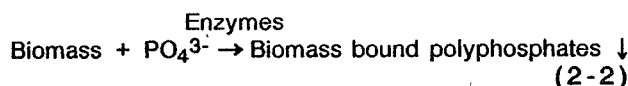
insoluble floc formed is necessary to promote good settling properties, and unit processes should be provided with adequate capacities to ensure efficient liquid-solids separation.

2.2.1 Insolubilization of Phosphorus Compounds

Raw municipal wastewater contains a mixture of phosphorus compounds in the organically-bound, polyphosphate, and orthophosphate forms. The orthophosphate form is the species that is most efficiently insolubilized by the various chemicals used to precipitate phosphorus.

Organic phosphorus compounds can settle out and be incorporated in the primary sludge or be biologically converted to the orthophosphate form if transferred to the secondary portion of the treatment process. Polyphosphates are soluble compounds that pass through primary treatment into the secondary treatment process where biological enzymatic activity converts them to the orthophosphate form. Orthophosphates are soluble, and if not insolubilized by some mechanism, either deliberate or natural, will pass completely through primary and secondary processes and appear in the final effluent.

This chemistry has process implications. Since polyphosphates are not efficiently insolubilized by metallic salt cations, dosing of raw wastewater for removal of phosphorus in primary treatment is less effective than use of metallic salt cations after the polyphosphates have been converted to orthophosphates. The lowest primary effluent TP concentration that can be practically achieved by metallic salt addition to raw wastewater is 1.5 to 2 mg/l. Once all forms of phosphorus have been converted to orthophosphate, the chemical insolubilization of phosphorus with a metallic salt cation (M^{3+}), or biological incorporation of phosphorus into biomass, can be viewed as follows:



In the case of biological insolubilization, the biomass converts soluble orthophosphate to intracellular insoluble polyphosphates, which can be removed in the waste sludge.

2.2.2 Addition of Metallic Salt

Many of the schematics in this chapter show more than one site of injection of metallic salt into the wastewater flow. Experience has shown that with stringent effluent TP limits such as 0.5 mg/l or less, it is desirable to have multi-point injection capability. This arrangement is called split dosing and results in a lower overall mole ratio of metallic salt cation to phosphorus, thereby enhancing insolubilization. For less stringent effluent limits, such as 1 or 2 mg/l TP, a single injection site may be adequate. In either case, however, since the capital cost of an additional pump and piping is small, multi-injection capability should be considered in any retrofitting plan.

The general practice in split dosing is to apply the metal salt dose in a ratio of 2:1, divided between the first and second injection sites, respectively. Adjustment of this split may be necessary to suit local circumstances.

In any retrofit flow scheme with a primary clarifier, it is worthwhile to consider selection of the primary influent as the first chemical injection site. The addition of metal salt and polymer in the influent to the primary clarifier improves the suspended solids and organic substances capture capability of this process unit. This approach maximizes primary sludge production and, if anaerobic digestion of sludges is practiced, increases total methane production. In addition, the increased efficiency of primary clarification reduces the organic load to the secondary biological process. This can result in less secondary sludge production and aeration energy requirements, as well as assist in achieving nitrification, if desired.

The actual site for chemical injection into the secondary portion of a treatment process depends on local conditions of accessibility, turbulence, and the existing type of treatment process. Dosing points can be selected at the influent end of the reactor, at the exit end of the reactor, at intermediate points within the reactor, between the reactor and final clarifier, or using various combinations thereof.

As noted above, dosing into the secondary portion of a treatment process is more efficient than dosing the primary portion. Not only is it certain that phosphorus exists as orthophosphate, but the flow and concentration peaks can be somewhat dampened by the volumetric dilution afforded by the secondary reactor tankage.

2.2.3 Addition of Polymer

Most of the schematics in this chapter show the addition of polymer in combination with metallic salt

addition. Experience has shown that the efficiency of liquid-solids separation can be enhanced by polymer addition. However, the application of polymers in wastewater treatment is more art than science. While anionic polymers are usually the most effective polyelectrolytes in combination with metallic salts, the actual type, brand, and concentration must be determined on site. Suppliers are willing to assist in conducting laboratory jar tests for selection of the most suitable product.

Deciding on the need for polymer can be guided by laboratory jar tests. Since the capital cost for polymer storage and dosing equipment is minimal, however, polymer addition should be considered in any retrofitting plan. Provision for polymer addition is essential if phosphorus removal in the primary portion of treatment is to be optimized and in cases where an effluent of 0.5 mg/l TP or less is required. Polymer addition may not be necessary in cases where metallic salt is added to the secondary portion of treatment and/or the effluent TP requirements are 1 or 2 mg/l.

For the most efficient utilization of polymer, some finite time period must be provided between introduction of metallic precipitant and addition of polymer. The insolubilization reaction between metallic salt and orthophosphate must be completed before polymer becomes effective. A time lapse of 1 to 5 minutes has been found to be suitable (1).

2.2.4 Mixing Requirements

Maximization of metallic salt and polymer utilization requires provision for adequate mixing. At the addition points, conditions for rapid mixing are essential. This is necessary for several reasons. Contact between reacting molecules must be provided, and short-circuiting must be prevented. Also, the chemical solutions added have a greater density and viscosity and may be of a different temperature than the wastewater.

Rapid mix conditions may exist at points of turbulence caused by hydraulic jumps, aeration apparatus, or pump impellers. In some cases, if rapid mix conditions do not exist, in-line static mixers or impeller-type mixers may have to be retrofitted at the points of chemical addition.

After rapid mixing of the chemical additives, a short period of gentle mixing must be provided to allow newly formed individual floc particles to agglomerate into a settleable sludge mass. Suitable conditions can usually be found in exit piping from reactors, entrance sections of clarifiers, or center wells of clarifiers, if so equipped. It is seldom necessary to retrofit for slow mix conditions; hydraulic motion between unit processes usually suffices. It is important to realize, however, that agglomeration must occur for subsequent efficient liquid/solids separation.

References 1 and 2 are excellent discussions of chemical addition and mixing, respectively.

2.2.5 Sequence of Chemical and Physical Reactions

The conceptual sequence of reactions shown in Figure 2-1 summarizes the control points for ensuring efficient removal of phosphorus by chemical addition. The initial short period of rapid mix provides energy to force molecular contact between metallic ions and orthophosphate ions to form an insoluble compound, blending to prevent density currents, and prevention of major short-circuiting. Polymer is then introduced and blended by rapid mix to contact the newly formed precipitate and absorb to the particle surface, thereby enmeshing several particles into small individual flocs. Slow mixing then provides opportunity for individual flocs to adhere and form larger agglomerates that will settle by gravitational force in the quiescent zone. The settled sludge, containing the insolubilized phosphorus, is withdrawn to sludge handling operations, and the effluent flows to the next unit operation or is discharged to the receiving stream.

2.2.6 Importance of Suspended Solids Control

As the final effluent TP compliance level is reduced from 2 mg/l to 0.5 mg/l or less, it becomes increasingly important to control effluent suspended solids. Once phosphorus removal is instituted by retrofitting secondary treatment processes with chemical addition or biological phosphorus uptake capability, the character of these suspended solids changes. The major objective of phosphorus control is insolubilization and transfer of the phosphorus into the sludge mass. Therefore, the phosphorus content of the sludge increases.

Sludges generated from secondary treatment processes with either chemical addition or biological uptake for phosphorus control generally contain about 4.5 percent phosphorus on a dry solids basis. This value compares with the typical 1.5-percent phosphorus content (dry solids basis) of biological sludges produced where phosphorus removal is not practiced.

Figure 2-2 illustrates the critical need to control effluent suspended solids as the percent phosphorus in these solids increases due to phosphorus control practices. In the case of secondary treatment without phosphorus removal, with only 1.5 percent phosphorus in the suspended solids, the phosphorus content of the effluent would be largely in the form of soluble phosphorus. The contribution to effluent phosphorus from particulate matter in this case would be minor, provided the effluent total suspended solids (TSS) concentration did not exceed the Federal secondary treatment standard of 30 mg/l.

To achieve a 1-mg/l TP effluent limit in phosphorus removal systems with suspended solids containing 4.5 percent phosphorus, however, the effluent TSS could not exceed 22 mg/l. To achieve a 0.5-mg/l TP effluent limit, the effluent TSS would have to be limited to 11 mg/l. Of course, any soluble phosphorus in the effluent would make these suspended solids concentrations even more restrictive. An effluent limit of 2 mg/l TP is not likely to be impacted by effluent TSS concentrations if the Federal secondary treatment standard of 30 mg/l is achieved.

2.2.7 Engineering Guidance Provided on General Schematics

The schematics for each type of treatment process presented provide guidance on polymer dosage, metallic ion-to-phosphorus mole ratio, and final clarifier surface overflow rate (SOR) for four different TP limits. These are approximations to allow initial assessment of the feasibility of retrofitting a specific facility to achieve a stated effluent TP limit.

When considering the retrofit of a treatment plant with either chemical or biological phosphorus removal, it is unlikely that a TP concentration of 0.5 mg/l or less could be achieved if the existing final clarifier SOR exceeds 20 m³/m²/d (500 gpd/sq ft). At SORs above this level, the final effluent TSS would almost certainly be greater than the 8 to 11 mg/l range at which attainment of a 0.5-mg/l TP concentration is possible. In these cases, provision for additional final clarifier capacity and/or granular media filtration of the secondary effluent should be considered in the retrofit plan.

2.2.8 Sludge Production at Facilities Retrofitted for Phosphorus Removal

A survey was conducted on 185 Ontario, Canada wastewater treatment facilities regarding the impact of chemical addition for phosphorus removal on sludge quantity (3). The survey showed that to reach an effluent TP of 1.0 mg/l, sludge mass increased by an average of 40 percent at primary treatment plants and 26 percent at activated sludge plants. These data are summarized in Table 2-1. Information is provided on sludge mass, percent dry solids, and sludge volume for conventional primary and activated sludge processes before and after chemical addition.

In another study (4), it was concluded that the impacts of all types of phosphorus removal processes on sludge quantity, quality, stabilization, thickening, dewatering, incineration, and agricultural utilization are related to site-specific wastewater characteristics and process options employed and that generalizations of these impacts are not possible.

A recent technology evaluation (5) contains data for four full-scale biological phosphorus removal retrofit projects. Two were PhoStrip processes, and two were activated sludge processes modified to include an

Figure 2-1. Sequence of increased liquid/solids separation and phosphorus removal.

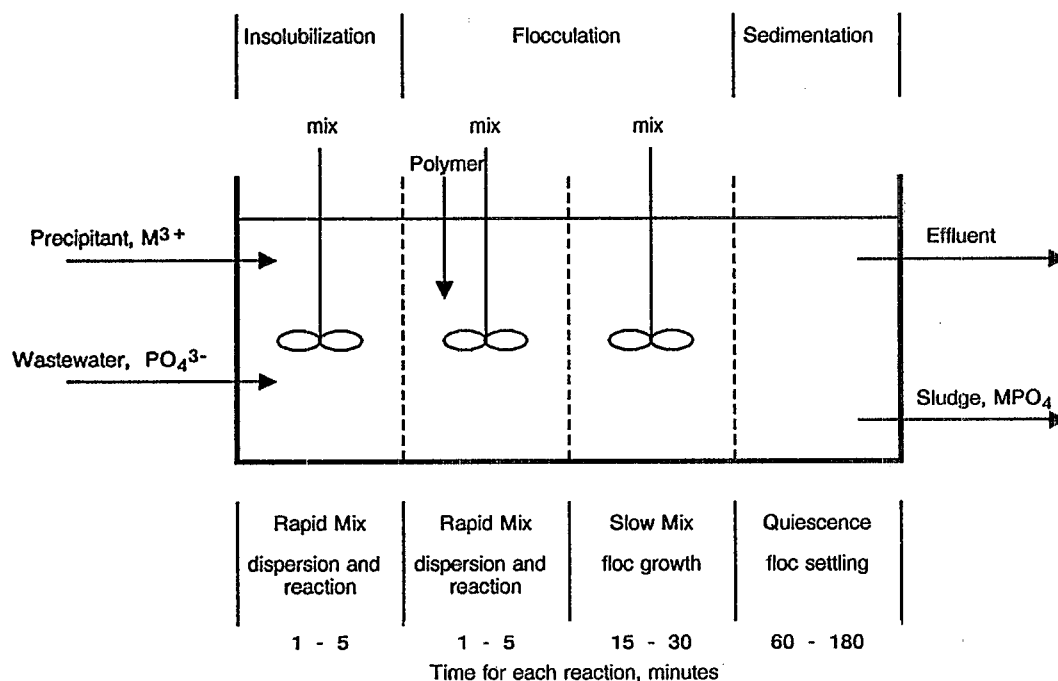
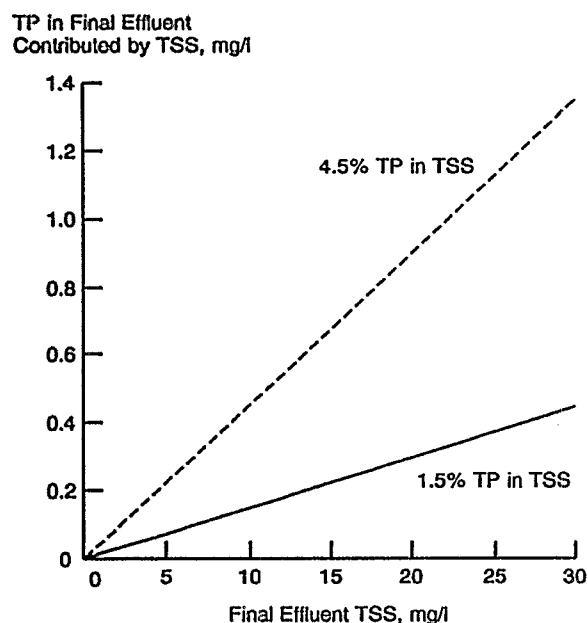


Figure 2-2. Importance of effluent TSS on effluent TP.



anaerobic stage at the head end of the aeration system. Waste activated sludge production for all four facilities ranged from 0.7 to 1.0 kg volatile suspended solids (VSS)/kg total BOD₅ (TBOD) removed. The high value of 1.0 kg VSS/kg TBOD was noted at a

facility that did not practice primary settling, and this higher value was attributed to nondegradable volatile solids. When the PhoStrip process is employed for biological phosphorus removal, additional solids are contributed by the lime added to insolubilize phosphorus released by the biomass in the anaerobic stripper. This generally equates to about 20 mg/l of lime, based on influent flow.

2.2.9 Sludge Production Related to Different Effluent TP Requirements.

The discussion in the preceding paragraphs concerns sludge production for facilities achieving compliance with a 1-mg/l TP requirement. If the requirement were 2 mg/l TP instead of 1 mg/l, no material difference in sludge production would be noted in either the chemical or biological systems. Regardless of the effluent TP requirement, a certain amount of chemical precipitant must be added to satisfy the initial chemical demand of the wastewater. This demand must be met before efficient insolubilization of phosphorus occurs. Once the demand is met, there is not much difference between the amount of precipitant required to achieve 1 mg/l vs. 2 mg/l TP, since the ratio of metal ion dose to phosphorus insolubilized is linear in this effluent concentration range. Effluent concentrations of 1 to 2 mg/l TP are about the practical limit for biological phosphorus removal processes.

A requirement for compliance with a 0.5-mg/l or less TP effluent limit would increase sludge production in

Table 2-1. Sludge Production With and Without Chemical Addition (3)

| | Type of Treatment | | | |
|--|-------------------|----------------------------------|-------------------------------|------------------------------------|
| | Primary | | Activated Sludge ¹ | |
| | Conventional | Metal Salt Addition ² | Conventional | Metal Salt Addition ^{2,3} |
| Dry Solids Produced, kg/1,000 m ³ | 120 | 169 | 173 | 217 |
| Dry Solids Produced, lb/Mgal | 1,000 | 1,410 | 1,443 | 1,810 |
| Dry Solids Content, percent | 6.0 | 5.3 | 4.5 | 4.2 |
| Sludge Volume, percent of influent flow | 0.20 | 0.32 | 0.38 | 0.51 |

¹ Primary plus waste activated sludges.

² Plant influent TP = 7 mg/l; final effluent TP = 1 mg/l.

³ Metal salt added to aerator.

both chemical and biological phosphorus removal processes compared with a 1- or 2-mg/l effluent TP requirement. As noted previously, effluent suspended solids would have to be controlled to near 10 mg/l to reduce effluent TP to this level. The additional suspended solids captured would result in increased sludge production and sludge handling requirements.

Chemical phosphorus removal processes would require an increase of about 20 percent in metal ion dose to achieve a 0.5-mg/l or less TP effluent. This increase would be necessary to ensure efficient phosphorus insolubilization and to control the solubility product of the metal phosphate precipitate.

Biological phosphorus removal processes would in all likelihood require a chemical supplement to achieve a 0.5-mg/l or less TP concentration. Sufficient metal ion would have to be added to insolubilize 0.5 to 1.5 mg/l TP after the initial chemical demand was met. This would result in chemical sludge production and increased total sludge production compared with achieving a 1- or 2-mg/l TP concentration.

2.3 Process Options for Retrofitting Existing CBDB Facilities to Achieve Phosphorus Control

The schematics illustrated in Figures 2-3 through 2-10 indicate that all of the various treatment processes existing in the CBDB could be retrofitted for chemical phosphorus control. Only the activated sludge processes, however, are considered for retrofitting to biological phosphorus control. Options for retrofitting to biological phosphorus control are limited in this document to the PhoStrip and Anaerobic/Oxic (A/O) processes, as depicted schematically in Figures 2-11 and 2-12, respectively.

2.3.1 Retrofitting CBDB Facilities with Chemical Control of Phosphorus

The following paragraphs and Figures 2-3 through 2-10 provide general guidance for adding chemical

phosphorus control to existing CBDB facilities. In the following chemical control examples, some form of iron or aluminum salt is assumed as the source of metal ion to insolubilize phosphorus. Lime addition to the full wastewater flow is not recommended to obtain the TP concentrations needed for compliance in the CBDB because of the many O&M problems associated with its handling.

The M³⁺/Inf. TP mole ratios shown in Figures 2-3 through 2-10 are initial chemical dose guidelines. It is well recognized that only soluble phosphorus is actually precipitated by metal salts. Particulate and soluble phosphorus taken up biologically do not consume chemical.

Based on recent and ongoing research (6,7) claims have been made that the remaining soluble phosphorus (SP) not taken up biologically reacts with metal ion at stoichiometric mole ratios of about 1.4 to 1.5 down to residual SP concentrations of 1 to 2 mg/l. As shown in Figures 2-3 through 2-10, much higher chemical doses are needed to achieve effluent TP concentrations of 0.2 or 0.5 mg/l. The investigators carrying out the above research (6,7) have developed a model that predicts that chemical dose is independent of influent phosphorus concentration in meeting low (<1 mg/l) effluent TP concentrations. Rather, their theory suggests that any variability in the ratio between M³⁺ dose and influent SP or influent TP required to reach low (<1 mg/l) effluent TP concentrations is a function of the initial pH and alkalinity of the wastewater, microbial activity, and mode of aeration and not the influent phosphorus concentration itself.

While the above research studies (6,7) are being completed and field tests conducted for verification, a conventional chemical dosing strategy based on influent TP is used in this document for all four effluent TP limits considered. In addition to its impact on the dosing guidance provided in Figures 2-3 through 2-10, this conventional strategy was utilized in: 1) displaying the chemical phosphorus removal effluent quality data in Figures 3-1 and 3-2 and the

chemical phosphorus removal sludge production data in Figure 3-4; 2) developing the chemical dose requirements of the design synopses in Chapter 4; 3) preparing the chemical storage and supply system layouts in Figures 5-13 through 5-22; 4) developing the estimated chemical phosphorus removal cost curves in Figures 8-1 through 8-8; 5) estimating chemical phosphorus removal capital costs for different plant sizes and effluent TP limits in Tables 9-1 through 9-3; and 6) summarizing annual chemical costs for different effluent TP limits in Table 9-4.

If the above theory (6,7) is confirmed, those portions of the above figures and tables involving the 0.5- and 0.2-mg/l effluent TP limits would require modification.

2.3.1.1 Retrofitting Plug Flow, Step Aeration, Complete Mix, Pure Oxygen, and Single-Stage Nitrification Activated Sludge Systems for Chemical Phosphorus Removal

Figure 2-3 indicates that all the above activated sludge process alternatives have basically the same general flow scheme. Provided that the chemical dose and effluent clarification guidelines discussed previously are complied with, each process alternative has the capability to achieve an effluent TP concentration of 2, 1, 0.5, or 0.2 mg/l. Considerations specific to each option are discussed below.

When compliance with an effluent limitation of 0.5 mg/l TP or less is required, a split dose of metal salt is recommended. Tertiary filtration may also be necessary. Tertiary filtration is essential, however, to achieve 0.2 mg/l TP. A separate rapid mix and flocculation basin may be installed between the secondary reactor and final clarifier to promote more efficient use of chemicals and to minimize generation of chemical sludge.

Well-operating plug flow and complete mix systems should offer no problems for retrofitting other than finding the optimum dosing points for metal salt and polymer, if required. Step aeration systems may need adjustment in the location of primary effluent feed points into the aeration basin. It may be necessary to increase wastewater aeration time to ensure the enzymatic conversion of polyphosphates to orthophosphates. This would be particularly important if a 0.5-mg/l TP or less effluent limit had to be achieved.

Retrofitting single-stage nitrification systems for chemical phosphorus removal requires evaluation of two process operating considerations. First, the chemicals commonly used for phosphorus removal are acidic. Furthermore, biological nitrification reactions also produce hydrogen ions. If the wastewater does not contain enough alkalinity to

neutralize the acidity generated by these two sources, some provision for pH control will be necessary.

Second, the metal ion side-products and metal phosphate precipitates formed and occluded into the activated sludge mass contribute an inert fraction to the biomass that lowers the volatile content of the mixed liquor suspended solids (MLSS) below that normally encountered where mineral addition is not practiced. Historical wasting schedules for control of the sludge retention time (SRT) may have to be altered from usual operational experience at a given facility to sustain efficient single-stage nitrification. This usually involves operating at a higher MLSS concentration so that the overall quantity of volatile solids under aeration remains equal to or greater than the prechemical addition level. These two process considerations will be discussed in more detail in Chapter 7.

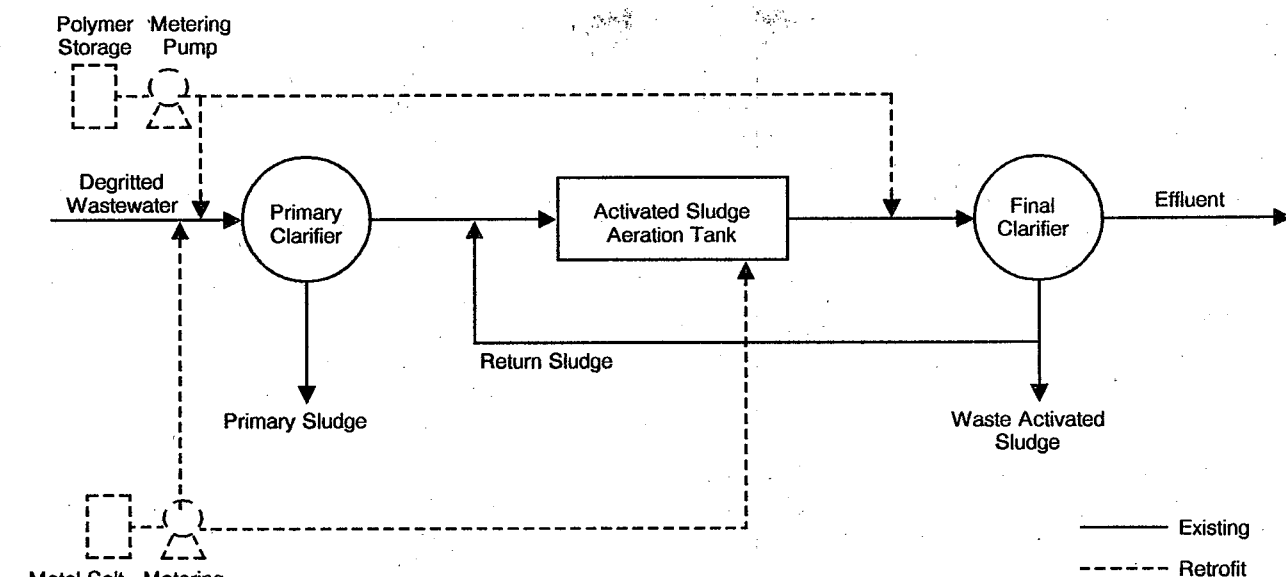
The pH value of the bioreactor mixed liquor is also of concern in retrofitting pure oxygen activated sludge systems with chemical phosphorus control. This type of reactor is typically covered to provide a gas-tight environment for efficient utilization of oxygen. Since only the last aeration compartment is normally vented to the atmosphere, carbon dioxide resulting from biological oxidation of wastewater constituents is trapped in solution rather than being continually air stripped from the reactor. Carbon dioxide in solution acts as a weak acid and, coupled with the acidic nature of most chemicals used for phosphorus control, can result in pH values low enough to inhibit normal microbiological metabolic reactions.

This coupled pH effect could occur regardless of where the acidic metal salt was dosed into the system. If supplemental alkalinity is required, soluble alkalis such as sodium hydroxide, bicarbonate, or carbonate should be selected. Lime would not be recommended due to the possibility of calcium carbonate scale formation from the reaction of calcium ions with dissolved carbon dioxide.

2.3.1.2 Retrofitting Extended Aeration and Oxidation Ditch Activated Sludge Systems for Chemical Phosphorus Removal

Figure 2-4 illustrates that these two processes have similar secondary treatment flow schemes and typically are constructed without primary clarification. Degritted wastewater flows directly to the activated sludge bioreactor. Both processes usually are designed for nominal aeration tank detention times of 20-24 hours. Extended aeration systems are of conventional aeration tankage design, while oxidation ditches are constructed in an oval, race-track tank configuration. The process considerations for retrofitting chemical phosphorus removal in these systems are similar to those discussed for single-stage nitrification. Due to their long aeration times and high SRTs, these processes usually nitrify under

Figure 2-3. Retrofitting plug flow, step aeration, complete mix, pure oxygen, and single-stage nitrification activated sludge systems for chemical phosphorus removal.



| Final Effluent TP mg/l | Polymer Dose mg/l | M ³ + /Inf. TP Ratio mole | Final Clarifier SOR* gpd/sq ft | Final Effluent Filtration Required |
|---------------------------|----------------------|--|-----------------------------------|---------------------------------------|
| 2 | 0.1 - 0.2 | 1.0 - 1.2 | 800 | No |
| 1 | 0.1 - 0.2 | 1.2 - 1.5 | 600 | No |
| 0.5 | 0.1 - 0.2 | 1.5 - 2.0 | 500 | Maybe |
| 0.2 | 0.5 - 1.0 | 3.5 - 6.0 | 500 | Yes |

* at peak sustained flow

summer conditions. Therefore, pH control can be a seasonal process problem when acidic metal salts are added. Supplemental alkalinity may be required during the summer months.

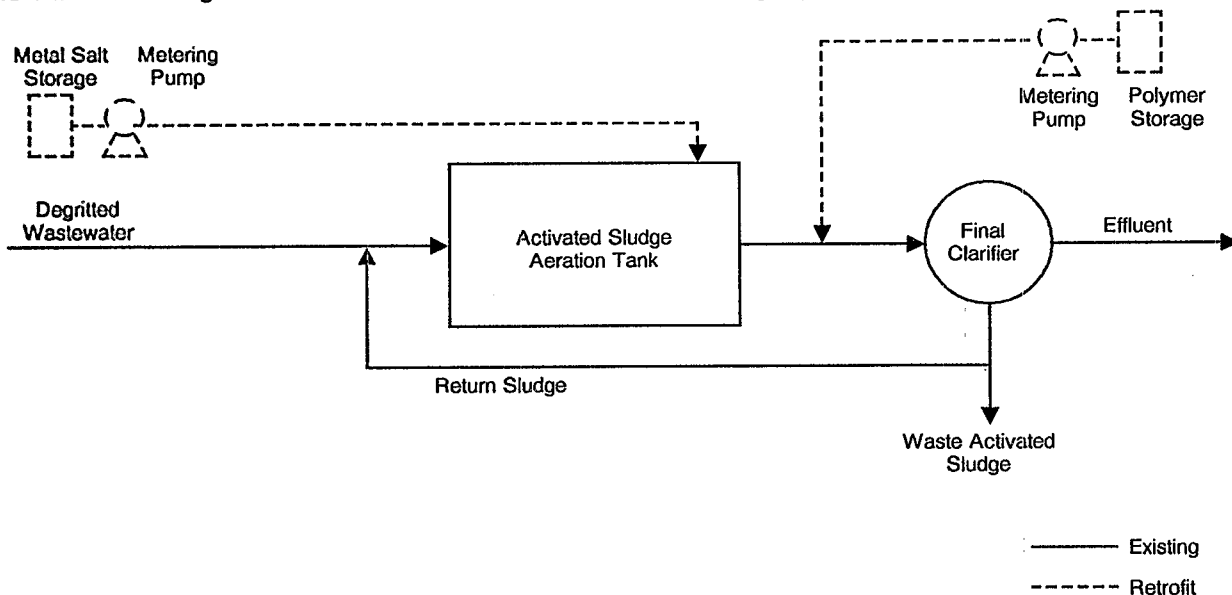
The usual design and operational parameters for both processes are low food-to-microorganism (F/M) loadings, long SRTs, long aeration detention times, and low biological sludge yields per mass of BOD removed. These interrelated factors produce a MLSS that typically has a high inert fraction. Additional inert material contributed by metal ion addition can result in MLSS with an even lower volatile fraction. Volatile fractions below 50 percent can lead to unstable operation. Sludge wasting schedules may have to be adjusted to prevent loss of active biomass.

Another operational adjustment that can be considered for an extended aeration system is isolation of a portion of the aeration tankage to reduce aeration detention time. This should result in an increase in biological sludge yield and help control the

inert-to-volatile ratio of the MLSS. This operational adjustment may not be possible with an oxidation ditch system, however, because of the oval configuration of the aeration tank.

With both processes, the above points become more critical if a 0.5-mg/l TP or less effluent limit is required. This criticality arises from the extra metal ion required and the lack of a primary clarifier to remove inert solids. If an engineering evaluation indicates that the buildup of inert material could become extensive, tertiary media filtration with a polish dose of metal ion prior to the filter might be considered to ease the inerts problem. Solids in the filter backwash should be transferred directly to sludge processing units and not returned to the secondary system. A jar test should be conducted to determine the necessary dosage of chemicals. If the required dosage is excessive, a separate-stage tertiary chemical reactor-clarifier is recommended to achieve an effluent TP concentration of 0.5 mg/l or less. A pH adjustment system should also be considered.

Figure 2-4. Retrofitting extended aeration and oxidation ditch activated sludge systems for chemical phosphorus removal.



| Final Effluent TP mg/l | Polymer Dose mg/l | M ³ +/Inf. TP Ratio mole | Final Clarifier SOR* gpd/sq ft | Final Effluent Filtration Required |
|---------------------------|----------------------|---|--------------------------------------|--|
| 2 | 0.1 - 0.2 | 1.0 - 1.2 | 800 | No |
| 1 | 0.1 - 0.2 | 1.2 - 1.5 | 600 | No |
| 0.5 | 0.1 - 0.2 | 1.5 - 2.0 | 500 | Maybe |
| 0.2 | 0.5 - 1.0 | 3.5 - 6.0 | 500 | Yes |

* at peak sustained flow

2.3.1.3 Retrofitting Contact Stabilization Activated Sludge Systems for Chemical Phosphorus Removal

The configuration of the contact stabilization activated sludge process is shown in Figure 2-5. The major process consideration for retrofitting contact stabilization facilities is similar to that for step aeration. The contact tank usually has a hydraulic detention time (HDT) of only 30 to 60 minutes for the main stream primary effluent flow. This may not be enough HDT to provide for enzymatic conversion of polyphosphates to orthophosphates. The short contact time could also restrict the biological conversion of organic phosphorus compounds to the orthophosphate form. These items become more important if the effluent TP compliance level is 0.5 mg/l or less. Laboratory testing could quantify the aeration HDT necessary for these conversions to ensure efficient insolubilization of phosphorus. Once phosphorus has been insolubilized by metal salt addition and occluded into the mixed liquor biomass, no resolubilization occurs in the reaeration tank. If additional aeration HDT is required, the split of tankage volume between the contact tank and the

sludge reaeration or stabilization tank could be modified if the plant layout permits.

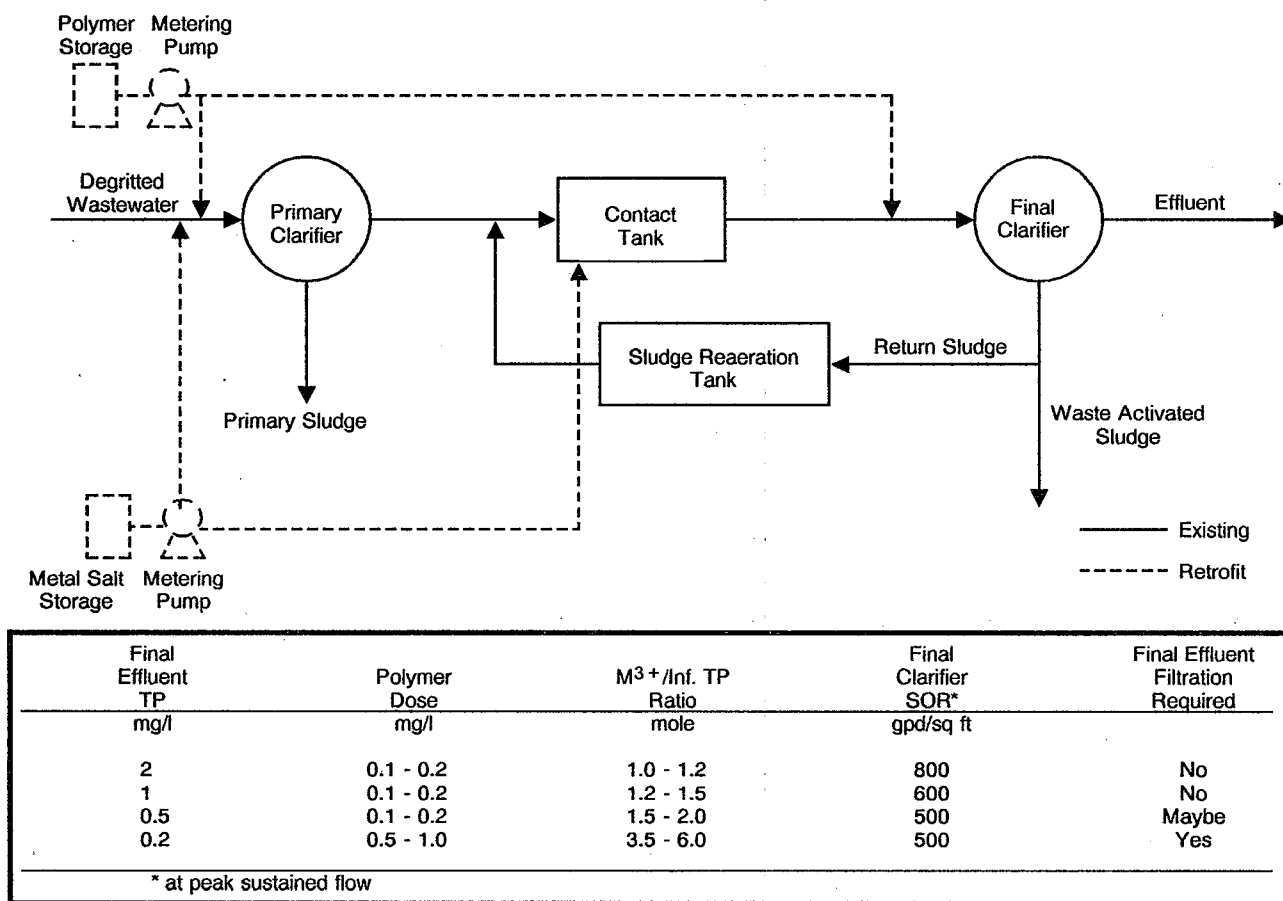
2.3.1.4 Retrofitting Two-Stage Biological Nitrification Systems for Chemical Phosphorus Removal

The schematic provided in Figure 2-6 indicates that two-stage nitrification facilities offer great flexibility for metal salt dosing because of the multiple unit processes employed. Many variations of both suspended growth and attached growth processes in different combinations have been utilized for two-stage nitrification.

To achieve a 1- or 2-mg/l TP effluent concentration, it may only be necessary to dose one unit process with metal salt. The primary clarifier or first-stage carbonaceous reactor would normally be selected. If the required effluent concentration was 0.5 mg/l TP or less, a polish dose could be provided at the second-stage nitrification reactor.

The cautions noted previously relative to the combined effect of metal salt addition and nitrification

Figure 2-5. Retrofitting contact stabilization activated sludge systems for chemical phosphorus removal.



on lowering pH should be considered. Second-stage processes also have very low net cell synthesis. Therefore, the discussion on retrofitting extended aeration systems is relevant to the second-stage nitrification reactor. This implies that only a polish dose of metal salt be added to second-stage reactors to avoid a large buildup of inerts in the MLSS.

2.3.1.5 Retrofitting Standard-Rate Trickling Filters for Chemical Phosphorus Removal

Standard-rate trickling filters (Figure 2-7) can achieve the effluent phosphorus concentrations required in the CBDB. Both rock and plastic media trickling filters have been retrofitted for phosphorus removal.

Since flow through a trickling filter is typically more laminar than turbulent, metal salt is not normally dosed directly to the filter media. Therefore, it may be necessary to provide a rapid mix chamber prior to the secondary clarifier when the metal salt is added after the filter.

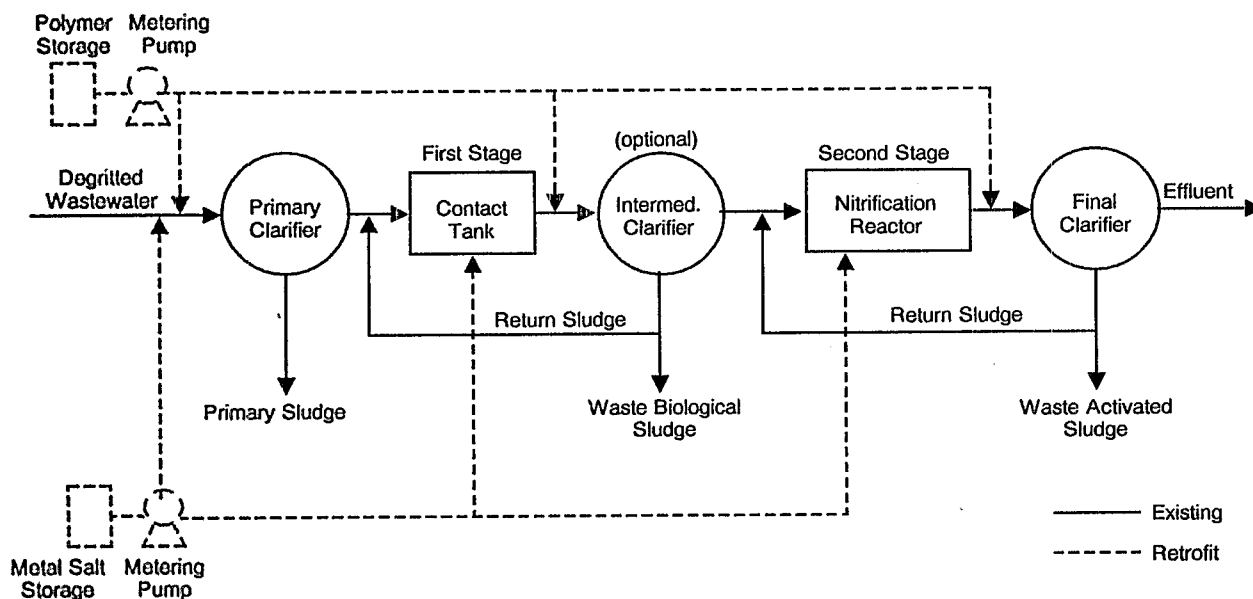
Polymer addition capability is considered necessary for any trickling filter facility retrofitted for chemical

phosphorus control. If metal salt is dosed to the primary clarifier, polymer is needed to ensure that a large amount of inorganic solids does not carry over to the trickling filter and produce a biofilm with a high inert solids fraction. Standard-rate filter biomass is similar to the biomass of an extended aeration process; i.e., it has a low net cell synthesis and a long SRT.

If chemical addition to the secondary clarifier is planned, a critical review should be made of existing secondary clarifier performance to determine if the SOR and depth are adequate to handle the increased solids loading. This is particularly important with older trickling filter installations that often were equipped with shallow secondary clarifiers with relatively high SORs. When existing clarifiers are found inadequate, consideration should be given to adding new clarifiers as required.

Typically, trickling filters produce effluents that contain both sloughed and colloidal solids, and polymer addition to the secondary clarifier would be necessary to meet a 0.5-mg/l TP or less effluent limit.

Figure 2-6. Retrofitting two-stage biological nitrification systems for chemical phosphorus removal.



| Final Effluent TP mg/l | Polymer Dose mg/l | M ³ + /Inf. TP Ratio mole | Final Clarifier SOR* gpd/sq ft | Final Effluent Filtration Required |
|------------------------|-------------------|--------------------------------------|--------------------------------|------------------------------------|
| 2 | 0.1 - 0.2 | 1.0 - 1.2 | 800 | No |
| 1 | 0.1 - 0.2 | 1.2 - 1.5 | 600 | No |
| 0.5 | 0.1 - 0.2 | 1.5 - 2.0 | 500 | Maybe |
| 0.2 | 0.5 - 1.0 | 3.5 - 6.0 | 500 | Yes |

* at peak sustained flow

2.3.1.6 Retrofitting High-Rate Trickling Filters for Chemical Phosphorus Removal

The high-rate trickling filter process (Figure 2-8) represents the most difficult process in the CBDB to retrofit for chemical phosphorus control. The typical designs for these systems favor high SORs for both primary and secondary clarifiers. Additionally, the trickling filter unit process is designed with a high hydraulic application rate that leads to a short contact time of wastewater with the biofilm and incomplete bio-oxidation of organics. Final effluent from this process typically is turbid and contains dispersed suspended solids and undegraded organics. Conversion of organically-bound phosphorus and polyphosphates to orthophosphates is limited by the short contact time. High-rate trickling filter systems have marginal capability to produce a final effluent of 30 mg/l TBOD and TSS.

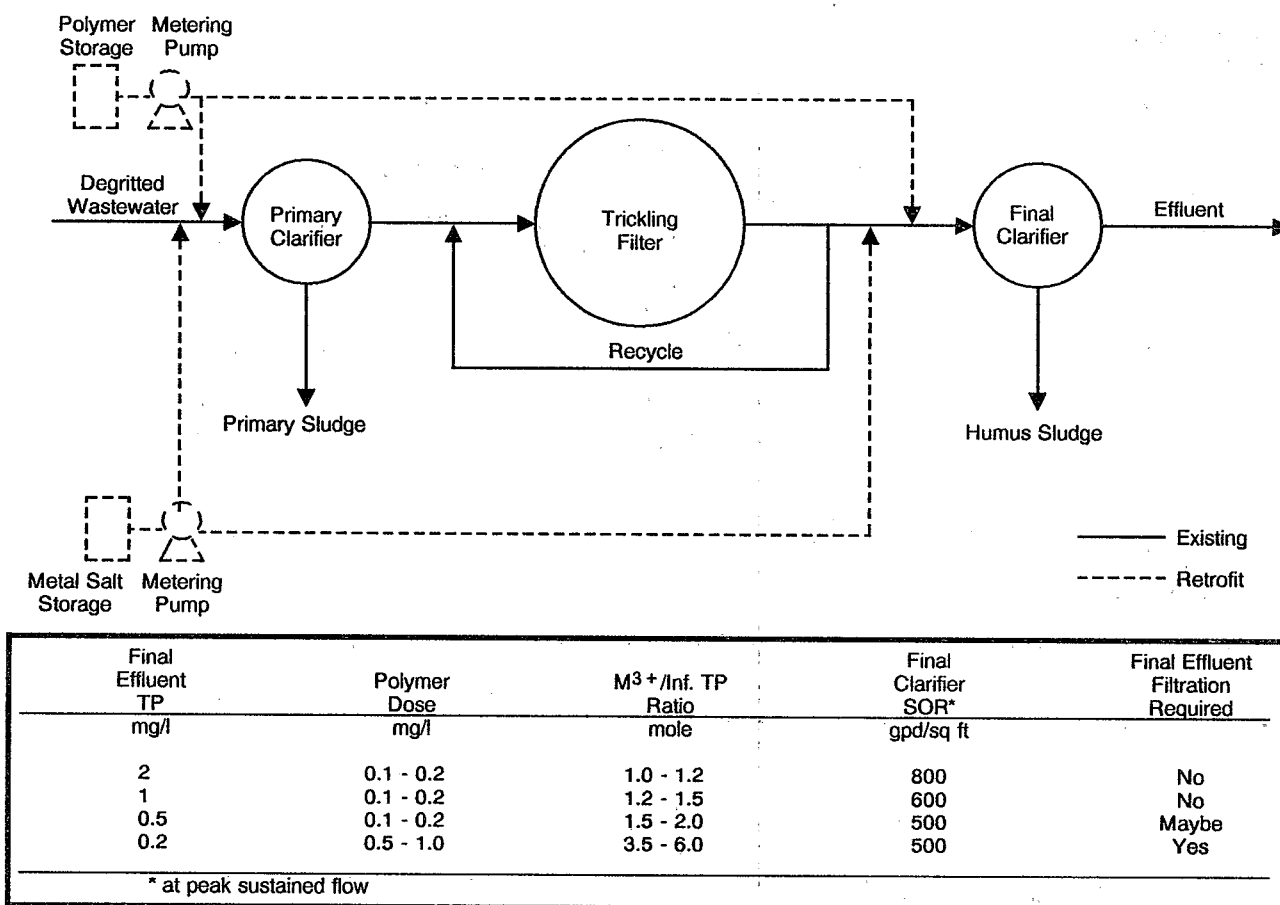
All of these process characteristics are contrary to achievement of efficient phosphorus removal. Major emphasis for retrofitting a high-rate trickling filter has to be placed on provision of efficient rapid mix and flocculation capabilities to enhance solids capture. In

all likelihood, stringent effluent phosphorus limits would also be accompanied by more stringent effluent BOD requirements, so the retrofit design would also need to address enhanced organic removal. Polymer addition capability would also be essential in any chemical phosphorus removal retrofit of a high-rate trickling filter system.

To meet a 2-mg/l TP effluent limit, metal salt and polymer addition to the primary clarifier would be the preferred choice. This dosing arrangement would reduce the organic load on the high-rate filter and provide some improvement in BOD removal.

Attainment of a 1-mg/l TP effluent limit with a high-rate filter system is questionable due to the limited solids capture of clarifiers and the presence of phosphorus forms that are not efficiently insolubilized by metal ions. A 1-mg/l concentration might be achieved by adding a second dose of metal salt and polymer after the high-rate filter, thus improving both phosphorus and BOD removals above the levels obtainable with primary clarifier metal salt addition alone.

Figure 2-7. Retrofitting standard-rate trickling filters for chemical phosphorus removal.



A 0.5- or 0.2-mg/l TP effluent limit would probably require construction of a second-stage bioreactor and clarifier, or expansion of the existing high-rate trickling filter system to reduce hydraulic and organic loadings to standard-rate trickling filter loadings.

A phased approach to the attainment of a 0.5- or 0.2-mg/l TP effluent limit with the existing system could be instituted. After the retrofit for dosing the primary clarifier was in place to achieve a 2-mg/l TP effluent concentration, laboratory and pilot testing could be conducted to provide guidance on the need for new construction to further reduce phosphorus levels in the effluent.

2.3.1.7 Retrofitting Rotating Biological Contactors for Chemical Phosphorus Removal

Retrofitting a rotating biological contactor (RBC) system for chemical phosphorus removal is shown schematically in Figure 2-9. A split dose arrangement is recommended for attainment of a 0.5- or 0.2-mg/l TP effluent limit. Provided that the chemical dosage and clarification guidelines discussed previously are adhered to, no major problems with implementing chemical phosphorus control should be encountered.

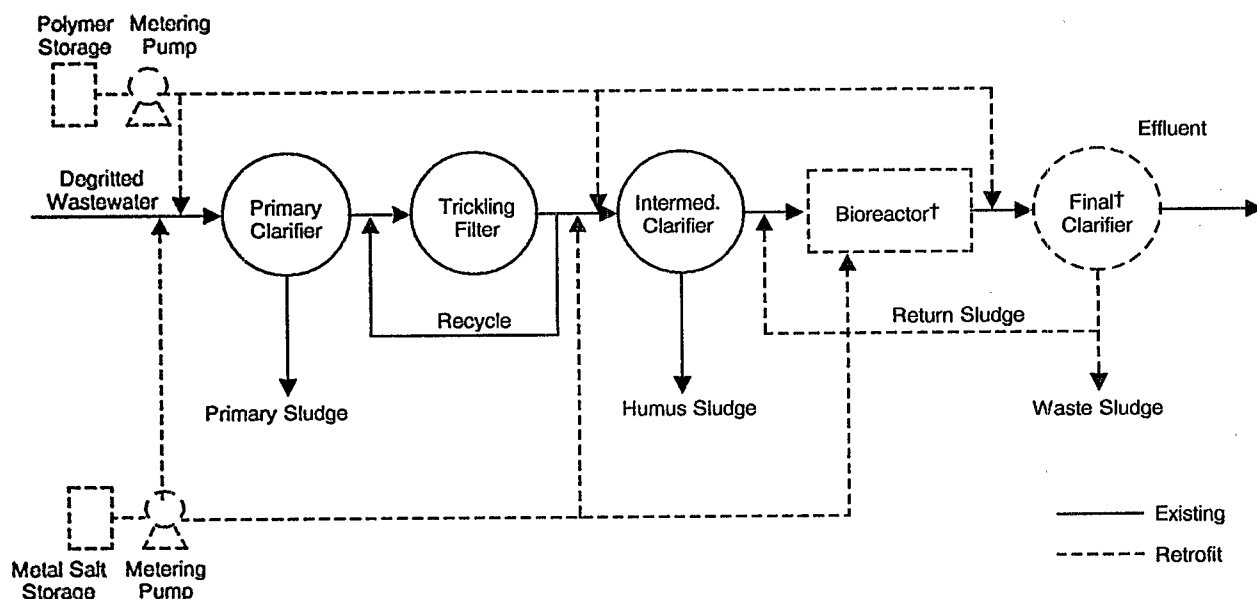
An RBC system is similar to a standard-rate trickling filter system, and considerations discussed in that section of this chapter apply to RBC retrofits. Since the RBC is an attached growth process and shear forces act on the biofilm during the liquid immersion portion of the rotational cycle, the effluent can contain both sloughed and colloidal suspended solids. Polymer addition to the final clarifier is recommended to meet a 0.5- or 0.2-mg/l TP effluent limit.

2.3.1.8 Retrofitting Wastewater Lagoons for Chemical Phosphorus Removal

Figure 2-10 depicts a multi-cell lagoon, with aeration provided in the first cell, retrofitted for chemical phosphorus control. Information on phosphorus removal technology for lagoon systems is scarce, due in part to the fact that most of these systems have flows less than 0.04 m³/s (1 mgd) and many systems of this size are exempt from nutrient control requirements.

