#### CHEMICAL TREATMENT AND ENHANCED BIOLOGICAL REMOVAL OF PHOSPHATES AT WASTEWATER TREATMENT PLANTS

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#### A LITERATURE SURVEY

AND COST ANALYSIS

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#### A SHORT SUMMARY

Chemical treatment is a practical and effective means of removing phosphate and other waste constituents from sewage. A number of items of fact which support this conclusion are listed below (page references are for the attached survey):

CHEMICAL TREATMENT IS A SIMPLE AND PRACTICAL MEANS FOR REMOVING PHOSPHATES AT EXISTING WASTEWATER TREATMENT PLANTS.

- Conventional municipal wastewater treatment plants provide means for removing solid and liquid wastes. Chemical treatment is a simple process in which phosphate is removed along with other solids in the sewage. Page 1.
- Standard wastewater treatment plant equipment, techniques, and operations are employed for handing and disposal of solids. Page 12.
- 3) Chemical treatment can be installed in most existing wastewater treatment plants within months. Page 5.
- 4) The chemicals used for chemical treatment are widely available and of proven safety, having been used for treating drinking water supplies for many years. Page 28.
- 5) A one mg P/L total phosphorus limitation is readily achievable. The Province of Ontario has been achieving this limitation for the total municipal discharge to Lake Erie since 1975. Several U.S. states (Indiana, Wisconsin, and Minnesota) have subsequently met this goal for discharges to the Great Lakes. Page 3.
- 6) The practice of chemical treatment in over 600 Canadian and U.S. plants in the Great Lakes region supports the above statements. Page 1.

CHEMICAL TREATMENT IS A COST-EFFECTIVE APPROACH TO MUNICIPAL PHOSPHATE DISCHARGE CONTROL.

- 7) The cost of achieving 1 mg P/L is quite reasonable. Total capital and operating costs, including sludge handling and disposal costs, average about \$8 per capita per year. Page 34.
- 8) A further reduction to 0.5 mg P/L with current technology is costly and the beneficial effects on water quality could be vanishingly small. Page 4.
- 9) Chemical treatment, while removing phosphate, enhances sewage treatment plant efficiency significantly. Because of this, much of the cost of chemical precipitation can be assigned to the removal of other waste components such as BOD, suspended solids, nitrogen, parasite eggs, viruses, bacterial color and heavy metals. The improved removal of particulate organic material also significantly reduces the chlorine demand of plant effluent. Pages 5 to 9.

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#### Introduction\*

The technology required for the chemical treatment of wastewater to remove phosphates is well developed<sup>2,126</sup>. The chemical precipitation process generally involves the addition of one or two chemicals. Phosphorus is insolubilized and suspended solids are coagulated by the addition of a precipitating chemical, usually an aluminum or iron salt and sometimes lime. The removal by settling of the precipitated phosphates and other suspended particles may be enhanced by the subsequent addition of a second chemical. This chemical is called a flocculant. The chemicals and the concentrations of the chemicals required to precipitate phosphates and enhance flocculation are dependent on the characteristics of the influent wastewater and are estimated by laboratory tests. The chemical doses are then adjusted by in-plant trials, which also determine the point of chemical addition that optimizes phosphate removal.

Several nations have recognized the capabilities of chemical treatment and have undertaken national and regional programs to require or encourage the installation of chemical treatment facilities at municipal wastewater treatment plants. In Sweden 766 plants serving 75% of the sewered population had implemented chemical treatment by 1979. If these plants, 141 utilize chemical treatment without biological treatment<sup>4</sup>. Similarly, by 1977 wastewaters from 30% of the population in Switzerland were being chemically treated<sup>5</sup>. By the end of 1979, 212 plants in the Province of Ontario were practicing chemical treatment<sup>147</sup>. There are currently over 400 facilities in the U.S. states bordering the Great Lakes that practice chemical treatment<sup>151,152,73,153,154,155,156</sup>.

<sup>\*</sup>Notes: The superscript numbers refer to documentation listed in the biobliography. Abbreviations are listed in attached Appendix I. All costs presented in this paper are in 1983 first quarter U.S. Dollars, except where noted. See Appendix II for the cost indices used. All gallons are U.S. Gallons.