Guidance is not offered in Figure 2-10 for attaining a 0.5-mg/l TP or less effluent limit with a retrofitted lagoon system. Mixing patterns, stratification, short-circuiting, algal growth, pH fluctuations, large

Figure 2-8. Retrofitting high-rate trickling filters for chemical phosphorus removal.



| Final Effluent TP mg/l | Polymer Dose mg/l | M ³ +/Inf. TP Ratio mole | Final Clarifier SOR* gpd/sq ft | Final Effluent Filtration Required |
|---------------------------|----------------------|---|--------------------------------------|--|
| 2 | 0.1 - 0.2 | 1.0 - 1.2 | 800 | No |
| 1 | 0.1 - 0.2 | 1.2 - 1.5 | 600 | No |
| 0.5** | 0.1 - 0.2 | 1.5 - 2.0 | 500 | Maybe |
| 0.2** | 0.5 - 1.0 | 3.5 - 6.0 | 500 | Yes |

* at peak sustained flow
 ** major expansion may be necessary
 † may be necessary for 0.5 and 0.2 mg/L effluent TP

surface-to-volume ratios, and long hydraulic retention times (HRTs) combine to indicate that a simple retrofit could not reliably achieve this concentration. To meet this limit would probably require construction of a separate tertiary chemical treatment system (consisting of a flocculation tank and a clarifier) followed by filtration. The same considerations are also the reason Figure 2-10 shows slightly higher metal salt dosages to achieve a 2- or 1-mg/l TP effluent concentration than recommended for the other secondary treatment processes discussed previously.

Because of the large liquid volume of cells in a lagoon system, mixing of metal salt with wastewater can be a major process problem. If aeration devices are present, the turbulence produced during aeration could be utilized. If a quiescent cell is selected for chemical dosing, a mixing device must be installed to ensure adequate mixing of chemical additives and cell contents.

Polymer addition is not shown in Figure 2-10 because not enough experience has been reported

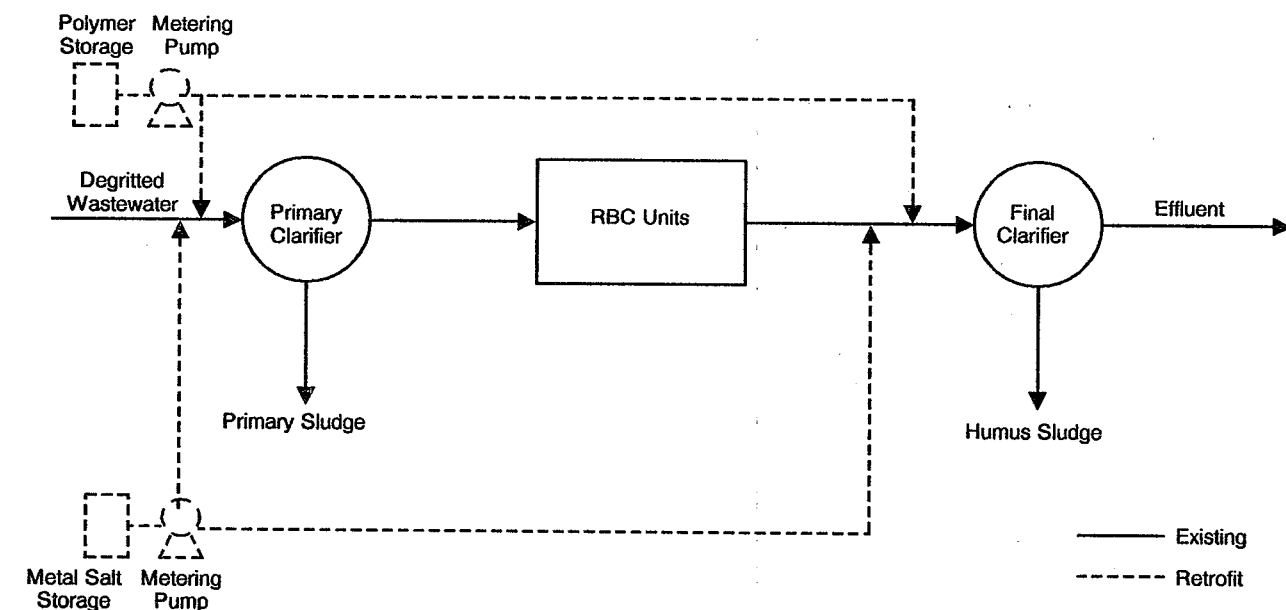
for a general recommendation to be made. Reference 8 contains several citations on lagoon systems dosed with metal salt to achieve a 1-mg/l TP effluent concentration.

2.3.2 Retrofitting CBDB Facilities with Biological Control of Phosphorus

The following sections and Figures 2-11 and 2-12 provide general guidance for retrofitting selected suspended growth activated sludge process configurations at existing facilities in the CBDB with biological phosphorus control. Two proprietary processes are considered, the PhoStrip process and the Anaerobic/Oxic (A/O) process. The PhoStrip process utilizes a sidestream unit operation to chemically insolubilize phosphorus that has been stripped or leached from phosphorus-rich biomass. The A/O process operates as a main stream biological phosphorus removal process.

These biological phosphorus removal processes are implemented by maintaining a cyclic exposure of aeration tank biomass to anaerobic and aerobic

Figure 2-9. Retrofitting RBCs for chemical phosphorus removal.



| Final Effluent TP mg/l | Polymer Dose mg/l | M ³ + /Inf. TP Ratio mole | Final Clarifier SOR* gpd/sq ft | Final Effluent Filtration Required |
|---------------------------|----------------------|--|--------------------------------------|--|
| 2 | 0.1 - 0.2 | 1.0 - 1.2 | 800 | No |
| 1 | 0.1 - 0.2 | 1.2 - 1.5 | 600 | No |
| 0.5 | 0.1 - 0.2 | 1.5 - 2.0 | 500 | Maybe |
| 0.2 | 0.5 - 1.0 | 3.5 - 6.0 | 500 | Yes |

* at peak sustained flow

conditions. A period of acclimation is necessary to allow time for natural selection of microorganisms that can survive under these conditions. This period can vary from 2 to 4 weeks for establishment of a steady-state population.

During the anaerobic cycle, these microorganisms release intercellular-stored phosphorus to the bulk liquid while simultaneously sorbing organics. Upon entering the subsequent aerobic cycle, the same microorganisms will degrade the sorbed organics and remove the liberated phosphorus from the bulk liquid by incorporating it into intercellular granules. Reference 9 is an excellent discussion of biological phosphorus removal processes from an engineering viewpoint. Reference 10 discusses the relationship of wastewater composition to the feasibility of utilizing a biological process for phosphorus removal at a specific site.

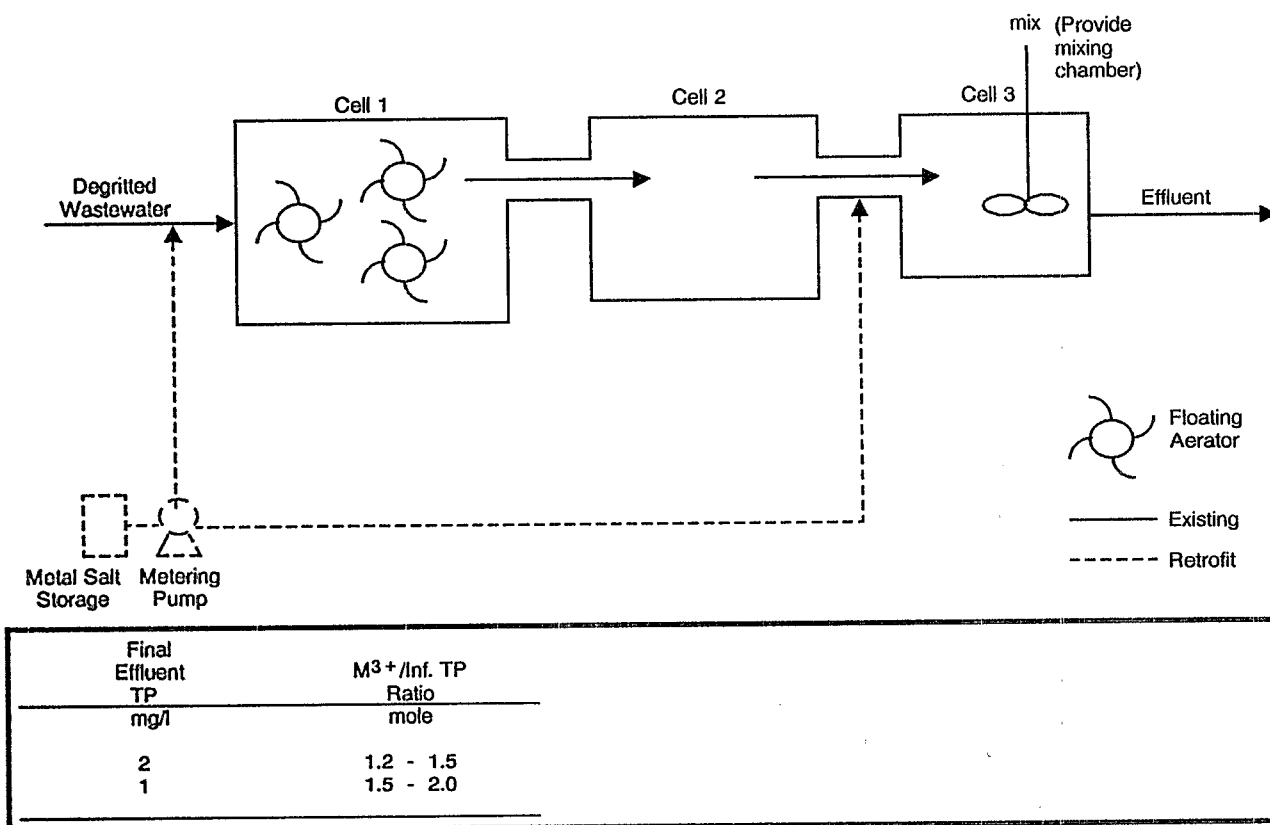
2.3.2.1 Retrofitting Activated Sludge Systems for Biological Phosphorus Removal Using the PhoStrip Process

Figure 2-11 represents an activated sludge system that has been retrofitted to include the PhoStrip

process. A portion of the return sludge stream is subjected to anaerobic conditions in a reactor called an "anaerobic stripper." The portion of return sludge sent to the stripper can vary from 15 to 30 percent of total plant flow. The purpose of the stripper tank is to provide conditions conducive to release of intercellular phosphorus from the microorganisms in the return sludge (phosphorus stripping). Some modifications of the PhoStrip process employ an elutriation stream with the stripper operation; this is not shown in Figure 2-11. The elutriation stream may be stripper tank recycle, primary effluent, secondary effluent, lime precipitation tank overflow, or digester supernatant return. The choice and magnitude of the elutriation stream is a site-specific selection based on operational and wastewater composition criteria. The purpose is to increase the efficiency of phosphorus stripping (5).

The SRT of the return sludge solids in the stripper tank can vary from 5 to 20 hours, and the HDT can vary from 1 to 10 hours. The return sludge solids in the underflow from the stripper tank, which have now been partly stripped of intercellular phosphorus, are returned to the aerobic aeration tank to biologically

Figure 2-10. Retrofitting wastewater lagoons for chemical phosphorus removal.



insolubilize phosphorus from the main stream flow and then be recycled back to the anaerobic stripper.

Overflow from the stripper is treated with lime in a precipitation tank to chemically insolubilize the stripped phosphorus. Lime dosages of 100 to 150 mg/l are typically used to increase the pH to 9.0 to 9.5. This equates to about 20 to 25 mg/l of lime based on plant influent flow. Some facilities route the precipitation tank contents directly to the primary clarifier as shown in Figure 2-11. Once insolubilized by lime, the phosphorus does not resolubilize in the primary clarifier. The lime-phosphorus sludge co-settles with the primary sludge. Other facilities employ a reactor-clarifier in lieu of a precipitation tank and route only reactor-clarifier overflow to the primary clarifier. The underflow lime-phosphorus sludge is disposed of separately.

As further described in Chapter 6, aeration tank HDT should be between 4 and 10 hours for effective PhoStrip operation. Detention time in extended aeration plants may, therefore, need to be shortened by blocking a portion of the tankage. This will also result in a higher organic loading rate, which is desirable for biological phosphorus removal. On the other hand, aerobic contact time in the contact

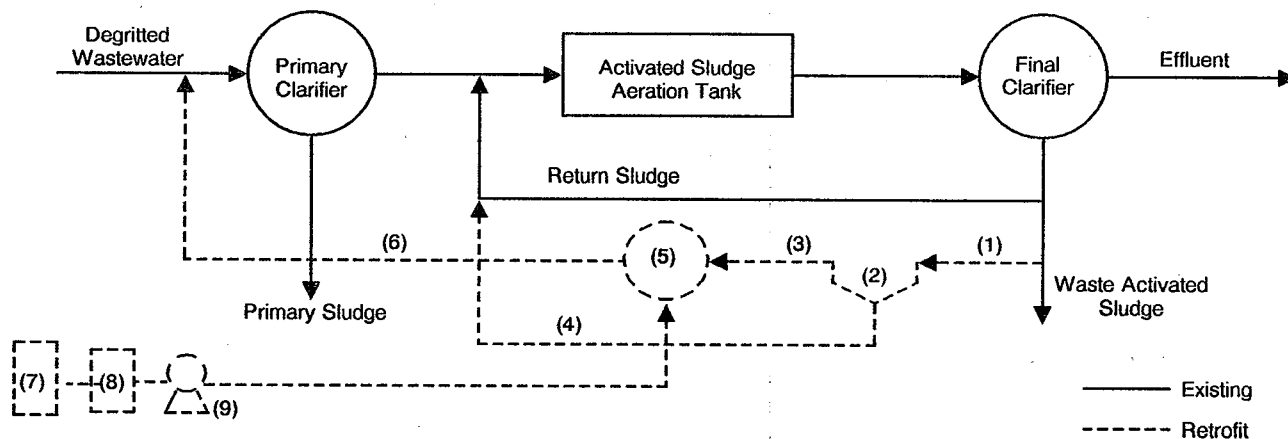
stabilization process may be too short, necessitating the use of all or a portion of the sludge reaeration volume as additional contact volume. Typically, this can be accomplished with minor modifications.

The key process feature that determines the efficiency of the PhoStrip concept is the differential phosphorus content of the return sludge solids entering and leaving the anaerobic stripper. This differential times the mass of solids passing through the stripper is equivalent to the amount of phosphorus removed from the main stream wastewater flow by cycling a portion of the return sludge through the stripper.

The other non-effluent outlet for phosphorus in a PhoStrip process is the waste activated sludge removed from the system. The phosphorus removed at a PhoStrip facility, therefore, is accomplished through a combination of stripping of return sludge and sludge wasting.

A 0.3- to 0.6-percent quantitative loss in the phosphorus content of the return sludge volatile solids entering and leaving the anaerobic stripper when the aeration tank volatile solids ranged between 3.3 and 4.6 percent phosphorus has been reported (5). A

Figure 2-11. Retrofitting plug flow, step aeration, complete mix, and pure oxygen activated sludge systems with the PhoStrip process for phosphorus removal.



Legend

- (1) Portion of return sludge going to anaerobic stripper.
- (2) Anaerobic stripper tank for leaching of phosphorus.
- (3) Stripper tank overflow.
- (4) Stripper tank underflow returned to activated sludge aeration tank.
- (5) Tank containing lime slurry to precipitate phosphorus leached from return sludge in anaerobic stripper. Lime dose (CaO) = 20-25 mg/l based on plant influent flow.
- (6) Insolubilized phosphorus returned to primary clarifier for co-settling with primary sludge.
- (7) Lime storage.
- (8) Lime slurry tank.
- (9) Pump for transfer of lime slurry to phosphorus precipitating tank.

phosphorus mass balance at one facility without primary clarification showed that 67 percent of the overall phosphorus removal occurred by operation of the stripper and lime precipitation and 33 percent was removed via the waste activated sludge.

The PhoStrip process can achieve 2- and 1-mg/l TP effluent concentrations without effluent polishing. A 0.5-mg/l TP effluent concentration is possible when effluent suspended solids concentrations are low (5). To achieve an effluent limit of 0.2 mg/l TP with PhoStrip, filtration and split dosing of chemicals should be considered.

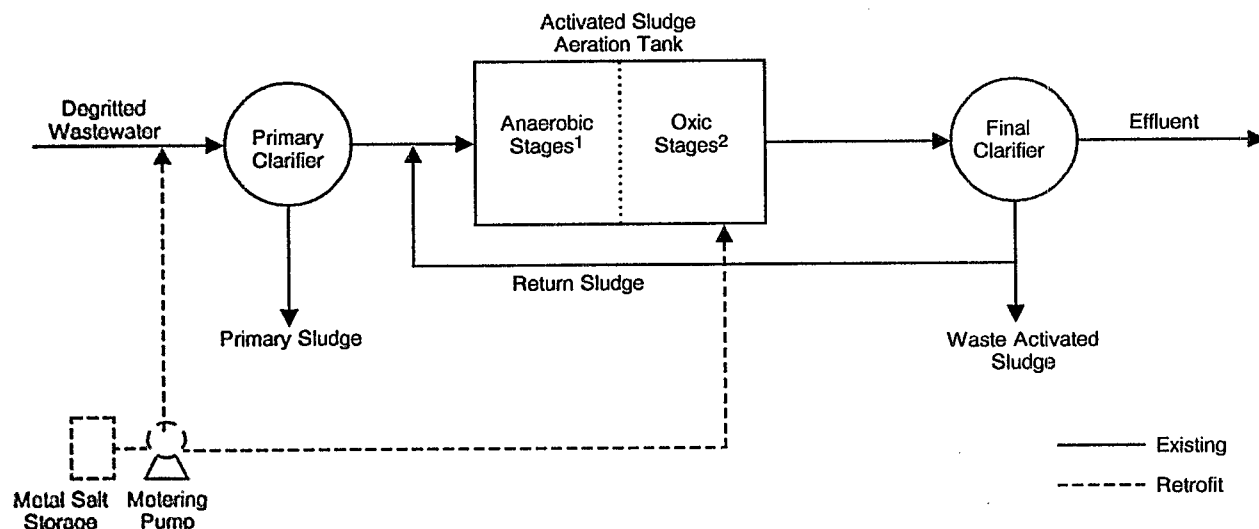
Because the PhoStrip process utilizes a sidestream chemical addition unit process, and since key operational parameters such as return sludge flow rate through the stripper, elutriation stream quality, and elutriation stream flow rate can be readily controlled, effluent phosphorus concentrations are not as sensitive to influent wastewater composition as are other biological phosphorus removal approaches.

2.3.2.2 Retrofitting Activated Sludge Systems for Biological Phosphorus Removal Using the A/O Process

A schematic of an activated sludge system retrofitted for biological phosphorus removal employing the A/O process is presented in Figure 2-12. A critical design feature of the A/O process is provision of sequential stages of two different environments for the biomass to cycle through. Therefore, if an existing complete mix activated sludge system could not be retrofitted into a staged reactor by baffling, the A/O process would not be suitable. Installation of a chemical backup feed system in an A/O process retrofit is recommended to ensure that effluent TP concentrations of 1 and 0.5 mg/l can be consistently achieved. Due to the high phosphorus content of effluent solids, consideration of effluent filtration is also recommended if effluent concentrations of less than 1 mg/l TP must be obtained.

Retrofit with the A/O process is most easily accomplished in plug flow activated sludge tanks, but can also be adapted to most of the other activated

Figure 2-12. Retrofitting plug flow, step aeration, and pure oxygen activated sludge systems with the A/O process for biological phosphorus removal.



Legend

- (1) Mixing by submersible pump or mixers. No DO is present.
 (2) Conventional aeration devices for achieving satisfactory DO levels.

| Final Effluent TP mg/l | Probable Need for Chemical Addition |
|------------------------------|--|
| 2 | None |
| 1 | Occasional |
| 0.5 | Continuous polish dose |
| 0.2 | Continuous polish dose |

sludge flow configurations. The ease of retrofit is determined by the ability to delineate and convert a portion of the tankage to an anaerobic stage. Anaerobic here is defined as the absence of all DO and oxidized nitrogen, while anoxic refers to the conditions where DO is low or absent but oxidized nitrogen is present. Space for construction of retrofit facilities is normally not required for the A/O process, and generally an A/O retrofit is more easily accomplished than a retrofit for PhoStrip.

The A/O process induces a natural selection of phosphorus-accumulating microorganisms to occur by providing alternate environments of anaerobic and aerobic (oxic) conditions. Wastewater and return sludge are mixed in the anaerobic stage. It is not necessary to cover this stage if suitable non-turbulent mixing is provided. For example, mixing can be accomplished by submersible pumps or impeller mixers in a manner that does not cause oxygen transfer from excessive exposure of liquid surface to air. The HRT of the anaerobic stage can vary from 1

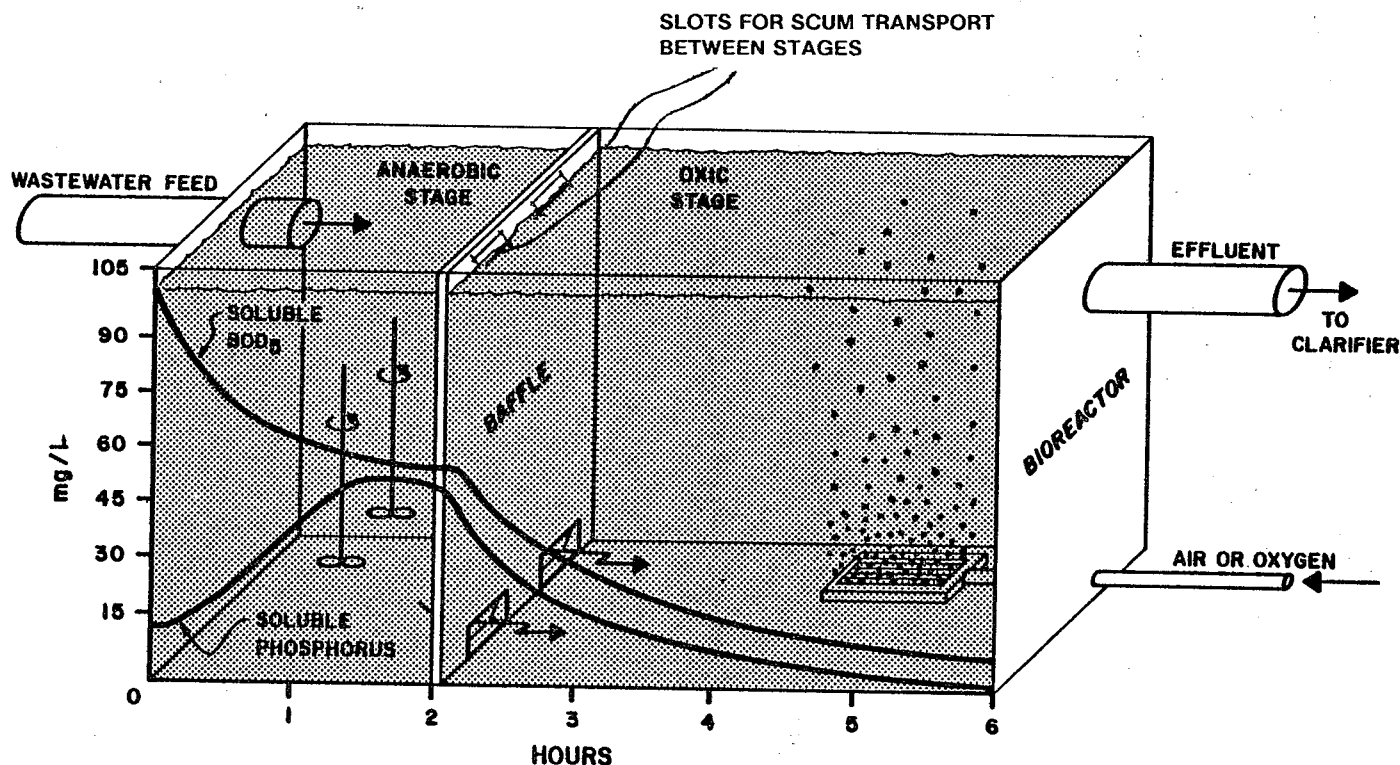
to 2 hours. During this time, soluble phosphorus is released from the biomass into the bulk liquid and, concurrently, organic matter (BOD) is sorbed from the bulk liquid and stored by the biomass.

In the subsequent oxic stage with DO levels of 1 to 2 mg/l, the stored organics are biodegraded and new cellular growth occurs coincident with transport of soluble phosphorus into intercellular granules. The HRT of the oxic stage can vary from 2 to 4 hours.

This sequence of anaerobic and aerobic events is shown in Figure 2-13. These reactions are common to all biological phosphorus removal processes. These processes must be designed and operated to accommodate the anaerobic sorption of BOD and release of soluble phosphorus, followed by aerobic cellular synthesis and phosphorus uptake.

The efficiency of phosphorus removal is affected by the ratio of soluble BOD₅ (SBOD) to SP in the system influent. A ratio of influent SBOD to SP of 10

Figure 2-13. Conceptual sequence of reactions in the A/O process.



to 15 is necessary to achieve a 1-mg/l TP effluent concentration with main stream biological phosphorus removal processes such as A/O (5). To achieve a TP effluent concentration of 0.5 mg/l, the ratio would have to be about 20 to 25. The effect of internal recycle streams, such as digester supernatant, sludge thickener overflow, and filter press or vacuum filter filtrates on the influent SBOD-to-SP ratio must also be considered.

An evaluation of four full-scale biological phosphorus removal facilities (5) revealed that none of the facilities practiced anaerobic digestion of sludges. Chemical treatment of some sludge handling recycle streams was necessary to prevent previously removed phosphorus from re-entering the secondary system and adversely affecting attainment of effluent phosphorus limitations.

Final clarifier design and operation is important for biological phosphorus removal processes. A long sludge blanket residence time in a clarifier can lead to development of anaerobic conditions in the blanket and cause leaching of soluble phosphorus from the phosphorus stored in the biomass granules. Provisions for rapid sludge removal from the clarifier

and reserve return sludge pumping capacity are recommended where biological phosphorus removal is contemplated.

2.4 References

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Chapter 3

Summary of Existing Phosphorus Removal Performance Data

3.1 Introduction

The chemical phosphorus removal performance data presented in the first part of this chapter represent a collection of information from 76 wastewater treatment plants located in the Great Lakes Drainage Basin, including the states of Michigan, Ohio, Indiana, Wisconsin, and Minnesota, as well as the Province of Ontario, Canada. Data from a limited number of plants in the CBDB are included for comparison: two from Virginia, two from Maryland, and two from Pennsylvania. Information from the plants in the Great Lakes area was obtained from various sources. These sources include the published literature and direct contacts in the past and during preparation of this manual. This data base includes treatment process sequence and performance information, methods of phosphorus removal including chemical dosages and application points, and costs for chemical usage and overall sludge disposal.

Biological phosphorus removal is relatively new, and only a few full-scale plants are currently in operation that employ this technology. Performance of the PhoStrip and A/O processes is discussed in the last part of this chapter.

3.2 Chemical Phosphorus Removal

Performance data for 82 plants that chemically remove phosphorus are summarized in Tables 3-1 through 3-11. The plants are grouped together by the type of secondary treatment process employed as follows:

- 15 Plug Flow Activated Sludge Systems
- 15 Complete Mix Activated Sludge Systems
- 11 Contact Stabilization Activated Sludge Systems
- 2 Pure Oxygen Activated Sludge Systems
- 5 Step Aeration Activated Sludge Systems
- 8 Extended Aeration Activated Sludge Systems
- 1 Two-Stage Nitrification Activated Sludge System
- 4 High-Rate Trickling Filters
- 10 Standard-Rate Trickling Filters
- 9 RBCs
- 2 Oxidation Ditches

Influent TP concentrations ranged from 1.2 to 11.6 mg/l, reflecting the impacts of inflow/infiltration and industrial inputs, as well as other site-specific conditions.

Chemicals used included ferric chloride, ferrous chloride, ferrous sulfate, alum, sodium aluminate, and lime, as well as a variety of polymers. The effluent TP permit limits range from 0.2 to 2.0 mg/l. For most of these plants the limit is 1.0 mg/l. Actual effluent TP concentrations varied between 0.2 and 2.7 mg/l, with only eight plants producing average effluent TP concentrations above 1.0 mg/l.

Chemicals were applied at most plants at a single location within the treatment system except for a few that practiced split dosing at two locations. The principal application point was ahead of the primary clarifier for 42 percent of the plants, in the secondary biological process for 39 percent of the plants, and ahead of the secondary clarifier for 19 percent of the plants. It should be noted, however, that many of these plants do have the flexibility to split feed at multiple locations. Polymer was used in conjunction with the metal salts in about half of the plants.

Some form of tertiary suspended solids removal was employed at 29 percent of the plants.

3.2.1 Effect of Application Point on Chemical Use

A review of the plants in Tables 3-1 through 3-11 was made of chemical dosages for various points of application as expressed by the ratios of metal salts to influent TP concentrations on a weight basis. A summary is provided in Table 3-12 for alum, ferric chloride, and ferrous chloride. Data for other chemicals are not included due to the limited data base.

The general trend is that less chemicals are used when dosed to the secondary process as compared with the primary process. For those plants that use polymer, the alum dose does not vary widely with application point but a definite trend to lower doses was revealed for ferric chloride the later it was applied in the treatment sequence. A trend was not evident for ferrous chloride.

Table 3-1. Phosphorus Removal Performance and Cost Data for Existing Plug Flow Activated Sludge Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inf. TP | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Sludge O&M Cost \$/lb TP Remvd | Annual Chem. Sludge O&M Cost \$/lb TP Remvd |
|-------------------|--------------------|---------------------|--|--|--------------------------------------|---|-----------------|-----------------|-------------------|--|------------------------------------|--|------------------------------------|--|--|
| | | | | | | | | | | | | | | | |
| Waupaca, WI | 1.25 | 0.58 | Alum | Sec. Clarifier | 24.6 | 3.25 | 7.56 | 0.86 | 11,830 | - | 23,800 | 12,500 | - | 2.01 | 1.06 |
| Clintonville, WI | 1.0 | 0.72 | Ferrous Sulfate | Sec. Clarifier | 5.3 | 1.47 | 3.6 | 0.75 | 6,246 | - | 2,000 | 7,500 | - | 0.32 | 1.20 |
| Grand Ledge, MI | 1.5 | 0.81 | Ferrous Chloride | Sec. Biol. Process | 5.8 | 1.24 | 4.5 | 0.7 | 9,370 | - | 1,500 | 8,300 | - | 0.16 | 0.89 |
| Mason, MI | 1.5 | 1.31 | Ferric Chloride Chemco P504 | Prim. Clarifier Prim. Clarifier | 9.1 0.05 | 1.4 | 6.5 | 0.88 | 22,451 | - | 3,900 | 9,100 | - | 0.17 | 0.41 |
| Big Rapids, MI | 2.4 | 1.55 | Ferrous Chloride Polymer | Sec. Clarifier Sec. Clarifier | 8.7 0.4 | 1.74 | 5.0 | 1.1 | 18,400 | - | 26,300 | 23,400 | - | 1.43 | 1.27 |
| Flushing, MI | 1.15 | 1.58 | Ferric Chloride SecoDyne 450 | Sec. Biol. Process Sec. Biol. Process | 5.3 0.15 | 1.56 | 3.4 | 0.48 | 14,044 | - | 8,000 | 1,900 | - | 0.43 | 0.14 |
| Shawano, MI | 3.0 | 1.7 | Ferrous Chloride Calgon WT3000 | Sec. Biol. Process Sec. Clarifier | 7.7 0.1 | 1.64 | 4.7 | 0.64 | 21,010 | - | 6,400 | 6,300 | - | 0.30 | 0.30 |
| Goshen, IN | 5.0 | 3.9 | Ferrous Chloride | Sec. Biol. Process | 48.5 | 6.06 | 8.0 | 0.8 | 85,478 | - | 73,300 | 21,700 | - | 0.86 | 0.26 |
| Bowling Green, OH | 8.0 | 5.3 | Ferrous Chloride Anionic Percol 763 | Sec. Clarifier Sec. Clarifier | 5.2 | 0.62 | 8.4 | 0.75 | 123,420 | - | 12,000 | 16,300 | - | 0.10 | 0.13 |
| Appleton, WI | 16.5 | 13.8 | Ferrous Chloride | Plant Influent | 16.8 | 1.6 | 10.5 | 0.8 | 407,480 | - | 60,000 | 185,000 | - | 0.15 | 0.45 |
| East Chicago, IN | 20.0 | 14.4 | No Coagulant Arco IPC6615 | Sec. Clarifier | 1.0 | 3.99 | 1.45 | 0.3 | 50,410 | - | 33,400 | 87,500 | - | 0.66 | 1.74 |
| East Chicago, IN | 20.0 | 15.8 | Alum Arco IPC6615 | Sec. Clarifier Sec. Clarifier | 7.7 1.0 | 3.99 | 1.93 | 0.38 | 74,550 | - | 92,500 | 87,500 | - | 1.24 | 1.17 |
| Kenosha, WI | 28.0 | 23.9 | Ferrous Sulfate | Prim. Clarifier | 5.35 | 1.43 | 3.74 | 0.36 | 245,900 | - | 10,000 | 106,800 | - | 0.04 | 0.43 |
| South Bend, IN | 48.0 | 38.3 | Ferric Chloride Nalco 8733 | Sec. Biol. Process Tert. Clarifier | 7.9 0.2 | 3.46 | 2.28 | 0.52 | 205,200 | - | 105,300 | 58,500 | - | 0.51 | 0.29 |
| Toledo, OH | 102.0 | 82.0 | Ferrous Sulfate Hercules 1123 (gel) | Prim. Clarifier Prim. Clarifier | 3.6 | 1.3 | 2.76 | 0.35 | 601,575 | - | 78,300 | 164,300 | - | 0.13 | 0.27 |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-2. Phosphorus Removal Performance and Cost Data for Existing Complete Mix Activated Sludge Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inf. TP | | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$/lb TP Remvd | Annual Chem. Sludge O&M Cost \$/lb TP Remvd |
|-------------------|--------------------|---------------------|---------------------------------------|--|--------------------------------------|--|------|-----------------|-----------------|-------------------|--|------------------------------------|--|--|
| | | | | | | | | | | | | | | |
| Charlevoix, MI | 1.0 | 0.22 | Ferrous Chloride Axchem | Sec. Biol. Process Sec. Clarifier | 48.5 0.8 | 8.66 | 5.6 | 0.9 | 3,150 | 21,000 | 8,500 | 5,000 | 6.70 | 1.59 |
| Eaton Rapids, MI | 1.2 | 0.81 | Ferrous Chloride | Sec. Biol. Process | 11.1 | 2.52 | 4.4 | 0.6 | 9,370 | - | 3,600 | 6,000 | - | 0.38 |
| Thiensville, WI | 0.24 | 0.88 | Alum Nalco 7763 | Sec. Biol. Process Sec. Biol. Process | 9.3 0.82 | 2.46 | 3.78 | 0.29 | 9,350 | - | 14,700 | 3,800 | - | 0.41 |
| Two Harbors, MN | 1.2 | 0.9 | Alum | Sec. Clarifier | 9.6 | 1.6 | 6.0 | 0.25 | 15,750 | - | 8,700 | 4,500 | - | 0.29 |
| Hastings, MI | 1.0 | 1.14 | Lime | Prim. Clarifier | 74.0 | 11.8 | 6.3 | 0.9 | 18,740 | - | 15,200 | 2,700 | - | 0.14 |
| Escanaba, MI | 2.2 | 2.0 | Ferric Chloride Hercules 847 | Prim. Clarifier Prim. Clarifier | 4.7 0.35 | 1.04 | 4.5 | 0.82 | 22,292 | - | 14,500 | 3,800 | - | 0.17 |
| Cedarburg, WI | 3.0 | 2.0 | Ferrous Sulfate Nalco 7763 | Sec. Clarifier Sec. Clarifier | 9.9 | 2.99 | 3.31 | 0.67 | 16,073 | - | 11,200 | 7,200 | - | 0.45 |
| Crown Point, IN | 3.6 | 2.3 | Ferrous Chloride Dow Seperan AP-30 | Sec. Clarifier Sec. Clarifier | 11.0 0.94 | 2.0 | 5.5 | 0.7 | 33,610 | - | 34,400 | 22,500 | - | 0.67 |
| Virginia, MN | 2.0 | 2.78 | Alum | Sec. Clarifier | 3.2 | 0.81 | 3.93 | 0.73 | 27,080 | - | 16,800 | 11,000 | - | 0.41 |
| Niles, MI | 5.8 | 3.2 | Ferrous Chloride | Sec. Biol. Process | 10.9 | 2.66 | 4.1 | 0.7 | 32,706 | 16,700 | 7,900 | 16,800 | 0.59 | 0.51 |
| Alpena, MI | 5.5 | 3.39 | Ferrous Chloride Nalco 7763 | Sec. Biol. Process Sec. Clarifier | 15.1 0.22 | 4.42 | 3.42 | 0.67 | 28,378 | - | 18,900 | 16,000 | - | 0.58 |
| Grandville, MI | 3.2 | 3.6 | Ferric Chloride WT 80 | Sec. Biol. Process Sec. Clarifier | 6.6 0.18 | 1.06 | 6.2 | 0.92 | 35,378 | - | 11,000 | 11,300 | - | 0.32 |
| Traverse City, MI | 8.5 | 4.1 | Ferric Chloride Axchem AP 108 | Prim. Clarifier Prim. Clarifier | 6.8 0.2 | 1.89 | 3.6 | 1.3 | 28,706 | - | 28,000 | 12,100 | - | 0.42 |
| Sheboygan, WI | 18.4 | 12.3 | Ferric Chloride | Sec. Clarifier | 10.2 | 1.6 | 6.38 | 0.9 | 205,188 | - | 34,000 | 52,000 | - | 0.26 |
| Lima, OH | 18.5 | 13.4 | Ferrous Chloride SecoDyne 452 | Prim. Clarifier Prim. Clarifier | 13.2 0.07 | 3.38 | 3.9 | 0.5 | 138,690 | - | 60,000 | 15,000 | - | 0.11 |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-5. Phosphorus Removal Performance and Cost Data for Existing Step Aeration Activated Sludge Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to | | Inf. TP | mg/l | Eff. TP | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost | | Annual Chem. Sludge O&M Cost | | Annual Chem. Equip. Capital Cost | | Annual Chem. Sludge O&M Cost | |
|------------------|--------------------|---------------------|----------------------------------|----------------------------------|--------------------------------------|------------------------------------|------|---------|-----------|---------|-------------------|----------------------------------|----|------------------------------|------|----------------------------------|----|------------------------------|------|
| | | | | | | Inf. TP | mg/l | | | | | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ |
| Avon Lake, OH | 6.5 | 3.9 | Ferrous Chloride | Sec. Biol. Process | 13.9 | 4.6 | 3.02 | 0.52 | 29,680 | - | 17,000 | 5,000 | - | 0.57 | 0.17 | - | - | 0.57 | 0.17 |
| East Lansing, MI | 18.8 | 11.3 | Ferrous Chloride SecoDyne 450 | Sec. Clarifier Sec. Clarifier | 5.9 0.05 | 1.11 | 5.3 | 0.9 | 139,785 | - | 22,500 | 8,300 | - | 0.16 | 0.06 | - | - | 0.16 | 0.06 |
| Elkhart, IN | 20.0 | 15.9 | Ferrous Sulfate | Sec. Clarifier | 1.6 | 0.63 | 2.56 | 0.83 | 83,730 | - | 60,000 | 50,000 | - | 0.72 | 0.60 | - | - | 0.72 | 0.60 |
| Fort Wayne, IN | 60.0 | 45.1 | Ferrous Chloride | Sec. Biol. Process | 4.3 | 0.54 | 7.9 | 0.67 | 992,600 | - | 81,300 | 72,500 | - | 0.08 | 0.07 | - | - | 0.08 | 0.07 |
| Oak Creek, WI | 120.0 | 90.0 | Ferrous Sulfate | Sec. Biol. Process | 4.4 | 0.96 | 4.6 | 0.54 | 1,112,314 | - | 121,000 | 625,000 | - | 0.11 | 0.56 | - | - | 0.11 | 0.56 |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-6. Phosphorus Removal Performance and Cost Data for Existing Extended Aeration Activated Sludge Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to | | Inf. TP | mg/l | Eff. TP | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost | | Annual Chem. Sludge O&M Cost | | Annual Chem. Equip. Capital Cost | | Annual Chem. Sludge O&M Cost | |
|------------------|--------------------|---------------------|--------------------------------------|--|--------------------------------------|------------------------------------|------|---------|--------|---------|-------------------|----------------------------------|----|------------------------------|------|----------------------------------|----|------------------------------|------|
| | | | | | | Inf. TP | mg/l | | | | | \$ | \$ | \$ | \$ | \$ | \$ | \$ | \$ |
| Upper Allen, PA | 0.48 | 0.32 | Alum Polymer | Sec. Biol. Process Sec. Biol. Process | 8.2 0.37 | 0.92 | 8.9 | 2.0 | 52,309 | - | 10,262 | 1,855 | - | 0.20 | 0.04 | - | - | 0.20 | 0.04 |
| Aurora, MN | 0.5 | 0.44 | Alum | Prim. Clarifier | 16.9 | 5.83 | 2.9 | 0.76 | 2,866 | - | 2,000 | 500 | - | 0.70 | 0.17 | - | - | 0.70 | 0.17 |
| Corunna, Ontario | 1.0 | 0.53 | Alum | Sec. Clarifier | 5.0 | 0.65 | 7.74 | 0.36 | 16,925 | - | 11,300 | 4,000 | - | 0.67 | 0.24 | - | - | 0.67 | 0.24 |
| Saukville, WI | 2.0 | 0.64 | Ferrous Chloride | Prim. Clarifier | 10.3 | 1.61 | 6.4 | 0.59 | 11,326 | - | 3,500 | 12,500 | - | 0.31 | 1.10 | - | - | 0.31 | 1.10 |
| Sudbury, Ontario | 3.01 | 1.48 | Ferric/Ferrous Chloride | Sec. Biol. Process | 13.91 | 2.64 | 5.26 | 0.71 | 20,470 | - | 24,000 | 10,000 | - | 1.17 | 0.49 | - | - | 1.17 | 0.49 |
| Plymouth, WI | 1.65 | 1.52 | Ferrous Chloride | Sec. Biol. Process | 7.7 | 1.15 | 6.7 | 0.77 | 27,438 | - | 8,700 | 6,300 | - | 0.32 | 0.23 | - | - | 0.32 | 0.23 |
| Trenton, Ontario | 3.5 | 2.53 | Ferrous Chloride | Sec. Biol. Process | 2.56 | 0.42 | 6.1 | 0.65 | 11,095 | - | 25,300 | 45,000 | - | 2.28 | 4.06 | - | - | 2.28 | 4.06 |
| Seneca, MD | 5.0 | 4.0 | Sodium Aluminate Cationic Polymer | Plant Influent Sec. Clarifier | 4.3 2.4 | 0.61 | 7.1 | 1.6 | 73,667 | - | 102,768 | 62,234 | - | 1.40 | 0.84 | - | - | 1.40 | 0.84 |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-7. Phosphorus Removal Performance and Cost Data for Existing Two-Stage Nitrification Activated Sludge Plant

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inl. TP | | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ |
|----------------|--------------------|---------------------|-----------------------|----------------------------------|--------------------------------------|--|-------------------|-----------------|-------------------|--|------------------------------------|--|------------------------------------|--|------------------------------------|
| | | | | | | Inl. TP mg/l | TP Remvd lb/yr | | | | | | | | |
| Piscataway, MD | 30.0 | 14.5 | Alum Nalco Polymer | Sec. Clarifier Sec. Clarifier | 8.8 3.8 | 1.44 | 6.13 | 0.2 | 261,747 | - | 316,940 | 323,050 | - | 1.21 | 1.24 |

1 Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

2 Weight basis.

Table 3-8. Phosphorus Removal Performance and Cost Data for Existing High-Rate Trickling Filter Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio-2 of Metal Ion to Inf. TP | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost | | Annual Sludge O&M Cost | | |
|------------------|--------------------|---------------------|---------------------------|---------------------|--------------------------------------|--|-----------------|-----------------|-------------------|----------------------------------|--------|------------------------|----------------|------|
| | | | | | | | | | | \$ | \$ | \$/lb TP Remvd | \$/lb TP Remvd | |
| Oconto Falls, WI | 0.5 | 0.37 | Ferric Chloride | Sec. Biol. Process | 8.81 | 2.4 | 3.67 | 0.45 | 3,825 | - | 5,000 | 8,400 | 1.38 | 2.32 |
| Geneva, OH | 2.0 | 1.02 | Alum | Sec. Clarifier | 12.1 | 4.03 | 3.0 | 0.4 | 8,073 | - | 34,400 | 4,500 | 4.26 | 0.56 |
| Coldwater, MI | 2.3 | 1.96 | Ferric Chloride Polymer | Sec. Clarifier | 8.3 | 2.02 | 4.1 | 0.88 | 19,200 | 13,500 | 22,000 | 30,000 | 1.15 | 1.56 |
| Kendalville, IN | 2.68 | 2.0 | Ferric Chloride Mifloc 80 | Sec. Biol. Process | 14.7 | 4.05 | 3.63 | 0.35 | 19,970 | - | 13,100 | 7,000 | 0.86 | 0.35 |

1 Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

2 Weight basis.

Table 3-9. Phosphorus Removal Performance and Cost Data for Existing Standard-Rate Trickling Filter Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inf. TP | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. O&M Cost \$ | Annual Chem. Equip. Capital Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Sludge O&M Cost \$/lb TP Remvd |
|--------------------------|--------------------|---------------------|----------------------------------|--------------------------------------|--------------------------------------|---|-----------------|-----------------|-------------------|--|-----------------------------|--|------------------------------------|--|
| | | | | | | | | | | | | | | |
| Mackinac Island, MI | 1.5 | 0.38 | Alum Nalco 7763 or 7768 | Sec. Biol. Process Sec. Clarifier | 8.5 0.7 | 1.52 | 5.6 | 1.7 | 3,253 | - | 10,000 | 1,300 | - | 3.07 |
| Brighton, MI | 0.8 | 0.72 | Ferric Chloride Polymer | Prim. Clarifier Prim. Clarifier | 32.7 0.3 | 7.98 | 4.1 | 0.3 | 8,329 | 7,500 | 31,200 | 10,100 | 0.90 | 3.75 |
| Durand, MI | 0.8 | 0.73 | Ferric Chloride | Prim. Clarifier | 11.2 | 2.2 | 5.1 | 0.83 | 9,489 | - | 8,500 | 8,000 | - | 0.90 |
| Willard, OH | 1.35 | 1.26 | Alum Hercules Polymer | Prim. Clarifier Prim. Clarifier | 6.3 0.14 | 1.21 | 5.2 | 0.82 | 16,800 | - | 16,500 | 37,500 | - | 0.98 |
| Coloma, MI | 2.2 | 1.4 | Ferrous Chloride | Prim. Clarifier | 4.1 | 1.71 | 2.4 | 0.65 | 7,245 | - | 4,000 | 10,000 | - | 0.55 |
| Saline, MI | 1.9 | 1.45 | Ferric Chloride Chemco P-504 | Prim. Clarifier Prim. Clarifier | 18.4 0.83 | 3.17 | 5.8 | 2.71 | 13,594 | - | 30,000 | 7,500 | - | 2.21 |
| Saginaw, MI | 4.4 | 1.7 | Ferric Chloride Hercufloc 831 | Prim. Clarifier Prim. Clarifier | 9.6 0.1 | 0.99 | 9.7 | 1.5 | 42,435 | - | 21,000 | 1,700 | - | 0.49 |
| Elizabethtown, PA | 3.0 | 1.72 | Alum Anionic Polymer | Sec. Clarifier Sec. Clarifier | 12.8 0.4 | 2.51 | 5.1 | 1.7 | 17,801 | - | 25,751 | 4,394 | - | 1.45 |
| Little Hunting Creek, VA | 4.5 | 3.81 | Ferric Chloride Polymer | Prim. Clarifier Prim. Clarifier | 42.5 2.8 | 4.57 | 9.3 | 0.2 | 105,541 | - | 174,303 | 488,226 | - | 1.65 |
| Bay City, MI | 20.0 | 8.8 | Ferric Chloride Axchem 115 | Sec. Clarifier Sec. Clarifier | 9.5 0.29 | 2.07 | 4.6 | 0.5 | 109,830 | - | 80,000 | 200,000 | - | 0.73 |
| | | | | | | | | | | | | | | 1.82 |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.² Weight basis.

Table 3-10. Phosphorus Removal Performance and Cost Data for Existing RBC Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inf. TP | | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. O&M Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$/lb TP Remvd | Annual Chem. O&M Cost \$/lb TP Remvd | Annual Chem. Sludge O&M Cost \$/lb TP Remvd |
|-------------------|--------------------|---------------------|-----------------------------------|------------------------------------|--------------------------------------|--|------|-----------------|-----------------|-------------------|--|-----------------------------|------------------------------------|--|---|--|
| | | | | | | Inf. TP | TP | | | | | | | | | |
| Hartford, MI | 0.35 | 0.2 | Ferrous Chloride Hava Floe | Prim. Clarifier Prim. Clarifier | 13.0 0.6 | 3.25 | 4.0 | 0.75 | 1,977 | - | 3,000 | 2,500 | - | 1.52 | 1.26 | |
| Dexter, MI | 0.58 | 0.21 | Ferric Chloride Mifloc 80 | Sec. Clarifier Sec. Clarifier | 10.2 0.5 | 2.0 | 5.11 | 0.46 | 2,973 | - | 6,000 | 4,500 | - | 2.02 | 1.51 | |
| Chesaning, MI | 0.58 | 0.52 | Ferric Chloride Axchem AF 100 | Prim. Clarifier Prim. Clarifier | 9.0 0.4 | 3.46 | 2.6 | 0.6 | 3,166 | - | 7,300 | 500 | - | 2.31 | 0.16 | |
| Plainwell, MI | 1.3 | 0.53 | Ferric Chloride Axchem Polymer | Prim. Clarifier Prim. Clarifier | 6.7 0.38 | 0.84 | 8.0 | 0.8 | 11,616 | - | 19,600 | 6,200 | - | 1.69 | 0.53 | |
| Charlotte, MI | 1.2 | 0.71 | Ferrous Chloride Axchem AF 100 | Prim. Clarifier Sec. Clarifier | 13.7 0.18 | 2.45 | 5.6 | 0.68 | 10,694 | - | 4,400 | 5,000 | - | 0.41 | 0.47 | |
| Romeo, MI | 1.6 | 0.86 | Alum Hercules 847 | Prim. Clarifier Prim. Clarifier | 7.1 0.77 | 2.4 | 2.96 | 0.46 | 6,545 | - | 12,900 | 6,500 | - | 1.97 | 0.99 | |
| Negaunee, MI | 1.6 | 0.88 | Ferric Chloride Nalco 7768 | Prim. Clarifier Prim. Clarifier | 7.5 1.0 | 3.75 | 2.0 | 0.95 | 2,993 | - | 9,000 | 200 | - | 3.11 | 0.07 | |
| New Baltimore, MI | 1.75 | 1.33 | Ferric Chloride Magnifloc 6120 | Prim. Clarifier Prim. Clarifier | 6.6 0.93 | 5.16 | 1.28 | 0.24 | 4,211 | - | 21,000 | 13,500 | - | 4.99 | 3.21 | |
| St. Johns, MI | 1.9 | 1.66 | Ferrous Chloride Chemco P-504 | Prim. Clarifier Prim. Clarifier | 5.01 0.04 | 1.38 | 3.7 | 0.5 | 16,170 | - | 7,100 | 1,300 | - | 10.44 | 0.08 | |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-11. Phosphorus Removal Performance and Cost Data for Existing Oxidation Ditch Plants

| Plant | Design Flow mgd | Average Flow mgd | Chemicals | Chemical Feed Point | Chemical Dosage ¹ mg/l | Ratio ² of Metal Ion to Inf. TP | | Inf. TP mg/l | Eff. TP mg/l | TP Remvd lb/yr | Annual Chem. Equip. Capital Cost \$ | Annual Chem. O&M Cost \$ | Annual Chem. Sludge O&M Cost \$ | Annual Chem. Equip. Capital Cost \$/lb TP Remvd | Annual Chem. O&M Cost \$/lb TP Remvd | Annual Chem. Sludge O&M Cost \$/lb TP Remvd |
|-------------|--------------------|---------------------|------------------|---------------------|--------------------------------------|--|-----|-----------------|-----------------|-------------------|--|-----------------------------|------------------------------------|--|---|--|
| | | | | | | Inf. TP | TP | | | | | | | | | |
| Lapeer, MI | 1.85 | 1.89 | Ferric Chloride | Sec. Clarifier | 4.65 | 0.88 | 5.3 | 1.2 | 23,590 | 12,600 | 10,800 | 50,000 | 0.53 | 0.46 | 2.12 | |
| Portage, IN | 3.5 | 2.23 | Ferrous Chloride | Sec. Clarifier | 9.9 | 1.65 | 6.0 | 1.5 | 30,550 | - | 11,500 | 3,000 | - | 0.38 | 0.10 | |

¹ Precipitant, mg/l as metal ion; polymer, mg/l of chemical.