Chemical treatment is currently applied in many existing types of treatment plants, including primary plants, activated sludge plants (including complete mix, step aeration, extended aeration, contact stabilization, and pure oxygen), rotating biological contactors, trickling filters, oxidation ditches and lagoons (Table 1). Chemical treatment has also been shown to improve phosphate removal in overland flow, land treatment systems<sup>8,9</sup>. Laboratory and pilot-scale studies indicate that chemical addition can be utilized for the treatment of stormwater<sup>162</sup> and septic tank effluents<sup>34</sup>.

Chemical treatment can be practiced in the largest wastewater treatment plants and is realistic for communities as small as 500 to 1,000 people. Finland has chemical treatment plants functioning for groups as small as 100 to 200 people<sup>10</sup>. The State of Wisconsin presently requires phosphorus removal at plants in the Lake Michigan basin serving as few as 2,500 people<sup>21</sup>.

Package treatment plants treating 2,000 to 100,000 gallons per day (equivalent to 20 to 1,000 people) capable of achieving 1 mg P/L\* total phosphorus, 10 mg BOD/L, and 5 mg suspended solids/L using chemical treatment are available from many manufacturers in the U.S.<sup>113</sup>. These plants have the advantages of small land requirements and the ability to be relocated. However, package plants typically have higher costs per unit of sewage treated due to their small size and require daily inspection to minimize sub-standard performance. Selection of the appropriate type of package plant and manufacturer should be made by personnel experienced in wastewater treatment plant design and operation<sup>113</sup>.

<sup>\*</sup> mg P/L is a means of expressing the concentration of phosphorus species of interest in a water sample, i.e., milligrams of phosphorus per liter.

#### Achievable Effluent Phosphorus Concentrations

A one mg P/L total phosphorus effluent limitation for municipal wastewater is achievable. Although not all wastewater treatment plants in the Province of Ontario were achieving the 1 mg P/L effluent total phosphorus level, by 1975 the Province had reduced its municipal phosphate load contribution to Lake Erie to a level equivalent to achieving a 1 mg P/L effluent limitation<sup>14</sup>. The states of Indiana (in 1977), Wisconsin (in 1978), and Minnesota (in 1980) have met this goal for all of their major plants ( 1 MGD) in the Great Lakes Drainage Basin<sup>14</sup>. In all of these areas a strong commitment was made at the state or provincial level to meet this goal.

During 1981, 216 Canadian and U.S. wastewater treatment plants in the Great Lakes Drainage Basin achieved average annual effluent total phosphorus concentrations of 1 mg P/L or less<sup>14</sup>. Effluent total phosphate concentrations below 1 mg P/L can be obtained routinely without filtration equipment at many plants<sup>12</sup>. For example, chemical addition at an activated sludge plant, the Jones Island, Milwaukee plant, has consistently achieved effluent total phosphorus concentrations below 1 mg P/L since start-up in 1970<sup>24</sup>. Mean total phosphorus effluent concentrations of 0.5 to 1.1 mg P/L have been reported for Swedish treatment plants using metal salts<sup>13</sup>.

Some Wisconsin plants were reported to be having difficulty achieving 1 mg P/L early in the phosphorus removal program in that state<sup>17,18</sup>. The authors reporting this noted that a successful program required monitoring, good technical advice, and effective enforcement. One reviewer  $agreed^{19}$ . The flow-weighted average effluent phosphate concentration for the 50 plants practicing

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chemical treatment was 1.5 mg P/L, demonstrating that the state was approaching 1 mg P/L with the technology available ten years ago, even though half of the plants were hydraulically overloaded  $^{17}$ .

Total phosphate effluent concentrations consistently below 1 mg P/L are technologically achievable at any municipality. However, they may be costly to achieve depending on individual circumstances. For instance, filtration may have to be used to remove particulate phosphorus and suspended solids that do not settle out in the final clarifier and thus appear in the final effluent. Filtration involves passage of the treatment plant's effluent through a sand bed or multi-media filter to remove suspended particles. This process in conjunction with chemical treatment may be necessary at some plants in order to consistently achieve effluent total phosphorus levels below 1.0 mg P/L. However, filtration is a capital-intensive process which greatly increases the costs of phosphorus removal. The capital cost increase for sand filtration at a 1 MGD plant may be over  $$100,000^2$ . It has been estimated for a 20 mgd plant that the capital costs for filtration would be \$2.8 million (2nd Q, 1979) and annual 0&M costs would be \$290,000 (August, 1979)<sup>81</sup>.