² Weight basis.

Table 3-12. Metal Ion-to-Influent TP Ratio (Weight Basis) for Various Points of Application

| | Point of Application* | | |
|------------------|-----------------------|------------------------------|---------------------|
| | Primary Clarifier | Secondary Biological Process | Secondary Clarifier |
| With Polymer | | | |
| Alum | 1.81 (2) | 1.63 (3) | 2.28 (4) |
| Ferric Chloride | 3.95 (11) | 3.02 (3) | 1.88 (4) |
| Ferrous Chloride | 2.26 (5) | 3.94 (4) | 1.62 (3) |
| Without Polymer | | | |
| Alum | 4.01 (2) | 1.00 (1) | 2.07 (5) |
| Ferric Chloride | 2.20 (1) | 2.40 (1) | 1.24 (2) |
| Ferrous Chloride | 1.77 (4) | 2.35 (9) | 2.13 (6) |

* Number of plants are indicated in parentheses.

Impacts of polymer addition on the metal salt dosage were not shown to be consistent. In some plants, the metal salt dosage was reduced when polymer was used. In other plants, however, the metal salt dosage increased. This is an apparent reflection of site-specific conditions such as background water chemistry, plant layout for mixing and flocculation, settling and control, and plant management operating strategies.

The above ratios should be examined with caution since they are based on influent concentration. Removal of phosphorus does occur in both the primary clarifier and the biological process; therefore, ratios calculated on an available phosphorus basis would be somewhat higher when chemicals are dosed to the secondary biological process or secondary clarifier.

3.2.2 Effect of Effluent Limit on Chemical Use

The relationships between metal-to-influent TP ratio on a weight basis and effluent phosphorus concentration for aluminum and iron salts for the plants summarized in Tables 3-1 through 3-11 are presented in Figures 3-1 and 3-2, respectively. Data for those plants with tertiary treatment are distinguished from those with secondary treatment, and chemical dosage ranges recommended for use in Chapter 2 are included.

Although some plants achieved low effluent phosphorus concentrations without tertiary treatment, higher chemical dosages were generally required to attain the same results. In both cases, the chemical dosage increased as the required effluent TP concentration decreases. Iron-to-influent TP weight ratios as high as 10 and aluminum-to-influent TP weight ratios over 4 were needed to achieve effluent TP concentrations of 0.2 mg/l, while corresponding ratios to achieve an effluent TP concentration of 1.0 mg/l were down to 4 for iron and 3 for aluminum.

In Table 3-13, expanded performance data for specific plants in the CBDB are shown. Five plants, four activated sludge and one trickling filter, used aluminum salts for two different effluent TP limits: Upper Allen, PA; Seneca, MD; and Elizabethtown, PA, with 2.0 mg/l, and Dale City, VA, and Piscataway, MD, with 0.2 mg/l. The corresponding Al^{3+} /influent TP feed rates (weight basis) were 0.85, 0.8, 2.5, 2.34, and 1.78, respectively. The dosage for the four activated sludge plants was two to three times more to reach the 0.2-mg/l TP effluent limit than the 2.0-mg/l limit. Two trickling filter plants used ferric chloride: Elizabethtown, PA, with an effluent limit of 2.0 mg/l TP and Little Hunting Creek, VA, with an effluent limit of 0.2 mg/l TP. The corresponding Fe^{3+} /influent TP feed rates (weight basis) were 1.39 and 4.69, respectively. Again, the dosage was over three times higher to achieve the lower effluent limit of 0.2 mg/l TP. The Elizabethtown plant added alum from July 1985 through January 1986, then switched to ferric chloride in February 1986. Data from one CBDB plant, Damascus, MD, that does not remove phosphorus chemically are included in Table 3-13 to provide baseline information.

Polymer dosage varied from none at Dale City and Elizabethtown to 2.8 mg/l at Little Hunting Creek and 3.8 mg/l at Piscataway.

3.2.3 Effect of Chemical Phosphorus Removal on Sludge Generation

Sludge generation resulting from chemical phosphorus removal was evaluated for selected plants in the Chesapeake Bay and the Great Lakes Drainage Basins as shown in Tables 3-13 and 3-14, respectively. Major contributing factors are the effluent phosphorus limit as described earlier, dosage rate, and sludge handling methods at the plant.

The impact on total sludge production when phosphorus removal chemicals are added to secondary treatment plants is depicted in Figure 3-3. Total sludge production is represented as multiples of mass of raw influent TSS and is plotted against effluent TP concentration. A marked increase in sludge production is evident at low effluent TP concentrations of 0.2 mg/l compared to 0.7 to 2.0 mg/l. The data in Figure 3-3 suggest that the quantity of sludge produced will be 2 to 3 times higher at very low effluent TP concentrations, such as 0.2 mg/l, than at more moderate effluent TP concentrations. The exact quantity further depends on the amount of chemicals added for sludge handling.

The type of biological treatment process also impacts the sludge quantity. The least sludge generation is expected from an extended aeration process, and the most is expected from a high-rate activated sludge process.

Figure 3-1. Alum-to-Influent TP ratio vs. effluent TP concentration.

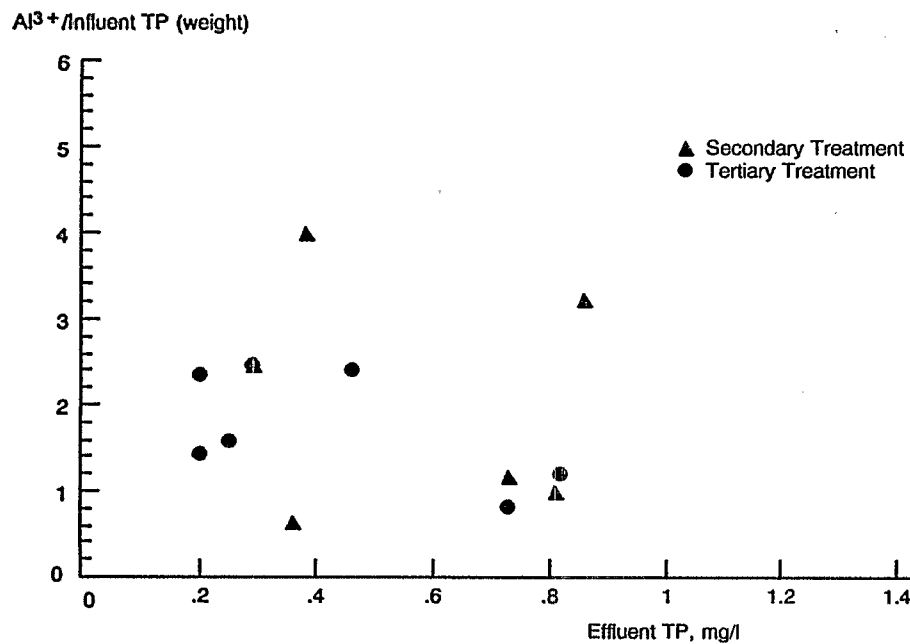


Figure 3-2. Ferric iron-to-Influent TP ratio vs. effluent TP concentration.

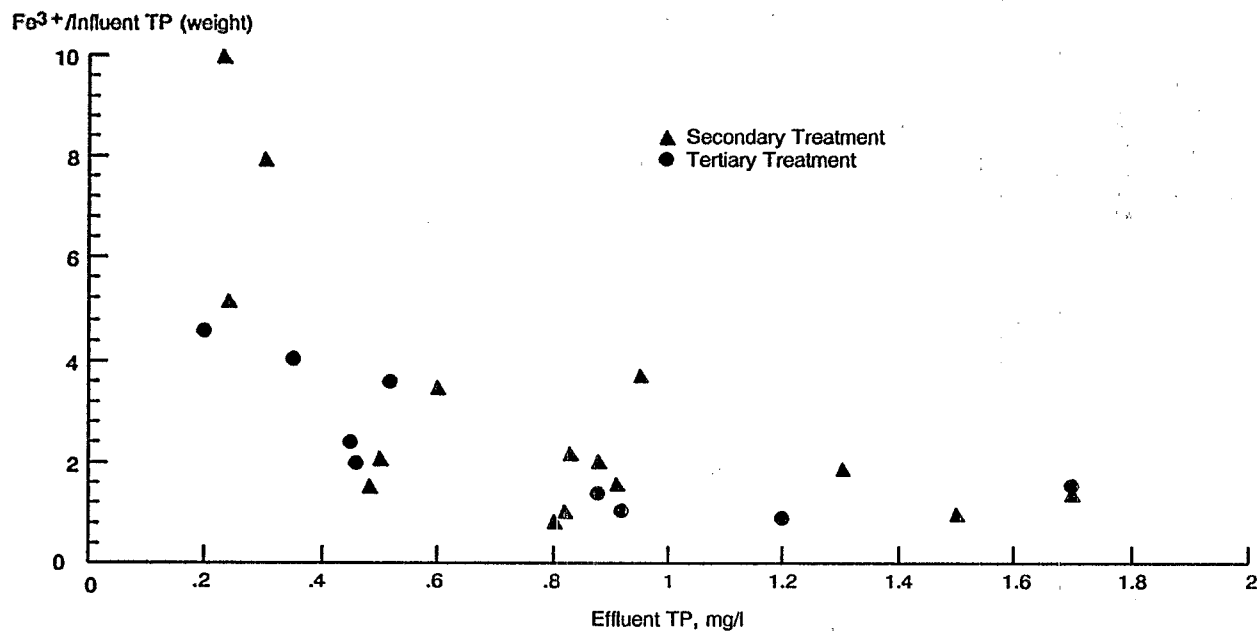


Table 3-13. Summary Information on Selected POTWs in the CBD8

| | Plant | | | | | |
|--|----------------------|-------------------------------|--------------------------------|--|---|---|
| | Damascus, MD | Upper Allen, PA | Seneca, MD | Piscataway, MD | Little Hunting Creek, VA | Elizabethtown, PA |
| Biological Process | | | | | | |
| Flow, mgd | Ext. Aeration 0.4 | Ext. Aeration 0.33 | Ext. Aeration 4.4 | Cont. Stab. 2.0 | Trickling Filter 3.8 | 2-Stage TF 2.3 |
| Influent TBOD, mg/l | 239 | 198 | 124 | 202 | 175 | 133 |
| Effluent TBOD, mg/l | 4 | 7 | 2 | 3.5 | 11 | 7 |
| Influent TSS, mg/l | 231 | 332 | 101 | 145 | 177 | 223 |
| Effluent TSS, mg/l | 2 | 12 | 3 | 2.3 | 8.3 | 15 |
| Influent TP, mg/l | 11.7 | 8.9 | 7.0 | 8.0 | 9.3 | 7.3 |
| Influent SP, percent | - | - | - | - | 62 | - |
| Effluent TP (limit), mg/l | none | 2.0 | 2.0 | 0.2 | 0.2 | 2.0 |
| Effluent TP, mg/l | 8.1 | 2.0 | 1.6 | 0.2 | 0.2 | 1.2 |
| Coagulant | none | Alum | Sodium Aluminate | Alum | FeCl ₃ | FeCl ₃ |
| Coagulant Dosage (metal ion), mg/l | - | 8.2 | 4.3 | 10.2 | 42.7 | 10 |
| Coagulant Dose Point | - | End of Aeration Tanks | Comminutor | Chemical Clarifiers | Head End of Plant | Rapid Mix Chamber Downstream of Sec. Clarifiers |
| Coagulant Dosage, metal ion/Inf. TP (weight) | - | 0.85 | 0.8 | 2.34 | 4.69 | 2.5 |
| Polymer Dosage, mg/l | none | 0.37 | 2.5 | 0 | 2.8 | 0.8 |
| Polymer Dose Point | - | Downstream of Alum Dose Point | Modular Activated Sludge Units | Downstream of Nitrification Aer. Tanks | Downstream of Parshall Flume and at Trickling Filter Effluent | Mix Chamber Upstream of Sec. Clarifiers |
| Sludge Conditioning | Aer. Digestion | Aer. Digestion | Aer. Digestion | Aer. Digestion | Lime and FeCl ₃ Vac. Filter | Anaer. Dig. |
| Sludge Dewatering | none | none | Filter Press | Filter Press | Vac. Filter | none |
| Total Sludge/Raw TSS, lb/lb | 0.55 | 0.36 | 1.1 | 2.0 | 2.32 | 0.9 |
| Chemical Sludge/TP Removed, lb/lb | - | 3.7 | 4.4 | 11.4 | 16.1 | 11.5 |
| Chemical Sludge/Total Sludge, lb/lb | - | 0.22 | 0.22 | 0.31 | 0.25 | 0.34 |
| Tertiary Filtration | yes | yes | yes | yes | no | no |
| Effluent pH Adjusted | no | no | NaOH (5.6 mg/l) | Lime (20 mg/l) | no | no |
| Nitrification | yes | yes | yes | no | no | no |
| Remarks | | | | | | Separate Stage Chemical Prec. |

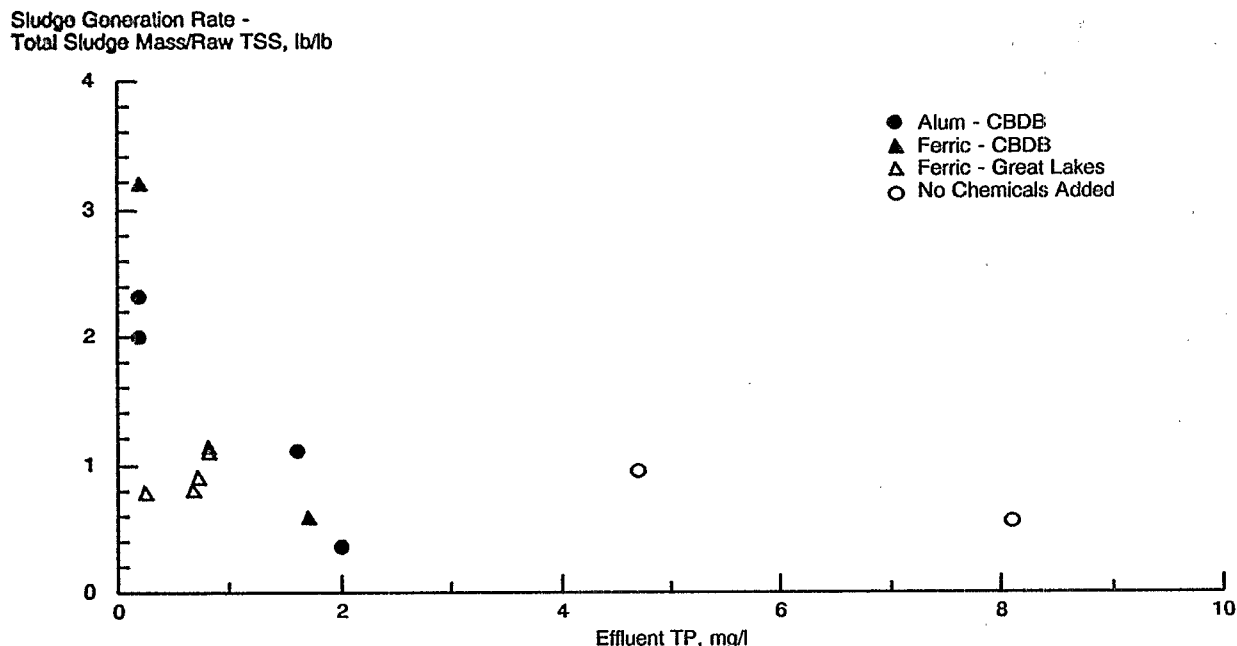
Table 3-14. Summary Information on Selected POTWs in Michigan

| Type of Plant | Plant | | | | | |
|--|--------------------------|-----------------------|--------------------------|--------------------------|--------------------------|-----------------------------|
| | Lansing | Tecumseh | Ann Arbor | Pontiac | Adrian | Iron Mountain/ Kingsford |
| Flow, mgd | Activated Sludge 23.8 | Contact Slab. 1.14 | Activated Sludge 16.9 | Activated Sludge 4.93 | Activated Sludge 5.35 | Activated Sludge 1.81 |
| Influent TBOD, mg/l | 199 | 224 | 133 | 125 | 102 | 128 |
| Effluent TBOD, mg/l | 4.8 | 12 | 13 | 3.1 | 6 | 18 |
| Influent TSS, mg/l | 206 | 305 | 166 | 114 | 157 | 146 |
| Effluent TSS, mg/l | 4.3 | 17 | 25 | 1.6 | 5 | 11 |
| Influent TP, mg/l | 5.95 | 8.9 | 5.1 | 3.71 | 4.9 | 43 |
| Effluent TP, mg/l | 0.65 | 4.7 | 0.7 | 0.17 | 1.49 | 0.8 |
| Fe ³⁺ or Al ³⁺ + Added, mg/l | 9.5 | 0 | | 11.5 | none (Phostrip) | 3.9 |
| Coagulant | FeCl ₃ | - | FeCl ₃ | FeCl ₃ | Lime | FeCl ₃ |
| Coagulant Dose Point | Aeration Tank | - | Aeration Tank | Prim. Clarif. Influent | - | Aeration Tank |
| Polymer | Anionic Polymer | none | Anionic Polymer | Anionic Polymer | - | Anionic Polymer |
| Polymer Dose, mg/l | 0.4 | - | 0.5 | 0.2 | - | 0.15 |
| Polymer Dose Point | Sec. Clarif. Influent | - | Sec. Clarif. Influent | Prim. Clarifier | - | Sec. Clarifier |
| Number of Stages | 1 | 1 | 1 | 1 | 2 | 1 |
| Sludge Conditioning | Zimpro | Anaer. Digestion | Anaer. Digestion | Anaer. Digestion | Anaer. Digestion | Anaer. Digestion |
| Fe ³⁺ /TP or Al ³⁺ + /TP Removed, lb/lb | 1.79 | - | | 3.23 | - | 3.32 |
| Sludge Dewatering | Vac. Filter | Drying Bed | Filter Press | Vac. Filter | no | Drying Bed |
| Sludge Generated/ Raw TSS, lb/lb | 0.82 | 0.96 | 0.91 | 1.12 | 0.54 | 1.10 |
| Chemical Sludge/ TP Removed, lb/lb | 4.51 | - | 8.72 | 7.74 | 0.76 | 12.17 |
| Chemical Sludge/ Total Sludge, lb/lb | 0.12 | - | 0.26 | 0.21 | 0.03 | 0.26 |
| Tertiary Filtration | yes | no | no | yes | yes | no |
| Effluent pH Adjusted | no | no | no | no | no | no |
| Nitrification | yes | no | partial | yes | partial | no |
| Sludge Disposal | Incineration | | Incineration | Incineration | Land Application | |

Table 3-14. Summary Information on Selected POTWs in Michigan (continued)

| Type of Plant | Plant | | | | |
|--|-------------------|------------------------|-------------------|------------------------|--------------------------|
| | Warren | Manistee | Midland | Traverse City | Port Huron |
| | Activated Sludge | Primary | TF + AS | Activated Sludge | Activated Sludge |
| Flow, mgd | 28.6 | 0.65 | 7.41 | 3.86 | 11.56 |
| Influent TBOD, mg/l | 112 | 117 | 85.5 | 176 | 89.2 |
| Effluent TBOD, mg/l | 1 | 61 | 9.6 | 23 | 12.4 |
| Influent TSS, mg/l | 115 | 102 | 126 | 118 | 75.6 |
| Effluent TSS, mg/l | 0.6 | 21 | 5.8 | 45 | 11.0 |
| Influent TP, mg/l | 4.6 | 2.6 | 3.05 | 3.7 | 2.74 |
| Effluent TP, mg/l | 0.7 | 0.9 | 0.23 | 1.5 | 0.68 |
| Fe ³⁺ or Al ³⁺ Added, mg/l | 7.91 | 13.1 | 14.6 | 8.8 | 6.44 |
| Coagulant | FeCl ₂ | FeCl ₃ | FeCl ₃ | FeCl ₂ | Alum |
| Coagulant Dose Point | Sec. Clarifier | Prim. Clarif. Influent | Grit Tank | Prim. Clarif. Influent | Prim. Clarif. Effluent |
| Polymer | none | Anionic Polymer | Anionic Polymer | Anionic Polymer | Anionic Polymer |
| Polymer Dose, mg/l | - | 0.2 | 0.6 | 0.2 | 0.4 |
| Polymer Dose Point | - | Prim. Clarifier | Prim. Influent | Prim. Clarifier | Prim. Clarif. Inf. (1/2) |
| Number of Stages | 1 | 2 TF + AS | 2 TF + AS | 1 | 1 |
| Sludge Conditioning | no | Anaer. Digestion | Zimpro | Anaer. Digestion | Lime Stab. |
| Fe ³⁺ /TP or Al ³⁺ /TP Removed, lb/lb | 2.03 | 5.1 | 4.8 | 3.98 | 3.33 |
| Sludge Dewatering | Belt Press | Drying Bed | Vac. Filter | Drying Bed | Centrifuge |
| Sludge Generated/ Raw TSS, lb/lb | 1.68 | 0.85 | 0.79 | 1.48 | 1.26 |
| Chemical Sludge/ TP Removed, lb/lb | 7.1 | 5.47 | 6.47 | 12.4 | 8.08 |
| Chemical Sludge/ Total Sludge, lb/lb | 0.15 | 0.15 | 0.18 | 0.16 | 0.17 |
| Tertiary Filtration | yes | no | yes | no | no |
| Effluent pH Adjusted | no | no | no | no | no |
| Nitrification | yes | no | no | no | partial |
| Sludge Disposal | Incineration | | | Incineration | Land. Appl. |

Figure 3-3. Sludge generation rate vs. effluent TP concentration.



The combined effects of effluent phosphorus concentration achieved and methods of sludge handling employed on sludge production is further illustrated in Figure 3-4. The extended aeration processes at Upper Allen and Seneca produced low sludge generation rates (SGRs), defined as total mass of sludge produced per unit of raw influent TSS received at the plant, while contact stabilization at Dale City yielded a high SGR of 2.0. High SGRs of 2 to 3 were noted for plants that use lime stabilization for sludge conditioning and have low effluent phosphorus limits.

The treatment/sludge handling scheme having the least impact on sludge generation with chemical phosphorus removal was aerobic digestion followed by land application of liquid sludge in an extended aeration plant. A good example is Upper Allen, PA, where alum addition is practiced, with an SGR of 0.36. Land application of anaerobically digested sludge at Elizabethtown, PA, produced an SGR of 0.9 where ferric chloride was added to this two-stage trickling filter plant.

The least desirable sludge handling alternative evaluated was lime stabilization followed by vacuum filtration. Not only was the quantity of lime necessary to stabilize sludge excessive, but significant maintenance problems also existed in plants utilizing this sludge handling sequence. Piscataway, MD, and Little Hunting Creek, VA, produced SGRs of 2.32 and 3.2, respectively, using this technology.

Polymer conditioning of sludge in general results in somewhat lower solids content in the cake, which

means higher handling costs. This alternative, however, does not increase the sludge quantity significantly.

3.2.4 Effect of Chemical Phosphorus Removal on pH

Two major factors contribute to reductions in pH during wastewater treatment: nitrification and coagulants such as aluminum and iron salts. Further description of these phenomena are presented in Chapter 7.

Low to moderate alkalinity necessitates pH adjustment in some parts of CBDB where chemical phosphorus removal is practiced. Examples were found in Seneca, MD, and Dale City, VA, where seasonal nitrification is also required. The dosages of caustic soda at Dale City and sodium hydroxide at Seneca necessary to prevent unacceptable pH depression vary with the seasonal nitrification operation. Other CBDB plants having facilities necessary to feed caustic chemicals were not operating these facilities at the time the plants were studied.

3.2.5 Cost of Chemicals

The cost of phosphorus removal chemicals was calculated on a pound removed basis and included the cost of metal salts and polymer (when used). Average costs were then determined for individual chemicals with and without polymer use and for effluent TP concentrations greater or less than 0.5 mg/l. These average costs are presented in Table 3-15.

Figure 3-4. Sludge generated vs. metal ion-to-influent TP ratio.

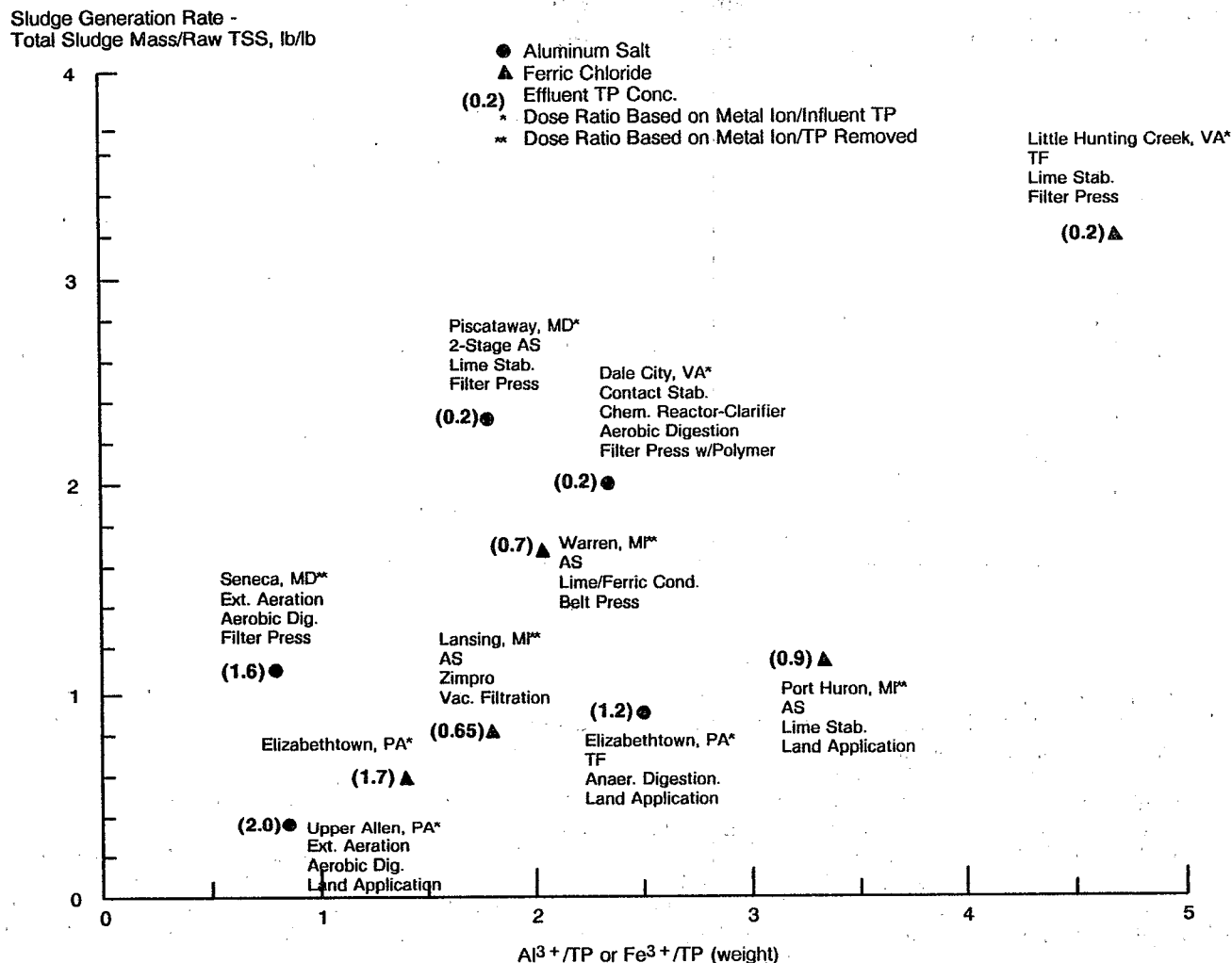


Table 3-15. Average Chemical Cost for Phosphorus Removal (\$/lb TP removed)*

| Chemical | Effluent TP > 0.5 mg/l | | Effluent TP < 0.5 mg/l | |
|------------------|------------------------|--------------|------------------------|--------------|
| | Without Polymer | With Polymer | Without Polymer | With Polymer |
| Alum | 1.29 (5) | 1.50 (5) | 1.91 (4) | 4.81 (4) |
| Sodium Aluminate | 1.54 (1) | 1.40 (1) | - | - |
| Ferric Chloride | 0.51 (3) | 1.30 (10) | 1.38 (1) | 2.39 (8) |
| Ferrous Chloride | 0.53 (19) | 1.02 (10) | 0.25 (1) | 0.44 (2) |
| Ferrous Sulfate | 0.33 (4) | 0.70 (1) | 0.10 (3) | - |
| Lime | 0.81 (1) | 0.81 (1) | - | - |

* Number of plants indicated in parentheses.

As expected, chemical costs were higher for those plants achieving effluent TP concentrations less than 0.5 mg/l, with the exception of those plants using ferrous salts. Alum was 40 percent more expensive than ferric chloride for plants at which polymer was

not used, and 100 percent more expensive when used in combination with polymer. Ferrous salts were used at only a handful of plants achieving effluent phosphorus concentrations less than 0.5 mg/l, and the average cost was very low, probably because

ferrous iron was available as pickle liquor for the cost of shipping only.

3.3 Biological Phosphorus Removal

3.3.1 PhoStrip Process

3.3.1.1 PhoStrip Process Performance

Thirteen full-scale plants have been constructed or retrofitted to the PhoStrip process to date, and a fourteenth is under construction at Ithaca, NY. Five of the completed facilities are no longer being operated with PhoStrip for phosphorus removal. Several have converted to chemical phosphorus removal, and in one case the need for phosphorus compliance was eliminated. Design flow rates for the PhoStrip process have ranged from 0.04 to 1.3 m³/s (0.9 to 30 mgd). Most of the plants were designed to achieve effluent TP concentrations of 1.0 mg/l, although two were designed for an effluent concentration of less than 0.5 mg/l TP with tertiary filtration.

Five PhoStrip plants were designed to operate with pure oxygen aeration, and nine with conventional air aeration. A variety of activated sludge flow regimes have been selected for use in conjunction with PhoStrip, including complete mix, plug flow, contact stabilization, step aeration, two-stage nitrification, and high-rate activated sludge. Equalization and tertiary filtration were incorporated in many of the PhoStrip treatment sequences. Over half the plants were designed with more than one anaerobic stripper. Eight plant designs used one or more reactor-clarifiers for lime precipitation, while the remaining six had one or more mixer/flocculators and co-settled the lime-phosphorus sludge in the primary clarifiers. Reactor-clarifier overflow was the most frequently chosen elutriation source, and stripper tank sludge recycle was provided in five of the plants. Primary effluent was the elutriation source for two plants.

Performance data are available for four of the eight PhoStrip plants currently in operation. The four for which data are not available are Tahoe-Truckee, CA; Southtowns, NY; Brockton, MA; and Rochester, MN. Brief descriptions of and performance summaries for the four operating plants are given below.

Adrian, MI. The 0.31-m³/s (7.0-mgd) Adrian PhoStrip plant has been in operation since 1980. PhoStrip was constructed as part of the first-stage activated sludge system followed by a second-stage nitrification system. Primary effluent serves as the elutriate, and lime precipitation is carried out in a flocculation tank with the lime-phosphorus sludge co-settled in the primary clarifiers. Secondary effluent receives tertiary filtration prior to discharge.

Overall, the performance of the PhoStrip process at Adrian has been good, with average removal efficiencies for TBOD, TSS, and TP of 95, 97, and 69

percent, respectively, during the period October 1981 through September 1982 without the second-stage system in operation.

Savage, MD. The Little Patuxent Wastewater Treatment Plant serving Savage, MD, is a two-stage, plug flow, activated sludge PhoStrip plant with two strippers and two reactor-clarifiers. Reactor-clarifier overflow is used as the elutriate. A 1985 data summary indicated that for an average flow of 0.39 m³/s (8.8 mgd) and an average influent (to the PhoStrip process) TP concentration of 8.6 mg/l, secondary effluent TP averaged 0.8 mg/l while the filtered effluent averaged 0.4 mg/l. Occasional daily excursions of the effluent TP above 1.0 mg/l have been encountered.

Reno-Sparks, NV. The Reno-Sparks Wastewater Treatment Facility is a single-stage, plug flow, activated sludge PhoStrip plant with five strippers and two mixer/flocculators using stripper sludge recycle as the elutriate. At an average flow of 1.1 m³/s (25.4 mgd) and an average influent TP concentration of 7.25 mg/l, the average effluent TP concentration was 0.31 mg/l for the period June 1985 through March 1986. Effluent phosphorus excursions above 1.0 mg/l rarely occurred on a daily basis. It should be noted that this excellent performance was achieved without tertiary filtration.

Lansdale, PA. This 0.1-m³/s (2.5-mgd) plant has no primary. Wastewater flows to an activated sludge-PhoStrip system for BOD and phosphorus removal. Reactor-clarifier overflow and secondary effluent are used to elutriate phosphorus in the stripper.

Nitrification occurs in a separate-stage activated sludge system. Waste biological sludges are combined with the waste chemical sludge from the PhoStrip process, gravity thickened, stabilized with lime, and then dewatered or spread on land.

A 1984-1985 data summary indicated average effluent concentrations of 0.8 mg/l for TP, 3 mg/l for TBOD and 4 mg/l for TSS were achieved with the first-stage activated sludge-PhoStrip system. Table 3-16 summarizes typical operating conditions for the Lansdale and Little Patuxent plants (1).

3.3.1.2 Cost for PhoStrip Process Retrofit

Retrofit costs for the PhoStrip process must be evaluated on a site-specific basis. Capital costs will include construction of a stripper tank, reactor-clarifier or chemical mix/flocculation tank, lime handling facilities, and associated piping, as well as a license fee charged for use of the proprietary process. O&M costs will include energy for pumping and mixing, lime, and maintenance associated with operating a lime feed system.

Table 3-16. Summary of PhoStrip Plant Operating Conditions for Lansdale and Little Patuxent

| Parameter | Lansdale | Little Patuxent | |
|---|----------|--------------------|------------|
| | 1982 | July 1984 | April 1985 |
| Stripper | | | |
| SDT, hr | 20 | 8 | 7 |
| Feed flow rate, percent of mainstream flow | 14 | 22 | 34 |
| Elutriation flow rate, percent of feed flow | 124 | 121 | 50 |
| Elutriation rate ¹ , l/g TSS/d | 0.14 | 0.72 | 0.25 |
| Underflow rate, percent of mainstream flow | 10 | 14 | 21 |
| Recycle rate, percent of stripper flow | 0 | 0 | 78 |
| Overflow rate, percent of mainstream flow | 23 | 35 | 31 |
| Effluent Total P, mg/l | 20.6 | 9.5 | 20.0 |
| Effluent Ortho P, mg/l | 16.4 | 7.2 | 17.6 |
| Reactor-Clarifier | | | |
| Effluent Total P, mg/l | 3.6 | 3.9 | 7.2 |
| Effluent Ortho P, mg/l | 0.9 | 0.9 | 1.2 |
| Overflow rate, gpd/sq ft | 1,600 | 1,120 | 840 |
| Lime dosage | | | |
| mg/l | 100 | 160 | 100 |
| pH | 9.0 | 9.5 | 9.5 |
| Activated Sludge Process | | | |
| F/M, kg TBOD/kg MLVSS/d | 0.16 | 0.52, ³ | 0.5 |
| MLSS, mg/l | 1,900 | 2,950 ² | 2,000 |
| TP/VSS, percent | 3.3 | 4.0 | 4.6 |
| SRT, days | 6.5 | 3.7 ^{2,3} | 2.8 |
| HRT, hr | 4.6 | 2.6 | 3.0 |
| Return sludge ratio | 0.16 | 0.32 | 0.57 |
| DO, mg/l | 2-3 | 1.3 | 2-5 |
| Sludge production ⁴ , kg VSS/kg TBOD | 1.0 | 0.7 | - |

¹ Based on mass of solids in stripper.² Estimated from solids balance.³ Calculated based on estimated MLSS.⁴ Based on removed carbonaceous TBOD.

The capital cost for the hardware for the PhoStrip process at Adrian, MI, in 1977, was \$556,000 for the design flow of 0.31 m³/s (7.0 mgd). The license fee was \$250,000, making the total cost \$806,000. The license fee amount may not be representative of the fee that would be charged today. The annual O&M cost in 1986 was approximately \$25,000, of which \$14,800 was for lime, \$6,000 for labor, and \$4,200 for excess sludge handling and disposal.

3.3.2 A/O Process

3.3.2.1 A/O Process Performance

Two full-scale A/O plants are currently in operation: Largo, FL, and Pontiac, MI. Another 13 full-scale A/O systems are currently in design or under construction with design capacities of 0.13 to 3.1 m³/s (3 to 70 mgd). Available data for the Largo and Pontiac facilities are summarized below.

Largo, FL. The Largo A/O system is a retrofit of a plug-flow activated sludge plant designed for a flow of 0.14 m³/s (3.2 mgd). Anaerobic and aerobic detention times are 1.5 and 2.6 hours, respectively. Influent TP averaged 8.9 mg/l during the performance test period, while the effluent TP averaged 1.85 mg/l. The effluent SP concentration during the same period averaged 0.51 mg/l. The plant was designed to

achieve an effluent TP of 1.5 mg/l. Sludge handling consists of aerobic digestion followed by mechanical dewatering.

Pontiac, MI. The A/O system in Pontiac is a 0.15-m³/s (3.5-mgd) retrofit of a plug-flow activated sludge train. Detention times for the anaerobic and aerobic stages are longer here, 2.1 and 7.7 hours, respectively. TP was reduced from an average influent concentration of 3.7 mg/l to an average effluent concentration of 0.9 mg/l on a U.S. EPA demonstration project during a period when nitrification was being achieved and the main treatment process was receiving full in-plant recycle of sidestreams, including anaerobic digester supernatant. During the 1-year demonstration project, average effluent TP concentrations exceeded 1 mg/l during only two 2-week periods. The excursions were attributed to the effect of extremes in pH caused by industrial discharges. The plant has been successfully operating for about 2 years with seasonal nitrification and recycle of anaerobic digester supernatant. It was shown that only a fraction of the phosphorus removed biologically was released into the digester supernatant under anaerobic conditions. The mechanism by which phosphorus is trapped in the solids in the digester is being further studied, but it is currently hypothesized

Table 3-17. Pontiac A/O Wastewater Treatment Facility Performance Data

| Parameter | Influent | | Effluent | |
|-------------|--------------------|-----------------------|--------------------|-----------------------|
| | With Nitrification | Without Nitrification | With Nitrification | Without Nitrification |
| Time Period | 10/1/84 - 11/14/84 | 2/6/85 - 3/31/85 | - | - |
| Flow, mgd | 2.86 | 4.28 | - | - |
| TBOD, mg/l | 163 | 136 | 9.4 | 11 |
| TSS, mg/l | 140 | 136 | 7 | 10 |
| TP, mg/l | 3.7 | 2.6 | 0.9 | 0.7 |

that phosphorus is being chemically precipitated in the presence of magnesium and ammonia in the digester to an insoluble compound called magnesium ammonium phosphate. The average performance of the Pontiac A/O system is summarized in Table 3-17 for a 45-day period with nitrification and full in-plant digester supernatant recycle and a 54-day period without nitrification, but with full in-plant digester supernatant recycle.

3.3.2.2 Cost for A/O Process Retrofit

As with PhoStrip, retrofit costs for the A/O process must be evaluated on a site-specific basis. Capital costs include construction of baffles to separate the various stages, removal of existing aeration devices in anaerobic stages, possible addition of aeration devices in aerobic stages, and installation of mixers in anaerobic stages. O&M costs include energy for internal recycle pumping, if required, and to operate the mixers. It has been reported that some savings in aeration power may be realized due to the decreased aerobic stage organic loading resulting from the BOD removal that occurs in the anaerobic stages (2).

Retrofit costs (in 1984 dollars) for the Pontiac project totaled \$57,000 for conversion of a 0.15-m³/s (3.5-mgd) plug flow activated sludge train to an A/O system. The license fee was waived for Pontiac because this was a demonstration project.

3.4 References

1. Tetreault, M.J., A.H. Benedict, C. Kaemfer, and E.F. Barth. *Biological Phosphorus Removal: A Technology Evaluation*. JWPCF 58:823, 1986.
2. Brannan, K.P., C.W. Randall, and L.D. Benefield. *The Anaerobic Stabilization of Organics in a Biological Phosphorus Removal System*. Presented at the 59th Annual Conference, Water Pollution Control Federation, Los Angeles, CA, October 1986.

Chapter 4

Process Design Synopses for Retrofitting Chemical Phosphorus Removal

This chapter is primarily directed to the plant designer who has the task of retrofitting an existing wastewater treatment plant to phosphorus removal by means of chemical precipitation. The designer should refer to the design synopsis that pertains to the plant category to be retrofitted. This chapter also should be of interest to plant operators and regulators charged with reviewing construction grant applications. There are nine design synopses covering the following plant categories:

1. Plug Flow, Complete Mix, and Step Aeration Activated Sludge Systems
2. Contact Stabilization Activated Sludge Systems
3. Pure Oxygen Activated Sludge Systems
4. Extended Aeration and Oxidation Ditch Activated Sludge Systems
5. Two-Stage Nitrification Activated Sludge Systems
6. High-Rate Trickling Filter Systems
7. Standard-Rate Trickling Filter Systems
8. RBC Systems
9. Lagoon Systems

Each design synopsis provides information on the following 12 areas, grouped by required effluent TP concentration (0.2, 0.5, 1, and 2 mg/l):

1. Chemical dose requirements
2. Points of metal salt addition
3. Points of polymer addition
4. Impact on overall secondary treatment process performance
5. Impact on sludge settling
6. Impact on sludge quantities and characteristics
7. Impact on sludge thickening
8. Impact on sludge handling/disposal facilities
9. Impact on return sludge and sludge handling recycle streams
10. Impact of wastewater temperature
11. Effluent polishing requirements
12. Process flexibility recommendations

The choice of chemical for use in phosphorus removal must be made on a site-specific basis and will depend primarily on cost and availability. The use of lime for chemical phosphorus removal is not

recommended due to the many associated problems in handling.

Metal salt-to-influent TP weight ratios were used as initial chemical dose guides for the design synopses in this chapter. Once a facility is in operation and a data base exists, more precise dosage ratios of metal salt-to-influent SP can be established for routine operational control.

Design Synopsis 1: Plug Flow, Complete Mix, and Step Aeration Activated Sludge Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

Ahead of both primary and secondary clarifiers.

For 1 and 2 mg/l effluent TP:

Ahead of primary or secondary clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):

Ahead of both primary and secondary clarifiers.

For 1 mg/l eff. TP (will be necessary):

Ahead of primary or secondary clarifier.

For 2 mg/l eff. TP (may be necessary):

Ahead of primary or secondary clarifier.

4. Impact on overall secondary treatment process performance:

When phosphorus removal chemicals are added to the secondary treatment process, metal phosphate precipitates and other metal ion precipitates are formed and occluded into the activated sludge mass. This contributes an inert fraction to the MLSS, and wasting schedules for control of SRT may have to be altered.

For 0.2 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 32 m³/m²/d (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Return activated sludge will contain a higher fraction of inert solids when phosphorus removal chemicals are used in the secondary treatment process. As a result, higher return sludge rates will normally be required.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may also increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers and tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers will be required. Additional clarifier capacity or tertiary filtration may be necessary.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | necessary |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | recommended |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | not required |

Design Synopsis 2: Contact Stabilization Activated Sludge Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ +/Influent TP Ratio (weight) | Polymer Dose |
|----------------------|--|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

Ahead of primary clarifier and at end of contact tank.

For 1 and 2 mg/l effluent TP:

Ahead of primary clarifier or at end of contact tank.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):

Ahead of both primary and secondary clarifiers.

For 1 mg/l eff. TP (will be necessary):

Ahead of primary or secondary clarifier.

For 2 mg/l eff. TP (may be necessary):

Ahead of primary or secondary clarifier.

4. Impact on overall secondary treatment process performance:

When phosphorus removal chemicals are added to the secondary treatment process, metal phosphate precipitates and other metal ion precipitates are formed and occluded into the activated sludge mass. This contributes an inert fraction to the MLSS, and wasting schedules for control of SRT may have to be altered.

For 0.2 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 32 m³/m²/d (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Return activated sludge will contain a higher fraction of inert solids when phosphorus removal chemicals are used in the secondary treatment process. As a result, higher return sludge rates will normally be required.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may also increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers and tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers will be required. Additional clarifier capacity or tertiary filtration may be necessary.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | necessary |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | recommended |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | not required |

Design Synopsis 3: Pure Oxygen Activated Sludge Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:
Ahead of both primary and secondary clarifiers.

For 1 and 2 mg/l effluent TP:
Ahead of primary or secondary clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):
Ahead of both primary and secondary clarifiers.

For 1 mg/l eff. TP (will be necessary):
Ahead of primary or secondary clarifier.

For 2 mg/l eff. TP (may be necessary):
Ahead of primary or secondary clarifier.

4. Impact on overall secondary treatment process performance:

With a covered pure oxygen reactor, carbon dioxide resulting from biological oxidation is trapped in solution rather than being air stripped from the mixed liquor. The chemicals used for phosphorus removal are also acidic. Depending on wastewater alkalinity, some provision for pH control may be necessary, therefore, to prevent an unacceptable degree of pH depression and subsequent interference with normal metabolic reactions.

In addition, when phosphorus removal chemicals are added to the secondary treatment process, metal phosphate precipitates and other metal ion precipitates are formed and occluded into the activated sludge mass. This contributes an inert fraction to the MLSS, and wasting schedules for control of SRT may have to be altered.

For 0.2 mg/l effluent TP:
Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:
Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 32 m³/m²/d (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Return activated sludge will contain a higher fraction of inert solids when phosphorus removal chemicals are used in the secondary treatment process. As a result, higher return sludge rates will normally be required.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may also increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers and tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Polymer addition to the primary and secondary clarifiers will be required. Additional clarifier capacity or tertiary filtration may be necessary.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | necessary |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | recommended |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | not required |

Design Synopsis 4: Extended Aeration and Oxidation Ditch Activated Sludge Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

End of aeration tank and a polish dose to the tertiary filter.

For 1 and 2 mg/l effluent TP:

End of aeration tank.

3. Points of polymer addition:

For 0.2 mg/l eff. TP (will be necessary):

Ahead of secondary clarifier and a polish dose to tertiary filter.

For 0.5 mg/l eff. TP (will be necessary):

Ahead of secondary clarifier.

For 1 and 2 mg/l eff. TP (may be necessary):

Ahead of secondary clarifier.

4. Impact on overall secondary treatment process performance:

Extended aeration and oxidation ditch systems nitrify during at least part of the year. Acidic hydrogen ions are a byproduct of the nitrification process. Depending on wastewater alkalinity, some provision for pH control may be necessary, therefore, to prevent an unacceptable degree of pH depression and subsequent interference with normal metabolic reactions.

In addition, when phosphorus removal chemicals are added to the secondary treatment process, metal phosphate precipitates and other metal ion precipitates are formed and occluded into the activated sludge mass. This contributes an inert fraction to the MLSS, and wasting schedules for control of SRT may have to be altered.

For 0.2 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Extended aeration and oxidation ditch systems generally are not preceded by primary clarification. When metal salts are dosed to or just ahead of secondary clarifiers in these systems, sludge settling rates are normally enhanced. Polymer addition may also be necessary, however, to agglomerate fine floc particles. Best results are attained when secondary clarifiers are greater than 2.7 m (9 ft) ddep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 32 m³/m²/d (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

Chemicals added to the secondary treatment process will effect an increase in sludge production due to the formation of insoluble metal hydroxides and phosphates. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in waste secondary sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in waste secondary sludge production of 100 to 200 percent have been reported when chemicals are added to the secondary treatment process in a plant that does have primary clarifiers. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l eff TP:

Increases in waste secondary sludge production of 40 to 100 percent have been documented when chemicals are added to the secondary treatment process in a plant that does not have primary clarifiers. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Return activated sludge will contain a higher fraction of inert solids when phosphorus removal chemicals are used in the secondary treatment process. As a result, higher return sludge rates will normally be required.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may also increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:**For 0.2 mg/l effluent TP:**

Tertiary filtration with polish doses of metal salt and polymer to the filter will be necessary.

For 0.5 mg/l effluent TP:

Tertiary filtration with a polish dose of metal salt to the filter may be necessary.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:**For 0.2 mg/l effluent TP:**

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | may be required |
| • Flow equalization: | not required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | not required |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | not required |

Design Synopsis 5: Two-Stage Nitrification Activated Sludge Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ +/Influent TP Ratio (weight) | Polymer Dose |
|----------------------|--|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

Ahead of either primary or intermediate clarifier with a polish dose to the second-stage nitrification reactor.

For 1 and 2 mg/l effluent TP:

Ahead of either primary or intermediate clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):

Ahead of either primary or intermediate clarifier with a polish dose to the second-stage nitrification clarifier.

For 1 and 2 mg/l eff. TP (will be necessary):

Ahead of either primary or intermediate clarifier.

4. Impact on overall secondary treatment process performance:

Acidic hydrogen ions are a byproduct of the nitrification process. Depending on wastewater alkalinity, some provision for pH control may be necessary, therefore, to prevent an unacceptable degree of pH depression and subsequent interference with normal metabolic reactions.

In addition, when phosphorus removal chemicals are added to the secondary treatment process, metal phosphate precipitates and other metal ion precipitates are formed and occluded into the activated sludge mass. This contributes an inert fraction to the MLSS, and wasting schedules for control of SRT may have to be altered.

For 0.2 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 32 m³/m²/d (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Return activated sludge will contain a higher fraction of inert solids when phosphorus removal chemicals are used in the secondary treatment process. As a result, higher return sludge rates will normally be required.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may also increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Metal salt and polymer addition to the second-stage nitrification reactor and second-stage nitrification clarifier, respectively, will be required. Tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Metal salt and polymer addition to the second-stage nitrification reactor and second-stage nitrification clarifier, respectively, will be required. Tertiary filtration may be necessary.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------------|
| ● Multiple metal salt and polymer addition points: | necessary |
| ● Flow equalization: | may be required |
| ● Polymer addition: | necessary |
| ● Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| ● Multiple metal salt and polymer addition points: | necessary |
| ● Flow equalization: | may be required |
| ● Polymer addition: | necessary |
| ● Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| ● Multiple metal salt and polymer addition points: | recommended |
| ● Flow equalization: | not required |
| ● Polymer addition: | may be required |
| ● Effluent polishing: | not required |

Design Synopsis 6: High-Rate Trickling Filter Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

Ahead of both primary and secondary clarifiers, as well as to retrofit bioreactor.

For 1 mg/l effluent TP:

Ahead of both primary and secondary clarifiers.

For 2 mg/l effluent TP:

Ahead of primary clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):

Ahead of both primary and secondary clarifiers, as well as to retrofit bioreactor.

For 1 mg/l eff. TP (will be necessary):

Ahead of both primary and secondary clarifiers.

For 2 mg/l eff. TP (will be necessary):

Ahead of primary clarifier.

4. Impact on overall secondary treatment process performance:

The trickling filter media should be protected from the effects of metal salts as much as possible. When these chemicals are added to the primary clarifier, inorganic solids may carry over to the trickling filter. This may result in the production of a biofilm with a higher inert fraction than desirable and interference with normal metabolic reactions. Polymer should be used to minimize the carry-over of inorganic solids from the primary clarifier to the trickling filter.