Sand filtration does not remove soluble phosphate, the form of wastewater phosphorus more readily available for biological uptake, 82% bioavailable versus 55% bioavailability for particulate wastewater phosphorus<sup>81,86</sup>. Where improved removal of suspended solids, including particulate phosphate, is required for any reason, the use of flocculation aids such as silica soils or polyelectrolytes, in addition to the coagulating metal salt, may obviate the need for filters.

An effluent concentration of 0.1 mg P/l is achievable through use of extraordinary means: tertiary two-stage lime coagulation and final effluent filtration<sup>2,123</sup>.

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## Use of Chemical Treatment to Improve Suspended Solids and BOD Removal

This is a specific, important beneficial use of chemical treatment<sup>6,61,71</sup>. Chemical coagulants and flocculants are often used to improve suspended solids and particulate BOD removal in plants hampered by hydraulic overloading. Further, chemical treatment during the primary stages of a treatment plant reduces the organic loading on to subsequent biological treatment units<sup>127</sup>, allowing smaller-sized secondary units to be used<sup>107</sup> and reportedly resulting in lower total sludge production<sup>165</sup>.

Adequate mixing and flocculation can be provided by existing facilities, avoiding the construction of additional treatment units  $^{88,123}$ . Wastewater residence times in existing plants are normally adequate for chemical treatment to be feasible  $^{32,117}$ .

Upgrading existing treatment plants through chemical treatment has been estimated to involve minimal capital expense compared to other improvement alternatives<sup>6,32</sup>. In addition, chemical treatment can be implemented in 3 to 12 months to improve the effluent qualities of hydraulically or organically overloaded treatment plants, while capital expansion to meet the problems attributed to the overloading would require 36 to 60 months depending on the plant capacity<sup>6</sup>.

The utility of chemical treatment for upgrading wastewater treatment has been widely recognized <sup>54</sup>,56,61,71,84,117. Improved BOD<sup>16</sup>,33,37,40,50,53,54,58,82,83, 90,100,102,104,107,110,115,116,117,123,133,135 and suspended solids <sup>33</sup>,37,40,50, 53,54,55,56,57,58,60,61,62,71,83,88,90,100,102,104,107,115,116,117,123,133,176, <sup>135</sup> removals have been reported by many. Over one hundred municipal plants in the U.S. without phosphate removal requirements chemically treat to achieve higher BOD and suspended solids removals<sup>12</sup>. The chemical and physical actions of coagulants that result in suspended solids removal are described elsewhere<sup>71</sup>. Laboratory and

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pilot-scale studies have shown improved removals of dissolved organic carbon, as well as suspended organic carbon, from raw wastewaters when treated with ferric chloride, alum, or lime<sup>52</sup>.

Chemical addition to primary clarifiers in secondary plants has been effective for upgrading performance in the following situations<sup>61</sup>:

- 1. intermittent or variable wastewater flows,
- 2. limited space is available for additional clarifiers,
- 3. industrial wastes interfere with biological treatment,
- 4. plant is hydraulically and/or organically overloaded, and
- existing treatment performance must be improved as an interim measure before new facilities go on-line.

Building moratoriums have been reported to be lifted as a result of higher BOD and suspended solids removals brought about by chemical treatment<sup>12</sup>. Chemical treatment has often been used to improve treatment plant performance as an interim measure while new facilities are under construction. In one case study on the use of chemical treatment as an interim measure a plant which was operated at 240% of design capacity achieved BOD and suspended solids removals of  $85-90\%^{72}$ . Although phosphorus removal was not a primary objective of this work, removal of phosphorus was increased to 95% (from 39%) at the same time. In a similar instance, alum effectively controlled sludge bulking during construction of expansion facilities at one plant operating at 150% at design capacity<sup>7,54</sup>.

In one case involving an activated sludge plant, besides improving normal operations, aluminum addition eliminated washout solids at peak flow and allowed the operators to avoid wet weather bypasses<sup>82</sup>.

Pronounced effects occur at plants exhibiting poor treatment<sup>61</sup>. A Canadian study showed that, generally, chemical addition to the primary stage of a plant

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increases BOD removal from a range of 20-30% to a range of 60-70% and increases suspended solids removal from a range of 40-50% to a range of  $80-90\%^{53}$ . One conclusion of the study was that chemical treatment for phosphorus removal may also reduce capital costs for primary or secondary plants, and even eliminate the need for secondary treatment at primary plants.