For 0.2 and 0.5 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5 Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed $32 \text{ m}^3/\text{m}^2/\text{d}$ (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Settled sludge from the secondary clarifier is normally not returned to and recycled through a high-rate trickling filter bioreactor.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Construction of a second-stage bioreactor and clarifier, or expansion of the trickling filter system, as well as tertiary filtration will be required. Addition of metal salt and polymer both after the trickling filter and to the second-stage bioreactor, if utilized, will also be required.

For 0.5 mg/l effluent TP:

Construction of a second-stage bioreactor and clarifier, or expansion of the trickling filter system, may be required. Addition of metal salt and polymer both after the trickling filter and to the second-stage bioreactor, if utilized, may also be required.

For 1 mg/l effluent TP:

Addition of metal salt and polymer after the trickling filter will be required.

For 2.0 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 and 1 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 2 mg/l effluent TP:

- | | |
|--|--------------|
| • Multiple metal salt and polymer addition points: | recommended |
| • Flow equalization: | not required |
| • Polymer addition: | necessary |
| • Effluent polishing: | not required |

Design Synopsis 7: Standard-Rate Trickling Filter Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:
Ahead of both primary and secondary clarifiers.

For 1 and 2 mg/l effluent TP:
Ahead of primary or secondary clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):
Ahead of both primary and secondary clarifiers.

For 1 mg/l eff. TP (will be necessary):
Ahead of primary or secondary clarifier.

For 2 mg/l eff. TP (may be necessary):
Ahead of primary or secondary clarifier.

4. Impact on overall secondary treatment process performance:

The trickling filter media should be protected from the effects of metal salts as much as possible. When these chemicals are added to the primary clarifier, inorganic solids may carry over to the trickling filter. This may result in the production of a biofilm with a higher inert fraction than desirable and interference with normal metabolic reactions. Polymer should be used to minimize the carry-over of inorganic solids from the primary clarifier to the trickling filter.

For 0.2 and 0.5 mg/l effluent TP:
Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:
Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:
Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed $32 \text{ m}^3/\text{m}^2/\text{d}$ (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Settled sludge from the secondary clarifier is normally not returned to and recycled through a standard-rate trickling filter bioreactor.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:**For 0.2 mg/l effluent TP:**

Polymer addition to the secondary clarifier and tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Polymer addition to the secondary clarifier will be required.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:**For 0.2 mg/l effluent TP:**

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | may be required |
| • Flow equalization: | not required |
| • Polymer addition: | necessary |
| • Effluent polishing: | not required |

Design Synopsis 8: RBC Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:

Ahead of both primary and secondary clarifiers.

For 1 and 2 mg/l effluent TP:

Ahead of primary or secondary clarifier.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (will be necessary):

Ahead of both primary and secondary clarifiers.

For 1 mg/l eff. TP (will be necessary):

Ahead of primary or secondary clarifier.

For 2 mg/l eff. TP (may be necessary):

Ahead of primary or secondary clarifier.

4. Impact on overall secondary treatment process performance:

The RBC media should be protected from the effects of metal salts as much as possible. When these chemicals are added to the primary clarifier, inorganic solids may carry over to the RBC media. This may result in the production of a biofilm with a higher inert fraction than desirable and interference with normal metabolic reactions. Polymer should be used to minimize the carry-over of inorganic solids from the primary clarifier to the RBC media.

For 0.2 and 0.5 mg/l effluent TP:

Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Sludge settling rates are normally improved when metal salts are added to primary and/or secondary clarifiers. Polymer addition is sometimes also necessary in conjunction with metal salt addition to aid in solids agglomeration and capture and prevent carry-over of inorganic solids to the secondary treatment process or fine floc particles to the final effluent. Best results are attained when clarifiers are greater than 2.7 m (9 ft) deep.

For 0.2 and 0.5 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 20 m³/m²/d (500 gpd/sq ft).

For 1 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed 24 m³/m²/d (600 gpd/sq ft).

For 2 mg/l effluent TP:

Secondary clarifier overflow rate at peak sustained flow should not exceed $32 \text{ m}^3/\text{m}^2/\text{d}$ (800 gpd/sq ft).

6. Impact on sludge quantities and characteristics:

When chemicals are added prior to primary clarifiers, sludge yields will increase due to the formation of insoluble metal hydroxides and the entrapment of BOD and suspended solids onto flocs. Primary sludge will, therefore, contain a greater amount of organic matter since it is captured with the inorganic flocs.

Solids production also increases when chemicals are added to the secondary treatment process, but not to as great an extent. Waste secondary sludge will contain a higher fraction of inert solids than normal.

For 0.2 mg/l effluent TP:

Increases in sludge production greater than 200 percent can be expected due to the extremely high dosages of chemicals necessary to achieve this low effluent limit. Actual increases, however, will depend on site-specific conditions.

For 0.5 mg/l effluent TP:

Increases in sludge production of 100 to 200 percent have been documented when chemicals are added to both the primary and secondary treatment processes. Actual increases, however, will depend on site-specific conditions.

For 1 and 2 mg/l effluent TP:

Increases in sludge production of 60 to 100 percent have been documented when chemicals are added to the primary treatment process, and 40 to 60 percent when chemicals are added to the secondary treatment process. Actual increases, however, will depend on site-specific conditions.

7. Impact on sludge thickening:

The increased sludge volumes resulting from chemical phosphorus removal will lead to both higher solids and hydraulic loading rates on gravity and flotation thickeners. Thickener design loading rates may, therefore, be exceeded in plants that are at or near treatment capacity. Solids capture may decrease when design loading rates are exceeded.

8. Impact on sludge handling/disposal facilities:

The increase in sludge production may cause the design loading rates of sludge handling/disposal facilities to be exceeded if the plant is at or near treatment capacity. Under these circumstances, sludge disposal facilities may not operate correctly and may need to be reviewed and upgraded to handle the additional quantities and types of sludges generated (e.g., conversion of low-rate digesters to high-rate digesters or a two-stage digestion system to a single-stage digestion system).

For 0.2 and 0.5 mg/l effluent TP:

Anaerobic sludge digestion may be inhibited due to the high proportion of chemical sludge resulting from high dosages of chemical. Use of this method of sludge stabilization should be avoided, therefore, if possible, where very low effluent phosphorus is required.

9. Impact on return sludge and sludge handling recycle streams:

Settled sludge from the secondary clarifier is normally not returned to and recycled through an RBC bioreactor.

The concentration of certain constituents in sludge handling recycle streams such as nitrogen, phosphorus, and soluble organics may increase when chemical phosphorus removal is imposed on an existing treatment plant. This factor needs to be considered in the overall retrofit design and is particularly important if biological reactor capacity is marginal.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Polymer addition to the secondary clarifier and tertiary filtration will be required.

For 0.5 mg/l effluent TP:

Polymer addition to the secondary clarifier will be required.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | necessary |

In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | may be required |
| • Polymer addition: | necessary |
| • Effluent polishing: | may be required |

For 1 and 2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | may be required |
| • Flow equalization: | not required |
| • Polymer addition: | necessary |
| • Effluent polishing: | not required |

Design Synopsis 9: Lagoon Systems

1. Chemical dose requirements:

| Required Effluent TP | M ³ + /Influent TP Ratio (weight) | Polymer Dose |
|----------------------|---|--------------|
| mg/l | | mg/l |
| 0.2 | 2.0-5.0 | 0.2-1.0 |
| 0.5 | 1.5-2.0 | 0.1-0.5 |
| 1 | 1.2-1.5 | 0.1-0.2 |
| 2 | 1.0-1.2 | 0.1-0.2 |

2. Points of metal salt addition:

For 0.2 and 0.5 mg/l effluent TP:
Retrofit tertiary chemical treatment system.

For 1 and 2 mg/l effluent TP:
Ahead of first and last cells; if unaerated, provide mixing chamber.

3. Points of polymer addition:

For 0.2 and 0.5 mg/l eff. TP (may be necessary):
Retrofit tertiary chemical treatment system.

For 1 and 2 mg/l effluent TP:
Not required.

4. Impact on overall secondary treatment process performance:

Dosing phosphorus removal chemicals directly to the lagoon creates the concern of imparting a high inert fraction to the active organisms that may decrease the capability for normal metabolic reactions.

For 0.2 and 0.5 mg/l effluent TP:
Process pH must be monitored since high dosages of metal salts can result in depressed pH values.

5. Impact on sludge settling:

Clarifiers are not normally used in a lagoon treatment system.

6. Impact on sludge quantities and characteristics:

Solids separation or effluent clarification is not normally practiced in lagoon treatment systems. If chemicals are added directly to the lagoon, it is expected that an accumulation of inert solids would eventually occur that may require removal at some point in time.

7. Impact on sludge thickening:

Thickeners are not normally used in conjunction with lagoon treatment systems.

8. Impact on sludge handling/disposal facilities:

Sludge handling/disposal facilities are not normally necessary for lagoon treatment systems.

9. Impact on return sludge and sludge handling recycle streams:

Return sludge and sludge handling recycle streams are not normally a factor in lagoon treatment systems.

10. Impact of wastewater temperature:

Phosphorus removal performance decreases in cold temperatures due to decreased settleability of chemical flocs resulting from greater liquid viscosity and density. Increased chemical dosages and polymer use may be required.

11. Effluent polishing requirements:

For 0.2 mg/l effluent TP:

Tertiary chemical treatment (consisting of a flocculation tank and a clarifier) and filtration will be necessary.

For 0.5 mg/l effluent TP:

Tertiary chemical treatment (consisting of a flocculation tank and a clarifier) and filtration will likely be required.

For 1 and 2 mg/l effluent TP:

Effluent polishing should not be necessary.

12. Process flexibility recommendations:

For 0.2 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | necessary |

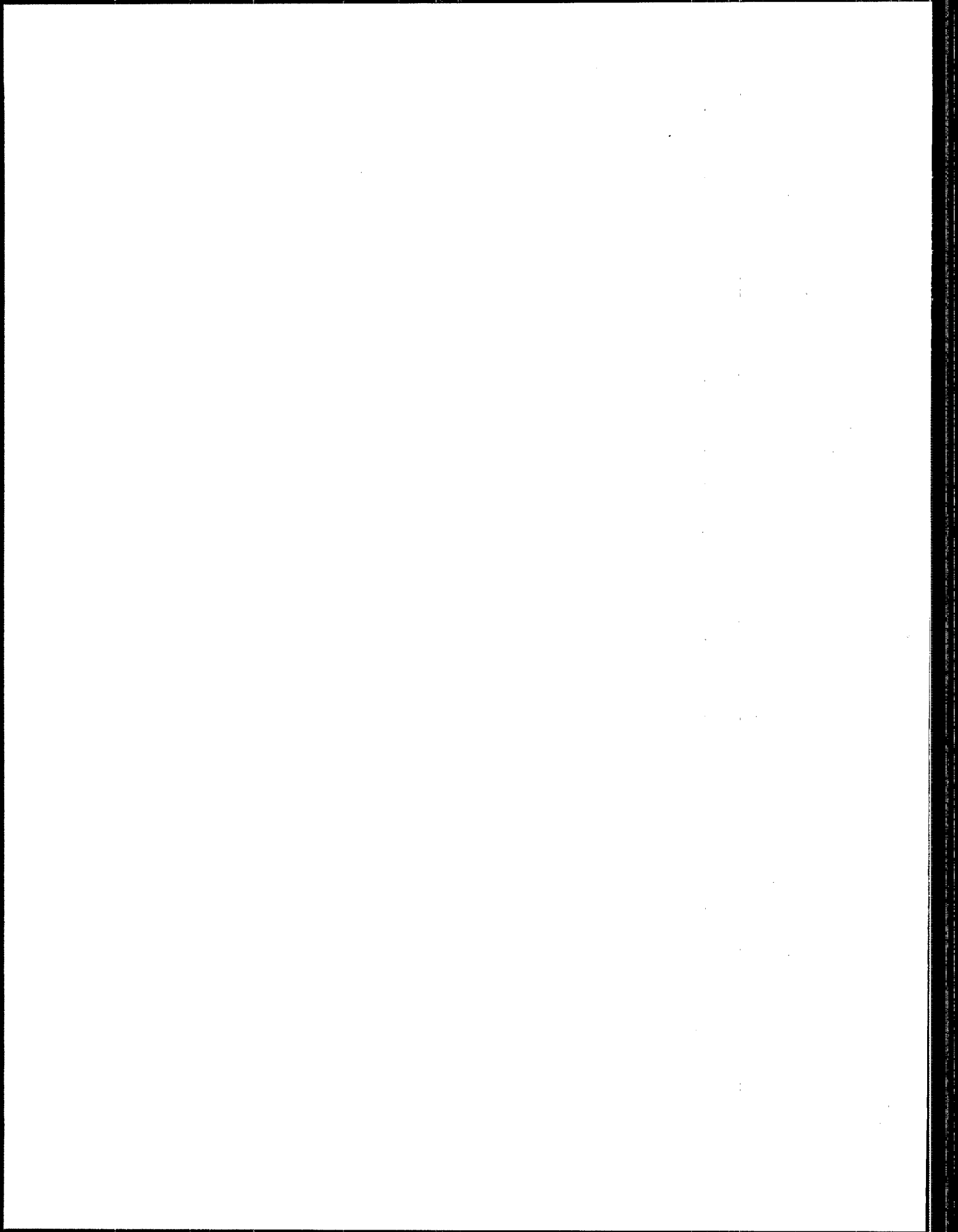
In addition, pH control instrumentation and dosing of pH neutralizing chemicals may be required.

For 0.5 mg/l effluent TP:

- | | |
|--|-----------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | not required |
| • Polymer addition: | may be required |
| • Effluent polishing: | necessary |

For 1 and 2 mg/l effluent TP:

- | | |
|--|--------------|
| • Multiple metal salt and polymer addition points: | necessary |
| • Flow equalization: | not required |
| • Polymer addition: | not required |
| • Effluent polishing: | not required |



Chapter 5

Hardware Design and O&M Considerations for Chemical Phosphorus Removal in Small to Medium Plants (< 10 mgd)

5.1 Introduction

This chapter presents information on the characteristics and properties of chemicals used for phosphorus removal, suppliers of chemicals to the Chesapeake Bay area, chemical costs for the Chesapeake Bay area, chemical storage and feeding facilities, typical chemical addition system layouts, staffing requirements and sampling and analytical needs for chemical addition, and safety precautions and OSHA requirements for chemical addition. This information has been derived from extensive experience with the design and operation of chemical addition systems in the Great Lakes region. Modifications have been incorporated, where appropriate, to make the information relevant to treatment plants in the CBDB.

The intent of this chapter is to assist engineers in the CBDB to design efficient site-specific chemical feed systems without "reinventing the wheel." It is also anticipated that the information contained in this chapter will aid plant operators in the CBDB to minimize problems associated with chemical addition operational continuity and system maintenance, thereby reducing downtime, waste of chemicals, and sludge handling difficulties.

5.2 Aluminum Compounds

The principal aluminum compounds that are commercially available and suitable for phosphorus precipitation are alum and sodium aluminate. Both are available in either liquid or dry forms. Alum is acidic in nature, while sodium aluminate is alkaline. This may be an important factor in choosing between them. Aluminum chloride should also be considered and is discussed herein.

5.2.1 Dry Alum

5.2.1.1 Properties and Availability

The commercial dry alum most used in wastewater treatment has the approximate chemical formula $Al_2(SO_4)_3 \cdot 14H_2O$ and a molecular weight of 594. The pH varies between 3.0 and 3.5 in aqueous alum

solutions having concentrations between 1 and 10 percent. Commercially available grades and their corresponding bulk densities and angles of repose are given in Table 5-1.

Table 5-1. Available Grades of Dry Alum

| Grade | Bulk Density | Angle of Repose |
|----------|--------------|-----------------|
| | lb/cu ft | ° |
| Lump | 62 - 68 | varies |
| Ground | 60 - 71 | 43 |
| Rice | 57 - 61 | 38 |
| Powdered | 38 - 45 | 65 |

Each grade has a minimum aluminum content of 17 percent, expressed as Al_2O_3 . This corresponds to a 9-percent concentration as aluminum. Viscosity and solution crystallization temperatures are included in the subsequent section on liquid alum.

The solubility of commercial dry alum at various temperatures is listed in Table 5-2.

Table 5-2. Solubility of Alum at Various Temperatures

| Temperature | Solubility |
|-------------|------------|
| °F | lb/gal |
| 32 | 6.03 |
| 50 | 6.56 |
| 68 | 7.28 |
| 86 | 8.45 |
| 104 | 10.16 |

Dry alum is not corrosive unless it absorbs moisture from the air, such as during prolonged exposure to humid atmospheres. Therefore, precautions should be taken to ensure storage space is free of moisture.

Alum is typically shipped in 45-kg (100-lb) bags or in bulk (minimum of 18,150 kg or 40,000 lb) by truck.

Bag shipments may be ordered on wood pallets. Information on suppliers of dry alum to the Chesapeake Bay area is given in Table 5-3.

5.2.1.2 General Design Considerations

Utilities usually use ground and rice alum because of their superior flow characteristics. These grades have less tendency to lump or arch in storage and, therefore, provide more consistent feeding qualities. Hopper agitation is seldom required with these grades, and, in fact, may be detrimental to feeding by causing packing of the contents of the bin.

Alum dust is present in the ground grade and will cause minor irritation of eyes and respiratory tract. A respirator will protect against alum dust. Alum dust should be thoroughly flushed from the eyes immediately and washed from the skin with water. Gloves should be worn to protect the hands. Because of minor irritation in handling and the possibility of alum dust causing rusting of adjacent machinery, dust removal equipment is desirable.

5.2.1.3 Storage

A typical storage and feeding system for dry alum is shown in Figure 5-1. Bulk alum can be stored in mild steel or concrete bins with dust collector vents located in, above, or adjacent to the equipment room. Recommended storage capacity is about 30 days. Dry alum in bulk can be transferred with screw conveyors, pneumatic conveyors, or bucket elevators made of mild steel. Pneumatic conveyor elbows should have a reinforced backing to withstand abrasion.

Bags and drums of alum should be stored in a dry location. Bag or drum loaded hoppers should have storage capacity for 8 hours at the nominal maximum feed rate so personnel are not required to charge the hopper more than once per shift. Converging hopper sections should have a minimum wall slope of 60° to prevent arching.

Bulk storage hoppers should have a discharge bin gate so feeding equipment may be isolated for servicing. The bin gate should be followed by a flexible connection and a transition hopper chute or a hopper that acts as a conditioning chamber over the feeder.

5.2.1.4 Feeding Equipment

The feed system includes all components required for preparation of the chemical solution. Capacities and configurations should be selected to fulfill individual system requirements. Three basic types of chemical feed equipment are used: volumetric, belt gravimetric, and loss-in-weight gravimetric. Volumetric feeders are usually used where low initial cost and lower delivery capacities are the basis of selection. Volumetric feeder mechanisms are usually exposed to corrosive vapors from the dissolving chamber.

Manufacturers normally control this problem by use of an electric heater to keep the feeder housing dry or by using plastic components in the exposed areas.

Volumetric dry feeders are generally of the screw type. Two designs of screw feed mechanism are available. Both allow even withdrawal across the bottom of the feeder hopper to prevent dead zones. One screw design is the variable pitch type with the pitch expanding evenly to the discharge point. The second screw design is the constant pitch-reciprocating type. This type has each half of the screw turned in opposite directions so the turning and reciprocating motion alternately fills one half of the screw while the other half is discharging. The variable pitch screw has one point of discharge, while the constant pitch-reciprocating screw has two points of discharge, one at each end of the screw. The accuracy of volumetric feeders is influenced by the character of material being fed and ranges between 1 percent for free-flowing materials to 7 percent for cohesive materials. This accuracy is volumetric and is not related to accuracy by weight (gravimetric).

Where the greatest accuracy and more economical use of chemical is desired, the loss-in-weight type feeder should be selected. This feeder is suited to low and medium feed rates with a maximum of approximately 1,500 kg (4,000 lb)/h. The unit consists of a material hopper and feeding mechanism mounted on enclosed scales. Continuous comparison of actual hopper weight with set hopper weight prevents cumulative errors. Accuracy of the loss-in-weight feeder is near 1 percent by weight of the set rate.

Belt-type gravimetric feeders span the capacity ranges of volumetric and loss-in-weight feeders and can be sized for most applications in wastewater treatment. Initial expense falls between that for the volumetric feeder and the loss-in-weight feeder. Belt-type gravimetric feeders consist of a basic belt feeder incorporating a weighing and control system. Feed rates can be varied by changing either the weight per unit length of belt, belt speed, or both. Controllers in general use are mechanical, pneumatic, electric, and mechanical-vibrating. Accuracy specified for belt-type gravimetric feeders should be within 1 percent of the set rate. This equipment normally includes mild steel hoppers, stainless steel mechanism components, and rubber surfaced feed belts.

Because alum solution is corrosive, dissolving or solution chambers should be constructed of type 316 stainless steel, fiberglass reinforced plastic (FRP), or plastics (polyvinyl chloride, polyethylene, polypropylene, and similar materials). Dissolvers should be sized for preparation of the desired solution strength. The most dilute solution strength usually recommended is 0.06 kg of alum/l (0.5 lb/gal) of water, or a 6-percent solution. The dissolving

Table 5-3. Dry Alum Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|------------------------|---|----------------|---|
| Manley-Regan Chemicals | East Emmaus Street P. O. Box 391 Middletown, PA 17057 | (717) 994-7471 | 100-lb bags: 20 bags - \$16.75/100 lb 50 bags - \$15.50/100 lb 100 bags - \$14.90/100 lb |
| Delta Chemicals | 12601 Cannery Avenue Baltimore, MD 21226 | (301) 354-0100 | 100-lb bags: 400 bags (minimum order) \$185/ton (\$9.25/100 lb) 40,000-lb hopper truck: \$165/ton (\$8.25/100 lb) |
| Coyne Chemicals | 3015 State Road Croyden, PA 19020 | (215) 785-3000 | 100-lb bags: 100 bags - \$14.60/100 lb 240 bags - \$12.10/100 lb 40,000-lb hopper truck: \$242/ton (\$12.10/100 lb) |

* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

chamber is designed for a minimum detention time of 5 minutes at the maximum feed rate. Because excessive dilution may be detrimental to coagulation, eductors or float valves that would ordinarily be used ahead of centrifugal pumps are not recommended. Dissolvers should be equipped with water meters and mechanical mixers so the water-to-alum ratio may be properly established and controlled.

5.2.1.5 Piping and Accessories

Pipe made FRP or plastic is recommended for alum solution. Care must be taken to provide adequate support for these piping systems, with close attention given to spans between supports so objectionable deflection will not occur. Lined steel pipe is generally tougher and more rigid, but the cost of providing a near perfect lining may detract from its suitability.

Solution flow by gravity to the point of discharge is desirable. When pumping is necessary, little or no dilution is required. When metering pumps or proportioning weir tanks are used, return of excess flow to a holding tank should be considered. Metering pumps are discussed in the section on liquid alum.

Valves used in solution lines should be plastic, type 316 stainless steel, or rubber-lined iron or steel.

5.2.1.6 Pacing and Control

Volumetric and gravimetric feeders are usually adaptable to operation from any standard instrument control and pacing signals. When solution must be pumped, consideration should be given to the use of holding tanks between the dry feed system and feed pumps; solution water supply should be controlled to prevent excessive dilution. The dry feeders may be started and stopped from tank level probes. Variable control metering pumps can transfer alum stock solution to the point of application without further dilution.

Means should be provided for calibration of chemical feeders. Volumetric feeders may be mounted on platform scales. Belt feeders should include a sample chute and box to check actual delivery with set delivery.

Gravimetric feeders are usually furnished with totalizers only. Remote instrumentation is frequently used with gravimetric equipment, but seldom used with volumetric equipment.

5.2.2 Liquid Alum

5.2.2.1 Properties and Availability

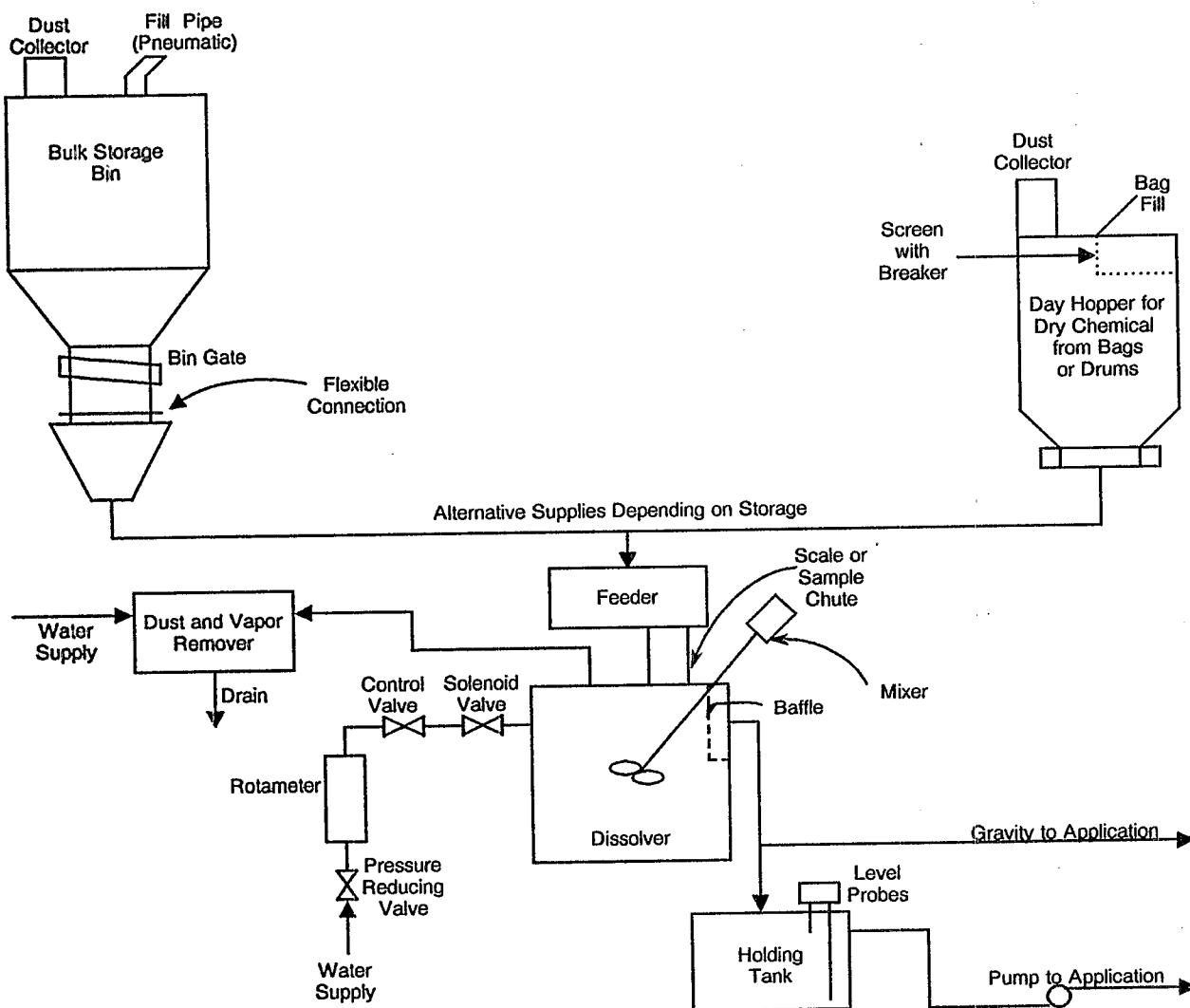
Liquid alum is shipped in insulated tank cars or trucks. During the winter, it is heated prior to shipment so crystallization will not occur during transit. Liquid alum is shipped at a solution strength of about 4.37 percent as aluminum, about 8.3 percent as Al_2O_3 , or 49 percent as $\text{Al}_2(\text{SO}_4)_3 \cdot 14\text{H}_2\text{O}$. This solution has a density of 1.33 kg/l (11.1 lb/gal) at 60°F and contains about 0.65 kg of dry alum/l (5.4 lb/gal) of liquid, or 17 percent Al_2O_3 . This solution will begin to crystallize at 30°F and crystallizes at 18°F.

Crystallization temperatures of other solution strengths are given in Table 5-4. The viscosity of various alum solutions is given in Figure 5-2.

Liquid alum is typically delivered in truck lots of 11,400 to 18,900 l (3,000 to 5,000 gal). Information on suppliers of liquid alum to the Chesapeake Bay area is presented in Table 5-5.

Since liquid alum is an intermediate compound in production of dry alum, the liquid form costs less. However, liquid alum costs more to transport since it is nearly half water by weight. Therefore, a cost tradeoff point can be established when exact chemical costs and local freight rates are determined. Liquid alum will generally be more economical than

Figure 5-1. Dry feed system alternatives.



dry alum if the point of use is within 100 miles of the manufacturing plant; ease of handling, storing, and feeding liquid alum extend its practical transport limit to 200 miles or more.

5.2.2.2 General Design Considerations

Bulk unloading facilities usually must be provided at the treatment plant. Railroad tank cars are constructed for top unloading and, therefore, require an air supply system and flexible connectors to pneumatically displace the alum from the car. U.S. Department of Transportation regulations concerning chemical tank car unloading should be observed. Tank truck unloading is usually accomplished by gravity or by a truck-mounted pump.

No particular industrial hazards are encountered in handling liquid alum. However, a face shield and gloves should be worn around leaking equipment.

The eyes or skin should be flushed and washed upon contact with liquid alum. Liquid alum becomes very slick upon evaporation, and, therefore, spillage should be avoided.

5.2.2.3 Storage

Liquid alum is stored without dilution at the shipping concentration. Storage tanks may be open if indoors, but must be closed and vented if outdoors. Outdoor tanks should also be heated, if necessary, to keep the temperature above 25°F to prevent crystallization. Storage tanks should be constructed of type 316 stainless steel, FRP, steel lined with rubber, polyvinyl chloride, or lead; see subsequent section for details. Liquid alum can be stored indefinitely without deterioration.

Storage tanks should be sized according to maximum feed rate, shipping time required, and quantity of

Table 5-4. Crystallization Temperatures of Liquid Alum

| Al ₂ O ₃ percent | Temperature of Crystallization °F |
|---|--------------------------------------|
| 5.19 | 26 |
| 6.42 | 21 |
| 6.67 | 19 |
| 6.91 | 17 |
| 7.16 | 15 |
| 7.40 | 13 |
| 7.66 | 12 |
| 7.92 | 14 |
| 8.19 | 17 |
| 8.46 | 20 |
| 8.74 | 28 |

shipment. Tanks should generally be sized for 1-1/2 times the quantity of shipments. A 10-day to 2-week supply should be provided to allow for unforeseen shipping delays.

5.2.2.4 Feeding Equipment

Various types of gravity or pressure feeding and metering units are available. Figures 5-3 and 5-4 illustrate commonly-used feed systems. The rotodip-type feeder or rotameter is often used for gravity feed and the metering pump for pressure feed systems.

The pressure or head available at the point of application frequently determines the feeding system to be used. The rotodip feeder can be supplied from overhead storage by gravity with the use of an internal level control valve, as shown in Figure 5-3. It may also be supplied by a centrifugal pump. The latter arrangement requires an excess flow return line to the storage tank, as indicated in Figure 5-4. Centrifugal pumps should be direct-connected but not close-coupled because of possible leakage into the motor, and should be constructed of type 316 stainless steel, FRP, or plastic.

Metering pumps currently available allow a wide range of capacity compared with the rotodip and rotameter systems. Hydraulic diaphragm-type pumps are preferable to other type pumps and should be protected with an internal or external relief valve. A backpressure valve is usually required in the pump discharge to provide efficient check valve action. Materials of construction for feeding equipment should be as recommended by the manufacturer for the service but, depending on the type of system, will generally include type 316 stainless steel, FRP, plastics, and rubber.

5.2.2.5 Piping and Accessories

Piping systems for liquid alum should be constructed of FRP, plastics (subject to temperature limits), type

316 stainless steel, or lead. Piping and valves used for alum solutions are also discussed in the preceding section on dry alum.

5.2.2.6 Pacing and Control

The feeding systems described above are volumetric, and the feeders generally available can be adapted to receive standard instrument pacing signals. The signals can be used to vary motor speed, variable-speed transmission setting, stroke speed, and stroke length, where applicable. A totalizer is usually furnished with a rotodip feeder, and remote instruments are available. Instrumentation is rarely used with rotameters and metering pumps.

5.2.3 Dry Sodium Aluminate

5.2.3.1 Properties and Availability

Dry sodium aluminate, Na₂Al₂O₄, is shipped in 23-kg (50-lb) bags and has a bulk density ranging from 640 to 800 kg/m³ (40 to 50 lb/cu ft). The Al₂O₃ content ranges from 41 to 46 percent. Dry sodium aluminate is noncorrosive, and the pH of a 1-percent solution is about 11.9. Manufacturers should be consulted for more precise specifications of their product.

Dry sodium aluminate is available in the Chesapeake Bay area from the supplier listed in Table 5-6.

5.2.3.2 General Design Considerations

Requirements for dry sodium aluminate feed systems are generally similar to those for dry aluminum sulfate. Dry sodium aluminate is not available in bulk quantities. Therefore, the small, day-type hoppers with manual filling arrangements as shown in Figure 5-1 are used. Precautionary measures for handling sodium aluminate are similar to those for strong alkalis, such as caustic soda. Contact with skin, eyes, and clothing should be avoided. Aluminate dust or solution spray should not be breathed.

5.2.3.3 Storage

Dry sodium aluminate is stored as received, in bags, and at optimum conditions of 60 to 90°F; the recommended storage limit is 6 months. Hopper material of mild steel is completely adequate. This chemical may or may not be free flowing, depending on the manufacturer and grade used. Therefore, hopper agitation may be required. Sodium aluminate deteriorates on exposure to the atmosphere, and care should be taken to avoid tearing of bags.

5.2.3.4 Feeding Equipment

Materials of construction for dissolving chambers may be mild steel or stainless steel, and selection may be influenced by conformity with adjacent equipment. Equipment similar to that shown in Figure 5-1 is applicable. Standard practice for the free-flowing grade of sodium aluminate calls for dissolvers sized for 0.06 kg/l (0.5 lb/gal) or 6-percent solution

Figure 5-2. Viscosity of alum solutions (courtesy of Allied Chemical Co.).

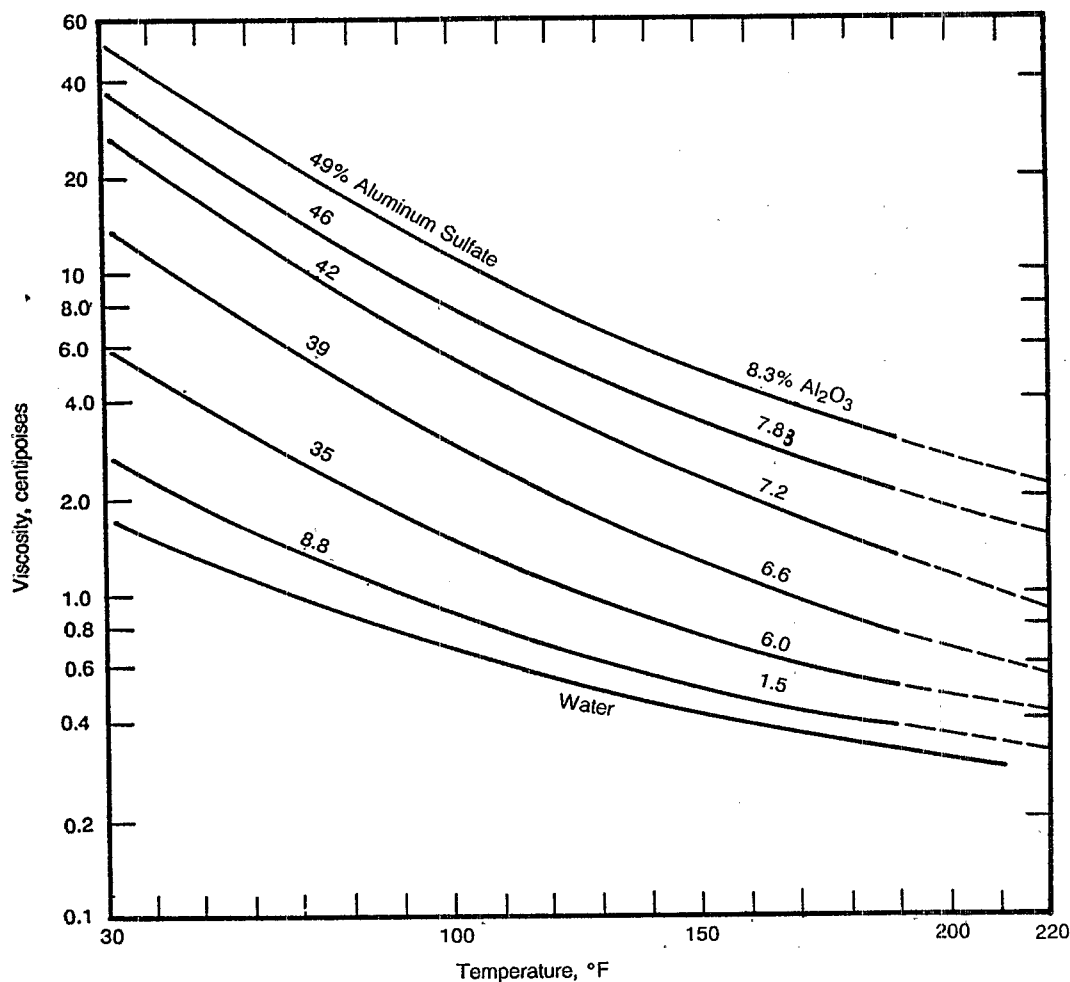


Table 5-5. Liquid Alum Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|------------------------|--|----------------|---|
| Manloy-Regan Chemicals | East Emmaus Street P. O. Box 391 Middleton, PA 17057 | (717) 944-7471 | \$145/ton of dry alum. A 4,600-gal tank truck contains 25,000 lb (12.5 ton) of dry alum. Cost per truck - \$1,813. Cost per gal - \$0.40 |
| Delta Chemicals | 12601 Cannery Avenue Baltimore, MD 21226 | (301) 354-0100 | \$145/ton of dry alum. |
| Coyne Chemicals | 3015 State Road Croyden, PA 19020 | (215) 785-3000 | \$133/ton of dry alum. |

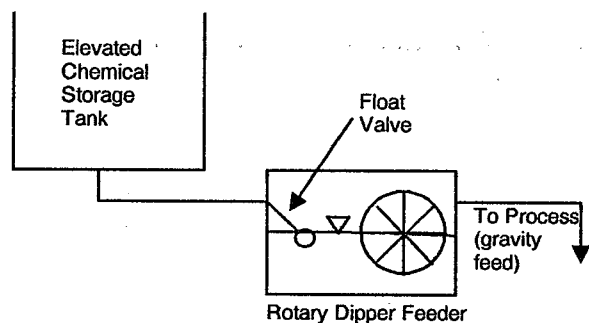
* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

strength with a dissolver detention time of 5 minutes at the maximum feed rate.

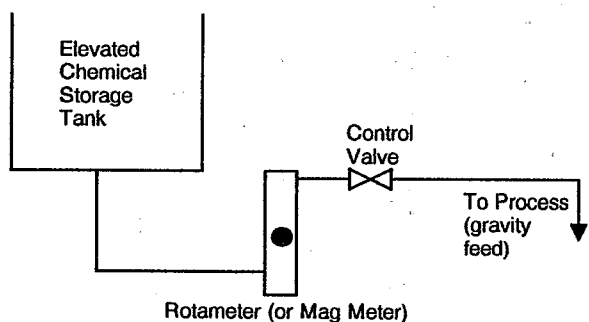
After dissolving dry sodium aluminate in the preparation of batch solutions, agitation should be

minimized or eliminated to prevent deterioration of the solution. Air agitation is not recommended, and solution tanks should be covered to prevent carbonation of the solution.

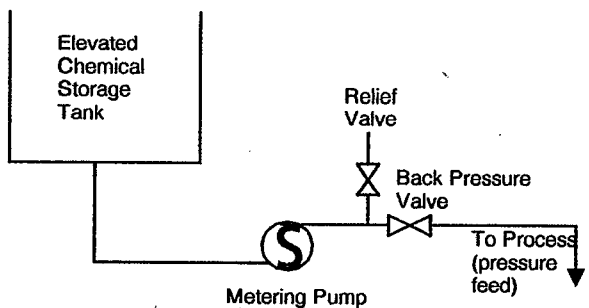
Figure 5-3. Liquid chemical feed system alternatives for elevated storage.



a. Rotary dipper feeder

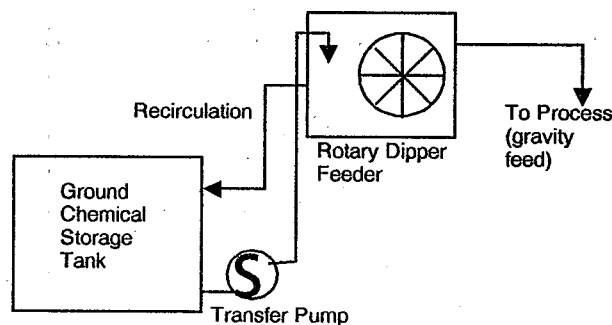


b. Rotameter with control valve

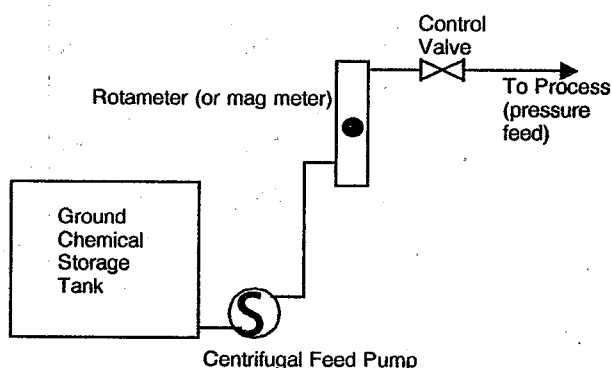


c. Metering pump

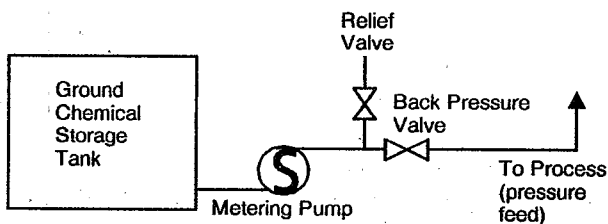
Figure 5-4. Liquid chemical feed system alternatives for ground storage.



a. Rotary dipper feeder



b. Centrifugal pump with rotameter and control valve



c. Metering pump

5.2.3.5 Piping and Accessories

Materials for piping and transporting dry sodium aluminate solution may be mild steel, iron, type 304 stainless steel, concrete, or plastics. The use of copper, copper alloys, and rubber should be avoided.

5.2.3.6 Pacing and Control

Pacing and control fundamentals are similar to those described for dry alum. The amount of dilution is not a consideration in the use of sodium aluminate. Therefore, the use of float valves to satisfy centrifugal pump suction and the use of eductors are permissible.

5.2.4 Liquid Sodium Aluminate

5.2.4.1 Properties and Availability

Liquid sodium aluminate is available in the Chesapeake Bay area from the suppliers listed in Table 5-7. There is considerable variety in the composition of liquid sodium aluminate from the manufacturers listed. The Al_2O_3 content varies from 4.9 to 26.7 percent. The lower solution strengths are usually more expensive because of the cost of transporting the solution water. Because of the variety of solution strengths available, the manufacturers should be contacted for more specific information on density, viscosity, and cost. Liquid sodium aluminate

Table 5-6. Dry Sodium Aluminate Supplier to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations |
|----------------|--|----------------|--|
| Nalco Chemical | 170 Forbes Road Braintree, MA 02184 | (617) 944-7471 | 50-lb bags: 120 bags or less - \$0.50/lb > 120 bags - \$0.45/lb Freight not included. |

Table 5-7. Liquid Sodium Aluminate Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|-------------------|--|----------------|--|
| Nalco Chemical | 2901 Butterfield Road Oak Brook, IL 60521 | (312) 887-7500 | Nalco "1" (12.8 lb/gal): 12-59 30-gal drums - \$0.45/lb > 59 30-gal drums - \$0.36/lb Bulk, 3,000-gal tank truck - \$0.20/lb Nalco "2" (12.1 lb/gal): 12-59 30-gal drums - \$0.38/lb > 59 30-gal drums - \$0.34/lb Bulk, 3,000-gal tank truck - \$0.18/lb |
| Vinings Chemicals | P. O. Box 773 Richboro, PA 18954 | (215) 322-5871 | Vinings "45": \$0.20/lb in drums \$0.14/lb in tank trucks Vinings "38": \$0.195/lb in drums \$0.135/lb in tank trucks |
| Coyne Chemicals | 3015 State Road Croyden, PA 19020 | (215) 785-3000 | Vinings "38": \$0.165/lb in tank trucks (Coyne does not supply Vinings "45" due to freezing problems.) |

* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

is typically available in 114-l (30-gal) drums and 11,400-l (3,000-gal) tank trucks.

5.2.4.2 General Design Considerations

Because of the alkaline nature of liquid sodium aluminate, it should not be used in contact with brass, copper, aluminum, or rubber. Liquid sodium aluminate is a strong alkali, and the same precautions should be exercised in handling it as in handling caustic soda.

5.2.4.3 Storage

Liquid sodium aluminate is usually stored at the shipping concentration, either in the shipping drums or in mild steel tanks. Storage tanks may be located indoors or outdoors; however, outdoor tanks should be provided with facilities for indirect heating. The maximum recommended length of storage is 2 to 3 months. Bulk shipments can be unloaded by gravity, pumping, or air pressure. If air is used, however, it should first be passed through lime-caustic soda breathers to remove carbon dioxide. To avoid this, some treatment plants do not allow shipments to be air unloaded. Steam injection facilities are required at the unloading site.

5.2.4.4 Feeding Equipment

Feeding equipment and systems as described for liquid alum generally apply to liquid sodium aluminate

except with changes of requirements regarding dilution and materials of construction as described above.

Liquid sodium aluminate may be fed at shipping strength or diluted to a stable 5- to 10-percent solution. Stable solutions are prepared by direct addition of low hardness water and mild agitation. Air agitation is not recommended.

5.2.4.5 Piping and Accessories

Piping requirements are the same as previously indicated for solutions of dry sodium aluminate.

5.2.4.6 Pacing and Control

System pacing and control requirements are the same as described for liquid alum.

5.2.5 Aluminum Chloride

Aluminum chloride is available in the Chesapeake Bay area from the supplier listed in Table 5-8.

Much of the aluminum chloride produced is in the form of semi-pure anhydrous crystals with an off-white color. This product is derived from direct chlorination of scrap aluminum and has a molecular weight of 133.3 and purities near 99 percent. In some instances, purities may drop to 96 percent, which is

Table 5-8. Aluminum Chloride Supplier to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|--|--------------------------------------|----------------|--|
| Pearsall Chemical Div. of Witco Corp. | P. O. Box 42817 Houston, TX 77242 | (800) 231-3452 | Bulk: 40,000 lb - \$0.48/lb delivered 50-lb bags: < 100 bags - \$0.61/lb 100-479 bags - \$0.60/lb FOB Philipsburg, NJ > 479 bags - \$0.59/lb delivered |

* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

satisfactory for wastewater treatment if analysis shows other compounds present are acceptable. Another solid form is produced by crystallization from hydrochloric acid in the form of a hexahydrate, in which six molecules of water attach to each molecule of aluminum chloride.

Containers for shipping and storing should be similar to those used for dry and liquid alum. Handling and feeding requirements are also similar to those used with alum. Designers should check with local producers for further details.

5.3 Iron Compounds

The principal iron compounds that are commercially available and suitable for phosphorus precipitation are liquid ferric chloride, ferrous chloride (waste pickle liquor), ferric sulfate, and ferrous sulfate.

5.3.1 Liquid Ferric Chloride

5.3.1.1 Properties and Availability

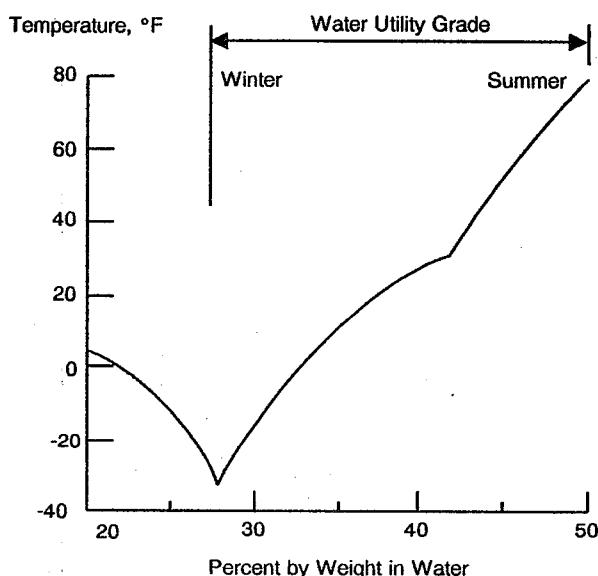
Liquid ferric chloride is a corrosive, dark brown, oily-appearing solution having a typical unit weight between 1.3 and 1.5 kg/l (11.2 and 12.4 lb/gal), or 35 to 45 percent FeCl_3 . The ferric chloride content of these solutions is 0.47 to 0.67 kg/l (3.95 to 5.58 lb/gal). Shipping concentrations vary from summer to winter due to the relatively high crystallization temperature of the more concentrated solutions as shown in Figure 5-5. The pH of a 1-percent solution is 2.0.

The molecular weight of ferric chloride is 162.22. Viscosities of ferric chloride solutions at various temperatures are presented in Figure 5-6.

Liquid ferric chloride is shipped in 11,400- to 15,100-l (3000- to 4,000-gal) bulk truckload lots. Information on suppliers of liquid ferric chloride to the Chesapeake Bay area are provided in Table 5-9.

Tank trucks are normally unloaded pneumatically, and operating procedures must be closely followed to avoid spills and accidents. The safety vent cap and assembly (painted red) should be removed prior to

Figure 5-5. Freezing point curve for commercial ferric chloride solutions.



opening the unloading connection to depressurize the tank truck.

5.3.1.2 General Design Consideration

Ferric chloride solutions are corrosive to many common materials and cause stains that are difficult to remove. Areas subject to staining should be protected with resistant paint or rubber mats.

Normal precautions should be employed when cleaning ferric chloride handling equipment. Workmen should wear rubber gloves, a rubber apron, and goggles or a face shield. If ferric chloride comes in contact with the eyes or skin, flush with copious quantities of running water and call a physician. If ferric chloride is ingested, induce vomiting and call a physician.

5.3.1.3 Storage

Ferric chloride solution can be stored as shipped. Storage tanks should have a free vent or vacuum relief valve. Tanks may be constructed of FRP,

Figure 5-6. Viscosity vs. composition of ferric chloride solutions at various temperatures.

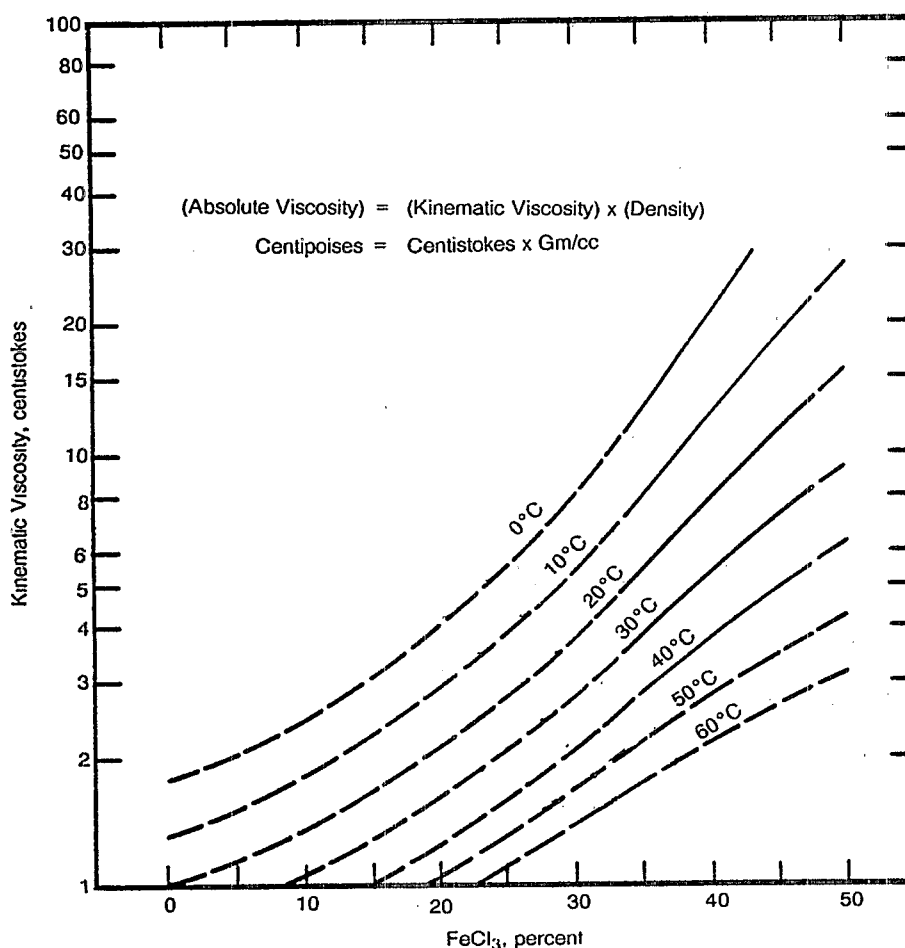


Table 5-9. Liquid Ferric Chloride Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|------------------------|---|----------------|--|
| Manley-Regan Chemicals | East Emmaus Street P. O. Box 391 Middletown, PA 17057 | (717) 994-7471 | \$235/ton A 4,600-gal tank truck contains 17,204 lb of Fe ³⁺ (@ 3.74 lb/gal). Tank Truck is, therefore, \$235/ton x 8.6 tons ÷ 4,600 gal = \$0.44/gal. |
| Coyne Chemicals | 3015 State Road Croyden, PA 19020 | (215) 785-3000 | 32-percent Fe ³⁺ - \$222/dry ton. |

* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

rubber-lined steel, or plastic-lined steel. Resin impregnated carbon or graphite are also suitable materials for storage containers.

It may be necessary in most instances to house liquid ferric chloride tanks in heated areas or provide tank

heaters or insulation to prevent crystallization. Ferric chloride can be stored for long periods of time without deterioration. The total storage capacity should be 1-1/2 times the largest anticipated shipment and should provide at least a 10-day to 2-week supply of the chemical at the design average dose.

5.3.1.4 Feeding Equipment

Feeding equipment and systems described for liquid alum generally apply to ferric chloride except for materials of construction and the use of glass tube rotameters.

It may not be desirable to dilute the ferric chloride solution from its shipping concentration to a weaker feed solution because of possible hydrolysis. Ferric chloride solutions may be transferred from underground storage to day tanks with impervious graphite or rubber-lined, self-priming centrifugal pumps having Teflon rotary and stationary seals. Because of a tendency for liquid ferric chloride to stain or deposit, glass tube rotameters should not be used for metering this solution. Rotodip feeders and diaphragm metering pumps are often used for ferric chloride and should be constructed of materials such as rubber-lined steel and plastics.

5.3.1.5 Piping and Accessories

Materials for piping and transporting ferric chloride should be rubber or Saran-lined steel, hard rubber, FRP, or plastics. Valving should consist of rubber- or resin-lined diaphragm valves, Saran-lined valves with Teflon diaphragms, rubber sleeved pinch-type valves, or plastic ball valves. Gasket material for large openings such as manholes in storage tanks should be soft rubber; all other gaskets should be graphite-impregnated blue asbestos, Teflon, or vinyl.

5.3.1.6 Pacing and Control

System pacing and control requirements are similar to those discussed previously for liquid alum.

5.3.2 Ferrous Chloride (Waste Pickle Liquor)

5.3.2.1 Properties and Availability

Ferrous chloride, FeCl_2 , is available as a liquid in the form of waste pickle liquor from steel processing. The liquor weighs between 1.2 and 1.3 kg/l (9.9 and 10.4 lb/gal) and contains 20 to 25 percent ferrous chloride or about 10 percent available iron. A 22-percent solution of ferrous chloride will crystallize at a temperature of -4°F . The molecular weight of ferrous chloride is 126.76. Free acid in waste pickle liquor can vary from 1 to 10 percent and usually averages about 1.0 to 1.5 percent. Ferrous chloride is slightly less corrosive than ferric chloride.

Ferrous chloride is available in the Chesapeake Bay area in 15,100-l (4000-gal) truckload lots from the supplier listed in Table 5-10.

5.3.2.2 General Design Considerations

Since ferrous chloride or waste pickle liquor may not be available on a continuous basis, storage and feeding equipment should be suitable for handling ferric chloride. Therefore, the ferric chloride section should be referred to for storage and handling details.

5.3.3 Ferric Sulfate

5.3.3.1 Properties and Availability

Ferric sulfate, $\text{Fe}_2(\text{SO}_4)_3 \cdot \text{H}_2\text{O}$, is marketed as a dry, partially hydrated product with seven water molecules. Typical properties are presented in Table 5-11.

Ferric sulfate is typically shipped in 45-kg (100-lb) moisture-proof paper bags. Ferric sulfate is available in the Chesapeake Bay area from the suppliers given in Table 5-12.

General precautions should be observed when handling ferric sulfate, such as wearing goggles and dust masks, and areas of the body that come in contact with the dust or vapor should be washed promptly.

5.3.3.2 General Design Considerations

Aeration of ferric sulfate should be held to a minimum because of the hygroscopic nature of the material, particularly in damp atmospheres. Mixing of ferric sulfate and quicklime in conveying and dust vent systems should be avoided as caking and excessive heating can result. The presence of ferric sulfate and lime in combination has been known to destroy cloth bags in pneumatic unloading devices. Because ferric sulfate in the presence of moisture will stain, precautions similar to those discussed for ferric chloride should be observed.

5.3.3.3 Storage

Ferric sulfate is usually stored in the dry state in the shipping bags.

5.3.3.4 Feeding Equipment

Feed solutions are usually made up at a water-to-chemical ratio of 2:1 to 8:1 (on a weight basis) with the usual ratio being 4:1 with a 20-minute detention time. Care must be taken not to dilute ferric sulfate solutions to less than 1 percent to prevent hydrolysis and deposition of ferric hydroxide. Ferric sulfate is actively corrosive in solution, and dissolving and transporting equipment should be fabricated of type 316 stainless steel, rubber, plastics, ceramics, or lead.

Dry feeding requirements are similar to those for dry alum except that belt feeders are rarely used because of their open-type construction. Closed construction, as found in the volumetric and loss-in-weight type feeders, generally exposes a minimum of operating components to the vapor and thereby minimizes maintenance. A water jet vapor remover should be provided at the dissolver to protect both the machinery and operator.

Table 5-10. Ferrous Chloride Supplier to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations |
|-----------------------|--|----------------|---|
| Byproducts Management | 1150 Junction Schereville, IN 46375 | (219) 322-2560 | \$0.26/lb of Fe^{2+} = \$0.31/gal 4,800-gal truck = 48,000 lb/truck @ 12 percent Fe^{2+} = 5,760 lb Fe^{2+} /truck = \$1,500/truck. Prices include delivery to Chesapeake Bay area. |

Table 5-11. Properties of Ferric Sulfate

| | |
|--|-------|
| Molecular Weight | 526 |
| Bulk Density, lb/cu ft | 56-60 |
| Water Soluble Iron as Fe^{3+} , percent | 21.5 |
| Water Soluble Fe^{3+} , percent | 19.5 |
| Insolubles Total, percent | 2.0 |
| Free Acid, percent | 2.5 |
| Moisture @ 105°C, percent | 2.0 |

5.3.3.5 Pipe and Accessories

Piping systems for ferric sulfate should be FRP, plastics, type 316 stainless steel, rubber, glass, or ceramics.

5.3.3.6 Pacing and Control

System pacing and control are the same as discussed for dry alum.

5.3.4 Ferrous Sulfate

5.3.4.1 Properties and Availability

Ferrous sulfate or copperas is a byproduct of steel pickling and is produced as granules, crystals, powder, and lumps. The most common commercial form of ferrous sulfate is $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ with a molecular weight of 278 and containing 55 to 58 percent FeSO_4 and 20 to 21 percent Fe. The product has a bulk density of 990 to 1,060 kg/m³ (62 to 66 lb/cu ft). When dissolved, ferrous sulfate is acidic. The composition of ferrous sulfate may be quite variable and should be established by consulting the nearest manufacturers.

Ferrous sulfate is available in bags and in the Chesapeake Bay area in 18,200-l (4,800-gal) truckload lots from the supplier given in Table 5-13.

Dry ferrous sulfate cakes at storage temperatures above 68°F, is efflorescent in dry air, and oxidizes and hydrates further in moist air.

General precautions similar to those for ferric sulfate with respect to dust and handling acidic solutions should be observed when working with ferrous sulfate. Mixing quicklime and ferrous sulfate produces high temperatures and the possibility of fire.

5.3.4.2 General Design Considerations

The granular form of ferrous sulfate has the best feeding characteristics, and gravimetric or volumetric feeding equipment may be used.

The optimum chemical-to-water ratio for continuous dissolving is 0.06 kg/l (0.5 lb/gal), or a 6-percent solution with a detention time of 5 minutes in the dissolving tank. Mechanical agitation should be provided in the dissolver to assure complete solution. Lead, rubber, iron, plastics, and type 304 stainless steel can be used as construction materials for handling solutions of ferrous sulfate.

Storage, feeding, and transporting systems probably should be suitable for handling ferric sulfate as an alternative to ferrous sulfate.

5.4 Polyelectrolytes

5.4.1 Dry Polymers

5.4.1.1 Properties and Availability

Types of polymers vary widely in characteristics. Manufacturers should be consulted for properties, availability, and cost of the polymer being considered. Some polymer suppliers available to the Chesapeake Bay area are given in Table 5-14.

5.4.1.2 General Design Considerations

Dry polymer and water must be blended and mixed to obtain a recommended solution for efficient action. Solution concentrations vary from a fraction of a percent to 1 percent or more. Preparation of the stock solution involves wetting of the dry material and usually an aging period prior to application. Solutions can be very viscous, and close attention should be paid to piping size and length and pump selections. Metered solution is usually diluted just prior to injection into the process to obtain better dispersion at the point of application.

5.4.1.3 Storage

General practice for storage of bagged dry chemicals should be observed. The bags should be stored in a dry, cool, low humidity area and used in proper rotation, i.e., first in, first out. Solutions are generally stored in type 316 stainless steel, FRP, or plastic-lined tanks.

Table 5-12. Ferric Sulfate Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations* |
|------------------------|---|----------------|---|
| Manley-Regan Chemicals | East Emmaus Street P. O. Box 391 Middletown, PA 17057 | (717) 994-7471 | 100-lb bags: 20 bags - \$15.30/100 lb 60 bags - \$14.05/100 lb 100 bags - \$13.55/100 lb |
| Coyne Chemicals | 3015 State Road Croydon, PA 19020 | (215) 785-3000 | \$19.75/100 lb |

* Call for applicable freight charges, if any. Generally, prices include freight up to varying distances from the point of manufacture.

Table 5-13. Ferrous Sulfate Supplier to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations |
|-----------------------|--|----------------|--|
| Byproducts Management | 1150 Junction Schereville, IN 46375 | (219) 322-2560 | \$0.31/lb of Fe^{2+} = \$0.20/gal 4,800-gal truck = 48,000 lb/truck @ 6.5 percent Fe^{2+} = 3,120 lb Fe^{2+} /truck = \$970/truck. Prices include delivery to Chesapeake Bay area. |

Table 5-14. Polymer Suppliers to the Chesapeake Bay Area

| Name | Address | Telephone | 1986 Price Quotations |
|--|--|----------------|---|
| Pollu-Tech | 853 2nd Street Pike Brownstone 2 Suite B-200 Richboro, PA 18954 | (215) 357-1821 | Prices vary widely depending on the nature of the product and amount required. Prices typically range from \$1.00 to \$3.00/lb. Call for freight charges. |
| Nalco | 2901 Butterfield Oakbrook, IL 60521 | (312) 887-7500 | |
| Hercules | 910 Market Street Wilmington, DE 19899 | (302) 575-6500 | |
| Calgon | P. O. Box 1346 Pittsburgh, PA 15230 | (412) 777-8000 | |
| American Cyanamid | Berdan Avenue Wayne, NJ 07470 | (201) 831-2000 | |
| Dow | 1603 Santa Rosa Road Richmond, VA 23288 | (904) 288-1601 | |
| DuBois Chemicals Div. W. R. Grace and Co. | 3630 E. Kemper Road Sharonville, OH 45241 | (513) 762-6000 | |

5.4.1.4 Feeding Equipment

Two types of systems are frequently combined to feed polymers. The solution preparation system includes a manual or automatic blending system with the polymer dispensed by hand or by a dry feeder to a wetting jet and then to a mixing-aging tank at a controlled ratio. The aged polymer is transported to a holding tank where metering pumps or rotodip feeders dispense the polymer to the process. A schematic of such a system is shown in Figure 5-7. It is generally advisable to keep the holding or storage time of polymer solutions to a minimum, 1 to 3 days or less, to prevent deterioration of the product.

5.4.1.5 Piping and Accessories

Selection must be made after determination of the polymer; however, type 316 stainless steel or plastics are generally used.

5.4.1.6 Pacing and Control

Controls as described for liquid alum apply to the control of dispensing feeders for polymer solutions. The solution preparation system may be an automatic batching system, as illustrated by the schematic in Figure 5-8, that fills the holding tank with aged polymer as required by level probes. Such a system is usually provided only at large plants. Unitized solution preparation units are available, but have a limited capacity.

5.4.2 Liquid Polymers

5.4.2.1 Properties and Availability

As with dry polymers, a wide variety of products exists and manufacturers should be consulted for specific information. See Table 5-14 for Chesapeake Bay area suppliers.

Figure 5-7. Manual dry polymer feed system.

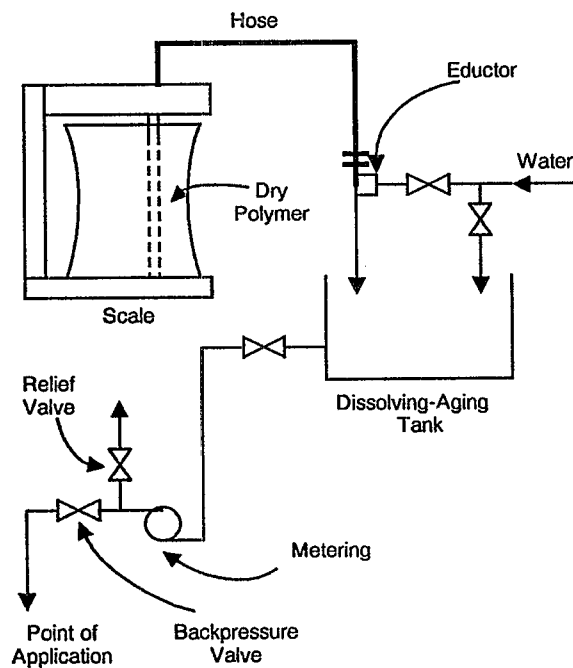
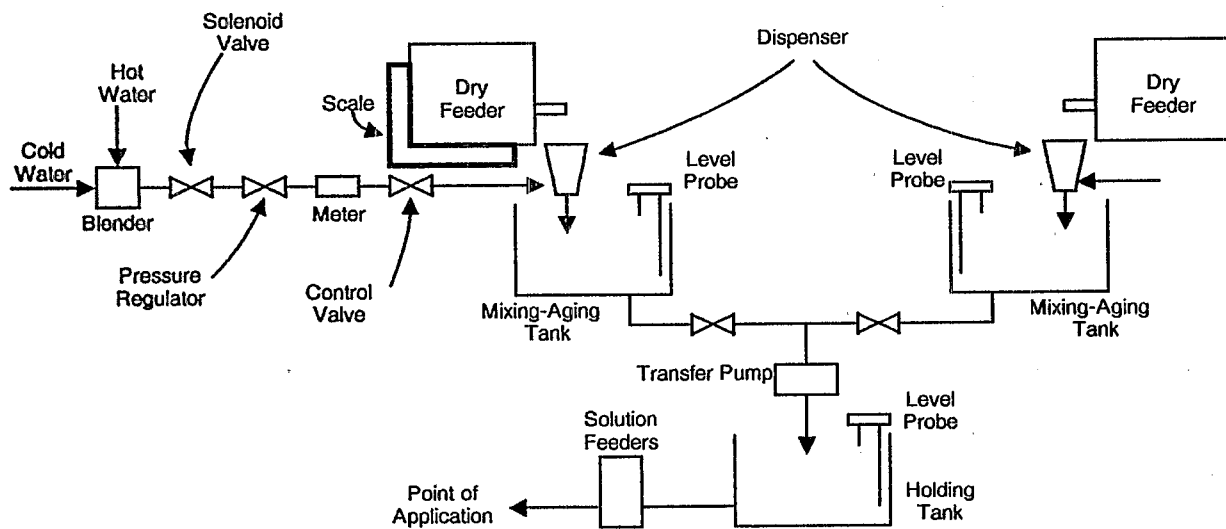


Figure 5-8. Automatic dry polymer feed system.



5.4.2.2 General Design Considerations

Liquid systems differ from the dry systems only in the equipment to blend the polymer with water to prepare the solution. Liquid solution preparation is usually a hand-batching operation with manual filling of a mixing-aging tank with water and polymer.

5.4.2.3 Feeding Equipment

Liquid polymers need no aging, and simple dilution is the only requirement for feeding. The dosage of liquid polymers may be accurately controlled by metering pumps or rotodip feeders.

The remainder of the feed system is generally the same as described for dry polymers.

5.5 Design of Chemical Feed Systems

5.5.1 Chemical Feed Systems

Chemical feed systems must be flexibly designed to provide for a high degree of reliability in view of the many contingencies that may affect their operation. Thorough wastewater characterization in terms of flow extremes and chemical requirements should precede the design of the chemical feed system. The design of the chemical feed system must take into account the form of each chemical desired for feeding, the particular physical and chemical characteristics of the chemical, maximum waste flows, and the operational reliability of the feeding devices.

The capacity of a chemical feed system is an important consideration in both storage and feeding. Storage capacity design must take into account the advantage of quantity purchase vs. the disadvantage of construction cost and chemical deterioration with time. Potential delivery delays and chemical use rates are necessary factors in the total picture. Storage tanks or bins for solid chemicals must be designed with proper consideration of the angle of repose of the chemical and its necessary environmental requirements, such as temperature and humidity. Size and slope of feeding lines are important along with their materials of construction with respect to the corrosiveness of the chemicals.

5.5.2 Chemical Feeders

The chemicals added to wastewater to remove phosphorus are either in liquid or solid form. Those in solid form are usually converted to solution or slurry form prior to introduction into the wastewater stream; however, some chemicals are fed in a dry form. In either case, some type of solids feeder is usually required. Chemical feeders are available in a variety of types because of wide ranges in chemical characteristics, feed rates, and degree of accuracy required. Liquid feeding is somewhat more restrictive, depending mainly on liquid volume and viscosity.

Chemical feeders must accommodate the minimum and maximum feeding rates required. Manually

controlled feeders typically have a range of 20:1, but this range can be increased to about 100:1 with dual control systems. Chemical feeder control can be manual, automatically proportioned to flow, dependent on some form of process feedback, or a combination of any two of these. More sophisticated control systems are feasible if proper sensors are available. If manual control systems are specified with the possibility of future automation, the feeders selected should be amenable to this conversion with a minimum of expense. An example would be a feeder with an external motor that could easily be replaced with a variable speed motor or drive when automation is installed. Standby or backup units should be included for each type of feeder used. Reliability calculations will be necessary in larger plants with a greater multiplicity of these units. Points of chemical addition and piping to them should be capable of handling all possible changes in dosing patterns to provide proper flexibility of operation. Designed flexibility in hoppers, tanks, chemical feeders, and solution lines is the key to maximum benefits at least cost.

5.5.2.1 Liquid Feeders

Liquid feeders are generally furnished in the form of metering pumps or orifices. Usually these metering pumps are of the positive displacement variety, plunger type, or diaphragm type. The choice of liquid feeder is highly dependent on the viscosity, corrosivity, solubility, suction and discharge heads, and internal pressure-relief requirements. Some examples are shown in Figures 5-9 and 5-10. In some cases, control valves and rotameters may be all that is required. In other cases, such as polymer feeding, progressive cavity pumps are used with appropriate controls. More complete descriptions of liquid feeder requirements can be found in the literature and in manufacturer's catalogs.

5.5.2.2 Dry Feeders

Solids characteristics vary greatly, and the choice of feeder must be considered carefully, particularly in the smaller-sized facility where a single feeder may be used for more than one chemical. Generally, provisions should be made to keep all chemicals cool and dry. Dryness is very important, as hygroscopic (water absorbing) chemicals may become lumpy, viscous, or even rock hard; other chemicals with less affinity for water may become sticky from moisture on the particulate surfaces, causing increased arching in hoppers. In either case, moisture will affect the density of the chemical and may result in under-feed. Dust removal equipment should be used at shoveling locations, bucket elevators, hoppers, and feeders for neatness, corrosion prevention, and safety reasons. Collected chemical dust may often be reused.

The simplest method for feeding solid chemicals is by hand. Chemicals may be preweighed or simply

Figure 5-9. Plunger-type metering pump (courtesy of Wallace & Tiernan).

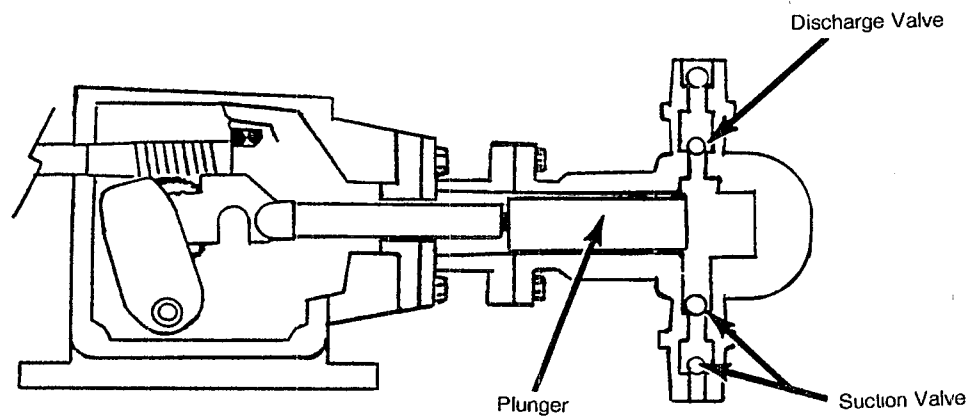
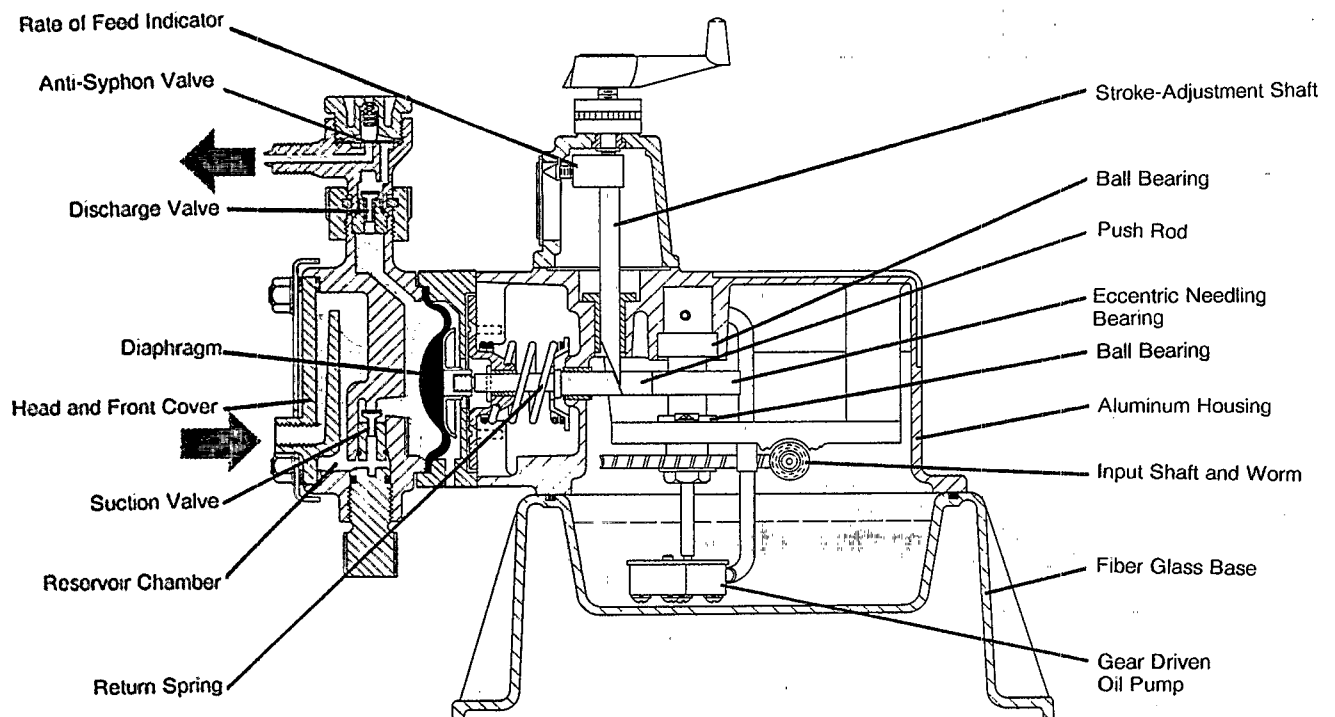


Figure 5-10. Diaphragm-type metering pump (courtesy of Wallace & Tiernan).



shoveled or poured by the bagful into a dissolving tank. This method is limited to very small wastewater plants, or to chemicals used in very weak solutions. Also, dry chemicals can be drawn into the dissolving tank by means of an eductor.

Because of the many factors, such as moisture content, grades, and compressibility, that can affect chemical density (weight-to-volume ratio), volumetric feeding of solids is normally restricted to smaller wastewater plants, specific types of chemicals that are reliably constant in composition, and low rates of feed. Within these restrictions, several volumetric types are available. Accuracy of feed is usually limited to plus or minus 2 percent by weight, but may be as high as plus or minus 5 percent.

One type of volumetric dry feeder uses a continuous belt of specific width moving from under the hopper to the dissolving tank. A mechanical gate mechanism regulates the depth of material on the belt, and the rate of feed is governed by the speed of the belt and/or the height of the gate opening. The hopper normally is equipped with a vibratory mechanism to reduce arching. This type of feeder is not suited for easily fluidized chemicals.

Another type employs a screw or helix from the bottom of the hopper through a tube opening slightly larger than the diameter of the screw or helix. Rate of feed is governed by the speed of the screw or helix rotation. Some screw-type designs are self-cleaning, while others are subject to clogging. A typical screw feeder is shown in Figure 5-11.

Most remaining types of volumetric feeders generally fall into the positive displacement category. All designs incorporate some form of moving cavity of a specific or variable size. In operation, the chemical falls by gravity into the cavity and is more or less fully enclosed and separated from the hopper's feed. The size of the cavity and the rate at which the cavity moves and is discharged govern the amount of material fed. One unique design is the progressive cavity metering pump, a non-reciprocating type. Positive displacement feeders often utilize air injection to enhance flowability of the chemical.

The basic drawback of volumetric feeder design, its inability to compensate for changes in the density of materials, can be overcome by including a gravimetric or loss-in-weight controller. This modification allows for weighing of the chemical as it is fed. The beam balance type, shown in Figure 5-12, measures the actual mass of chemical. This is considerably more accurate, particularly over a long period of time, than the less common spring-loaded gravimetric designs. Gravimetric feeders are used where feed accuracy of about plus or minus 1 percent is required for economy (as in large-scale operations) or when chemicals are used in small, precise quantities. It

should be noted, however, that even gravimetric feeders cannot compensate for weight added to the chemical by excess moisture. Many volumetric feeders can be converted to a loss-in-weight function by placing the entire feeder on a platform scale that is tared to neutralize the weight of the feeder.

Good housekeeping and the need for accurate feed rates dictate that the gravimetric feeder be shut down and thoroughly cleaned on a regular basis. Although many of these feeders have automatic or semi-automatic devices that compensate to some degree for accumulated solids on the weighing mechanism, accuracy is affected, particularly on humid days when hygroscopic chemicals are fed. In some cases, built-up chemicals can actually jam the equipment.

5.5.2.3 Dissolvers

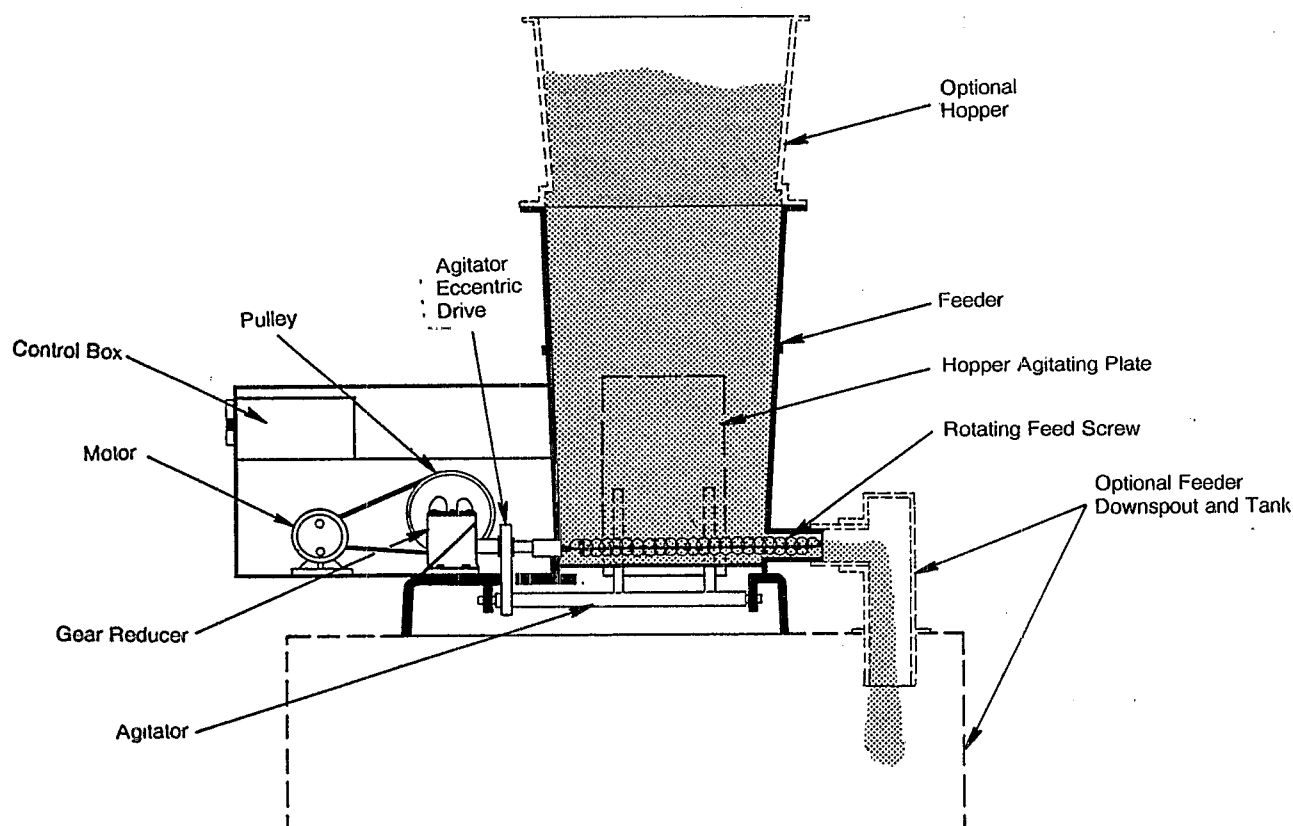
Most feeders, regardless of type, discharge their material to a small dissolving tank that is equipped with a nozzle system and/or mechanical agitator depending on the solubility of the chemical being fed. Solid chemicals, such as polymers, can be carefully spread into a vortex spray or washdown jet of water immediately before entering the dissolver. It is essential that the surface of each particle become thoroughly wetted before entering the feed tank to ensure accurate dispersal and to avoid clumping, settling, or floating.

A dissolver for a dry chemical feeder is unlike a chemical feeding mechanism, which by simple adjustment and change of speed can vary its output tenfold. The dissolver must be designed for the job to be done. A dissolver suitable for a rate of 4.5 kg (10 lb)/hr may not be suitable for dissolving at a rate of 45 kg (100 lb)/hr. As a general rule, dissolvers may be oversized, but dissolvers for commercial ferric sulfate do not perform well if greatly oversized due to a hydrolysis reaction with water.

It is essential that specifications for dry chemical feeders include specifications on dissolver capacity. A number of factors need to be considered in designing dissolvers of proper capacity. These include detention times and water requirements, as well as other factors specific to individual chemicals.

The capacity of a dissolver is based on detention time, which is directly related to the wettability (or rate of solution) of the chemical. Therefore, the dissolver must be large enough to provide the necessary detention for both the chemical and the water at the maximum rate of feed. At lower rates of feed, the strength of solution or suspension leaving the dissolver will be less, but the detention time will be approximately the same unless the water supply to the dissolver is reduced. When the water supply to any dissolver is controlled for the purpose of forming a constant strength solution, mixing within the

Figure 5-11. Screw feeder (courtesy of Wallace & Tiernan).



dissolver must be accomplished by mechanical means because sufficient power will not be available from the mixing jets at low rates of flow. Hot water dissolvers are also available to minimize the required tankage.

5.5.2.4 Chemical Feeders Summary

The foregoing descriptions give some indication of the wide variety of materials that may be handled. Because of this variety, a facility may contain any number of different types of feeders with combined or multiple materials capability. Ancillary equipment to the feeder also varies according to the material to be handled. Liquid feeders encompass a limited number of design principles that account for density and viscosity ranges. Solids feeders, relatively speaking, vary considerably due to the wide range of physical and chemical characteristics, feed rates, and the degree of precision and repeatability required. Table 5-15 describes several types of chemical feeders commonly used in wastewater treatment.

5.5.3 Sizing Chemical Feed System Components

Components of the chemical feed system must be sized so that chemicals can be applied at the required

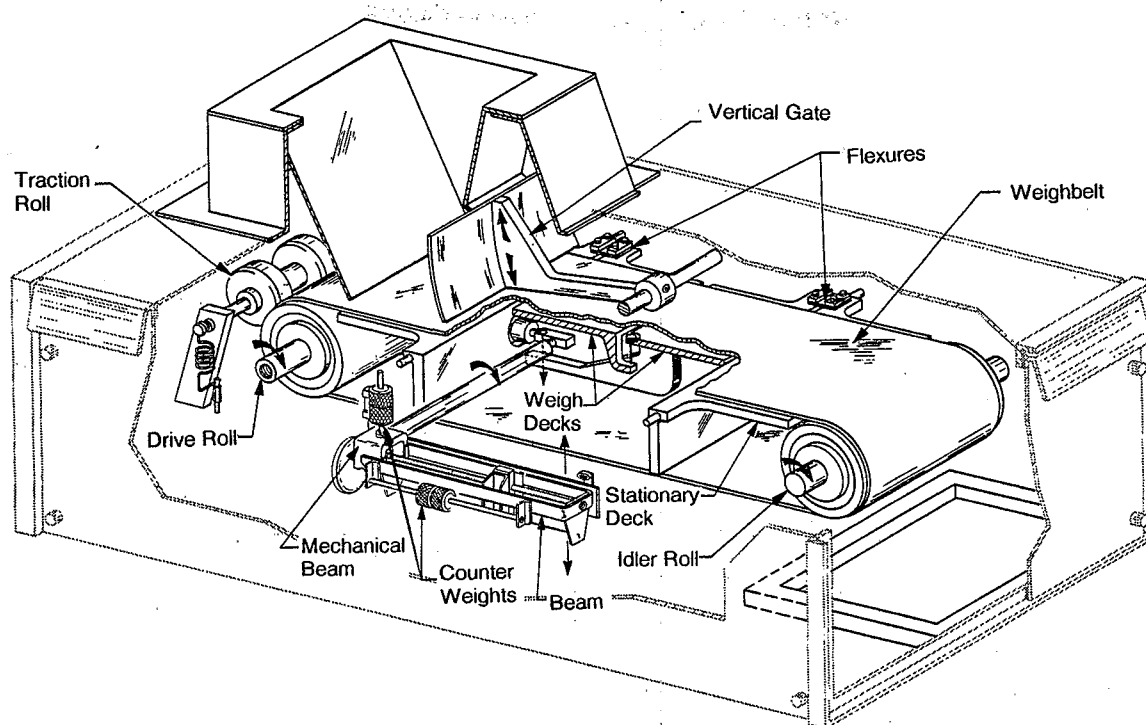
rates and so that manpower required to receive, transfer, and mix chemicals is kept to a minimum. The chemical feed system consists of storage tanks or bins, day tanks or hoppers, liquid or dry feeders, and the necessary transfer systems.

Chemical storage facilities are sized so that a capacity equal to approximately 30 days of storage is available at average chemical rates of application. Chapter 4 provides details on chemical usage rate calculations. Bulk facilities for smaller plants must have a capacity great enough to hold 1-1/2 times the minimum shipment of chemical.

At smaller wastewater plants where chemicals are mixed in a batch, or with polymer systems, day tanks are normally provided. Day tanks act as aging vessels for polymer systems and allow the operator to visually judge the amount of chemical fed during a shift or 24-hour period. Day tanks are typically sized to hold a 24-hour supply of chemical at the maximum rate of chemical application.

At larger wastewater plants where dry chemicals can be stored in bulk, hoppers are usually located above

Figure 5-12. Beam balance-type gravimetric feeder (courtesy of Wallace & Tiernan).



the dry chemical feeders to provide a continuous supply of chemical to the feeder. The chemical hopper is generally a part of the bulk storage bin. If the bulk storage bin cannot be located above the dry chemical feeders, it may be necessary to provide a day hopper with a pneumatic conveying system to transfer dry chemical from bulk storage to the day hopper. The day hopper should be large enough to hold a minimum of 8 hours of chemical at maximum feed rates. A 24-hour capacity at the rate of maximum supply is preferable. Smaller dry feeders and dissolvers typically have integral hoppers large enough to hold 1-1/2 bags of chemical.

Both liquid and dry feeders must be sized so that they are capable of delivering both the maximum and minimum chemical dosages. In some cases, it may be necessary to provide multiple pumps or feeders to span the required chemical feed rates.

5.5.4 Optimum Feed Points and Feed Point Flexibility

Phosphorus removal chemicals can be added at many different points in the wastewater treatment process. It is best to design feed point flexibility into the chemical feed system. Provisions should be made to feed chemicals ahead of primary clarification as well as ahead of secondary clarification. With the required pipework in place, the necessary feed point

or combination of feed points can be used to attain the desired level of treatment in the most efficient manner.

Addition of metal salts ahead of primary clarification typically results in a greater usage of chemical than would be the case if added ahead of or to the secondary system. Suspended solids and BOD reduction in primary clarification are enhanced with the addition of metal salts. This enhanced performance leads to the production of greater volumes of primary sludge, but also improves the treatment process efficiency by reducing the load to the secondary system.

Metal salts added ahead of or to the secondary system can be utilized more efficiently, particularly with the activated sludge process. With addition ahead of or to the secondary system, final clarifier performance is improved and, in the case of the activated sludge process, a large fraction of the metal salt is returned to the head of the aeration tank with the return sludge. See Chapter 2 for a more detailed discussion of chemical feed application points.

5.5.5 Room Layouts for Chemical Storage, Preparation, and Pumping

Typical room layouts for storage, solution preparation, and pumping of ferric chloride and polymer are

Table 5-15. Types of Chemical Feeders

| Type of Feeder | Use | Limitations | |
|-------------------------------------|---|-----------------------------------|---------------------------|
| | | Capacity cu ft/hr | Range |
| Dry Feeder: | | | |
| <u>Volumetric</u> | | | |
| Oscillating plate | Any material, granules or powder. | 0.01 - 35 | 40 to 1 |
| Oscillating throat (universal) | Any material, any particle size. | 0.002 - 100 | 40 to 1 |
| Rotating disc | Most materials including NaF, granules, or powder | 0.01 - 1.0 | 20 to 1 |
| Rotating cylinder (star) | Any material; granules or powder. | 8 - 2,000 or 7.2 - 300 | 10 to 1 or 100 to 1 |
| Screw | Dry, free-flowing material, powder or granular. | 0.05 - 18 | 20 to 1 |
| Ribbon | Dry, free-flowing material, powder, granular, or lumps. | 0.002 - 0.16 | 10 to 1 |
| Belt | Dry, free-flowing material up to 1.5-in size, powder or granular. | 0.1 - 3,000 | 10 to 1 or 100 to 1 |
| <u>Gravimetric</u> | | | |
| Continuous-belt and scale | Dry, free-flowing, granular material or floodable material. | 0.02 to 2 | 100 to 1 |
| Loss in weight | Most materials, powder, granular, or lumps. | 0.02 to 80 | 100 to 1 |
| Solution Feeder: | | | |
| <u>Nonpositive Displacement</u> | | | |
| Decanter (lowering pipe) | Most solutions or light slurries. | 0.01 to 10 | 100 to 1 |
| Orifice | Most solutions. | 0.16 to 5 | 10 to 1 |
| Rotameter (calibrated valve) | Clear solutions. | 0.005 to 0.16 or 0.01 to 20 | 10 to 1 |
| Loss in weight (tank control valve) | Most solutions. | 0.002 to 0.20 | 30 to 1 |
| <u>Positive Displacement</u> | | | |
| Rotating dipper | Most solutions or slurries. | 0.1 to 30 | 100 to 1 |
| <u>Proportioning Pump</u> | | | |
| Diaphragm | Most solutions, special unit for 5-percent slurries.* | 0.004 to 0.15 | 100 to 1 |
| Piston | Most solutions, light slurries. | 0.01 to 170 | 20 to 1 |

* Uses special heads and valves for slurries.

presented in Figures 5-13 through 5-22. The figures cover the range of 0.004 to 0.44 m³/s (0.1 to 10 mgd); 6 to 10 mg/l and 3 to 6 mg/l influent TP; and 0.2, 0.5, 1.0, and 2.0 mg/l effluent TP. These layouts are suitable for conceptual design applications and observe all regulatory requirements.

(Note: For alum, the storage volume requirements are approximately 50 percent more than for ferric chloride. However, due to standard storage tank sizes, this does not always translate into larger tank requirements. Also, an anti-siphon leg should be installed downstream of the feed pump for alum or ferric chloride when the application point is below the level of the day tank.)

As indicated previously in Chapter 2, a theoretical model being developed from research currently in progress (1,2) predicts that metal ion dose requirements to attain low effluent TP concentrations of <1 mg/l are independent of influent TP concentration. Published data confirming this model are lacking at this time. In the absence of such data, the room layouts in Figures 5-13 through 5-22 were developed on the basis of conventional metal ion-to-influent TP dose relationships for all four effluent TP limitations considered in this document. If

the above theory (1,2) is eventually verified, separate room layouts would not be appropriate for the 0.5- and 0.2-mg/l TP effluent limits. Accordingly, a portion of Figure 5-13 (0.2-mg/l effluent TP limit at influent TP of 3-6 mg/l and plant flow of 1 mgd) would become identical to Figure 5-15 (0.2-mg/l effluent TP limit at influent TP of 6-10 mg/l and plant flow of 1 mgd). Similarly, Figure 5-16 (0.5-mg/l effluent TP limit at influent TP of 3-6 mg/l and plant flow of 5 mgd) would become identical to Figure 5-19 (0.5-mg/l effluent TP limit at influent TP of 6-10 mg/l and plant flow of 5 mgd).

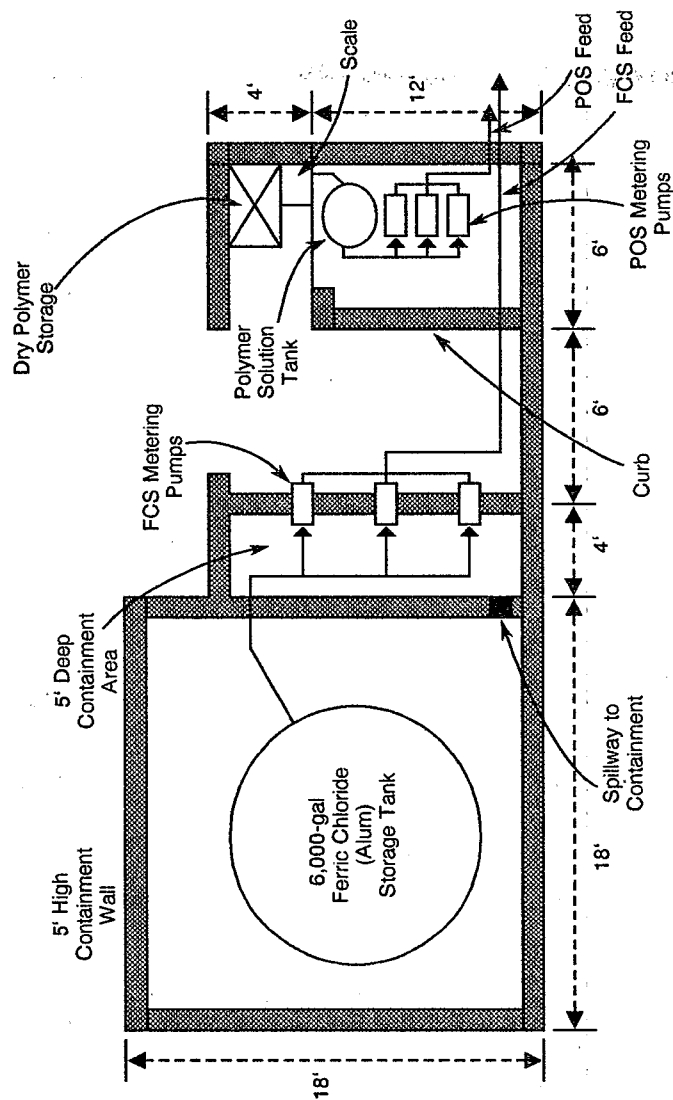
5.6 Chemical Equipment Suppliers

The various manufacturers and local Chesapeake Bay Area representatives of chemical feed equipment (dry chemical feeders, chemical feed pumps, polymer preparation systems, and chemical storage tanks) are listed in Tables 5-16 through 5-19.

5.7 Staffing Requirements for Chemical Addition

A treatment plant that is retrofitted to remove phosphorus by chemical addition will require additional man-hours to operate and maintain the

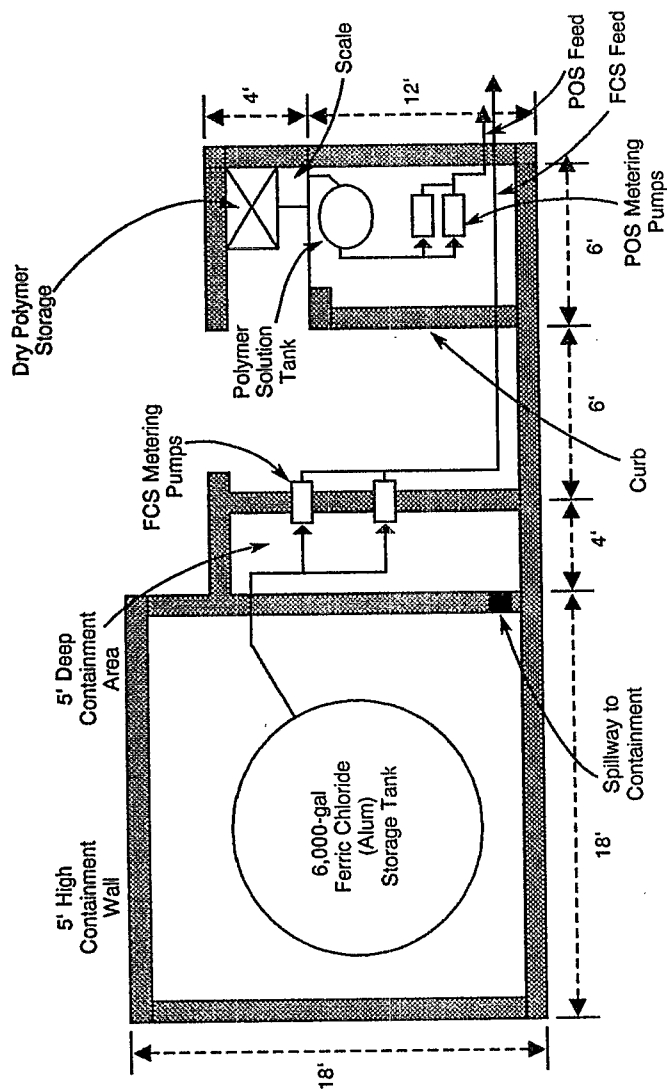
Figure 5-13. Typical chemical system layout No. 1.



FCS - Ferric Chloride (Alum) Solution
POS - Polymer Solution

| Plant Flow (mgd) | This Layout Applies To: | |
|---------------------|-------------------------|-----------------------|
| | Influent TP (mg/l) | Effluent TP (mg/l) |
| 0.1 | 3-6 | 0.2 |
| 0.1 | 6-10 | 0.2 |
| 1 | 3-6 | 0.2 |

Figure 5-14. Typical chemical system layout No. 2.