An early study of sodium aluminate addition to a trickling filter plant showed no improvements in BOD or suspended solids removal and low phosphorus removals<sup>108</sup>. Subsequently, chemical treatment has been shown to improve the phosphorus, BOD, and suspended solids removal of many trickling filter plants<sup>33</sup>, 54,93,107. A recent EPA study of fourteen single-stage trickling filter plants determined that implementation of chemical treatment is an extremely effective, low cost method of improving their operating performance<sup>107</sup>.

Chemical treatment has also been shown to result in significant effluent improvements when implemented in a pilot-scale extended aeration plant. While improving overall phosphate removal efficiency from 23% to 90%, chemical treatment reduced the effluent BOD and suspended solids concentrations by  $50\%^{37}$ . Alum also reduced BOD, suspended solids, and phosphates by 90%, 84%, and 92%, respectively, when added to an oxidation ditch system<sup>104</sup>.

The addition of polymers alone to primary clarifiers has been shown to improve BOD and suspended solids removals<sup>61</sup>.

#### Additional Benefits Attributable to Chemical Treatment

<u>Removal of other wastewater constituents</u>. Chemical treatment increases the ability of treatment facilities to remove other waste components, in addition to

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phosphorus, suspended solids, and BOD including the following: 1) nitrogen<sup>37,52</sup>, 2) parasite eggs<sup>37</sup>, 3) bacteria <sup>58,57,165</sup> and virus<sup>57,64,65,66,165</sup> 4) color<sup>57</sup>, <sup>123,133</sup>, 5) heavy metals<sup>57,58,67,68,69,91,117,127,165</sup> and 6) carbonaceous oxygen demand (COD)<sup>58,124</sup>. In two separate studies, alum was reported to have no effect on nitrification<sup>82</sup> and in the other to have a significant effect<sup>150</sup>. In the latter study, it was speculated that the observed improvement in nitrification could have been due to the pH reduction caused by alum addition. Improved removals of suspended solids, BOD, heavy metals, chlorinated hydrocarbons, poorly biodegradable organics, parasites and, in some cases, nitrogen have also been reported for Swedish plants using chemical treatment<sup>5,13,77,63,49</sup>. Improved removals of bacteria observed in a pilot study were attributed to improved suspended solids removal<sup>58</sup>. Lime addition to pH 11.0 has been reported to result in complete removal of polio virus Type 1<sup>135</sup>.

<u>Metals Removal</u>. Laboratory studies have shown that activated sludge effectively removes heavy metals<sup>11,20</sup>. Numerous jar tests and pilot plant studies have shown that chemical treatment also removes metals (Table 2). The concentration of some metals have been reported to increase during chemical treatment due to their direct association with the chemical or their presence as contaminants<sup>23</sup>.

Improved removal of mercury upon chemical treatment was reported in one study not to be due to direct precipitation by the chemical, but was attributed to mercury adsorption to wastewater constituents which exhibited greater removals as a result of chemical treatment<sup>67</sup>. The removal of one metal (vanadium) has been shown to be pH dependent<sup>1</sup>.

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Full-scale plant data on heavy metal removal by chemical treatment are limited. Addition of ferric chloride and/or polymer at one plant increased removal of chromium and zinc, but did not "dramatically" affect nickel or copper removals<sup>127</sup>.

<u>Reduced chlorine usage</u>. A number of treatment plants have reported reductions in chlorine demand due to chemical treatment:  $5\%^{55,57}$ ,  $15.8\%^{55,89}$ ,  $28\%^{87}$ , and  $50\%^{82}$ . These reductions have been attributed to reductions in effluent particulate matter which contribute to chlorine demand. One plant reported a reduction in maintenance requirements for the chlorine contact tank due to reduced chlorine use<sup>82</sup>. Chlorination of final effluent from a conventional secondary plant (without chemical addition) has been shown not to have an effect on total phosphorus removal<sup>132</sup>.

<u>Cold temperature operation</u>. Chemical treatment operates well at very low temperatures when biological treatment is least efficient  $^{5,13,59,107}$ , although care should be taken to avoid freezing in the chemical feed lines  $^{26,167}$ .

As noted by the State of Michigan Department of Natural Resources<sup>28</sup>, "the beneficial side effect [from chemical addition for phosphate removal in the treatment plant] is in virtually all cases significant." In summary, significant amounts of other wastewater components are also being removed. Therefore, much of the cost of chemical treatment can be assigned to the improved removal of these components.