This Layout Applies To:

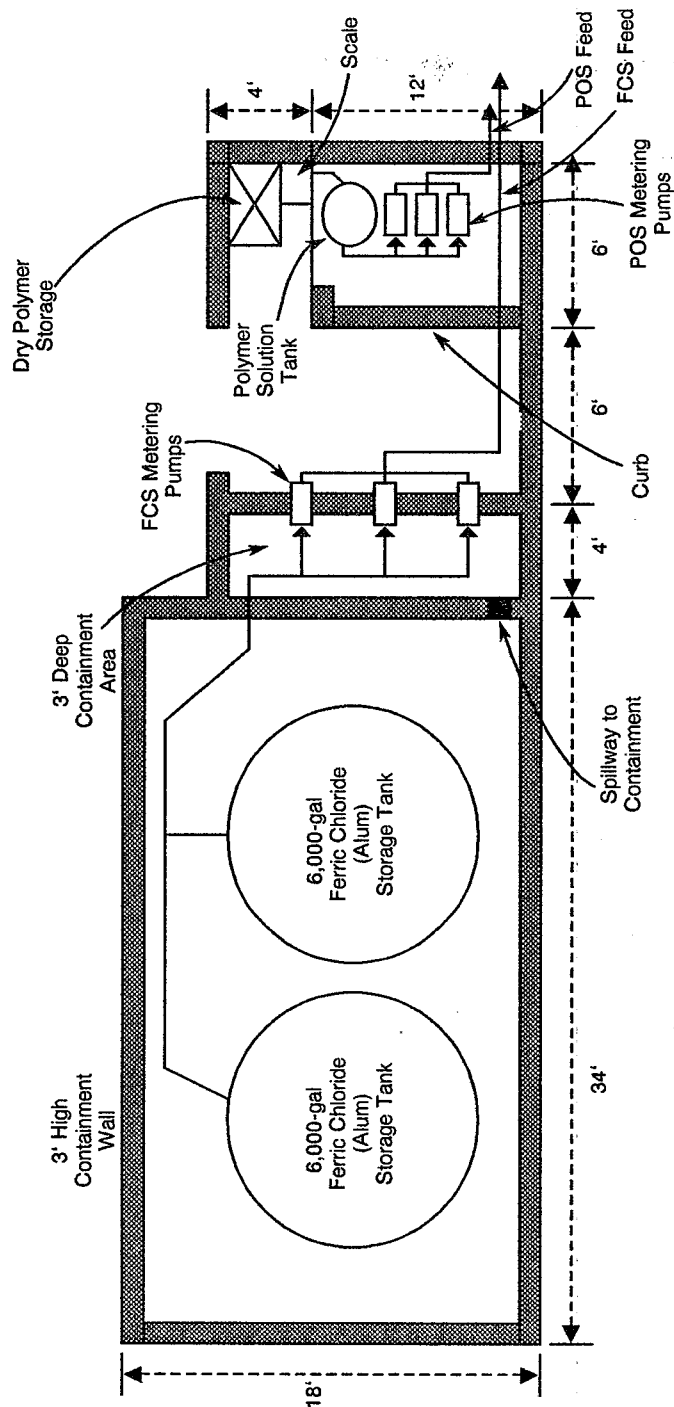
| Influent TP (mg/l) | Effluent TP (mg/l) |
|-----------------------|-----------------------|
| 3-6 | 0.5 |
| 3-6 | 1-2 |
| 6-10 | 0.5 |
| 6-10 | 1-2 |
| 3-6 | 0.5 |
| 3-6 | 1-2 |
| 6-10 | 0.5 |
| 6-10 | 1-2 |

FCS - Ferric Chloride (Alum) Solution
POS - Polymer Solution

Plant Flow
(mgd)

0.1
0.1
0.1
0.1
1
1
1
1

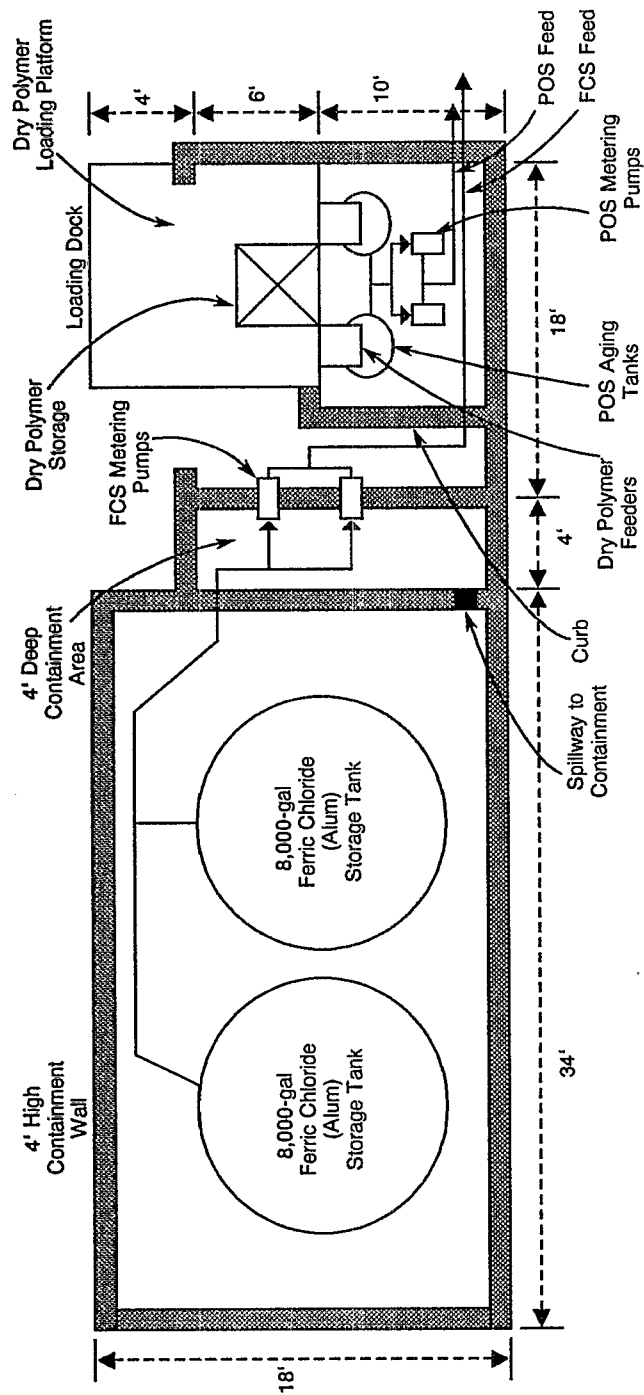
Figure 5-15. Typical chemical system layout No. 3.



FCS - Ferric Chloride (Alum) Solution
POS - Polymer Solution

| Plant Flow (mgd) | This Layout Applies To: | |
|---------------------|-------------------------|-----------------------|
| | Influent TP (mg/l) | Effluent TP (mg/l) |
| 1 | 6-10 | 0.2 |

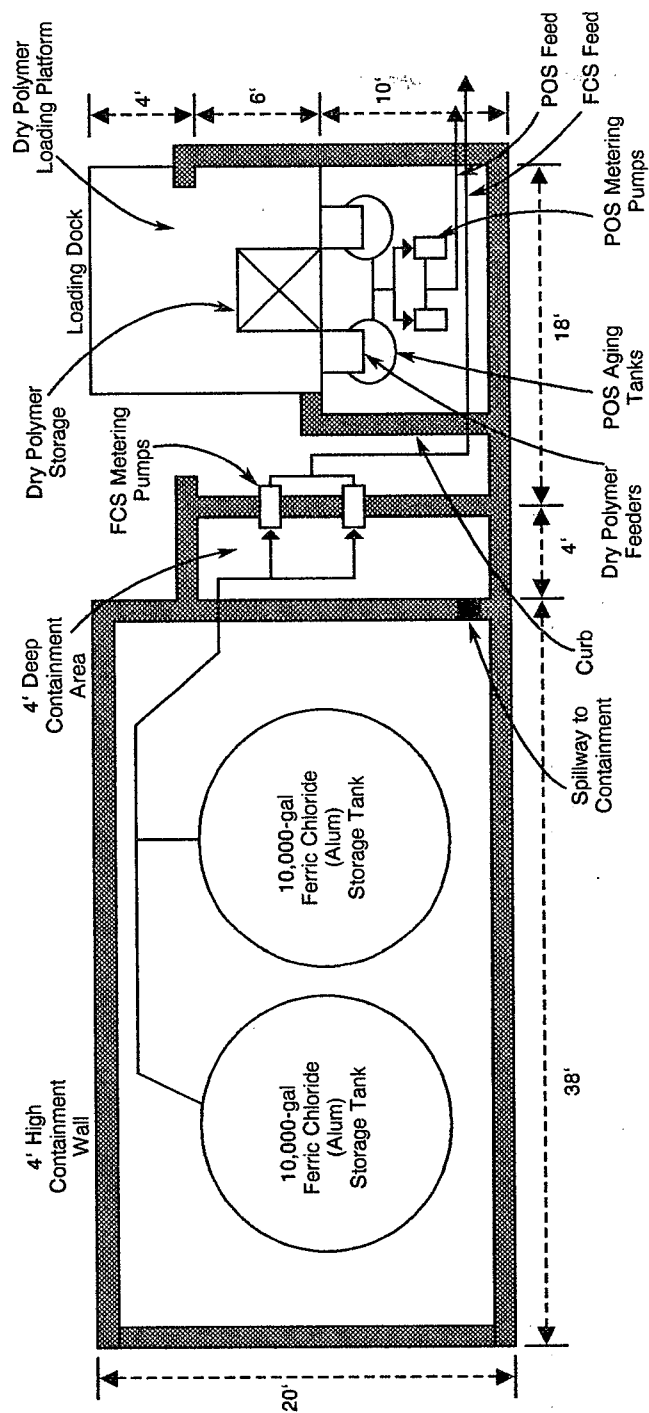
Figure 5-16. Typical chemical system layout No. 4.



FCS - Ferric Chloride (Alum) Solution
POS - Polymer Solution

| This Layout Applies To: | | |
|-------------------------|-----------------------|-----------------------|
| Plant Flow (mgd) | Influent TP (mg/l) | Effluent TP (mg/l) |
| 5 | 3-6 | 0.5 |

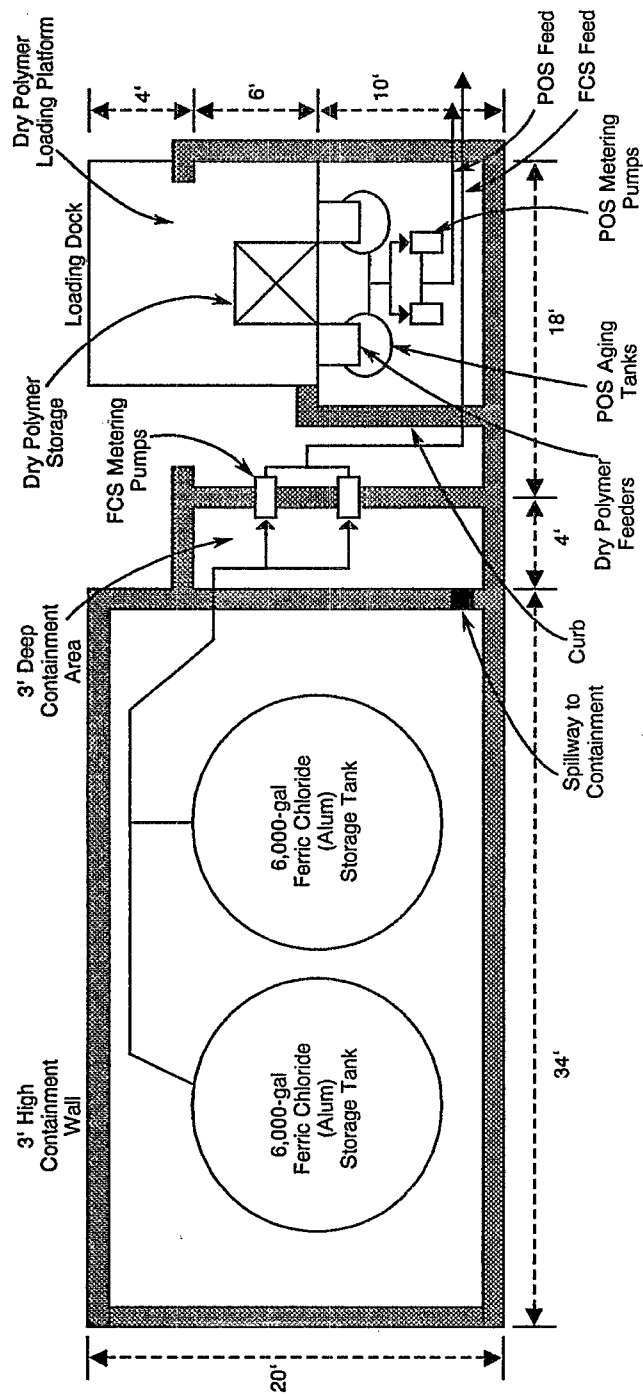
Figure 5-17. Typical chemical system layout No. 5.



FCS - Ferric Chloride (Alum) Solution
 POS - Polymer Solution

| Plant Flow (mgd) | This Layout Applies To: | |
|---------------------|-------------------------|-----------------------|
| | Influent TP (mg/l) | Effluent TP (mg/l) |
| 5 | 6-10 | 1-2 |

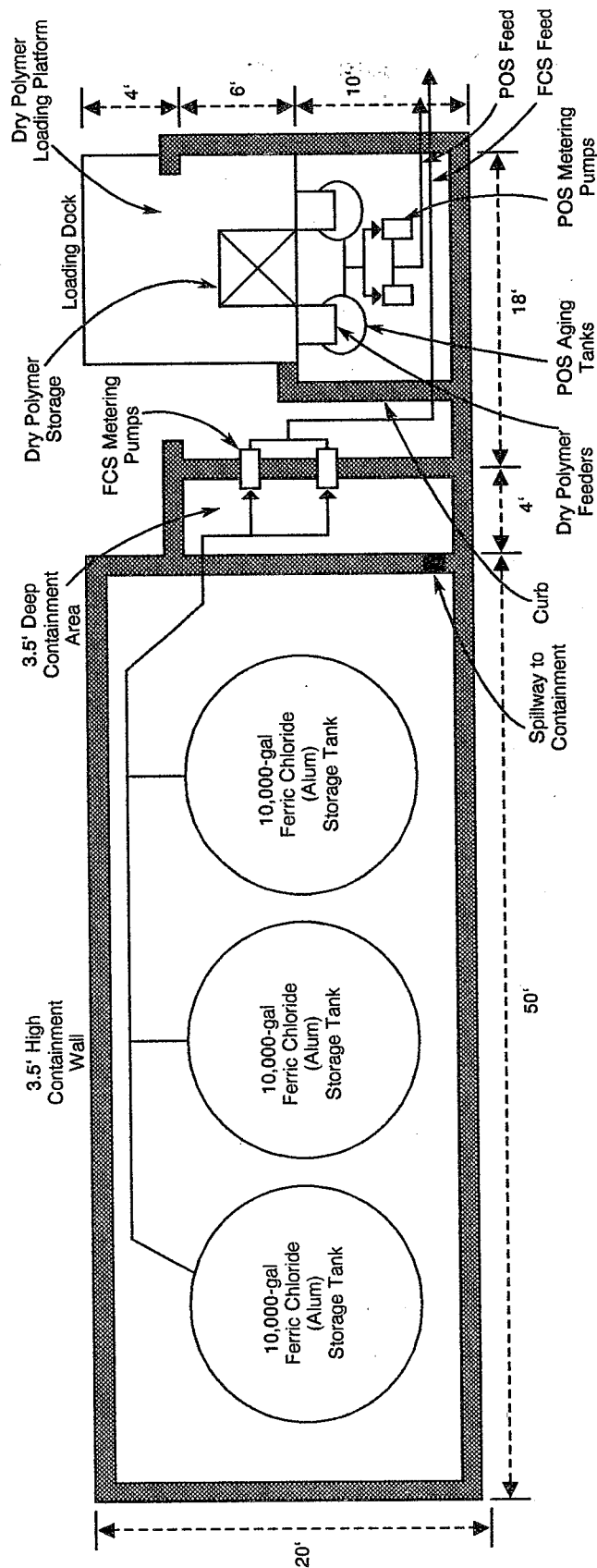
Figure 5-18. Typical chemical system layout No. 6.



FCS - Ferric Chloride (Alum) Solution
 POS - Polymer Solution

| Plant Flow (mgd) | This Layout Applies To: | |
|---------------------|-------------------------|-----------------------|
| | Influent TP (mg/l) | Effluent TP (mg/l) |
| 5 | 3-6 | 1-2 |

Figure 5-19. Typical chemical system layout No. 7.



| | | |
|---|-------------------------|-----------------------|
| FCS - Ferric Chloride (Alum) Solution POS - Polymer Solution | This Layout Applies To: | |
| | Plant Flow (mgd) | Influent TP (mg/l) |
| | 5 | 6-10 |
| | | Effluent TP (mg/l) |
| | | 0.5 |

Figure 5-20. Typical chemical system layout No. 8.

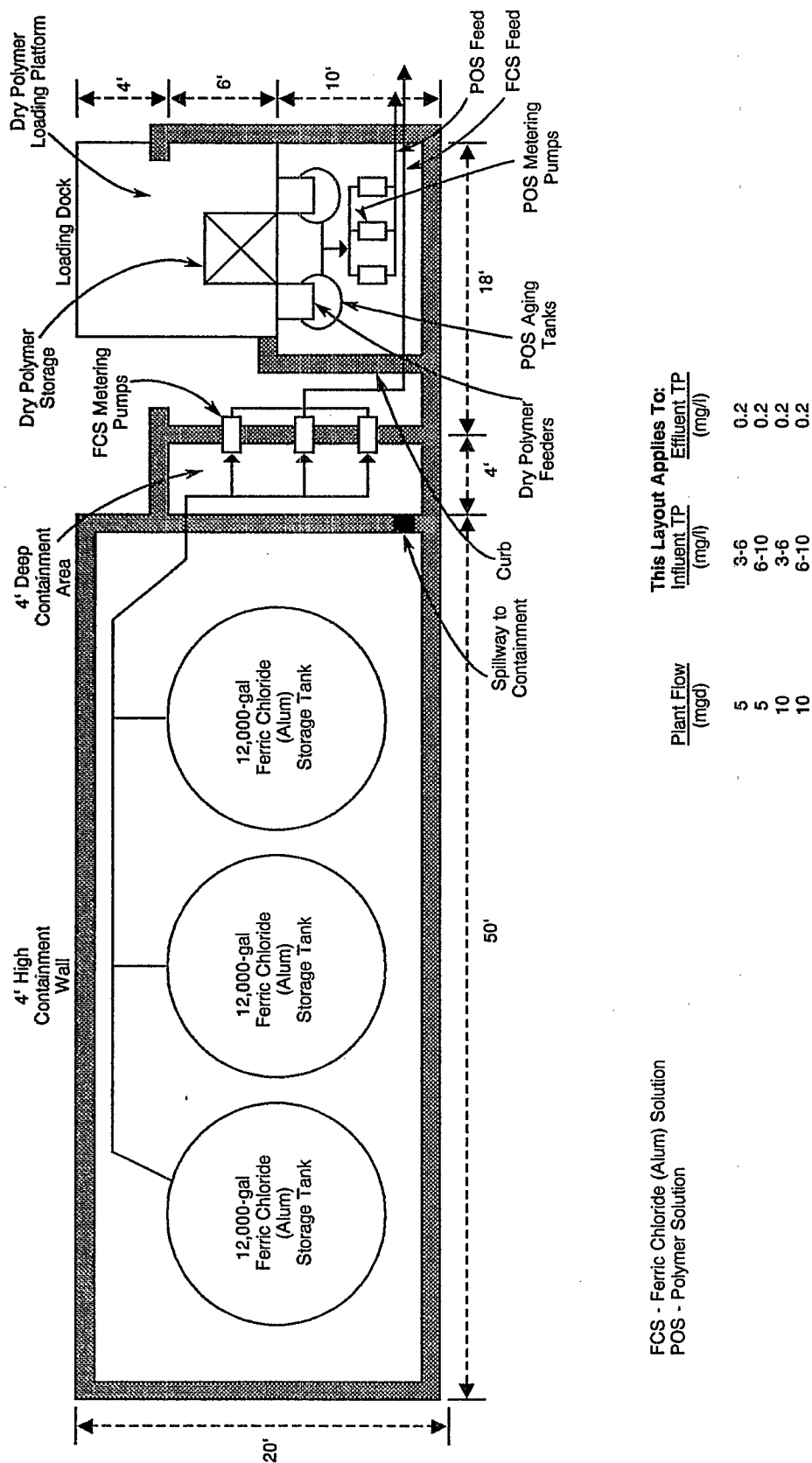
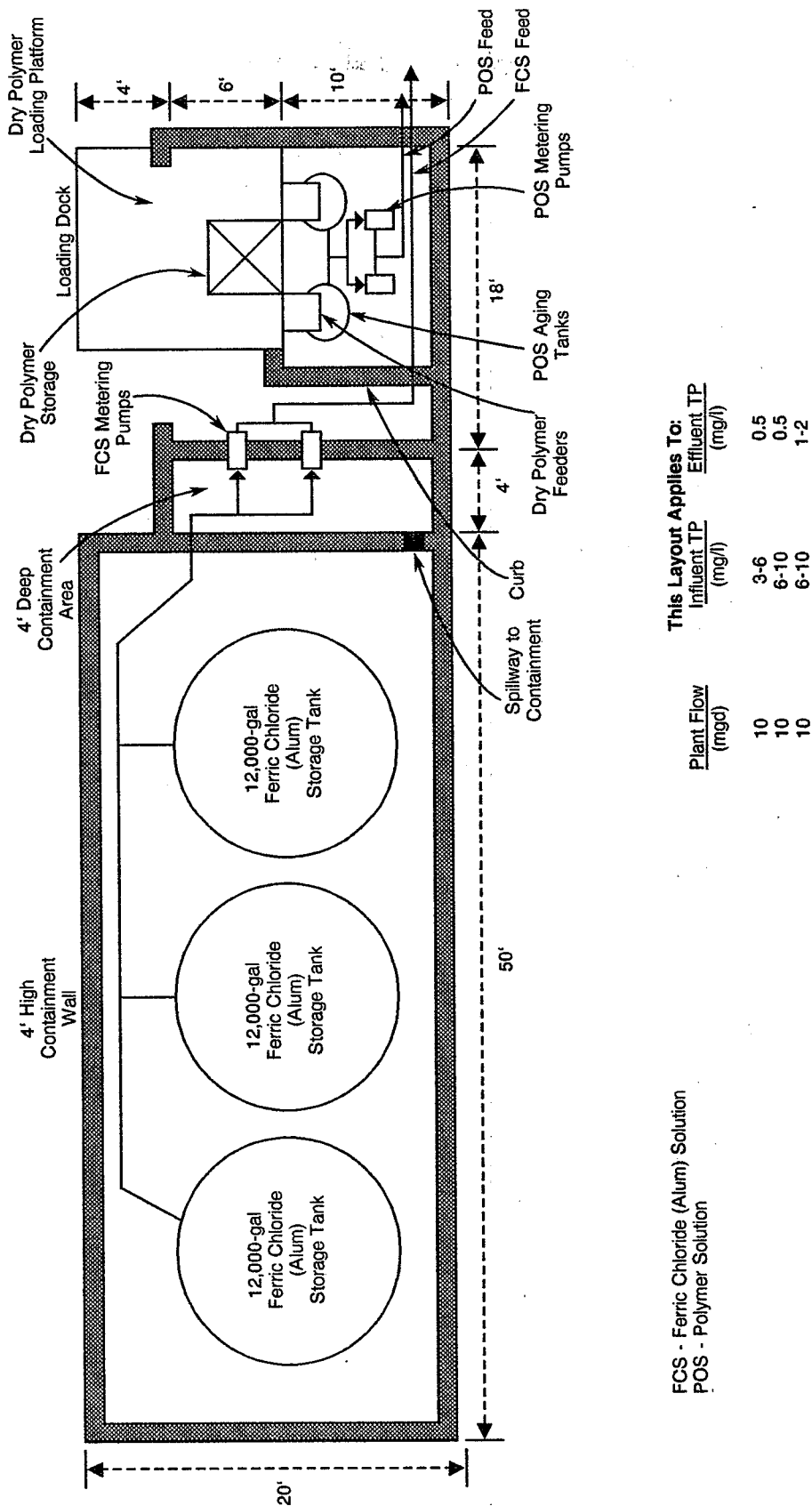


Figure 5-21. Typical chemical system layout No. 9.



FCS - Ferric Chloride (Alum) Solution
 POS - Polymer Solution

| This Layout Applies To: | | |
|-------------------------|-----------------------|-----------------------|
| Plant Flow (mgd) | Influent TP (mg/l) | Effluent TP (mg/l) |
| 10 | 3-6 | 0.5 |
| 10 | 6-10 | 0.5 |
| 10 | 6-10 | 1-2 |

This Layout Applies To:

| | | |
|-------------------|--------------------|--------------------|
| <u>Plant Flow</u> | <u>Influent TP</u> | <u>Effluent TP</u> |
| (mgd) | (mg/l) | (mg/l) |

Table 5-16. Dry Chemical Feeder Suppliers

| Name | Main Office | Chesapeake Bay Area Representative |
|--|--|---|
| BIF, a unit of General Signal | 1600 Division Road West Warwick, RI 02893 (401) 885-1000 | T. E. Byerly Co., Inc. 262 M Cedar Lane Suite 5 Vienna, VA 22180 (703) 849-8170 Pyrz Water Supply Co., Inc. P. O. Box 1271 43 Becker Road North Wales, PA 19454 (215) 699-9550 Tri-Star 300 Vine Street P. O. Box 255 Middletown, PA 17057 (717) 944-1234 |
| Wallace & Tiernan Div. Pennwalt Corp. | 25 Main Street Belleville, NJ 07109 (201) 759-8000 | Wallace & Tiernan The Woods, Suite 511 985 Old Eagle School Road Wayne, PA 19087 (215) 687-4930 Wallace & Tiernan Suite 210 11501 Georgia Road Wheaton, MD 20902 (301) 933-2110 |

chemical feed systems. Plants that use ferric chloride rather than alum will require more man-hours due to the corrosiveness of ferric chloride. The approximate number of man-hours required per year to operate and maintain chemical feed systems for different size plants up to 0.44 m³/s (10 mgd) are summarized in Table 5-20.

5.8 Sludge Considerations

The application of metallic salts at various points in a wastewater treatment plant creates new and additional sludges. Depending on the point of chemical addition, increased amounts of primary and/or secondary sludges will be generated. The ratio of primary to secondary sludge will be affected by chemical usage. For example, if a mineral salt is added to the primary settling tank, floc production and solids capture will increase; since more primary sludge will be produced, the primary sludge-to-secondary sludge ratio will increase. The additional solids loading resulting from chemical sludges must be considered in the design of sludge handling and treatment facilities. Metallic salts usage can result in as much as a 200-percent increase in sludge solids for disposal over that produced in strict biological treatment, depending on dosage and feed points.

Sludges generated in wastewater treatment processes to which phosphorus removal chemicals are added may be handled and disposed of by any of the conventional methods. However, sludge

conditioning characteristics will change according to the chemical content of the sludge. The gelatinous properties of aluminum hydroxide floc result in somewhat lower filter yields when alum is present in a sludge. A typical comparison is presented in Table 5-21, where total sludge production and filter yields are given for a conventional activated sludge process operating with a) no chemical treatment and b) alum addition to the aeration tanks.

As shown in Table 5-21, the use of alum may result in a 50-percent increase in sludge solids produced per volume of wastewater treated. The use of ferric chloride or other iron salts will result in a similar increase in sludge solids as discussed in Chapter 3. Dewaterability as measured by vacuum filter yield is typically lower with alum sludge as compared to ferric chloride sludge. Other data indicate no significant handling or conditioning problems for sludges from processes incorporating ferric chloride.

The handling of sludges containing products of chemical coagulation poses no special problems. The design engineer must be aware, however, of the greater solids production that results from chemical usage and the impact of the greater solids loading on handling and conditioning unit processes. The varying characteristics of the different chemical sludges also are a factor in the design of conditioning equipment. Laboratory filterability tests can be useful in this respect.

Table 5-17. Chemical Feed Pump Suppliers

| Name | Main Office | Chesapeake Bay Area Representative |
|--|--|---|
| BIF, a unit of General Signal | 1600 Division Road West Warwick, RI 02893 (401) 885-1000 | T. E. Byerly Co., Inc. 262 M Cedar Lane Suite 5 Vienna, VA 22180 (703) 849-8170 Pyrz Water Supply Co., Inc. P. O. Box 1271 43 Becker Road North Wales, PA 19454 (215) 699-9550 Tri-Star 300 Vine Street P. O. Box 255 Middletown, PA 17057 (717) 944-1234 |
| Wallace & Tiernan Div. Ponnwalt Corp. | 25 Main Street Belleville, NJ 07109 (201) 759-8000 | Wallace & Tiernan The Woods, Suite 511 985 Old Eagle School Road Wayne, PA 19087 (215) 687-4930 Wallace & Tiernan Suite 210 11501 Georgia Road Wheaton, MD 20902 (301) 933-2110 |
| Robbins & Meyers | 409 Plymouth Road Plymouth, MI 48170 (313) 459-4336 | Robbins & Meyers 102 North Main, Suite 101 Bell Aire, MD 21014-3542 (301) 879-9566 Robbins & Meyers 108 Willowbrook Lane West Chester, PA 19382-5592 (215) 693-2331 |
| Milton Roy Co. Flow Control Division | 203 Ivyland Road Ivyland, PA 18974 (215) 441-0800 | Geiger Pump 8851 Kelso Drive Baltimore, MD 21221 (301) 682-2600 Milton Roy Pumps 2500 Maryland Avenue Willow Grove, PA 19090 (215) 657-7770 |

5.9 Laboratory Requirements

The estimated sampling and analytical needs for phosphorus removal by chemical addition to mainstream processes are shown in Table 5-22.

5.10 Safety and OSHA Requirements for Chemical Addition

5.10.1 Ferric Chloride

5.10.1.1 General

Common sense safety precautions should be observed around storage tanks. Washing of contaminated areas from spills that occur at delivery time is recommended. Brown stains occur rapidly

following a spillage. Containment walls around the tanks will confine the tank contents in case of leakage. Containment areas should be kept clean and dewatered at all times.

Ferric chloride is a reddish-brown solution varying in strength from 35 to 45 percent, by weight, depending on time of shipment. Precautions for handling the chemical should be followed as given below. Water hoses, emergency showers, and eye washes should be located within 15 m (50 ft) of the ferric chloride unloading station and storage tank(s) and near the ferric chloride pumps.

The following discussion also applies to ferrous chloride and ferrous sulfate.

Table 5-18. Polymer Preparation Systems

| Name | Main Office | Chesapeake Bay Area Representative |
|--|--|---|
| BIF, a unit of General Signal | 1600 Division Road West Warwick, RI 02893 (401) 885-1000 | T. E. Byerly Co., Inc. 262 M Cedar Lane Suite 5 Vienna, VA 22180 (703) 849-8170 Pyrz Water Supply Co., Inc. P. O. Box 1271 43 Becker Road North Wales, PA 19454 (215) 699-9550 Tri-Star 300 Vine Street P. O. Box 255 Middletown, PA 17057 (717) 944-1234 |
| Wallace & Tiernan Div. Pennwalt Corp. | 25 Main Street Belleville, NJ 07109 (201) 759-8000 | Wallace & Tiernan The Woods, Suite 511 985 Old Eagle School Road Wayne, PA 19087 (215) 687-4930 Wallace & Tiernan Suite 210 11501 Georgia Road Wheaton, MD 20902 (301) 933-2110 |
| Stranco "Polyblend" | P. O. Box 389 Bradley, IL 60915-0389 (815) 932-8154 | Heyward, Inc. 717 East Blvd. Charlotte, NC 28203 (704) 372-5805 Riordan Materials Corp. 1413 Ormsby Place Crofton, MD 21114 (301) 858-0609 |

Table 5-19. Chemical Storage Tanks

| Name | Main Office | Chesapeake Bay Area Representative |
|------------------------------|--|---|
| Owens - Corning Fiberglas | Fiberglas Tower Toledo, OH 43659 (419) 248-7000 | 900 W. Valley Road Suite 1101 Wayne, PA 19087 (215) 688-9306 7501 Forbes Blvd. Suite 102 Seabrook, MD 20770 (301) 390-6900 |
| Process Equipment Corp. | 500 Reed Street Belding, MI 48809 (616) 794-1230 | Rodem, Inc. 5095 Crookshank Road Cincinnati, OH 45238 (513) 922-6140 Whitney Packaging, Inc. 50 Kearny Road Needham, MA 02194 (617) 444-5050 |

Table 5-20. Manpower Required to Operate and Maintain Chemical Feed Systems

| Plant Design Flow (mgd) | Ferric Chloride (man-hr/yr) | | | Alum (man-hr/yr) | | |
|-------------------------|-----------------------------|-------------|---------------|------------------|-------------|---------------|
| | Operation | Maintenance | Total | Operation | Maintenance | Total |
| < 0.1 | 150 - 300 | 50 - 100 | 200 - 400 | 110 - 220 | 35 - 70 | 145 - 290 |
| 0.1 - 1.0 | 300 - 460 | 100 - 140 | 400 - 600 | 220 - 320 | 70 - 100 | 290 - 420 |
| 1 - 5 | 460 - 1,100 | 140 - 360 | 600 - 1,460 | 320 - 800 | 100 - 250 | 420 - 1,050 |
| 5 - 10 | 1,100 - 1,700 | 360 - 540 | 1,460 - 2,240 | 800 - 1,200 | 250 - 380 | 1,050 - 1,580 |

Table 5-21. Comparison of Filter Yields With and Without Alum Addition

| Metal Salt | Dose | Feed Sludge | Sludge Solids Produced | Vacuum Filter Yield |
|------------|------|-------------|------------------------|---------------------|
| | mg/l | % solids | tons/Mgal | lb/hr/sq ft |
| None | - | 6.2 | 0.8 | 5.2 |
| Alum | 150 | 5.7 | 1.2 | 4.6 |

5.10.1.2 Precautions for Handling Ferric Chloride.

- 1. Protective Equipment for Eyes.** Wear suitable eye protection such as chemical worker's goggles or their equivalent. All emergency showers and eye washes should be tested once a day.
- 2. Hazards to Eyes.** Eyes contaminated with ferric chloride may rapidly become irritated; prolonged or permanent impairment of vision or even total loss of sight may occur. Dilution of ferric chloride to 20 percent or less tends to reduce the intensity of effect. Tests indicate that such concentrations may cause mild conjunctival irritation and possibly some transient corneal injury.
- 3. First Aid for Eye Contact.** In cases of splashes of liquid ferric chloride into the eyes, flush immediately and thoroughly with large amounts of water for 20 to 30 minutes and then rinse with a weak solution of sodium bicarbonate or boric acid. Consult a physician, preferably an eye specialist, immediately. Chemical burns to the eye must be treated promptly. Repeatedly flooding the eye with water within seconds after contact with a chemical is the most effective way to prevent permanent damage. In the opinion of medical experts, if a victim can reach an eyewash station within 10 to 15 seconds, his chances of recovering with no permanent damage to the eyes are excellent. After 15 seconds, the chances of recovery decline rapidly.
- 4. Protective Equipment for Skin.** Most people are not sensitive to ferric chloride and need wear only regular work clothing with whatever protection is desired to minimize staining, e.g., rubber or plastic sleeves, apron, and gloves. Since ferric chloride deteriorates leather rapidly, people working with

ferric chloride should wear rubber shoes or regular work shoes with rubber soles and heels and waterproofed leather uppers.

- 5. Hazard to Skin.** When in contact with the skin, ferric chloride solution may cause blistering and superficial burns unless washed off promptly. Such contact will also stain the skin. Repeated prolonged skin contact with strong solutions may cause superficial burns, especially if confined to the skin as might occur when contaminated clothing or shoes are worn.
- 6. First Aid for Skin Contact.** Remove contaminated clothing and wash affected skin with soap and plenty of water until the wash water is essentially colorless. A physician should be consulted if any irritation or injury to the skin develops.
- 7. Ingestion Hazard.** If large amounts of ferric chloride are swallowed, it may cause burns to the mucous membranes and severe irritation of the gastrointestinal tract.
- 8. First Aid for Ingestion.** If large amounts of ferric chloride are swallowed, a physician should be called immediately. While the physician is on the way, the patient should be induced to vomit.
- 9. Spills.** Spills should be neutralized with caustic soda or lime and the areas flushed with water. Adequate diking and drainage should be provided at unloading and storage areas to prevent spills or leaks from harming surrounding equipment and facilities. To prevent spills and splashing, tank cars and trucks containing ferric chloride solution should never be moved unless all openings are secured and lines drained and disconnected.

5.10.2 Polymer

There are so many types of polymers on the market that the operator should obtain complete instructions from the supplier as to the safe handling of the particular brand product being used. Polymers can be purchased in either liquid or dry powder form and in various size containers.

In general, polymers are not considered to be toxic, but it is well to avoid unnecessary contact with either

Table 5-22. Estimated Sampling and Analytical Needs for Phosphorus Removal by Chemical Addition

| Analytical Measurement | Plant Size (mgd) | Test Frequency | Location of Sample | Method of Sample | Reason for Test |
|---------------------------|------------------|---------------------|--|---------------------|--|
| pH | All | 1/day | Clarifier Influent Clarifier Effluent | 24-hr Composite | Process Control Recordkeeping/Permit Compliance |
| Alkalinity | All | 2/week | Clarifier Influent Plant Effluent | 24-hr Composite | Recordkeeping/Permit Compliance |
| TSS | All | 1/day | Clarifier Influent Clarifier Effluent | 24-hr Composite | Process Control Recordkeeping/Permit Compliance |
| TBOD | All | 1/day | Clarifier Influent Clarifier Effluent | 24-hr Composite | Process Control Recordkeeping/Permit Compliance |
| Jar Test | All | Spot Check | Clarifier Influent | 24-hr Composite | Process Control Cost Control |
| Total Solids | > 1 | 1/week | Sludge Underflow | Grab Composite | Process Control |
| Total Solids ¹ | < 1 | 3/week | Sludge Underflow | Grab Composite | Process Control |
| Flow ¹ | All | Record Continuously | Sludge Underflow | Record Continuously | Process Control |
| Total P ^{1,2} | All | 3/week | Clarifier Influent Clarifier Effluent Plant Effluent | 24-hr Composite | Process Control Recordkeeping/Permit Compliance |
| Ortho P ¹ | All | 3/week | Clarifier Influent Plant Effluent | 24-hr Composite | Process Control Recordkeeping/Permit Compliance |

¹ Suggested minimum.

² Or as prescribed by permit.

the powder or liquid. Goggles, gloves, and aprons should be used to protect the skin and eyes. The use of a face mask when handling the powder should be required.

Anionic polyelectrolytes have a low acute oral toxicity. Eye contact with either the undiluted or diluted material may result in mild transitory irritation. The materials are not irritating to the skin.

Polymers, when in solution, are highly viscous and, therefore, very slippery and dangerous to foot traffic if allowed to spill.

Handling polymers should cause no health problems if reasonable care, good housekeeping, and personal cleanliness are practiced to avoid skin and eye contact.

5.10.3 OSHA Requirements

Detailed state OSHA requirements may vary between the Chesapeake Bay area states. However, as a minimum, the following guidelines are recommended.

1. Provide a water hose, eyewash, and shower within 15 m (50 ft) of any hazardous chemical unloading, storage, and feed area.
2. Provide a spill containment dike around each storage tank. The dike containment volume should

be equal to at least 150 percent of the volume of the storage tank.

3. Provide a means for removing water or chemicals from within each containment dike.
4. Provide a 15-cm (6-in) high concrete curb around all chemical feed areas for containment of spillage.
5. Provide splash guards at all pumps.
6. Provide spray shields under all hazardous chemical piping crossing walkways or passage ways.

5.11 References

1. Personal communication from R.I. Sedlak, The Soap and Detergent Association, New York, NY, to R.C. Brenner, U.S. EPA, Cincinnati, OH, May 20, 1987.
2. Personal communication from D. Jenkins, University of California, Berkeley, CA, to S.J. Kang, McNamee, Porter and Seeley, Ann Arbor, MI, July 31, 1987.



Chapter 6

Process and Hardware Design Considerations for Retrofitting Activated Sludge Plants with Biological Phosphorus Removal

6.1 Introduction

As discussed in Chapters 2 and 3, two proprietary processes are considered in this manual for retrofitting selected suspended growth activated sludge systems with biological phosphorus removal: the PhoStrip process and the A/O (anaerobic/oxic) process. Although the major mechanism for removing phosphorus with these processes is biological, the PhoStrip process employs a sidestream to chemically precipitate biologically removed phosphorus, while the A/O process is a mainstream process where phosphorus is removed in the waste activated sludge.

Both processes can be retrofitted only to activated sludge systems, including plug flow, complete mix, contact stabilization, pure oxygen, step aeration, extended aeration, and two-stage nitrification configurations. Activated sludge is alternately cycled through an anaerobic stage where phosphorus is released and an aerobic stage where phosphorus-stripped biomass takes up phosphorus at an increased rate. Biological phosphorus removal is most applicable for treatment of wastewaters with relatively low (3-6 mg/l) influent TP concentrations. The probability that chemical polishing will be required becomes greater with higher influent TP concentrations.

Activated sludge plants retrofitted with biological phosphorus removal may experience improved settling characteristics and suspended solids removals resulting from the anaerobic/aerobic cycling of activated sludge. Additional process design and operating considerations are presented below for each process.

6.2 PhoStrip Process

Retrofit with the PhoStrip process can be accomplished for any of the commonly used activated sludge flow regimes given an adequate site for construction of a stripper tank, a precipitation tank or reactor-clarifier for chemical precipitation, and lime handling facilities. The PhoStrip process is owned and marketed by Biospherics Incorporated, 4928

Wyaconda Rd., Rockville, MD 20852-2496, (301) 770-7700.

6.2.1 Conditions Prerequisite to PhoStrip Retrofit

The conditions listed below indicate the operating ranges experienced to date for PhoStrip systems and should be considered prerequisite operating conditions for retrofit.

Influent TBOD = 70 to 300 mg/l
Influent TP = 3 to 10 mg/l
Secondary clarifier oxidized nitrogen = 3 to 30 mg/l
Wastewater temperature = 10 to 30°C
Aeration tank HDT = 4 to 10 hr
MLSS = 600 to 5,000 mg/l
F/M loading = 0.1 to 0.5 g TBOD/g MLVSS/d

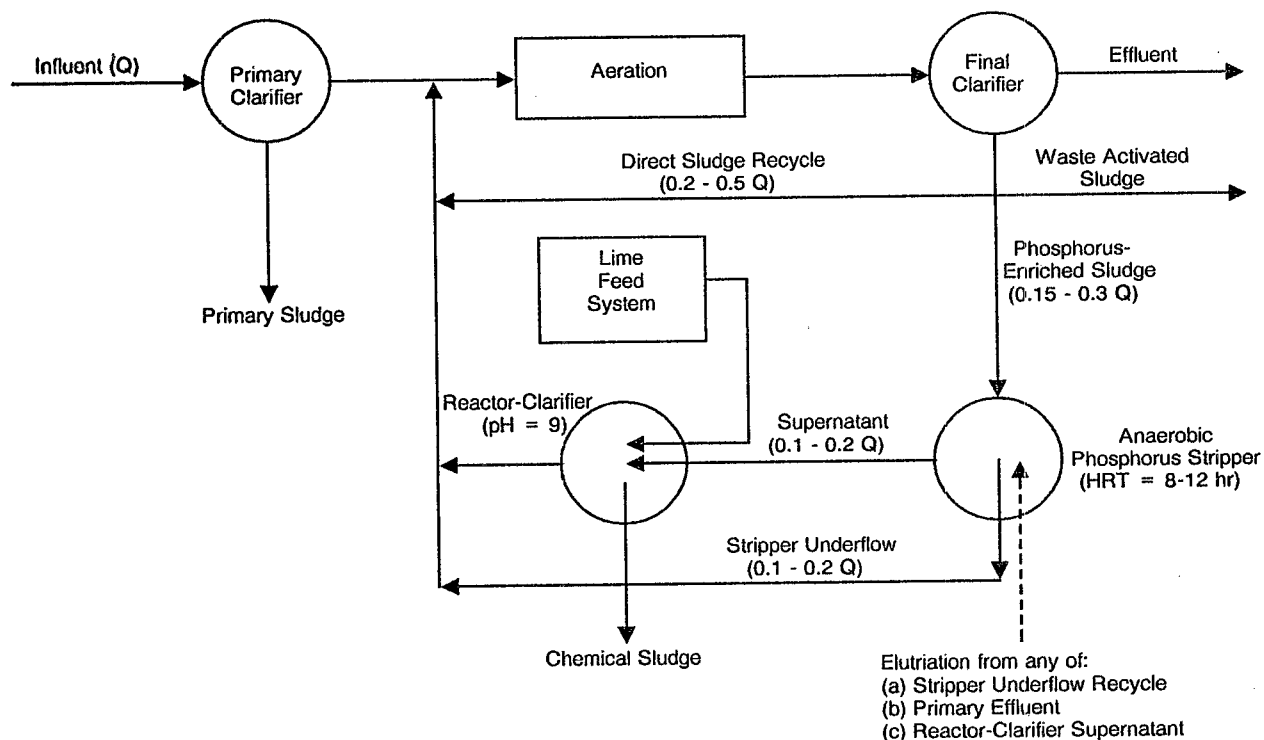
If a PhoStrip retrofit is being considered for a plant where operating conditions within the range presented above cannot be achieved, a pilot study is warranted prior to full-scale design and construction.

6.2.2 Design Considerations

A generic PhoStrip process schematic including key sidestream flow rates and other information is presented in Figure 6-1. For plants that are not operating at primary clarifier design capacity, a chemical precipitation tank can be substituted for the reactor-clarifier, the contents of which would go to the primary clarifier.

As shown in Figure 6-1, the range for the direct return activated sludge rate (0.2 to 0.5 times the influent flow rate) is that normally observed for activated sludge plants. In addition, return sludge is cycled through the stripper tank at 0.15 to 0.3 times the influent flow rate. Anaerobic conditions are maintained in the stripper tank, with a detention normally between 8 and 12 hours. It is here that phosphorus is released in a soluble form for subsequent chemical precipitation. A longer anaerobic stripper detention time is required when oxidized nitrogen is present. This is because denitrifying microorganisms that convert nitrate nitrogen to nitrogen and oxygen under anaerobic conditions compete with microorganisms responsible for

Figure 6-1. PhoStrip process flow diagram.



phosphorus removal for the readily biodegradable substrate. In addition, it has been theorized that nitrate nitrogen acts as a terminal electron acceptor for phosphate-accumulating bacteria. As a result, sufficient anaerobic contact time must be provided for denitrification, i.e., removal of nitrate nitrogen, to be carried to completion first and then be followed by phosphorus release.

The volume of the stripper tank is determined by the sludge flow into the stripper and the required anaerobic detention time. The stripper SOR, typically selected in accordance with gravity thickener designs at 16 to 24 m³/m²/d (400 to 600 gpd/sq ft), determines the stripper surface area. The stripper volume divided by the surface area determines the sludge blanket depth, and normally 0.9 to 1.2 m (3 to 4 ft) is added to the depth for supernatant storage.

Phosphorus release is encouraged in the stripper tank by the elutriation of the sludge with a stream low in phosphorus content such as primary effluent, secondary effluent, or lime precipitation tank overflow. The elutriation flow rate is normally 50 to 100 percent of the stripper feed rate. Stripper tank underflow recycle or digester supernatant recycle can also be used as elutriate sources. The higher organic content of these streams encourages phosphorus release. As stated in Chapter 2, the choice and magnitude of the elutriation stream is a site-specific selection based on operational and wastewater composition criteria.

The underflow rate from the stripper tank typically amounts to 0.1 to 0.2 times the plant influent flow rate, and the sludge solids in this stream can double in concentration through the stripper's thickening function. The phosphorus-poor biomass in the underflow from the stripper tank is returned to the activated sludge aeration tank to insolubilize primary effluent phosphorus via the process of enhanced or "luxury" biological uptake. F/M loading rates used are typical of most activated sludge processes and can range from 0.1 to 0.5 kg TBOD/kg MLVSS/d, although it is noted that increased organic loadings lead to greater phosphorus removal through the waste activated sludge resulting from increased sludge yields.

Supernatant from the anaerobic stripper tank carries high SP concentrations in the range of 15 to 100 mg/l and flows continuously to the chemical precipitation tank at a rate of 0.1 to 0.2 times the plant influent flow. Here the phosphorus is chemically insolubilized with lime at dosages of 100 to 200 mg/l to maintain a pH of 9.0 to 9.5. These dosages amount to 20 to 30 mg/l of lime based on plant influent flow. It is noted that lime becomes a much more economical chemical for use in phosphorus precipitation when the phosphorus stream is concentrated than iron or aluminum based salts due to the differences in stoichiometries between those salts. Lime dosage is in general independent of phosphorus concentration

and depends primarily on the alkalinity of the water, since it will first react with alkalinity to precipitate CaCO_3 and then precipitate phosphorus. Iron and aluminum salts must be applied on roughly an equal molar basis to phosphorus; therefore, the same amount would be necessary whether the stream was small in flow and concentrated in phosphorus or high in flow and less concentrated.

Where sufficient primary clarifier capacity exists, the contents of the chemical precipitation tank (used in lieu of a reactor-clarifier) can be routed there for co-settling with primary sludge. Alternately, the precipitation tank contents can be clarified separately with only clarifier overflow from the operation routed to the primary clarifier. A typically-used chemical precipitation clarifier overflow rate is approximately $50 \text{ m}^3/\text{m}^2/\text{d}$ ($1,200 \text{ gpd}/\text{sq ft}$). The lime-phosphorus sludge is generally disposed of separately with this option.

A variation of the PhoStrip process called PhoStrip II was recently unveiled, but to date has not been used in a full-scale application. PhoStrip II makes use of a prestripper tank with 30 minutes of detention where return sludge and a BOD source are mixed. This mixture then flows to a down-sized stripper tank with 4 to 8 hours of detention where elutriation is not required. Other design parameters are similar to the original PhoStrip process.

6.2.3 Attainability of Effluent Limits

Effluent limits of 2 and 1 mg/l TP can be reliably attained using the PhoStrip process. An effluent TP limit of 0.5 mg/l can be met if effluent suspended solids are reliably controlled, but tertiary filtration may be necessary. Achieving an effluent limit of 0.2 mg/l TP may require a tertiary chemical polishing step in addition to tertiary filtration. Provisions for metal salt addition to the aerator as well as just prior to filtration should also be made for achieving a 0.2-mg/l TP effluent limit.

6.2.4 Lime Handling

Lime used for the PhoStrip process is available in two forms: quicklime (CaO) or hydrated lime [$\text{Ca}(\text{OH})_2$]. Quicklime contains about 90 percent CaO and must first be hydrated or slaked to the $\text{Ca}(\text{OH})_2$ form prior to application to the wastewater. Hydrated lime, a dry powder, has already been slaked and contains 72 to 74 percent CaO and 23 to 24 percent water of hydration. Slaking refers to the process of adding water to quicklime to produce hydrated lime.

Lime is available in bulk by rail or truck, or in bags. In general, bagged hydrated lime is recommended for applications requiring less than 450 kg ($1,000 \text{ lb}$)/d. This would be the case for PhoStrip retrofits of less than $0.18 \text{ m}^3/\text{s}$ (4 mgd). In bulk, hydrated lime is recommended for applications up to $2,700$ to $3,600 \text{ kg}$ ($6,000$ to $8,000 \text{ lb}$)/d, or PhoStrip retrofits up to 1

m^3/s (24 mgd). Thus, quicklime and associated slaking equipment would be cost-effective only for very large retrofit applications.

Storage areas for both bulk and bagged lime must be kept covered and dry. Hydrated lime may be stored for up to 1 year, while quicklime should not be stored more than 3 months. Lime bags can be stacked 20 high, or higher when pallets are used. Bulk storage of lime is usually done in conventional steel or concrete bins and silos with conical bottoms. Hydrated lime does not flow as well as quicklime, and tall storage bins with height-to-diameter ratios of 2.5 to 4 are recommended. Vibrating bin bottoms or discharge chutes can help prevent arching or bridging of the lime.

Lime is normally added to water to form a slurry prior to being applied to the wastewater. For small applications, bagged hydrated lime can be added manually to a batch mixing tank to form a slurry for feeding to the chemical precipitation tank. Bulk hydrated lime is fed with a dry chemical feeder to a batch or continuous mixing tank for subsequent feed to the chemical precipitation tank. Bulk quicklime must be fed to a slaker, where it is first hydrated. It is then further diluted in a separate tank prior to application. Gravimetric dry chemical feeders are somewhat more costly than the volumetric type, but offer several advantages and are the preferred choice.

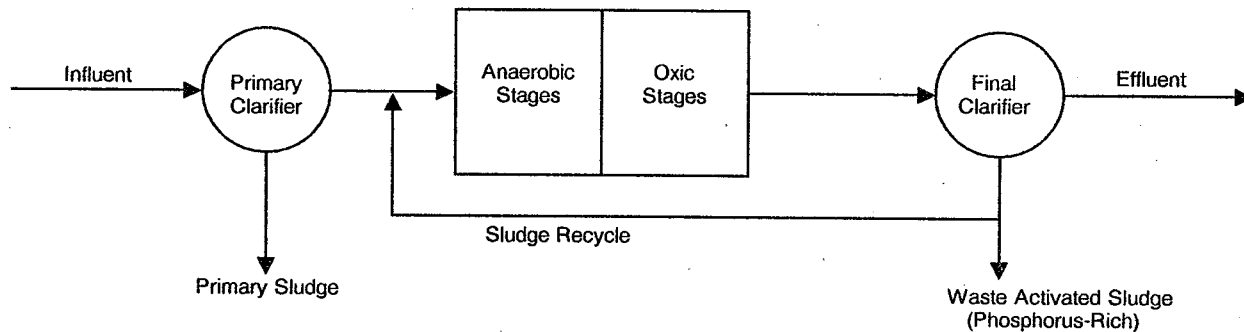
Diaphragm pumps, progressive cavity pumps, or dipper wheel feeders are used to feed the lime solution, typically at a concentration of 5 percent. A recommended maximum solution concentration is 1 kg lime to 17 l water (1 lb to 2 gal water), and the solution tank detention time should be 5 minutes.