#### **Operating Considerations**

<u>Clarifier overflow rate</u>. Clarifier overflow rates play an important role in determining total phosphorus, BOD, and suspended solid concentrations in the effluent<sup>33,53,79,127,150,160,178</sup>. The removal of phosphorus is related to effluent suspended solids concentrations since suspended solids contain

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phosphorus. Effluent total and insoluble phosphorus concentrations have been shown to be highly correlated with effluent suspended solids concentrations<sup>99,150,178</sup>.

Clarifier overflow rates of  $580-1440 \text{ gpd/ft}^2$  have been recommended for adequate removals to occur as a result of chemical treatment, with the lower end of the range preferred<sup>2</sup>. Canadian experiences with chemical treatment indicate that with adequate chemical addition effluent total phosphorus concentrations of

l mg P/L can be achieved by maintaining effluent suspended solids below 15 mg/L<sup>160,164</sup>. Final clarifier maximum overflow rates of less than 800-830 gal/ft<sup>2</sup>/day are recommended<sup>32,160,164</sup>. However, overflow rates of 2000 gpd/ft<sup>2</sup> did not significantly affect effluent quality at several Ontario primary plants<sup>53</sup>.

One study determined that decreasing removals of total phosphorus caused by increasing overflow rates could be compensated for by greater additions of chemical (e.g., ferric chloride)<sup>127</sup>.

<u>pH and alkalinity</u>. The insolubilization of phosphorus by the coagulants in major use is optimized at the following pH values:

Alum 6.0<sup>2</sup>,175,13,165,59,40 Iron 4.5-5.0<sup>2</sup>,175,99,40 Lime 9.5-10 (low lime)<sup>165</sup> 11 (high lime)<sup>165,2</sup>

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Low residual concentrations of soluble phosphorus can be achieved in a pH range of 5.5 - 6.5 using  $alum^{12,57,115,59,40}$ . Pilot-scale research indicates that optimum removals of suspended solids occur at the same pH for optimum removal of soluble phosphorus by iron (4.5-5.0)<sup>58</sup>. In low lime treatment, lime is added to react with phosphorus in the primary stage with additional phosphorus removal

occurring during subsequent biological treatment<sup>2</sup>. A lower pH is adequate (i.e., 9.5-10) than with high lime treatment. The latter involves adding enough lime to achieve a pH 11 or greater<sup>2</sup>.

Plant investigations have confirmed minimum  $AlPO_4$  solubility occurs at pH 6, corresponding to a residual soluble phosphorus concentration of 0.01 mg P/L<sup>13</sup>. Optimizing alum addition by pH adjustment reduces residual total soluble phosphorus concentrations and minimizes sludge production<sup>2,175</sup>.

Alum and ferric chloride addition lower the pH of the wastewater toward optimum levels<sup>2,150,12,57</sup>. The pH depression observed by alum addition has been demonstrated to be greater when alum is added at the end of an aeration unit than when it is added at the influent end of the aeration  $unit^{150,110}$ . In the latter instance, the buffering and mixing effects of the aeration unit were believed to have minimized the pH change. The point of alum addition allows for obtaining optimum pH for phosphorus removal, while allowing aeration units to maintain optimum pH for oxidation of carbonaceous material<sup>2,175</sup>. pH measurements should be made <u>in situ</u> due to the observation that such pH measurements differ from those in collected and stored samples<sup>110</sup>.

Wastewater pH can be adjusted by excess metal salt addition or acid plus metal salt addition<sup>2,57,115,187</sup>. It has been suggested that unusually high alum doses used at some plants may be due to high wastewater alkalinity, possibly caused by digestor supernatant recycle or caustic industrial wastes<sup>115</sup>. Therefore, alkalinity measurements should be made of wastewaters that are known to be impacted by sources of alkalinity. Alum and ferric chloride cause a loss of alkalinity in wastewaters without sufficient buffering capacity and can

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result in an undesirable pH reduction<sup>178</sup>. Wastewater alkalinities can also be diluted by storm waters, either by infiltration or the presence of combined sanitary and storm sewers<sup>2,175,71</sup>. Adding a source of alkalinity, such as lime, can compensate for such losses in alkalinity<sup>175</sup>. Alternately, sodium aluminate, which increases wastewater pH, could be used as a precipitant<sup>175</sup>. Caution must be exercised when using excess metal salt to lower wastewater pH since excessive coagulant can result in flocs which are not easily settled or filtered. Similarly, in the case of lime addition, the pH must be raised to a level providing optimum phosphorus insolubilization as well as good flocculation and settling.