Scaling is a major problem in pumps, pipes, and valves. Piping distances should be minimized, and flow should be by gravity. Sodium hexametaphosphate can be added to dilution water and polymers can be used to inhibit scale formation. Troughs and channels or flexible hose are preferred to rigid pipe for slurry transport. Provisions for acid flushing and the use of "pigs" should be made for lime slurry lines.

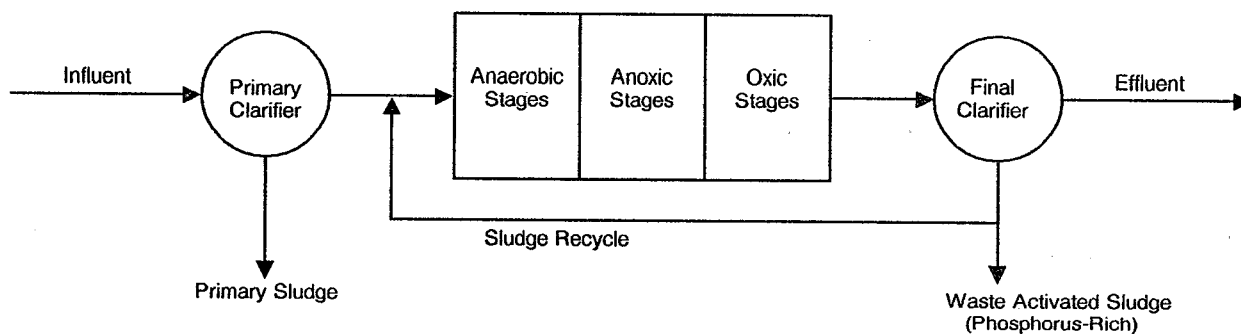
6.3 A/O Process

Although the A/O process is most easily retrofitted to plug flow activated sludge tanks, it can also be adapted to most of the activated sludge flow regimes. The ease of retrofit is determined by the ability to delineate and convert a portion of the aeration tankage to an anaerobic zone. Anaerobic here is defined as the absence of all DO and oxidized nitrogen, while anoxic refers to the conditions where DO is low or absent but oxidized nitrogen is present. Space for construction of retrofit facilities is normally

Figure 6-2. A/O process flow diagrams.



A/O Schematic for Phosphorus Removal Without Nitrification



A/O Schematic for Phosphorus Removal With Nitrification

operating at the lower end of this range, it is important that appropriate valving be provided to accurately control return sludge rates for proportional pacing with low influent flows. The sludge blanket depth in the secondary clarifier should be maintained at less than 0.6 m (2 ft) to prevent development of anaerobic conditions and subsequent leakage of phosphorus into the secondary effluent. Secondary clarifier SORs can range between 24 and 26 m³/m²/d (600 and 650 gpd/ sq ft).

The organic loading rate is an important consideration in successful operation of the A/O process. Higher organic loading rates result in higher sludge yields and, therefore, greater removals of phosphorus since the only exit for phosphorus in the A/O process is through the waste activated sludge. Although higher rates have been successfully used, the recommended volumetric organic loading rate for concurrent nitrification is 0.15 kg TBOD/kg MLVSS/d or 0.08 kg SBOD/kg MLVSS/d. Higher volumetric organic loading rates up to 0.6 kg TBOD/kg MLVSS/d may be applied when nitrification is not required.

When the method of sludge handling includes anaerobic digestion or other operations where the sludge is subjected to anaerobic conditions, at least a portion of the biologically-removed phosphorus will be released in a soluble form. This can then find its way back to the influent of the plant through recycle streams.

The effects of recycle streams such as digester supernatant, sludge thickener overflow, and filter press or vacuum filter filtrates on mainstream process operation and performance must also be carefully considered. These streams may carry a large loading of phosphorus back to the influent and may upset the required influent BOD-to-phosphorus ratio. Segregation of the recycle streams may be necessary in extreme cases.

6.3.3 Attainability of Effluent Limits

An effluent limit of 2 mg/l TP should be attainable for most wastewaters where an A/O retrofit is used. An effluent limit of 1 mg/l TP could be attainable most of the time with the A/O process and perhaps all of the

time at some locations. However, a backup feed system for dosing selected chemicals to the aerobic zone is recommended for any necessary polishing.

In achieving effluent limits of 0.5 mg/l TP or less, the influent SBOD-to-SP ratio becomes more important, with a desired ratio of 20 to 25. Provisions for chemical polishing in the aerobic zone would be necessary to achieve an effluent TP concentration of 0.5 mg/l, and a tertiary chemical polishing stage plus tertiary filtration would be required to achieve an effluent TP concentration of 0.2 mg/l.

Chapter 7

Compatibility of Chemical and Biological Phosphorus Removal with Nitrogen Control

7.1 Introduction

At some locations in the CBDB, there may be a need to simultaneously control both nitrogen and phosphorus in municipal effluents. Nitrogen control requirements may be contingent on several environmental impacts: provision for nitrification for protection of the receiving water from ammonium nitrogen oxidation demand, protection of aquatic life from ammonia nitrogen toxicity, nitrogen removal to prevent eutrophication of the receiving water, and/or control of health hazards due to nitrate ions.

Requirements for dual nutrient control, i.e., phosphorus removal and nitrification or nitrogen removal, can greatly affect the biological, chemical, and engineering considerations of retrofitting wastewater treatment facilities.

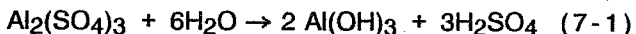
7.2 Process Considerations for Complying with Dual Nutrient Control Requirements

When a chemical or biological phosphorus removal process must be modified to also include nitrogen control, the impact of side reactions must be carefully evaluated. Topics discussed in the following sections are essential considerations for all dual nutrient control processes.

7.2.1 Control of Process pH Value

Currently, all nutrient control processes are either biological processes supplemented by chemical additions or specially managed biological processes. Therefore, control of process pH in the range of 6.0 to 8.0 is necessary to protect biomass from the toxic effects of hydrogen ions.

As noted in Chapter 2, metallic salts used for chemical removal of phosphorus are acidic in nature. This acidity is due to the hydrolysis of metal ions when added to water. For example, when aluminum sulfate is added to wastewater the following reaction occurs:

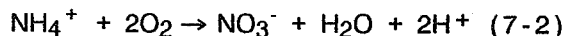


The sulfuric acid produced by this reaction consumes a portion of the alkalinity of the wastewater. If Equation 7-1 is calculated on the basis of aluminum,

the acid produced is equivalent to 5.6 mg/l of calcium carbonate alkalinity for each 1 mg/l of aluminum added to the wastewater.

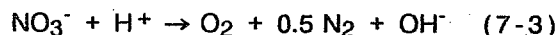
Similar calculations for ferric salts show that each 1 mg/l of ferric ion dosed to wastewater will consume 2.5 mg/l of calcium carbonate alkalinity. If the source of metallic precipitant selected for phosphorus removal is waste pickle liquor in the form of ferrous sulfate or ferric chloride, it should be noted that these products may also contain free acid, which will also consume alkalinity in addition to the metal hydrolysis reaction.

When a nitrified effluent must be produced, the biological conversion of ammonium nitrogen to nitrate nitrogen can also deplete alkalinity. The conversion is a sequential two-step biological oxidation accomplished by two specialized microorganisms; however, the overall nitrification reaction can be viewed as follows:



Calculated on a nitrogen basis, for each 1 mg/l of ammonium nitrogen converted to nitrate nitrogen, the amount of hydrogen ions produced will consume 7.1 mg/l of calcium carbonate alkalinity. This depletion can be severe. If, for instance, 20 mg/l of ammonium nitrogen were oxidized, the calcium carbonate alkalinity would be reduced by 142 mg/l. As a rule of thumb, if a wastewater has a carbonate/bicarbonate buffer system with a pH value between 7.0 and 8.5, the concentration of ammonium nitrogen that can be oxidized before the pH value decreases below 6.0 is about 0.1 of the wastewater calcium carbonate alkalinity.

Another important reaction must be taken into account if a denitrification process is instituted for nitrogen removal requirements. Biological denitrification is a very complex series of biochemical reactions; however, for process control purposes, the reaction can be considered to occur as follows:



For each nitrate ion converted to nitrogen gas, one hydrogen ion is consumed and one hydroxyl ion is

produced. This has the overall effect of increasing the alkalinity of the wastewater. For each 1 mg/l of nitrate nitrogen converted to nitrogen gas, 3.5 mg/l of calcium carbonate alkalinity will be produced. In certain process configurations, this alkalinity production can partially offset the alkalinity depleting reaction of nitrification and assist in maintaining control of process pH.

7.2.2 Biomass Environmental Management

The discussion of biological phosphorus removal in Chapter 2 describes the different environments that the biomass of these processes must cycle through for proper population selection. These environments must be managed to be anaerobic, anoxic, and aerobic.

When nitrification or nitrification/denitrification is coupled with biological phosphorus removal, it becomes necessary to further define these environments as follows:

1. An anaerobic stage should not contain DO, and nitrate should not be present.
2. An anoxic stage should not contain DO, but should contain nitrate.
3. An aerobic stage should contain at least 1 mg/l DO and may contain nitrate.

It has been found that the presence of DO or nitrate in the anaerobic stage of a biological phosphorus removal process will inhibit the release of intercellular phosphorus. As long as either of these is present, the microorganisms will utilize these oxygen resources to oxidize organics instead of sorbing organics and releasing phosphorus. Thus, phosphorus uptake in the subsequent aerobic stage may be prevented.

If a PhoStrip or A/O process must also be retrofitted to produce a nitrified effluent, the nitrate content of the return sludge flow into the side stream stripper tank or main stream anaerobic stage, respectively, would have to be taken into account to allow adequate HRT for oxygen resources to be consumed and phosphorus release to occur.

For nitrogen removal processes, anoxic stages are provided for biological denitrification, which transforms nitrate nitrogen into nitrogen gas. The microorganisms performing this transformation are facultative organisms that can metabolize substrate using either DO or oxygen from the nitrate radical. If both DO and nitrate are present, the microorganisms will preferentially use DO. Therefore, to ensure efficient denitrification, an anoxic stage must be operated to exclude DO.

Aerobic stages are incorporated into all dual nutrient control processes for provision of the proper

environmental conditions for oxidation of organics and nitrification.

If a phosphorus removal process, either biological combined with chemical or biological by itself, must also achieve nitrification or nitrogen removal via denitrification, the dominant design and operational considerations become the selection of SRT and management of the several environments the biomass must cycle through to foster population selection and achieve effluent limitations.

7.2.3 Engineering Aspects

Dual nutrient control processes offer situations in which attention to engineering aspects of design and operation becomes critical. Consideration should be given to the following:

1. Reactor recycle flows
2. Mixing devices
3. Baffling between reactor stages
4. Clarifier mass loading
5. Reuse of oxygen contained in the nitrate radical

All processes combining dual biological phosphorus removal and denitrification for nitrogen removal entail recycling flows between various reactor stages. While these can be low-head pumping operations, the magnitude of recycle flows can be up to four times the influent flow. Power requirements for these recycle flows should be evaluated as an operational cost. Recycles between reactor stages with different environmental conditions can interfere with attainment of proper reactor stage performance such as introducing DO from an aerobic stage into an anoxic stage. Also, the effect of the magnitude of recycle flows on substrate residence time must be evaluated.

Mixing devices for anaerobic and anoxic stages can be submerged pumps, impeller mixers, or very coarse bubble, low volume aeration devices. The basic design requirement is supplying enough power to keep the biomass in suspension, yet not creating a turbulent surface that will cause oxygen transfer to occur. Typically, the power required to maintain biomass in suspension is about 20 kW/1,000 m³ of tank volume (0.75 hp/1,000 cu ft) for mechanical devices and about 25 m³ air/1,000 m³ of tank volume (25 cu ft/1,000 cu ft) for aeration devices.

Baffling between reactor stages is necessary to maintain proper environmental conditions in each stage and to prevent short circuiting. Baffle walls can be constructed from concrete, treated wood, or heavy duty plastic curtains. Material selection should be based on site-specific details such as cost, duration of the retrofit operation, and effluent requirements.

Generally, a retrofit for dual nutrient control processes places a greater solids load on an existing final clarifier. Either a chemical or biological phosphorus

removal process that must also achieve nitrogen control requires operating at a greater SRT. Chemical and biological phosphorus removal processes can be operated at SRTs of 3 to 4 days, irrespective of temperature considerations. However, nitrification or denitrification requires SRTs of 6 to 8 days for summer conditions and 15 to 20 days under winter conditions. This equates to a greater mass of mixed liquor in the reactor that must cycle through the final clarifier. The flux loading on the clarifier floor should not exceed 120 kg/m²/d (25 lb/sq ft/d).

Inspection of Equation 7-3 indicates that during biological denitrification, not only is alkalinity produced, but oxygen is liberated from the nitrate radical. Depending on the process configuration selected for retrofit and the facility's operational staff capability, this liberated oxygen can be a resource. The theoretical calculation for Equation 7-3 shows that 67 percent of the oxygen in the nitrate radical could be recovered for use in bio-oxidation of organics in wastewater. The following equation can be used as a first approximation of the magnitude of this recovered oxygen:

$$\frac{(\text{mg/l NO}_3\text{-N} \times 4.5 \times 8.3 \times \text{mgd} \times 0.67 \times \$/\text{wire hp-hr})}{\text{lb O}_2/\text{wire hp-hr (aeration efficiency)}} = \$/\text{d} \quad (7-4)$$

In Equation 7-4, the value of 4.5 is the oxygen factor for oxidation of ammonium nitrogen to nitrate nitrogen.

For a 0.48-m³/s (5-mgd) facility that recovered 15 mg/l of nitrate oxygen with an oxygen transfer efficiency of 1.0 kg O₂/kWh (1.65 lb/wire hp-hr) and an electrical energy cost of \$0.10/kWh (\$0.075/wire hp-hr), the theoretical value of the recovered oxygen would be \$85/day. This, of course, would be offset by efficiency factors due to process configuration, recycle pumping costs, and additional operating attention for process control. At larger facilities that are required to nitrify or denitrify, this source of oxygen should be evaluated in early retrofit decisions.

7.3 Dual Process Removal and Nitrification Processes

Aside from the items noted in the previous sections, mating of phosphorus removal with nitrification requires consideration of HRT, SRT, the F/M loading rate, and oxygen supply.

7.3.1 Chemical Phosphorus Removal and Nitrification

Combined activated sludge-chemical phosphorus removal processes that also achieve nitrification were shown previously in Figures 2-3 and 2-6. One- and two-stage systems for nitrification have been employed. The choice between the configurations should be based on wastewater temperature and wastewater quality. A requirement for wintertime

nitrification favors a two-stage system to reduce the total reactor detention time deriving from the ability to maintain a long SRT in the second stage. A two-stage system should also be selected if the organic content of the wastewater is high. The first-stage reactor reduces the organic loading to the nitrification stage, allowing attainment of the proper SRT to achieve nitrification in that stage.

In retrofit situations, spare aeration tankage or baffling of tankage may allow implementation of two-stage treatment. Existing secondary clarifier capacity may be the limiting factor in this decision.

If nitrification is required only during the summer months and the wastewater is of usual municipal organic strength, the retrofit choice would typically be single-stage nitrification. Reference 1 contains many examples of dual chemical phosphorus removal and nitrification employing a variety of options.

7.3.2 Biological Phosphorus Removal and Nitrification

Flow diagrams of biological phosphorus removal utilizing the PhoStrip and A/O processes were presented previously in Figures 2-11 and 2-12, respectively. Achieving nitrification with these processes in a retrofit situation depends on the temperature and organic loading at which the facility has to nitrify. At cold temperatures, both processes require a significant increase in SRT. Since the A/O process depends on sludge wasting as the phosphorus removal mechanism, it can be impacted by changes in SRT. The PhoStrip process, with a sidestream chemical operation, would not be impacted to as great an extent.

High organic loads would favor the A/O process, since this process depends on removal of phosphorus by cellular synthesis. However, the organic load could not be so great as to prevent achieving an SRT suitable for nitrification.

Reference 2 describes a full-scale PhoStrip process that produced a nitrified effluent during the summer of 1984. The F/M loading was 0.16 kg TBOD/kg MLVSS/d, an SRT of 7 days was maintained, and the aerator HRT was 4.6 hours.

This same reference provides data for two full-scale facilities utilizing a process configuration similar to the A/O process. Nitrification was achieved in the summer of 1984. Winter nitrification capability was not monitored. Based on the aerobic portion of the bioreactors, the HRT varied between 6 and 15 hours and the F/M loading between 0.12 and 0.33 kg TBOD/kg MLVSS/d. The SRT, based on total reactor volume, ranged from 7 to 11 days.

Reference 3 reports on the full-scale demonstration of a facility retrofitted for the A/O process to achieve

biological phosphorus removal and nitrification. This northern facility has a seasonal permit that requires the monthly average values of effluent ammonium nitrogen and TP never to exceed 3.2 and 1 mg/l, respectively. The ammonium nitrogen limitation applies from May 1 through September 30. Process loadings and operational parameters were not provided, but the facility was meeting the permit limitations.

The influence of nitrate nitrogen in the anaerobic stages and the anaerobic stripper, as discussed previously, was evident at all four of these facilities. A direct relationship was noted between SP and nitrate nitrogen concentrations in the plant effluents. Increases in nitrate nitrogen were followed by increases in SP. At 10 mg/l of nitrate nitrogen, the SP content of the effluents was approximately 0.5 mg/l.

7.3.3 Oxygen Requirements for Nitrification

When either a biological-chemical or biological phosphorus removal process must also be retrofitted to achieve nitrification, oxygen supply capability must be considered. Calculation of the consumption of oxygen by biological nitrification, as given previously in Equation 7-2, shows that for each 1 mg of ammonium nitrogen oxidized to nitrate nitrogen, 4.5 mg of oxygen will be required. This is in addition to the oxygen demand for carbonaceous oxidation and the oxygen required for meeting the endogenous demand of biomass.

In a retrofit situation, the anticipated peak oxygen requirement anticipated from these combined demands should be evaluated against the capability of the existing aeration system to transfer this amount of oxygen.

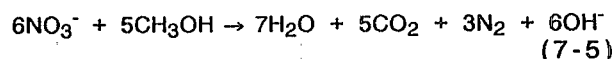
7.4 Dual Phosphorus Removal and Nitrogen Removal Processes

If a facility must remove both phosphorus and nitrogen to meet effluent requirements, the retrofit decisions will have to be carefully tailored to the numerical limits imposed. Numerous process options are available for controlling both nitrogen and phosphorus with a wide spectrum of overall efficiencies. An effluent specification that had stringent limits, such as 0.2 mg/l TP and 3 mg/l total nitrogen, would dictate consideration of a multi-stage biological process supplemented with chemical additions. A less stringent effluent requirement, such as 2 mg/l TP and 10 mg/l total nitrogen, would lead to consideration of managed biological systems. Between these two extremes are numerous options that could be evaluated.

To effectively remove both phosphorus and nitrogen, any process must be operated to control a series of transformations. As discussed in Chapter 2, influent phosphorus forms must be converted to

orthophosphate for efficient insolubilization by chemicals or incorporation into cellular material.

For nitrogen removal to occur, the various unoxidized forms of nitrogen in the influent must first be transformed into nitrate nitrogen. Then, conditions must be arranged for biological denitrification to convert the nitrate nitrogen to nitrogen gas. For this conversion, microorganisms utilize hydrogen bound in organic materials to combine with oxygen from the nitrate radical. This is an oxidation/reduction reaction with water, carbon dioxide, nitrogen gas, and hydroxyl ions as end products. Using methanol as an example of organic matter, the reaction is:



The velocity of this reaction is dependent on the type of organic substrate provided. Materials such as methanol are very soluble in wastewater and readily utilized by acclimated denitrifying organisms. In addition, the chemical is available in pure form and can be dosed into a denitrification process in a known ratio to nitrate nitrogen.

Managed biological processes depend on different types of organics. Some utilize organics (BOD) present in influent wastewater; others rely on organics liberated by endogenous hydrolysis of cellular organics present in biomass. The quality and quantity of these organics are largely unknown and can be highly variable. The extent of biological utilization of these materials is also subject to variability. Generally, these types of organics have slower reaction velocities than materials such as methanol. However, no implicit cost is associated with these in-plant sources of organics.

The trade-off that must be evaluated between externally added materials like methanol and in-plant organics is the cost of chemical and dosing equipment for the former vs. biological reactor size and recycle pumping costs for the latter, coupled with the effluent total nitrogen residual and degree of compliance required. Retrofitting for removal of both nitrogen and phosphorus at any facility that was near design hydraulic and organic loadings, no matter which option was chosen, would no doubt involve capital construction.

7.4.1 Phosphorus and Nitrogen Removal with Multi-Stage Biological Processes Supplemented with Chemicals

Many examples of multi-stage, chemically-assisted processes are provided in References 1 and 4. The data base for this technology is well established from both design and operational standpoints. The array of process options is large because various combinations of suspended and attached growth biological processes, operated in series, have been

constructed. The most complex are systems with separate reactors for carbonaceous oxidation, nitrification, and denitrification, each with its own clarifier. Other configurations combine carbonaceous oxidation and nitrification in a single reactor and have a separate stage for denitrification. The denitrification reactor has been designed both as a post-denitrification and a pre-denitrification process. In some systems, where an attached growth process is included in the design, the provision for clarification after this process may not be necessary.

Such a diversity of process options exists for these systems that recitation of all possibilities is not possible. One example will be discussed to illustrate this control technology. Reference 5 provides data on two municipal facilities that were designed and operated to comply with final effluent limitations of 5 mg/l TBOD, 5 mg/l TSS, 1 mg/l TP, and 3 mg/l total nitrogen. Both employ multi-stage treatment. A schematic of one of the facilities is given in Figure 7-1.

Influent flow of 0.09 m³/s (2 mgd) is degritted and routed to a flow equalization tank. Plant personnel consider equalization an essential feature to stabilizing downstream HRT, SORs, chemical dosages, and filter application rates. Flow is pumped at a constant rate to the first-stage, complete mix activated sludge-clarifier system. This is a carbonaceous oxidation process that reduces the organic load on subsequent processes. Metal salt is dosed to the first-stage reactor to insolubilize the major fraction of influent phosphorus, which is removed in the waste activated sludge.

Second-stage rotating biological contactors provide attached growth nitrification of the first-stage activated sludge effluent. Since the organic load to the contactors is very low and nitrifiers have a low net cell yield, there is little solids production in this unit operation and, therefore, no need to provide clarification.

Nitrified effluent passes to a third-stage, plug flow, suspended growth denitrification reactor that receives a dose of methanol in proportion to the nitrate nitrogen content. Mixing is provided by submerged, low-speed impeller mixers to prevent turbulence. Nitrogen is removed as nitrogen gas by the denitrification reaction. Any nitrogen gas bubbles adhering to sludge particles are scrubbed from the reactor flow as it passes through a flash aeration chamber. A small dose of metal salt is added to this chamber to insolubilize any remaining SP, which is then removed via the third-stage waste sludge stream.

At the final clarifier, polymer dosing capability is provided on an as-needed basis in the event that sludge settleability problems are encountered. The

clarifier overflow is further polished by dual media, gravity flow filters to ensure compliance with the stringent effluent standards.

Waste activated sludge and waste denitrification sludges are digested aerobically. Decanting is done on a batch basis. Insolubilized metal phosphate, precipitated in the sludges, does not resolubilize during aerobic digestion. After conditioning, the digested sludge is applied to agricultural land.

On a yearly basis, using monthly average data, the facility achieves compliance with the 1-mg/l TP limitation 90 percent of the time and complies with the 3-mg/l total nitrogen requirement 95 percent of the time.

7.4.2 Phosphorus and Nitrogen Removal with Managed Biological Systems

Currently, no large reservoir of full-scale operational experience is available with biological processes that cycle biomass through managed environments to achieve both nitrogen and phosphorus removal to meet prescribed effluent limitations.

Reference 3 states that three full-scale facilities (Lansdale, PA; Reedy Creek, FL; and DePere, WI) practicing dual biological phosphorus removal and nitrification did exhibit significant degrees of overall nitrogen removal. This was attributed to unintentional denitrification of nitrate nitrogen in recycle streams entering anaerobic zones of the processes.

A large number of process configurations have been evaluated for biological phosphorus and nitrogen removal, many only in laboratory or pilot-scale studies. The three that have received considerable attention in the United States are the Anaerobic/Anoxic/Oxic (A²O) process, the Bardenpho process, and a modified PhoStrip process. These processes will be presented and discussed in subsequent sections.

As noted in Chapter 2, for biological phosphorus removal, the wastewater should have a SBOD-to-SP ratio of at least 10 to 15. With the dual process approach, incorporating denitrification, the ratio of TBOD to total Kjeldahl nitrogen (TKN) also becomes important. Reference 6 recommends that the ratio of TBOD to TKN be 5 to 10. It is important with managed nutrient control processes, which are not provided with supplemental organic compounds, that the influent wastewater contain enough organic matter to enable the denitrification reaction between nitrate and organics to occur. If the TBOD-to-TKN ratio were lower, greater concentrations of nitrate nitrogen would appear in the final effluent.

It should be noted in the following process flow diagrams that all of these dual control systems recover some of the oxygen contained in the nitrate

The diagram illustrates the wastewater treatment process, including the main flow line, sludge handling, and chemical addition. The main flow starts with 'Dognritted Wastewater' entering a 'Flow Equalization' tank, followed by a '1st-Stage AS' tank, a 'Clarifier', a '2nd-Stage RBC' tank, a '3rd-Stage Suspended Growth Denitrification' tank, a 'Flash Aeration' tank, and finally a 'Final Clarifier'. From the 'Final Clarifier', the flow goes to a 'Dual Media Filter', then to 'Chlorine Contact', and finally to 'Final Effluent'. Sludge handling includes 'Return Sludge' from the 'Final Clarifier' back to the '1st-Stage AS' tank, and 'Waste Sludge Streams' from the 'Clarifier' and 'Final Clarifier' going to an 'Aerobic Digester'. The 'Aerobic Digester' produces 'Decant' (sent 'To Head Works') and 'Digested Sludge' (sent 'To Land'). Chemical addition involves 'Metal Salt Storage', 'Methanol Storage', and 'Polymer Storage' tanks, each with a 'Metering Pump' that adds chemicals to the '1st-Stage AS' tank. A legend at the bottom identifies the line types: solid for 'Wastewater', dashed for 'Sludge', and dotted for 'Chemicals'.

```

graph LR
    WWS[Dognritted Wastewater] -- Wastewater --> FE[Flow Equalization]
    FE -- Wastewater --> AS((1st-Stage AS))
    MS[Metal Salt Storage] -.-> MP1[Metering Pump]
    MP1 -.-> AS
    MS2[Methanol Storage] -.-> MP2[Metering Pump]
    MP2 -.-> AS
    AS -- Wastewater --> C((Clarifier))
    C -- Wastewater --> RBC[2nd-Stage RBC]
    RBC -- Wastewater --> SG[3rd-Stage Suspended Growth Denitrification]
    SG -- Wastewater --> FA[Flash Aeration]
    FA -- Wastewater --> FC((Final Clarifier))
    FC -- Wastewater --> DMF((Dual Media Filter))
    DMF -- Wastewater --> CC[Chlorine Contact]
    CC -- Wastewater --> FEff[Final Effluent]
    FC -- Return Sludge (Sludge) --> AS
    FC -- Waste Sludge Streams (Sludge) --> AD((Aerobic Digester))
    C -- Waste Sludge Streams (Sludge) --> AD
    AD -- Decant (Sludge) --> HW[To Head Works]
    AD -- Digested Sludge (Sludge) --> L[To Land]
    PSt[Polymer Storage] -.-> MP3[Metering Pump]
    MP3 -.-> FC
  
```

Legend:

- Wastewater
- Sludge
- Chemicals

Both biological nitrification and biological denitrification transformations are affected by wastewater temperature. Data on temperature coefficients for multi-stage systems from pilot- and full-scale studies are included in Reference 1. However, temperature data for dual biological systems in a variety of options are not extensive.

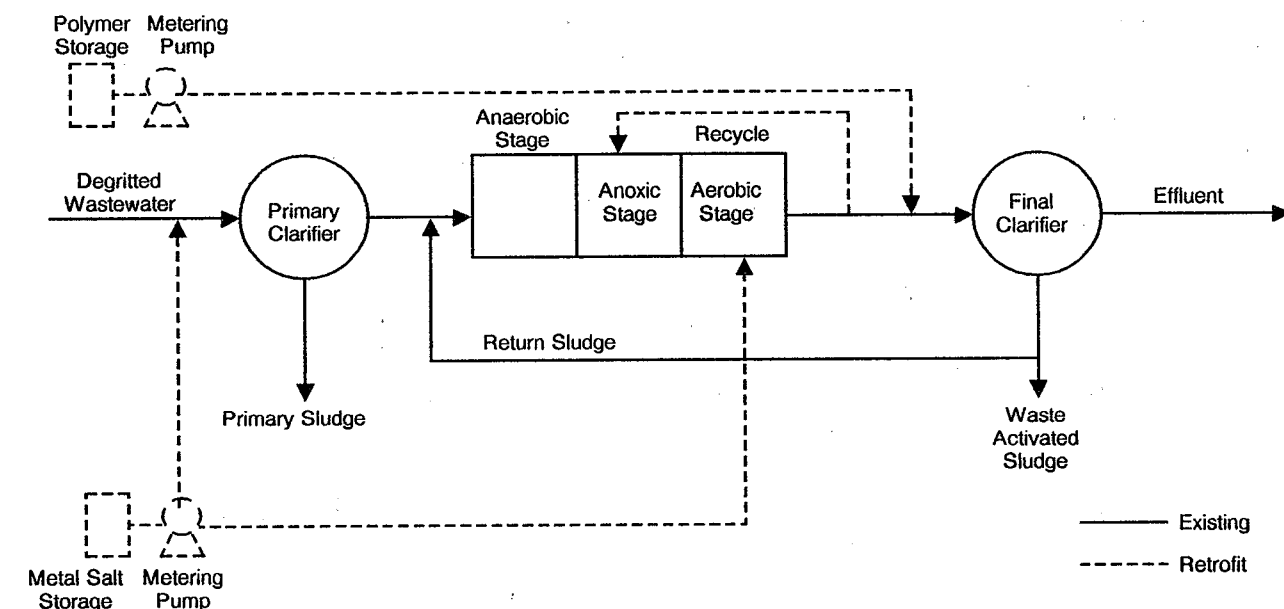
Since denitrification must be preceded by nitrification, conditions for survival of nitrifiers must be provided.

At the present time, due to the lack of a large data base on the influence of wastewater quality and component ratios, the magnitude of internal recycle streams necessary to achieve a given effluent residual, temperature effects on dual processes, and the need to balance SRT, it is recommended that any retrofit for these systems be guided by pilot plant studies.

The A²/O process configuration is presented in Figure 7-2. It is similar to the A/O process (Figure 2-12), except that an anoxic stage is inserted between the anaerobic stage and the oxic stage.

The system must be designed and operated to obtain phosphorus leaching in the anaerobic stage and subsequent biological cellular uptake in the following aerobic stage. The SRT of the biomass must be selected to ensure a steady-state population of nitrifiers at the design temperature. The detention time of the aerobic stage must be sufficient to accomplish nitrification and organic oxidation in this, the only aerated portion of the process.

Figure 7-2. Schematic of an activated sludge system retrofitted for the A²/O process.



| Final Effluent TP mg/l | Probable Need for Chemical Addition | Final Clarifier SOR* gpt/sq ft |
|---------------------------|-------------------------------------|-----------------------------------|
| 2 | None | 800 |
| 1 | Occasional | 600 |
| 0.5 | Continuous polish dose | 500 |
| 0.2 | Continuous polish dose | 500 |

* at peak sustained flow

Approximate final nitrogen concentrations (mg/l):

| | |
|---------------------|-----|
| Organic-N: | 3.5 |
| NH ₄ -N: | 1 |
| NO ₂ -N: | 0.1 |
| NO ₃ -N: | 6 |

Nitrified mixed liquor is recycled to the anoxic stage where biological denitrification occurs in response to organics (BOD) entering this stage from the anaerobic stage. By recycling mixed liquor from the aerobic to the anoxic stage for denitrification, the negative influence of nitrate nitrogen on phosphorus leaching in the anaerobic stage is somewhat alleviated, as only nitrate contained in the return sludge enters the anaerobic stage. Thus, in the A²/O process, denitrification can occur in both the anoxic and anaerobic stages.

The influent to the anaerobic stage must contain organics for two purposes: first, to serve as substrate to be sorbed by the phosphorus-accumulating organisms, and, second, to serve as organic substrate for anaerobic stage denitrification of return sludge nitrate, which in turn reduces the negative influence of nitrate on phosphorus leaching. Enough organic material must pass through the anaerobic stage to the anoxic stage, however, so that reduction of nitrate in the recycle mixed liquor is not inhibited. Consideration may be given to bypassing all or a portion of the raw wastewater around the primary clarifier to increase the organic concentration entering

the anaerobic stage if the influent wastewater has a low organic content.

Depending on the magnitude of the two recycle streams, the A²/O process recovers some fraction of the oxygen content of the nitrate radical. Additionally, the denitrification reactions in the anaerobic and anoxic stages will create alkalinity to help offset downstream alkalinity loss due to nitrification and metal salt addition, if required.

Operational control must be utilized to manage reactor influent organic concentration, select the rates of the two recycle streams, and maintain proper environmental conditions within each stage and appropriate sludge wasting schedules. It should be noted that as the magnitude of these internal recycles increases, the more closely the bioreactor approaches a complete mix process, with increasing loss of environmental control of the separate stages.

The effect of in-plant recycles, such as sludge processing and handling supernatants or filtrates, needs to be evaluated regarding their impact on organic, phosphorus, and nitrogen loadings received by the bioreactor.

To achieve an effluent TP concentration of 2 mg/l with the A²/O process, metal salt addition would probably not be needed. To achieve 1 mg/l might require occasional polish dosing. To achieve 0.5 or 0.2 mg/l would probably require continuous polish dosing.

7.4.2.2 Phosphorus and Nitrogen Removal with the Bardenpho Process

Inspection of Figure 7-3 shows that the Bardenpho process has a similar configuration to the A²/O process; however, it is segmented into a greater number of stages.

The lead stage is an anaerobic stage where phosphorus leaching from the microorganisms must occur. This is followed by four alternate stages that are managed to provide anoxic and aerobic environments. The first anoxic stage is the site of the major denitrification reaction. In the first aerobic stage, biological phosphorus cellular uptake, oxidation of ammonium nitrogen, and oxidation of organics occur.

The subsequent anoxic and aerobic stages are essentially polishing stages to provide low effluent residual total nitrogen and efficient organic removal. Any denitrification occurring in the second anoxic stage is due to the endogenous oxygen demand of the mixed liquor since there is no direct input of organics to this stage. Thus, three locations exist in the Bardenpho system where denitrification can occur: the anaerobic, first anoxic, and second anoxic stages. Nitrification and organic oxidation can occur in the two aerobic stages.

As with the A²/O process, the Bardenpho process has an interstage recycle between the first aerobic and anoxic stages for denitrification and reduction of the influence of nitrate nitrogen on phosphorus leaching in the anaerobic stage. The anaerobic stage receives only nitrate contained in the return sludge.

The highly baffled configuration approaching plug flow and the presence of the two internal recycles are conducive to the reuse of oxygen from the nitrate radical. Operating and environmental constraints for managing biological phosphorus and nitrogen removal discussed in the section for the A²/O process apply equally well to the Bardenpho process. Likewise, the influence of in-plant recycle streams must be evaluated.

Some descriptions of the Bardenpho process label the first stage in the process a fermentation zone instead of an anaerobic stage. In reality, the biological transformations that occur in this reactor, whether labeled fermentation zone or anaerobic stage, are the same. The fermentation zone concept originated at facilities where the wastewater was weak in organic content. The purpose of this fermentation zone was

to provide an anaerobic operation where particulate organics in influent wastewater could be hydrolyzed (fermented) to short-chain fatty acids, such as acetate (7). As previously discussed, soluble organics must be present in the initial anaerobic stage for sorption by the phosphorus-accumulating microorganisms.

The need for the presence of short-chain fatty acids in the anaerobic stage of all biological phosphorus uptake processes, not just the Bardenpho process, has been established (7). Various operational approaches have been applied to ensure that these materials are present. These include

1. adding increments of primary sludge to the anaerobic stage (8),
2. recycling in-plant streams such as thickener overflow to the anaerobic stage (9),
3. infrequent mixing of the anaerobic stage to allow sludge deposition and subsequent hydrolysis of the sludge (10),
4. provision of an off-line fermentation reactor for biological hydrolysis of primary sludge to produce fatty acids to be dosed into the anaerobic stage (11), and
5. addition of anaerobic digester supernatant to the anaerobic stage (2).

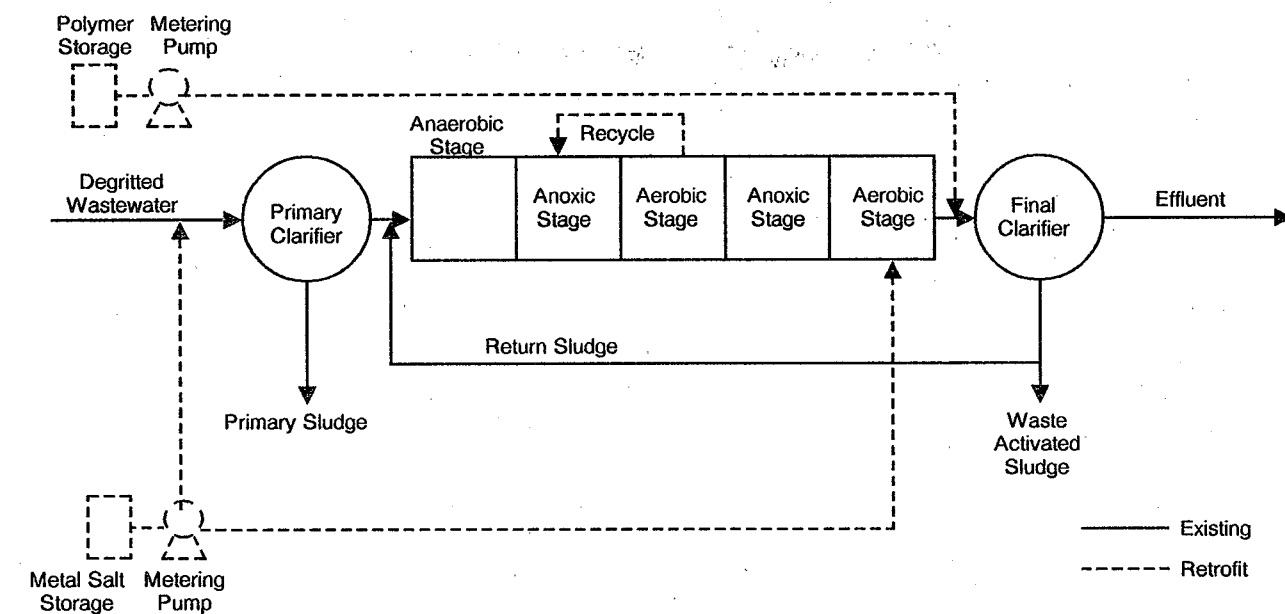
For the Bardenpho process, Figure 7-3 indicates that attainment of an effluent TP concentration of 1 mg/l may require an occasional supplemental dose of a metal salt and that a continuous polish dose of metal salt will probably be required to attain an effluent TP concentration of 0.5 mg/l or less. Attainment of an effluent total nitrogen concentration of 1.5 mg/l has been reported for a 0.07-m³/s (1.7-mgd) municipal facility. The effluent TP concentration was 3 mg/l (10).

7.4.2.3 Phosphorus and Nitrogen Removal with the University of Capetown (UCT) Process

The UCT process was developed at the University of Capetown, Capetown, South Africa (12). A flow schematic is given in Figure 7-4. There are currently no known installations of the UCT process in the United States.

The process is akin to the A²/O and Bardenpho processes. However, two interstage recycles are incorporated in the process flowsheet instead of one. As with the A²/O and Bardenpho processes, mixed liquor is recycled from the aerobic stage to the anoxic stage, but to protect the anaerobic stage from nitrate inhibition of phosphorus leaching, an engineering modification was made. Return sludge is directed into the anoxic stage instead of the anaerobic stage and

Figure 7-3. Schematic of an activated sludge system retrofitted for the Bardenpho process.



| Final Effluent TP mg/l | Probable Need for Chemical Addition | Final Clarifier SOR* gpl/sq ft |
|---------------------------|---|--------------------------------------|
| 2 | None | 800 |
| 1 | Occasional | 600 |
| 0.5 | Continuous polish dose | 500 |
| 0.2 | Continuous polish dose | 500 |

* at peak sustained flow

Approximate final nitrogen concentrations (mg/l):

| | |
|---------------------|-----|
| Organic-N: | 3.5 |
| NH ₄ -N: | 1 |
| NO ₂ -N: | 0.1 |
| NO ₃ -N: | 5 |

then mixed liquor from the anoxic stage is recycled to the anaerobic stage.

In evaluating this process for possible retrofit applications, careful consideration should be given to the detention times of the various stages since a high degree of recycling within the reactor could greatly alter the maintenance of proper stage environmental conditions and substrate utilization rates.

Metal salt addition would probably not be needed to achieve an effluent TP concentration of 2 mg/l. To achieve 1 mg/l might require occasional dosing. To achieve 0.5 or 0.2 mg/l would require a continuous polish dose.

7.4.2.4 Phosphorus and Nitrogen Removal with the Modified PhoStrip Process

A modification of the PhoStrip process that provides for biological denitrification of the nitrate nitrogen contained in the return sludge flow is discussed in Reference 13. This modification is presented schematically in Figure 7-5.

The modification retains all the features of the original PhoStrip process as previously described. For

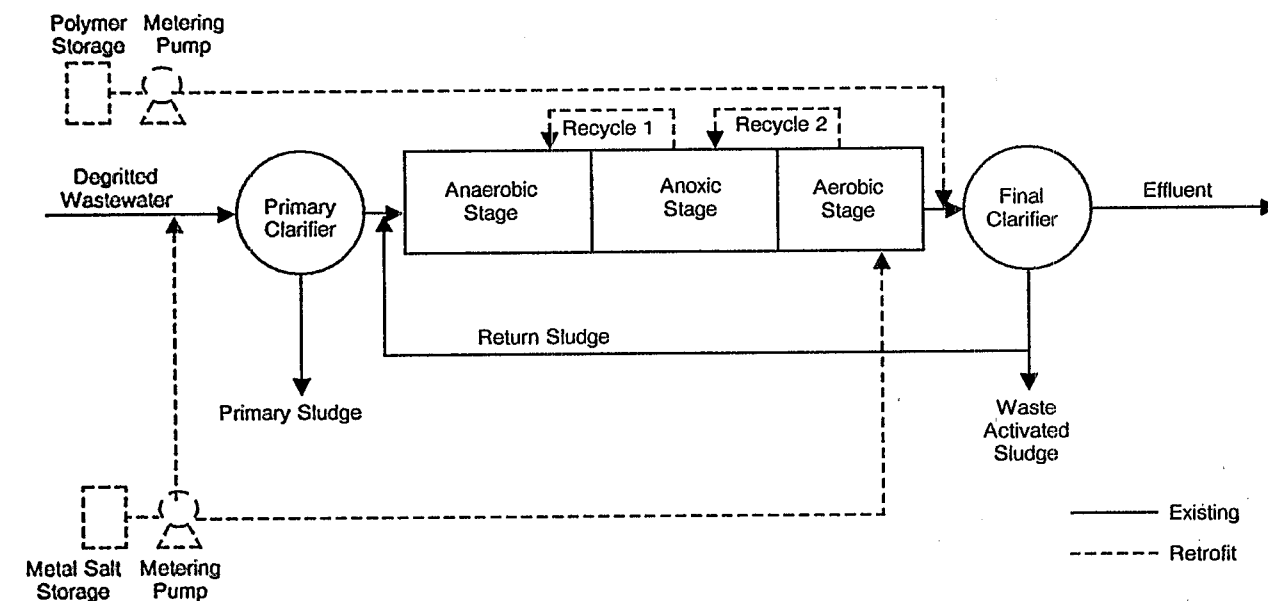
implementing removal of nitrogen, the main stream activated sludge system would have to be operated to achieve nitrification. The nitrate in the return sludge flow is directed to an anoxic reactor ahead of the anaerobic stripper tank.

The denitrification rate is dependent on the hydrolysis of organics due to endogenous respiration since a nitrified return sludge stream has very little soluble organics present. Consideration could be given to providing a bypass line to introduce primary effluent directly into the anoxic reactor to increase the denitrification rate.

The anoxic reactor is sized larger than the quantity of flow required for the anaerobic stripping of return sludge for phosphorus removal. A portion of the anoxic denitrified flow is routed directly back to the aeration tank. Denitrification of the return sludge flow in this modification also serves to protect the anaerobic stripper phosphorus leaching reaction from the inhibiting action of nitrate.

Theoretically, Figure 7-5 indicates that the denitrification removal capability of this modification would be limited to the percentage of return sludge

Figure 7-4. Schematic of an activated sludge system retrofitted for the UCT process.



| Final Effluent TP mg/l | Probable Need for Chemical Addition | Final Clarifier SOR* gpi/sq ft |
|---------------------------|-------------------------------------|-----------------------------------|
| 2 | None | 800 |
| 1 | Occasional | 600 |
| 0.5 | Continuous polish dose | 500 |
| 0.2 | Continuous polish dose | 500 |

* at peak sustained flow

Approximate final nitrogen concentrations (mg/l):

| | |
|---------------------|-----|
| Organic-N: | 3.5 |
| NH ₄ -N: | 1 |
| NO ₂ -N: | 0.1 |
| NO ₃ -N: | 5 |

flow. For instance, if the return flow were 50 percent of the influent plant flow, the amount of nitrate nitrogen that could be denitrified would be 0.5/1.5, or 33 percent. However, it has been reported (13) that a pilot plant operated in this mode denitrified 70 percent of the nitrate nitrogen present. The incremental removal was attributed to coincidental denitrification in the nitrifying activated sludge system. This agrees rather well with results presented elsewhere (2), where a full-scale PhoStrip plant producing a nitrified effluent with no anoxic reactor achieved an overall nitrogen removal of 31 percent.

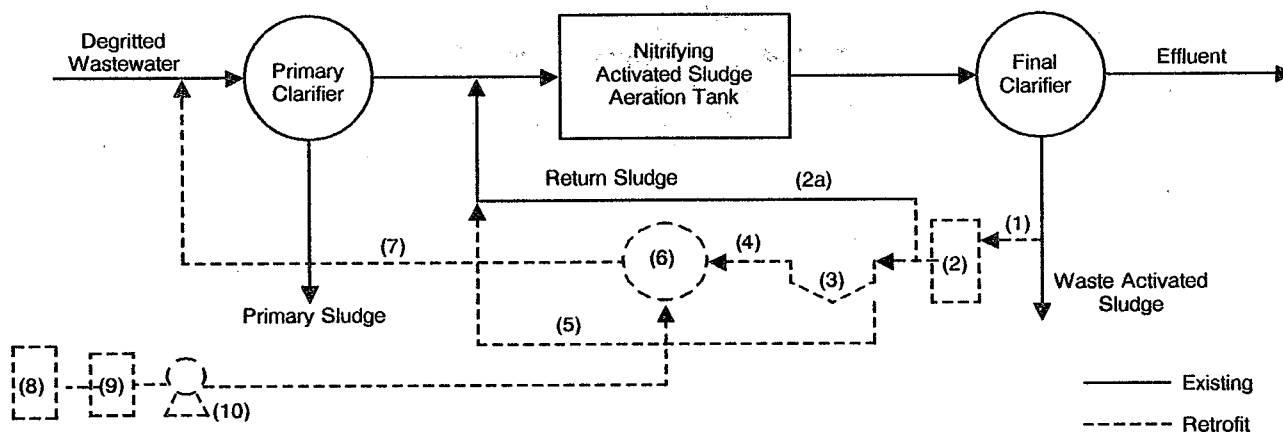
Currently, there are no known U.S. installations of the PhoStrip process modified for biological denitrification. Since the PhoStrip process is a sidestream process, there is no apparent reason that it should not be compatible with a variety of mainstream biological denitrification processes.

Metal salt addition would probably not be needed to achieve effluent TP concentrations of 2, 1 or 0.5 mg/l. To achieve 0.2 mg/l, an occasional polish dose might be required.

7.5 References

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2. Tetreault, M.J., A.H. Benedict, C. Kaempfer, and E. F. Barth. *Biological Phosphorus Removal: A Technology Evaluation*. JWPCF 58:823, 1986.
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4. *Wastewater Engineering: Treatment, Disposal, Reuse*. Revised by George Tchobanoglous. McGraw-Hill Book Company, New York, NY, 2nd Edition, 1979.
5. T. Comfort and L. Good. *Nitrogen and Phosphorus Control by Two Facilities in Florida*.

Figure 7-5. Schematic of activated sludge system retrofitted for the modified Bardenpho process.



Legend

- (1) Portion of return sludge going to anoxic tank.
- (2) Anoxic tank for return sludge flow.
- (2a) Portion of denitrified return sludge flow.
- (3) Anaerobic stripper tank for leaching of phosphorus.
- (4) Stripper tank overflow.
- (5) Stripper tank underflow returned to activated sludge aeration tank.
- (6) Tank containing lime slurry to precipitate phosphorus leached from return sludge in anaerobic stripper.
Lime dose (CaO) = 20-25 mg/l based on plant flow
- (7) Insolubilized phosphorus returned to primary for co-settling with primary sludge.
- (8) Lime storage.
- (9) Lime slurry tank.
- (10) Pump for transfer of lime slurry to phosphorus precipitating tank.

| Final Effluent TP mg/l | Probable Need for Chemical Addition | Final Clarifier SOR* gpl/sq ft |
|---------------------------|--|-----------------------------------|
| 2 | None | 800 |
| 1 | None | 600 |
| 0.5 | None | 500 |
| 0.2 | Occasional | 500 |

* at peak sustained flow

Approximate final nitrogen concentrations (mg/l):

| | |
|---------------------|-----|
| Organic-N: | 3.5 |
| NH ₄ -N: | 1 |
| NO ₂ -N: | 0.1 |
| NO ₃ -N: | 6 |

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7. *Summary Report of Workshop on Biological Phosphorus Removal in Municipal Wastewater Treatment*. Prepared by R. L. Irvine and Associates, Inc., Sponsored by U.S. EPA, Water Engineering Research Laboratory, Cincinnati, OH, Held at Annapolis, MD, September 1982.
8. Stensel, D., N. Sakakibara, D.R. Reffling, and C.R. Burdick. *Performance of First U.S. Full-Scale Bardenpho Facility*. Presented at International Seminar on Control of Nutrients in Municipal Wastewater Effluents, Sponsored by U.S. EPA, Cincinnati, OH, Held at San Diego, CA, September 1980.
9. Barnard, J. *Activated Primary Tanks for Phosphate Removal*. Water-South Africa, 10:121, 1984.
10. Nasr, S. and K. Knickerbocker. *Biological Nutrient Removal - Payson, Arizona*. Presented at the 58th Annual Conference of the Water Pollution

Control Federation, Kansas City, MO, October 1985.

11. Seyen, J., P. LeFlohic, G.M. Faup, M. Meganck, and J.C. Block. *A Separate Acetate Producing Reactor to Improve Biological Phosphorus Removal*. Proceedings of the International Conference: Management Strategies for Phosphorus in the Environment, Lisbon, Portugal. Published by Selper, Ltd., London, England, ISBN 0-948411-00-7, 1985.
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13. Match, L.C. and R.F. Drnevich. *PhoStrip; A Biological-Chemical System for Removing Phosphorus*. Advances in Water and Wastewater Treatment: Biological Nutrient Removal, Edited by M. Wanielista and W.W. Eckenfelder, Jr., Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 1978.