<u>Temperature</u>. The rate of chemical reaction between precipitating chemicals and phosphate is unaffected by temperatures between 10 and  $20^{\circ}C^{175}$ .

<u>Mixing</u>. Inadequate mixing contributes to poorer phosphorus removal efficiencies<sup>32</sup>. Points of addition that lead to efficient mixing have been identified in full plant studies<sup>32,99,40,190</sup>. In these studies, several cases were reported where phosphorus removal efficiency doubled as a result of increasing the mixing intensity at the point of chemical addition. One study reported a 20% increase in phosphorus removal occurred by increasing mixing at the point of addition<sup>101</sup>.

#### Impacts of Chemical Treatment on Sludge Handling and Disposal

Chemical precipitation and the use of a flocculant for phosphate removal is a process which converts soluble phosphates to a solid form which settles to produce a sludge. The phosphate sludge is then removed with the sludge normally formed in a wastewater treatment plant. Wastewater treatment plants are designed to remove and handle suspended solids of all types from the wastewater. A plant which is designed and operated to meet secondary suspended solids limitations can be

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expected to achieve an effluent total phosphorus concentration of 1 mg P/L with chemical treatment. Precipitating reactions with other soluble wastewater constituents and improved settling of suspended solids, including particulate BOD, can also be expected to create additional sludge.

<u>Changes in sludge volume and mass</u>. Chemical treatment might be expected to change the weight, the volume, and the handling characteristics of the sludge. Canadian field studies have demonstrated the difficulty in estimating chemical-primary and chemical-biological sludge production on the basis of stochiometry<sup>91</sup>. Based on these studies, design data for primary and activated sludge plants with and without chemical treatment using metal salts have been determined<sup>91</sup>.

Table 3 summarizes the observed changes in sludge production and sludge solids contents observed at 15 activated sludge plants and 7 primary plants in Canada when metal salts were added. The greater increase in sludge that occurs at primary plants can be attributed to increased removal of suspended solids. When lime is added to primary plants the expected increases in sludge dry weight and volume are 300% and 50%, respectively<sup>164</sup>. The volume increase is much less than the weight increase due to increases in sludge solids content, from 5-7% to 12-17%.

In a survey of 14 trickling filter plants, it was found that the increased loading on sludge treatment facilities did not necessitate changes in the existing facilities<sup>107</sup>. In one study, addition of sodium aluminate reduced sludge disposal costs at a secondary wastewater treatment plant due to the lower sludge volumes that resulted when chemical treatment was implemented<sup>82</sup>.

Sludge volume increases have been found to be greater at primary treatment plants upon implementation of chemical treatment for upgrading treatment. In a

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study of seven primary treatment plants in Ontario, total sludge weights and volumes were found to have increased 40% and 60%, respectively, as a result of chemical treatment<sup>91</sup>. The average sludge solids concentration decreased from 6.0 to 5.3% after chemical treatment was begun. At four Canadian secondary plants where chemicals were added to the primary stage, total solids production was reduced by chemical treatment<sup>91</sup>. It was suggested that improved organic removal in the primary stage due to chemical addition reduced the organic loading to the aeration unit resulting in reduced biosynthesis.

Based on data from primary treatment plants in Ontario, sludge mass production when lime is used depends largely on the alkalinity of the wastewater and the lime dosage required to attain a specific pH at which the desired effluent phosphate concentration is achieved<sup>91</sup>.

One report has predicted that chemical treatment to achieve a 0.1 mg P/L effluent total phosphorus concentration would increase sludge mass 108%<sup>91</sup>.

Although additional equipment for sludge handling and disposal may not be necessary at the time chemical treatment begins in an existing plant, it should be noted that some of the sludge treatment capacity held in reserve for the future will be used and capital investments for sludge handling and disposal equipment may be needed sooner than planned.

<u>Sludge digestion</u>. In a laboratory study, the chemical coagulation of organic materials with alum or ferric chloride resulted in a decrease in the anaerobic digestibility of the resulting sludge<sup>112</sup>. The materials most affected were those that are insoluble in water and/or known to complex with aluminum or iron. An early laboratory study determined that anaerobic digestion of ferrous-iron sludge resulted in a significant release of soluble phosphorus, but that the phosphorus in the recycled supernatant would not effect phosphorus removals in primary or aeration units<sup>125</sup>. The pH, alkalinity, volatile acids, and volatile material removal was also not different for the ferrous-iron sludge compared to a

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non-chemical control sludge. Concentrations of iron in the digesting sludge of up to 5.5% did not affect the quantity or quality of gas produced. One plant has reported reduced suspended solids and COD concentrations in anaerobic digester supernatant, as well as phosphorus, as a result of chemical additions<sup>178</sup>.

Aerobic and anaerobic digestion of chemical sludge produced by metal salt addition generally proceeds normally in full-scale plant operations, though the organic loading on the digesters may be increased due to the increased removal of volatile solids<sup>32,164</sup>. Pilot and full-plant studies have reported that both  $aerobic^{32,38,39,87,168}$  and  $anaerobic^{2,32,40,41,87,84,88,92,101,124,168,174,178}$ digestion processes are not adversely affected by the metal salts used in wastewater chemical treatment. Lime sludge has been reported to be satisfactorily treated by aerobic digestion  $4^{42}$ . However, a literature review indicated that upsets in aerobic digestion may occur at high chemical doses<sup>168</sup>. A pilot-scale study of aerobic digestion indicated that primary-alum sludge did not inhibit nitrification<sup>39</sup>. Biological nitrifrication during aerobic digestion is inhibited by the high pH's associated with lime sludge<sup>168</sup>. Phosphate is not significantly resolubilized during anaerobic digestion and the metal salts have been reported not to have inhibitive effects on the digestion process 32,41,42,44,79,88,92,101, 117,124,164,168,174,178,190 pH depression has been reported to occur in anaerobic digestors treating alum-based sludge  $^{61,33}$ . This can be corrected by the addition of lime<sup>33</sup>. Alum sludge has been reported to not produce any additional hydrogen sulfide when anaerobically digested<sup>174</sup>.

Surveys have been made of sludge digestion problems encountered at some Ontario plants when chemical treatment was initiated  $^{32,168}$ . It was concluded that the chemical sludges themselves were not the cause of upsets observed in anaerobic digestion systems, but rather the upsets were due to rapid overloading of the digesters following start-up of chemical addition  $^{32,168,190}$ . Step-wise increases in chemical dose could avoid the upsets  $^{168}$ . Only one of eleven plants using

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anaerobic digestion experienced resolubilization of phosphorus. Many operational problems were noted at plants using lime due to scaling<sup>168</sup>. Also, upsets in gas production have been reported due to high pH sludges resulting from lime addition<sup>32,190</sup>.

Some problems were observed in the digestion of a chemical-biological sludge mixed with a primary sludge in a study involving a trickling filter  $plant^{33}$ . The researchers recommended that the two types of sludge be digested separately. Also, dewatering of the increased sludge due to alum addition was determined to require around-the-clock operation of the existing dewatering equipment and/or installation of additional equipment.

Based on field data from plants in Ontario, Canada, equations have been developed for estimating the quantities of anaerobically-digested sludge produced at primary and secondary plants with and without chemical addition<sup>91</sup>. Higher sludge volumes for disposal are reported to occur at primary plants having anaerobic digestion problems compared to those without problems<sup>91</sup>.

<u>Sludge Dewatering</u>. Ferric-iron, alum, and biological sludge from a pilot extended aeration plant did not show significant differences in dewatering characteristics in three units studied: dissolved air flotation, basket centrifuge, and solid-bowl conveyer centrifuge<sup>97</sup>.

Sludges having higher amounts of inorganic components due to chemical addition are often less difficult to dewater than sludges normally encountered in a conventional biological treatment process<sup>2,6,27,35,36,79,82,92,127,174</sup>, particularly when flocculant aids are used. Chemical costs associated with vacuum filtration have been shown to be dependent on sludge solids concentration<sup>127</sup>. Where sludge solids concentrations are increased by chemical addition, chemical usage during vacuum filtration can be expected to be decreased<sup>127</sup>. One full-plant

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study determined that chemical-activated sludge resulting from alum addition could be dewatered by the same processes used to dewater conventional sludge<sup>16</sup>. It was also noted in this study that alum sludge thickening deteriorated at lower temperatures (9°C vs. 20°C).