Chapter 8

Estimating Costs for Chemical Phosphorus Removal in the CBDB

8.1 Introduction

This chapter contains cost data sheets (Figures 8-1 through 8-8) that summarize the estimated capital, annual alum and polymer, and total annual costs to retrofit existing treatment plants in the CBDB to achieve phosphorus removal by means of chemical treatment. These are incremental costs over and above the current costs to build and operate plants in the CBDB. The costs of pH instrumentation and controls, additional clarification capacity, increased sludge conditioning and handling capacities, additional building space for housing chemicals and chemical feed equipment, and effluent filtration are not included. The need for these items will be dictated by site-specific conditions such as present capacities of unit processes, wastewater quality, the existing sludge handling scheme, the phosphorus removal option selected, and applicable effluent limitations, among others.

Depending on the degree of excess sludge handling capacity available at a specific treatment plant and the type of sludge handling and disposal methods in use, only minor increases in capital and O&M costs may be necessary to process and dispose of the greater quantities of sludge resulting from chemical phosphorus removal. Conversely, if a plant is already operating at or near its existing sludge handling capacity and new sludge handling and disposal facilities must be built to accommodate the increased amounts of sludge produced, significant expenditures may be required.

Since the need for additional sludge handling capacity must be determined on a case-by-case basis, generalized cost estimates associated with increased sludge production resulting from chemical phosphorus removal could be misleading. For this reason, cost estimates to retrofit existing plants to chemical phosphorus removal are limited in this chapter to capital and O&M requirements directly related to the storage and feeding of chemicals.

The chemical retrofit costs summarized in Figures 8-1 through 8-8 apply to all of the treatment plant categories found in the CBDB except wastewater lagoons. These categories include:

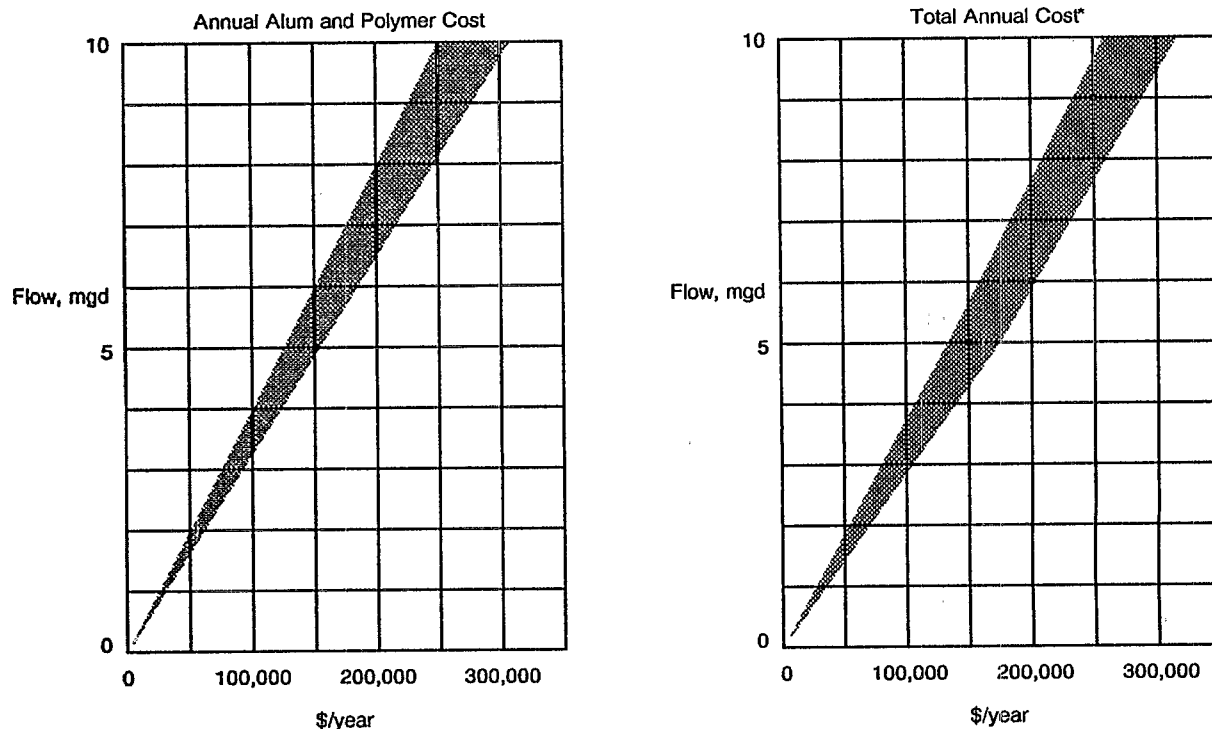
- plug flow activated sludge,
- step aeration activated sludge,
- complete mix activated sludge,
- contact stabilization activated sludge,
- pure oxygen activated sludge,
- single-stage nitrifying activated sludge,
- two-stage nitrifying activated sludge,
- extended aeration,
- oxidation ditches,
- standard-rate trickling filters,
- high-rate trickling filters, and
- RBCs.

Four of the cost data sheets (Figures 8-1 through 8-4), one for each of the effluent TP limitations (2, 1, 0.5, and 0.2 mg/l) considered in this manual, were developed for an influent TP concentration range of 6 to 10 mg/l. The other four cost data sheets (Figures 8-5 through 8-8) were developed for the same effluent TP limitations, but an influent TP concentration range of 3 to 6 mg/l.

Eighteen of the operating plants included in Tables 3-1 through 3-13 use alum for chemical phosphorus removal. For nine of these 18, the annual chemical costs of alum and polymer fall within the appropriate ranges of theoretical annual alum and polymer costs shown in Figures 8-1 through 8-8. The annual chemical costs for the other nine plants are less than those predicted by these figures. These comparisons indicate that an inherent conservatism is built into a theoretical stoichiometric dosing approach. The annual chemical cost curves presented in this chapter, therefore, should represent an adequate chemicals O&M budget for chemical phosphorus removal planning purposes for virtually all conceivable wastewater characteristics and influent conditions based on current chemical pricing structures.

In meeting 0.5- and 0.2-mg/l TP effluent limitations, it is realized that substantial additional costs could be involved in providing for improved effluent suspended solids removals. This is particularly true for high-rate trickling filters, which also might require additional biological reactor capacity to effectively insolubilize phosphorus to low effluent levels. Estimating average incremental costs for these site- and situation-specific requirements is impractical and beyond the

Figure 8-1. Estimated chemical phosphorus removal costs for an influent TP range of 6 - 10 mg/l and an effluent TP limitation of 2 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 130,000 |
| > 5 - 10 | 170,000 |

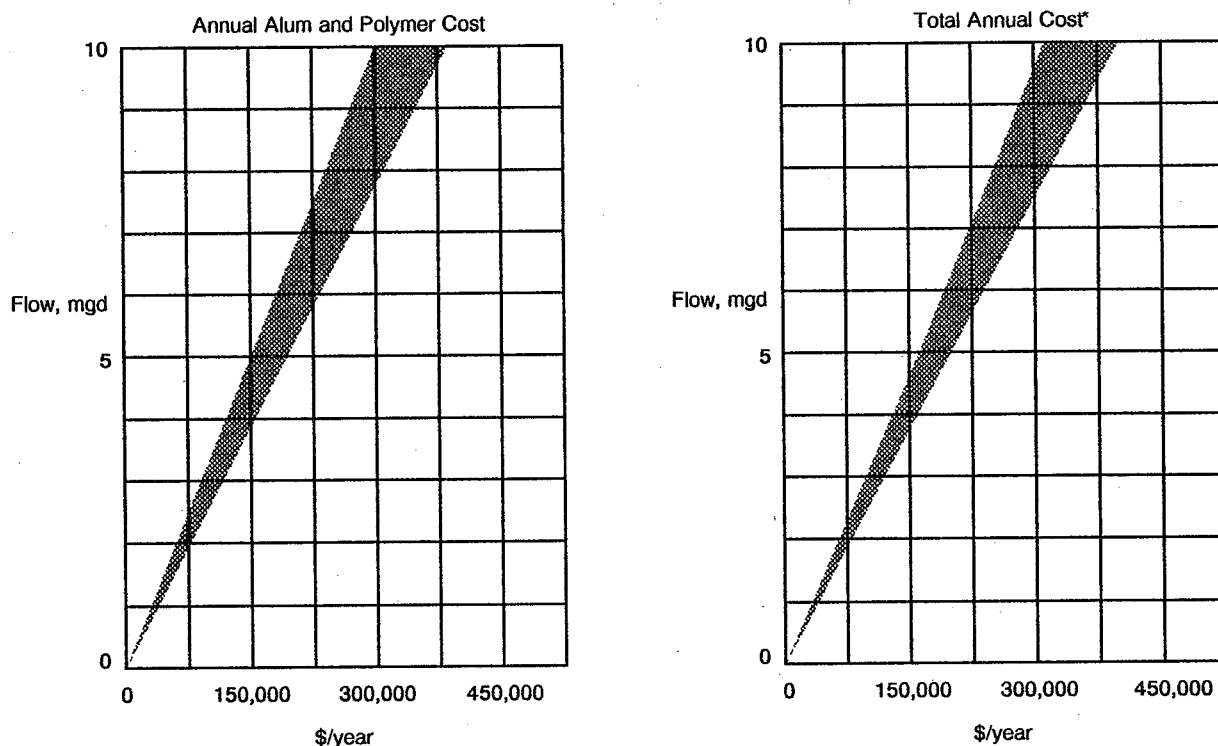
scope of this handbook. Rather, the designer is advised to carefully evaluate the potential impact of effluent polishing on the total cost of any anticipated retrofit project.

As indicated previously in Chapter 2, a theoretical model being developed from research currently in progress (1,2) predicts that metal ion dose requirements to attain low effluent TP concentrations of <1 mg/l are independent of influent TP concentration. Published data confirming this model are lacking at this time. In the absence of such data, the cost curves presented in this chapter are based on conventional metal ion-to-influent TP dose relationships for all four effluent TP limitations considered in this document. If the above theory (1,2) is eventually verified, Figure 8-3 (0.5-mg/l effluent

TP limit at influent TP of 6-10 mg/l) and Figure 8-7 (0.5-mg/l effluent TP limit at influent TP of 3-6 mg/l) would appropriately be merged into one figure as would Figure 8-4 (0.2-mg/l effluent TP limit at influent TP of 6-10 mg/l) and Figure 8-8 (0.2-mg/l effluent TP limit at influent TP of 3-6 mg/l)

Estimated costs for retrofitting existing plants using biological phosphorus removal processes are not provided in this manual because each retrofit must be uniquely designed and the necessary modifications can range from minimal to considerable. Usually, no significant net increase is experienced in operation and maintenance costs when a biological phosphorus removal system is installed. License fees are required for some biological phosphorus removal processes. The amount of the fees is determined on a case-

Figure 8-2. Estimated chemical phosphorus removal costs for an influent TP range of 6 - 10 mg/l and an effluent TP limitation of 1 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 130,000 |
| > 5 - 10 | 170,000 |

by-case basis by the process patent holders. These fees can sometimes be substantial and may preclude the use of a specific process.

8.2 Illustrative Example

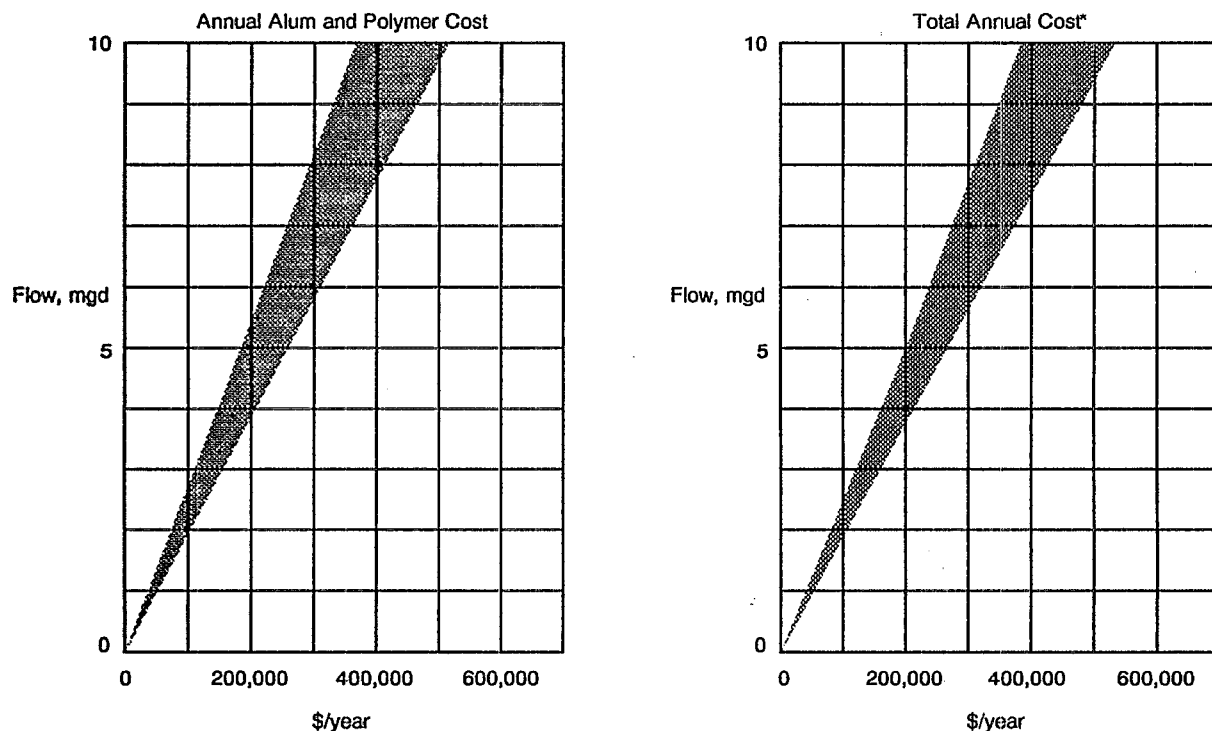
Figures 8-1 through 8-8 each contain a graph showing a range of annual alum and polymer costs as a function of plant size, a graph showing a range of total annual costs as a function of plant size, and a tabulation of estimated capital costs for four plant size ranges. For example, Figure 8-1 presents the cost data for chemical phosphorus removal for an influent TP concentration of 6 to 10 mg/l and an effluent TP limitation of 2 mg/l. To estimate the capital, annual alum and polymer, and total annual costs for a 0.18-

m³/s (4-mgd) plant with these influent and effluent conditions, the reader would proceed as follows:

Using the capital cost tabulation, the capital cost to retrofit any plant between 0.04 and 0.18 m³/s (1 and 5 mgd) is approximately \$130,000. This cost includes construction, engineering, legal, and administrative fees, and contingencies. This cost is for the chemical storage, feed, and distribution system only.

Moving to the first graph, the annual alum and polymer cost would range between \$100,000 and \$125,000 per year. As noted in Chapter 3, the cost of ferric chloride or ferrous chloride would be lower than the cost of alum. Therefore, the costs presented here are conservative.

Figure 8-3. Estimated chemical phosphorus removal costs for an influent TP range of 6 - 10 mg/l and an effluent TP limitation of 0.5 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

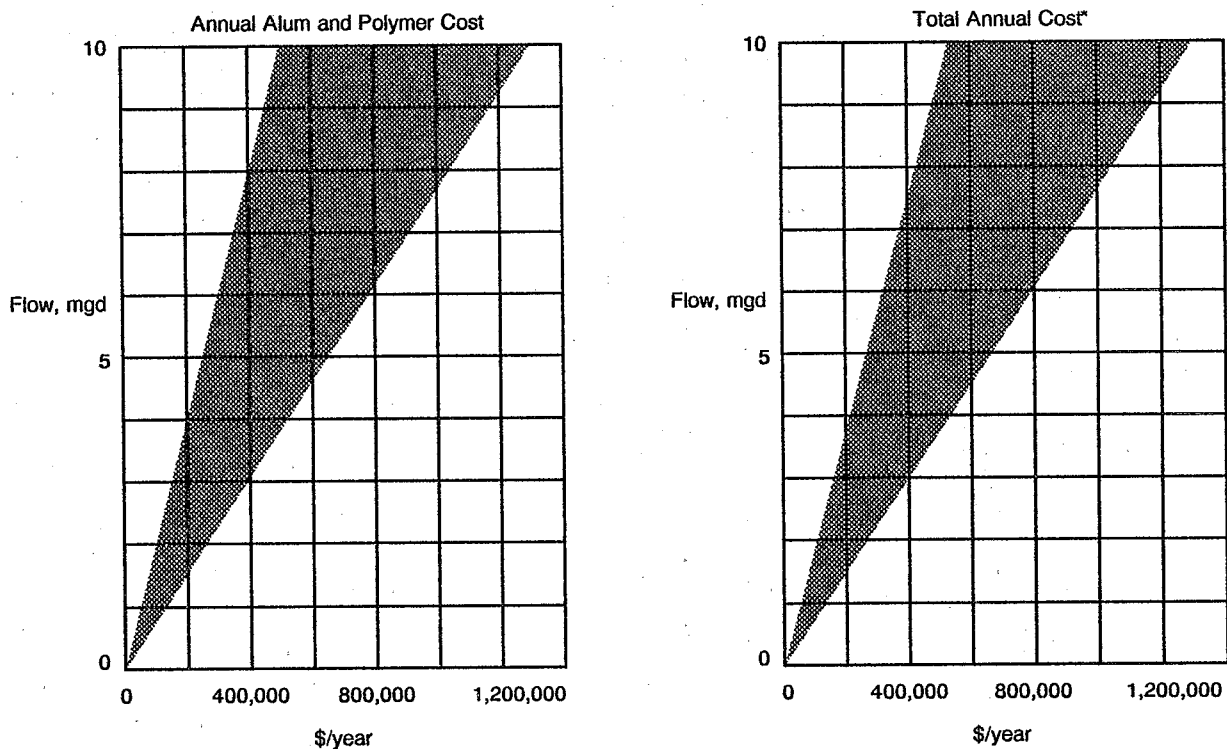
| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 145,000 |
| > 5 - 10 | 170,000 |

The second graph shows the estimated total annual cost. This graph is based on an assumed annual capital cost of 10 percent (based on 8 percent interest over a 20-year period) of the original capital cost (\$13,000 in this case) plus the annual alum and polymer cost range (\$100,000 to \$125,000 in this case). In this example, the estimated total annual cost would range between \$113,000 and \$138,000 per year.

8.3 References

1. Personal communication from R.I. Sedlak, The Soap and Detergent Association, New York, NY, to R.C. Brenner, U.S. EPA, Cincinnati, OH, May 20, 1987.
2. Personal communication from D. Jenkins, University of California, Berkeley, CA, to S.J. Kang, McNamee, Porter and Seeley, Ann Arbor, MI, July 31, 1987.

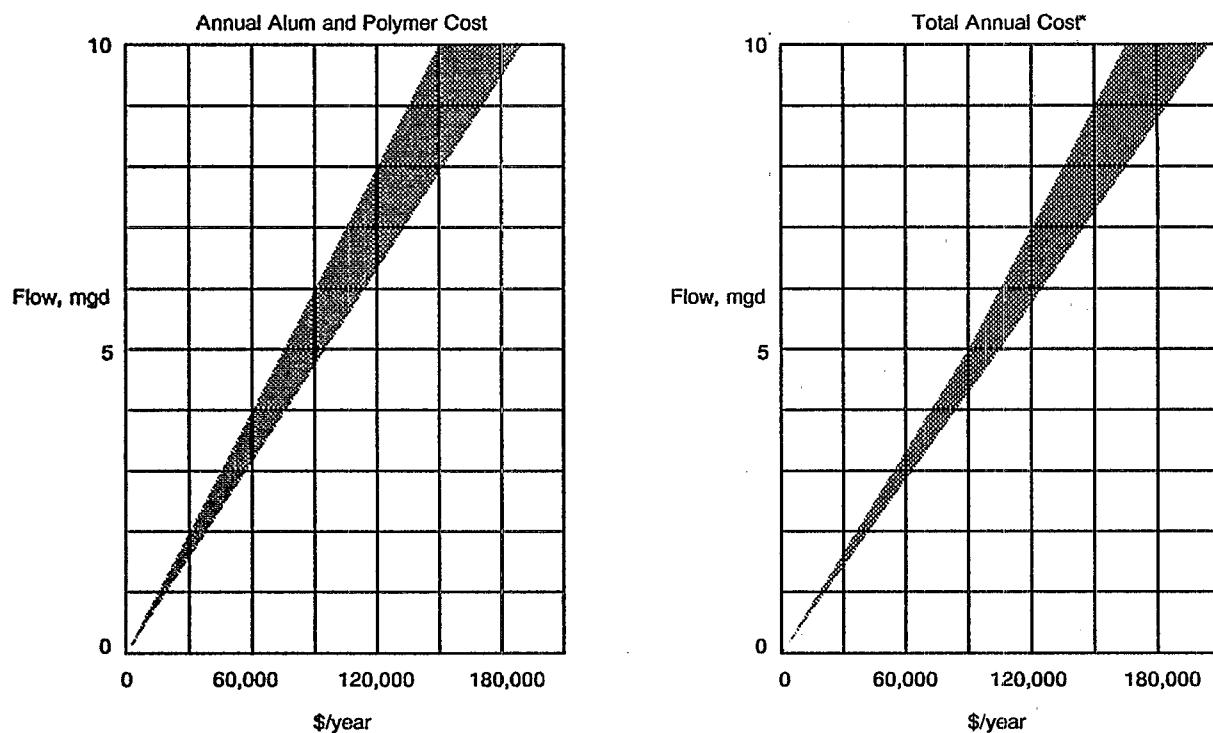
Figure 8-4. Estimated chemical phosphorus removal costs for an influent TP range of 6 - 10 mg/l and an effluent TP limitation of 0.2 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 41,000 |
| 0.1 - 1 | 87,000 |
| > 1 - 5 | 185,000 |
| > 5 - 10 | 200,000 |

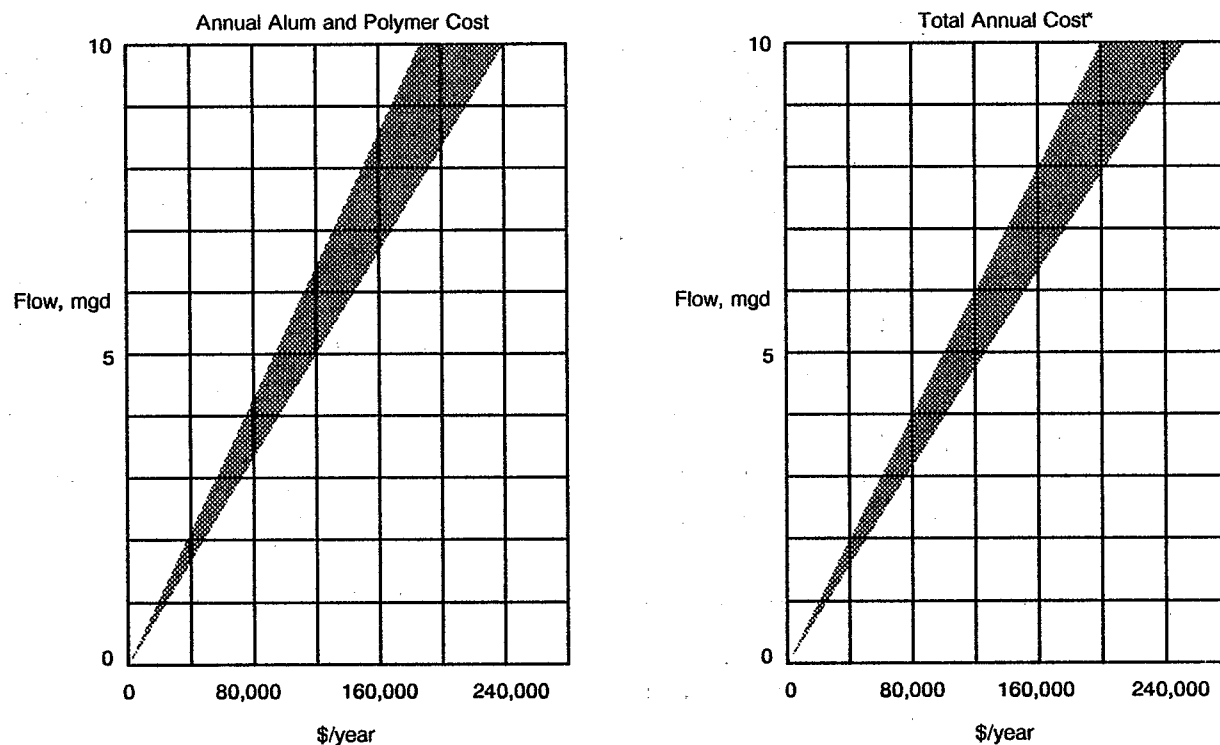
Figure 8-5. Estimated chemical phosphorus removal costs for an influent TP range of 3 - 6 mg/l and an effluent TP limitation of 2 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 115,000 |
| > 5 - 10 | 160,000 |

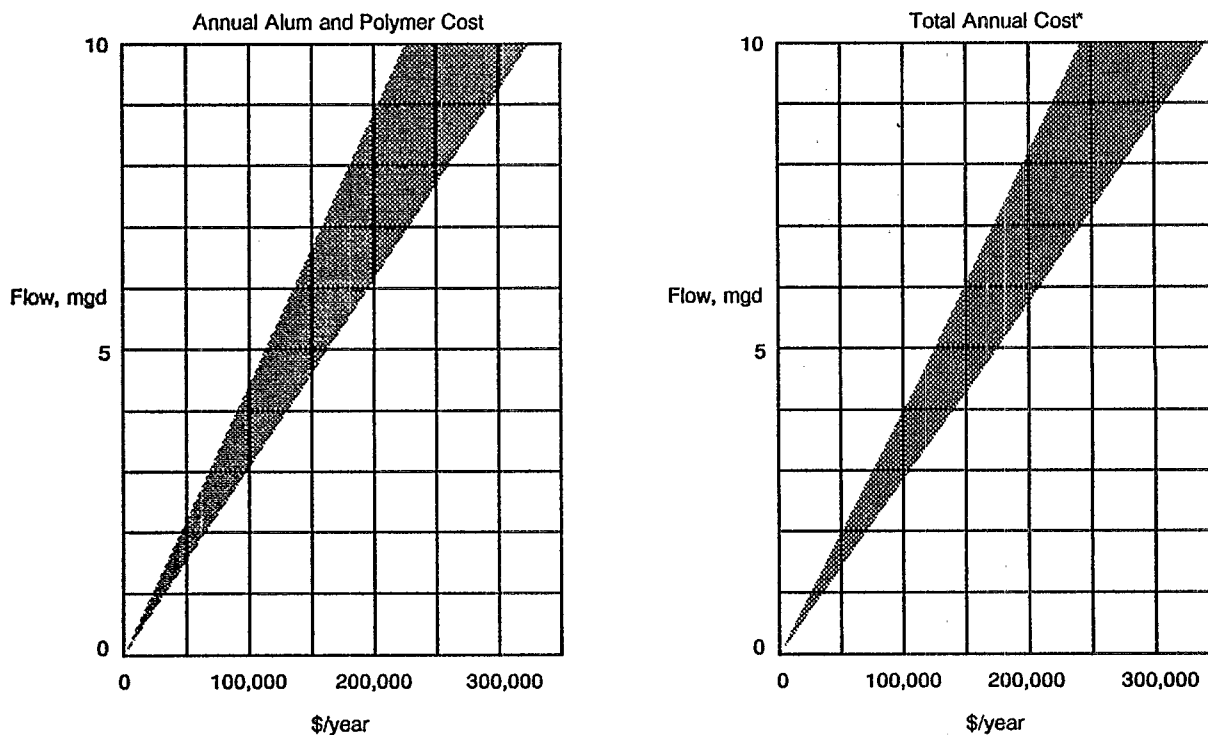
Figure 8-6. Estimated chemical phosphorus removal costs for an influent TP range of 3 - 6 mg/l and an effluent TP limitation of 1 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|----------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 115,000 |
| > 5 - 10 | 160,000 |

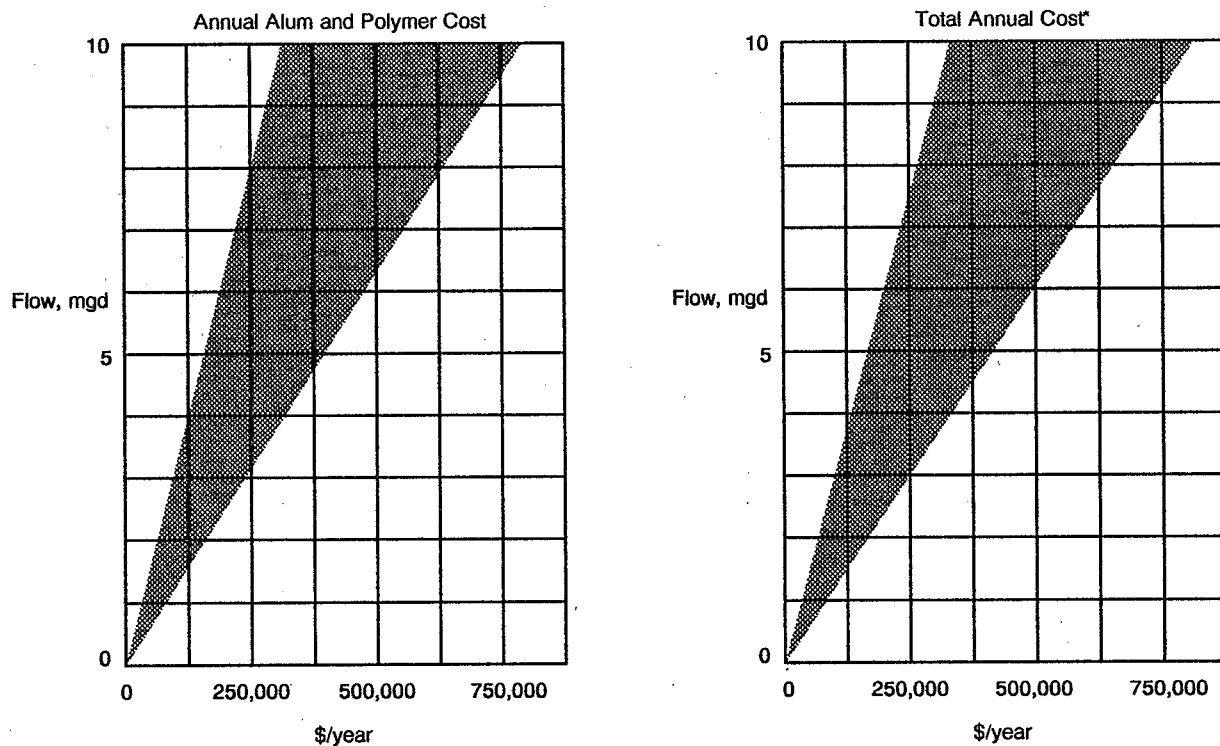
Figure 8-7. Estimated chemical phosphorus removal costs for an influent TP range of 3 - 6 mg/l and an effluent TP limitation of 0.5 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

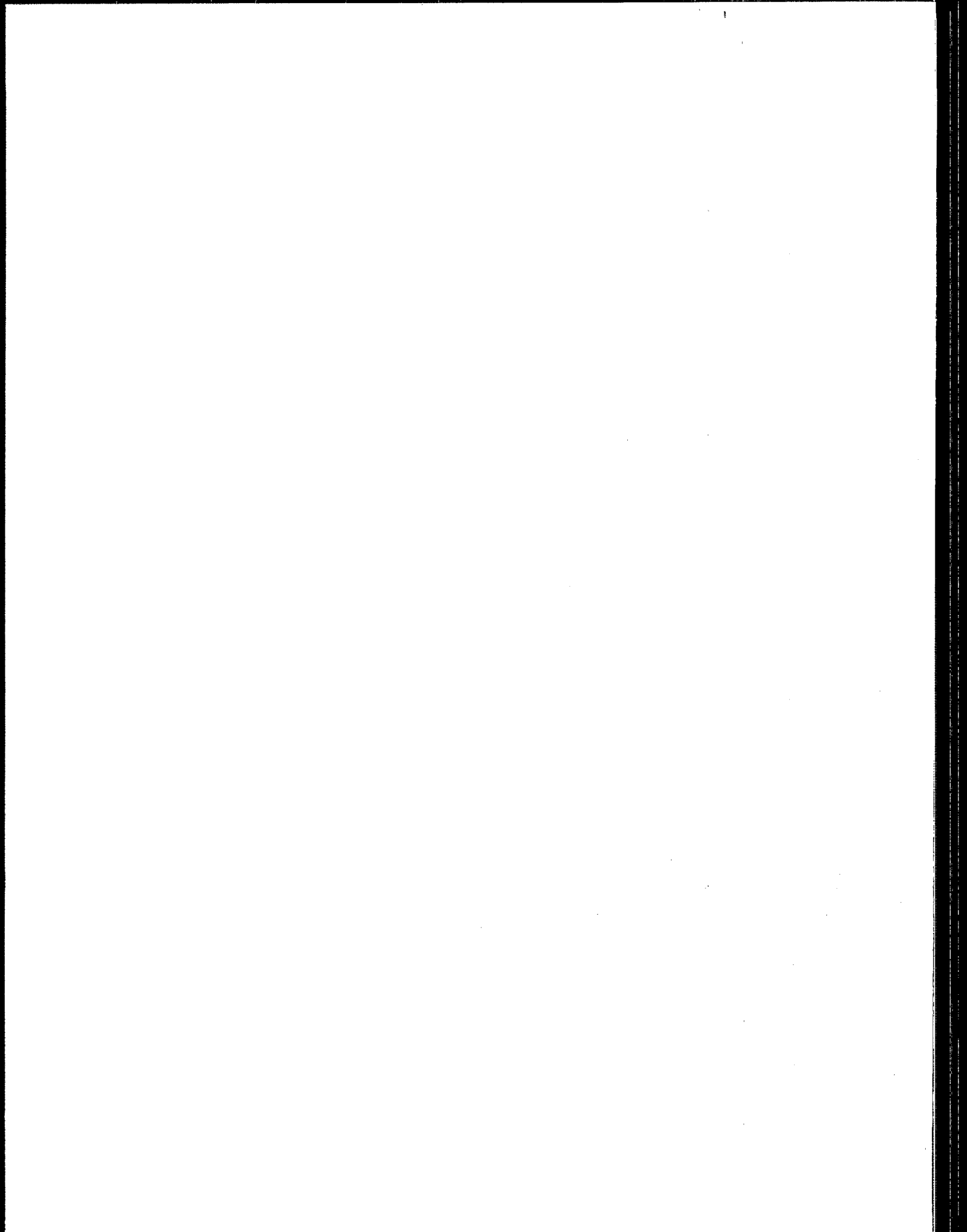
| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 34,000 |
| 0.1 - 1 | 54,000 |
| > 1 - 5 | 120,000 |
| > 5 - 10 | 170,000 |

Figure 8-8. Estimated chemical phosphorus removal costs for an influent TP range of 3 - 6 mg/l and an effluent TP limitation of 0.2 mg/l.



* Sum of the annual alum and polymer cost and the amortized chemical system capital cost. Costs associated with sludge treatment and disposal are not included.

| Plant Size mgd | Chemical System Capital Cost \$ |
|-------------------|---------------------------------------|
| < 0.1 | 41,000 |
| 0.1 - 1 | 79,000 |
| > 1 - 5 | 185,000 |
| > 5 - 10 | 200,000 |



Chapter 9

Factors Affecting Implementation of Phosphorus Removal in the CBDB

9.1 Introduction

The purpose of this chapter is to assist Chesapeake Bay Area government officials in visualizing the broad factors involved in implementing a comprehensive program of phosphorus removal in the CBDB.

9.2 Cost to Implement Phosphorus Removal

Based on the estimated costs to remove phosphorus by chemical addition given in Chapter 8, the approximate capital costs to retrofit CBDB plants based on size, influent phosphorus concentration range, and effluent phosphorus requirement are summarized in Table 9-1. To put these capital costs in perspective, the approximate costs of constructing secondary treatment plants (without phosphorus removal) are also given. The total costs to retrofit all 429 plants in the CBDB that are currently not practicing phosphorus removal for the four effluent TP limits considered in this manual are given in Tables 9-2 and 9-3 for the influent TP concentration ranges of 6 to 10 and 3 to 6 mg/l, respectively. These costs are for the chemical storage, feed, and piping systems only. They do not include the costs for pH control, additional plant capacity or sludge handling equipment, increased sludge disposal quantities, or effluent polishing.

Table 9-2 indicates that the total capital cost for chemical storage and feed to retrofit these 429 plants would be approximately \$29,000,000 for an influent TP concentration range of 6 to 10 mg/l and effluent TP limitations of 2, 1, or 0.5 mg/l. For an effluent TP limitation of 0.2-mg/l, the cost increases approximately 35 percent to \$39,000,000. For influent TP concentrations of 3 to 6 mg/l, the estimated capital costs are approximately 5 percent less than those for an influent TP in the range of 6 to 10 mg/l.

O&M cost totals are not shown because they must be calculated for each individual plant size in the CBDB matrix. This can be done by using the annual chemical cost range chart presented in Table 9-4.

As indicated previously in Chapter 2, a theoretical model being developed from research currently in

progress (1,2) predicts that metal ion dose requirements to attain low effluent TP concentrations of <1 mg/l are independent of influent TP concentration. Published data confirming this model are lacking at this time. In the absence of such data, the tabular summaries of estimated capital costs and estimated annual chemical costs for chemical phosphorus removal given in this chapter are based on conventional metal ion-to-influent TP dose ratios for all four effluent TP limitations considered in this document. If this theory (1,2) is eventually verified, the estimated capital costs to achieve 0.5- and 0.2-mg/l effluent TP concentrations in Table 9-1 would become the same for both the 6-10 and 3-6 mg/l influent TP ranges. Similarly, the estimated capital costs in the 0.5- and 0.2-mg/l effluent TP columns in Tables 9-2 and 9-3 would become identical. Finally, no distinction between the annual chemical costs for the 0.5- and 0.2-mg/l effluent TP limits in Table 9-4 would be appropriate for the two influent TP ranges.

Capital and O&M costs for necessary sludge handling improvements will vary depending on the amount of sludge handling capacity available at each plant, the types of sludge treatment and handling processes in use, and the plant location (urban versus rural), which generally dictates the methods of sludge disposal that can be considered.

9.3 Comparison of Chemical and Biological Retrofit Systems

Table 9-5 summarizes the major differences between chemical and biological phosphorus removal retrofit systems.

9.3.1 Effect of Excessive Infiltration/Inflow on Process Selection

Excessive infiltration/inflow has no major effect on the design of chemical retrofit systems. However, it can seriously affect biological retrofit systems (e.g., larger tank sizes may be required) and must be factored into the overall design.

9.3.2 Process Reliability

Chemical treatment is a very reliable process for phosphorus removal. It is estimated that wastewater

Table 9-1. Estimated Capital Costs to Retrofit CBDB Plants for Phosphorus Removal Using Chemical Addition, Arranged by Influent TP, Effluent TP, and Design Flow¹

| Plant Size | Effluent TP | | | |
|-------------------------------|-------------|----------|----------|----------|
| | 2.0 mg/l | 1.0 mg/l | 0.5 mg/l | 0.2 mg/l |
| | \$ | \$ | \$ | \$ |
| <u>Influent TP: 6-10 mg/l</u> | | | | |
| < 0.1 mgd | 34,000 | 34,000 | 34,000 | 41,000 |
| 0.1 - 1 mgd | 54,000 | 54,000 | 54,000 | 87,000 |
| > 1 - 5 mgd | 130,000 | 130,000 | 145,000 | 185,000 |
| > 5 - 10 mgd | 170,000 | 170,000 | 170,000 | 200,000 |
| > 10 mgd ² | 213,000 | 213,000 | 213,000 | 250,000 |
| <u>Influent TP: 3-6 mg/l</u> | | | | |
| < 0.1 mgd | 34,000 | 34,000 | 34,000 | 41,000 |
| 0.1 - 1 mgd | 34,000 | 54,000 | 54,000 | 79,000 |
| > 1 - 5 mgd | 115,000 | 115,000 | 120,000 | 185,000 |
| > 5 - 10 mgd | 160,000 | 160,000 | 170,000 | 200,000 |
| > 10 mgd ² | 200,000 | 200,000 | 213,000 | 250,000 |

¹ To put these capital costs in perspective, the approximate capital and annual O&M costs for conventional secondary treatment plants without phosphorus removal utilizing the activated sludge process, vacuum filter sludge dewatering, and landfilling of dewatered sludge are (3):

| Design Flow | Capital Cost | Annual O&M Cost |
|-------------|------------------------------|--------------------------|
| 0.1 mgd | \$2,400,000 (\$65,750/Mgal) | \$200,000 (\$5,480/Mgal) |
| 1 mgd | \$8,000,000 (\$21,920/Mgal) | \$700,000 (\$1,920/Mgal) |
| 5 mgd | \$18,600,000 (\$10,190/Mgal) | \$1,500,000 (\$820/Mgal) |
| 10 mgd | \$29,300,000 (\$8,030/Mgal) | \$3,000,000 (\$820/Mgal) |

² Since plant sizes over 10 mgd are not listed in this table, capital cost estimates of 25 percent above the 5-10 mgd estimates are assumed across the board.

treatment plants utilizing chemical addition for phosphorus removal achieve their effluent TP limits 90 percent of the time.

A sufficient data base is not available to judge long-term reliability of biological phosphorus removal at this time. Chemical feed equipment for backup dosing and/or effluent polishing can be installed to enhance reliability.

9.3.3 Potential Technological Advances

Technological advances can be expected to occur in the next several years in the area of biological phosphorus removal. The emerging processes/concepts include:

- A/O and A²/O
- PhoStrip II
- Bardenpho
- Magnesium ammonia phosphate precipitation during anaerobic digestion
- European technology using managed biological systems for nutrient control. Investigators in Denmark, Germany, Austria, and Japan are working with a variety of process options.
- Metal salt dose requirements and optimum dosage points to polish effluent TP concentrations to 0.5 mg/l and below in conjunction with biological phosphorus removal processes.

9.3.4 Impact of License Fees

Certain biological phosphorus removal processes require the payment of a license fee. The amount of the fee, which can be substantial, is determined on a case-by-case basis by the process patent holders. It is recommended that municipalities considering these technologies negotiate license fees prior to embarking on rigorous retrofit planning and design.

9.3.5 Degree of Operation and Control Difficulty

Biological phosphorus removal processes are generally more difficult to operate and control than chemical phosphorus removal processes. The degree of difficulty can be significant. Operations must be adjusted to account for 1) temperature effects on the biological activity of a complex sludge biomass, 2) the ratio of influent BOD to phosphorus, 3) internal recycle flows, 4) sludge removal rates from secondary clarifiers, and 5) the phosphorus content of in-plant recycle streams.

9.3.6 Additional Staffing Requirements

The estimated ranges of man-hours required per year to operate and maintain a ferric chloride or alum feed system were given previously in Table 5-20 as a function of plant size. These man-hours can be converted to numbers of personnel by dividing by 1,500. For example, from the chart, a maximum of

Table 9-2. Estimated Capital Costs to Retrofit CBDB Plants for Phosphorus Removal Using Chemical Addition; Influent TP Range: 6 - 10 mg/l

| Plant Size mgd | State | No. of Plants Not Currently Practicing Phosphorus Removal | Effluent TP (mg/l) | | |
|-------------------|-------|---|--------------------|--------|--------|
| | | | 2.0 or 1.0 | 0.5 | 0.2 |
| < 0.1 | VA | 32 | 1,088 | 1,088 | 1,312 |
| | MD | 138 | 4,692 | 4,692 | 5,658 |
| | PA | 11 | 374 | 374 | 451 |
| | Total | 181 | 6,154 | 6,154 | 7,421 |
| 0.1 - 1 | VA | 62 | 3,348 | 3,348 | 5,394 |
| | MD | 39 | 2,106 | 2,106 | 3,393 |
| | PA | 62 | 3,348 | 3,348 | 5,394 |
| | Total | 163 | 8,802 | 8,802 | 14,181 |
| > 1 - 5 | VA | 21 | 2,730 | 3,045 | 3,885 |
| | MD | 10 | 1,300 | 1,450 | 1,850 |
| | PA | 22 | 2,860 | 3,190 | 4,070 |
| | Total | 53 | 6,890 | 7,685 | 9,805 |
| > 5 - 10 | VA | 5 | 850 | 850 | 1,000 |
| | MD | 1 | 170 | 170 | 200 |
| | PA | 3 | 510 | 510 | 600 |
| | Total | 9 | 1,530 | 1,530 | 1,800 |
| > 10 | VA | 16 | 3,408 | 3,408 | 4,000 |
| | MD | 3 | 639 | 639 | 750 |
| | PA | 4 | 852 | 852 | 1,000 |
| | Total | 23 | 4,899 | 4,899 | 5,750 |
| Total | VA | 136 | 11,424 | 11,739 | 15,591 |
| | MD | 191 | 8,907 | 9,057 | 11,851 |
| | PA | 102 | 7,944 | 8,274 | 11,515 |
| Grand Total | | 429 | 28,275 | 29,070 | 38,957 |

1,580 man-hours per year is required to operate and maintain an alum feed system for a plant in the 0.22 to 0.4 m³/s (5 to 10 mgd) range. This equates to about one additional staff person.

Additional staff time will also be required to operate and maintain biological phosphorus removal systems. However, due to the newness of this technology, additional staff time has not been quantified.

9.3.7 Degree of Maintenance Difficulty

Chemical feed systems will typically require a higher degree of maintenance than biological phosphorus removal systems. Chemical feed systems require maintenance at the storage, makeup, and distribution points of the system, and sophisticated instrumentation maintenance for larger systems may be necessary. The maintenance problems are compounded when corrosive chemicals like ferric chloride must be handled. Maintenance on biological phosphorus removal systems should be limited to the tank mixers and recycle pumps, which is relatively simple, safe, and inexpensive to provide.

9.4 Administrative Issues

9.4.1 Planning and Construction Period Schedules

The estimated time periods necessary to retrofit a wastewater treatment plant for phosphorus removal

are shown in Table 9-6. The times shown are from the initiation of design through plant startup.

9.4.2 Operator Training Seminars

It is recommended that each state in the CBDB conduct operator training seminars for phosphorus removal. These seminars should be conducted at least twice a year at a central location. In addition, plant designers should make personnel available to conduct operator training sessions at each plant retrofitted. These sessions should cover the theory and operation of the phosphorus removal system to be used. Individual site training should begin a few months prior to, and be repeated after, plant startup.

9.5 References

1. Personal communication from R.I. Sedlak, The Soap and Detergent Association, New York, NY, to R.C. Brenner, U.S. EPA, Cincinnati, OH, May 20, 1987.
2. Personal communication from D. Jenkins, University of California, Berkeley, CA, to S.J. Kang, McNamee, Porter and Seeley, Ann Arbor, MI, July 31, 1987.
3. DeWolf, G., P. Murin, J. Jarvis, and M. Kelly. *The Cost Digest: Cost Summaries of Selected Environmental Control Technologies*. EPA-600/8-84-010, U.S. EPA, Washington, DC, October, 1984.

Table 9-3. Estimated Capital Costs to Retrofit CBDB Plants for Phosphorus Removal Using Chemical Addition; Influent TP Range: 3 - 6 mg/l

| Plant Size mgd | State | No. of Plants Not Currently Practicing Phosphorus Removal | Effluent TP (mg/l) | | |
|-------------------|-------|---|--------------------|---------|---------|
| | | | 2.0 or 1.0 | 0.5 | 0.2 |
| | | | \$1,000 | \$1,000 | \$1,000 |
| < 0.1 | VA | 32 | 1,088 | 1,088 | 1,312 |
| | MD | 138 | 4,692 | 4,692 | 5,658 |
| | PA | 11 | 374 | 374 | 451 |
| | Total | 181 | 6,154 | 6,154 | 7,421 |
| 0.1 - 1 | VA | 62 | 3,348 | 3,348 | 4,898 |
| | MD | 39 | 2,106 | 2,106 | 3,081 |
| | PA | 62 | 3,348 | 3,348 | 4,898 |
| | Total | 163 | 8,802 | 8,802 | 12,877 |
| > 1 - 5 | VA | 21 | 2,415 | 2,520 | 3,885 |
| | MD | 10 | 1,150 | 1,200 | 1,850 |
| | PA | 22 | 2,530 | 2,640 | 4,070 |
| | Total | 53 | 6,095 | 6,360 | 9,805 |
| > 5 - 10 | VA | 5 | 800 | 850 | 1,000 |
| | MD | 1 | 160 | 170 | 200 |
| | PA | 3 | 480 | 510 | 600 |
| | Total | 9 | 1,440 | 1,530 | 1,800 |
| > 10 | VA | 16 | 3,200 | 3,408 | 4,000 |
| | MD | 3 | 600 | 639 | 750 |
| | PA | 4 | 800 | 852 | 1,000 |
| | Total | 23 | 4,600 | 4,899 | 5,750 |
| Total | VA | 136 | 10,851 | 11,214 | 15,095 |
| | MD | 191 | 8,708 | 8,807 | 11,539 |
| | PA | 102 | 7,532 | 7,724 | 11,019 |
| Grand Total | | 429 | 27,091 | 27,745 | 37,653 |

Table 9-4. Estimated Annual Chemical Costs for Phosphorus Removal

| Influent TP mg/l | Effluent TP Limitation mg/l | Annual Chemical Cost \$/Mgal |
|---------------------|-----------------------------------|------------------------------------|
| 6 - 10 | 2 | 68 - 84 |
| | 1 | 82 - 104 |
| | 0.5 | 102 - 142 |
| | 0.2 | 137 - 350 |
| 3 - 6 | 2 | 42 - 52 |
| | 1 | 50 - 64 |
| | 0.5 | 62 - 88 |
| | 0.2 | 83 - 217 |

Table 9-5 Comparison of Chemical and Biological Retrofit Systems

| Items | Chemical System | Biological System |
|--------------------------------------|---|--|
| Attainable Effluent TP Concentration | 0.2 mg/l | 1.0 mg/l (0.5 mg/l or less requires chemical addition). |
| Amenable Unit Processes | All secondary treatment processes can be retrofitted. | Amenable only to activated sludge-type secondary processes. |
| Reliability | Reliable, proven technology. | Long-term reliability not proven. |
| Costs | High O&M in terms of chemical and sludge handling, more difficult to maintain. | Little or no excess sludge produced, low O&M costs. Payment of license fee may be required. |
| Sludge Quantities | A considerable amount of chemical sludge is produced for which additional sludge handling facilities may be required. | Sludge quantities will increase only slightly with the A/O and PhoStrip processes. |
| Operator Training | Relatively simple to operate. Some training will be required for operation of chemical feed pumps and systems. | More difficult to operate and control. Some training will be required for monitoring and chemical feed system operation for the PhoStrip process. |
| Additional Staffing Requirements | An additional person may be required depending on the size of the plant. | For the PhoStrip process, an additional person may be required depending on the size of the plant. Additional staff should not be necessary for the A/O process. |
| Infiltration/Inflow | No major effect on retrofit design. | Can significantly affect retrofit design. |
| Potential Technical Advantages | None anticipated. | Several anticipated. |

Table 9-6. Estimated Time Periods for Retrofitting an Existing Plant to Phosphorus Removal

| Plant Size mgd | Design, Plans, & Specs months | Construction months | Startup months | Total months |
|-------------------|-------------------------------------|------------------------|-------------------|-----------------|
| < 0.1 | 3 | 6 | 1 | 10 |
| 0.1 - 1 | 4 | 8 | 1 | 13 |
| > 1 - 5 | 6 | 12 | 3 | 21 |
| > 5 - 10 | 8 | 18 | 4 | 30 |
| > 10 | 10 | 24 | 6 | 40 |