The same chemicals that are used to remove phosphorus are commonly used to condition sludge<sup>117,149</sup>. Lime, various metal salts and polymers have been used for many years to improve the handling properties of conventional biological sludges<sup>103,105,106,117</sup>. Lime has also been used for stabilizing biological sludges<sup>149</sup>. Chemical requirements for sludge conditioning were reduced at one plant by chemical addition to the wastewater<sup>24</sup>. At an Ontario primary plant, reduced filter yield and cake solids concentration were observed with both alum and ferric chloride addition<sup>91</sup>. Conditioning costs increased at this plant. An Ontario activated sludge plant exhibited decreased filter cake solids concentration and increased requirements for conditioning chemicals, but no change in filter yield occurred as a result of ferric chloride addition<sup>91</sup>. In another study, alum enhanced the dewatering properties of raw sludge<sup>174</sup>. Sludges resulting from lime addition are reported to have superior dewatering characteristics compared to metal salt-based sludges<sup>91</sup>.

Polymer flocculant aids have been shown to reduce chemical use significantly and, therefore, operating expenditures  $^{37,85}$ .

The oxidation of pickle liquor using chlorine resulted in the South Shore, Milwaukee plant to reduce its chemical dose 60% and thereby reduce the iron content of the sludge<sup>163</sup>. This allowed the plant operators to increase by 25% loadings to the dissolved air flotation thickeners and reduce the quantities of sludge for final disposal.

<u>Final Disposal</u>. Basically, if the sludge is disposed of on land or in a landfill, trucking costs predominate and are proportional to the volume increase. Iron, alum, and lime sludges also can be effectively incinerated<sup>117</sup>. If the

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sludge is incinerated, the cost increase due to greater sludge production might be less than expected, as plant energy requirements can be reduced due to lower moisture content of a chemical sludge  $^{40,127}$ . However, more ash would be produced for disposal  $^{91,185}$ . Also, chemical addition may produce a sludge with lower caloric value or higher moisture content necessitating increased fuel consumption or may cause the formation of clinkers due to iron or aluminum, requiring that the temperature of incineration be lowered to below the fusion point<sup>185</sup>. Clinker problems would be expected at temperatures  $850^{\circ}$ C  $(1500^{\circ}$ F)<sup>185</sup>. The calorific values of several chemical sludges have been described, as well as the characteristics of ash, scrubber water, and stock emissions resulting from incineration of some chemical sludges<sup>185</sup>.

Research has shown that sludges resulting from chemical treatment of wastewater are acceptable for application to crops and agricultural soils 45,46,47, 48,165,179. Anaerobically digested sludges resulting from chemical treatment for phosphorus removal using lime, alum, or ferric chloride have been studied during 3 years of application to soils (loam, loamy sand, and clay loam) on which corn and bromegrass were grown<sup>169,45</sup>. Crop yields resulting from sludge addition were similar to crop yields resulting from ammonium nitrate addition. It was recommended that the rate of nitrogen application be limited to crop requirements in order to reduce the probability of nitrate pollution of water supplies 47,45,169. Soil pH was increased by the lime sludge, decreased by the iron sludge, and unaffected by the alum sludge  $^{169,45}$ . The effect of application of the three types of sludges on the phosphorus, magnesium, potassium, and calcium concentrations in the crops and soils was reported. Application of potassium to avoid observed deficiencies in this essential nutrient has been recommended<sup>47</sup>. Improved crop vields and cattle weight gain have been reported by Ontario farmers applying chemical sludge in excess of 5 years<sup>91</sup>.

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The nutrient, metal, organic (i.e., organochlorine pesticides, polychlorinated biphenyls, and petroleum hydrocarbons) and microbial concentrations in digested sludges from four Canadian plants practicing chemical treatment using alum, ferric chloride, and/or lime have been reported<sup>181</sup>. The heavy metals content of three of the sludges was determined to be significantly correlated to the total solids content of the sludge. The nutrient and heavy metal contents of digested sludges from 10 primary and 33 secondary Ontario plants practicing chemical addition have been summarized<sup>91</sup>.

The concentrations of heavy metals in the sludge and their rate of accumulation in soils and plants can dictate the total amount of sludge applied over the lifetime of a site<sup>47,91</sup>. The concentrations of nutrients and metals in soils and in the tissues of ryegrass, bromegrass and corn treated with fertilizers and lime, aluminum, and iron-containing sludges have been summarized<sup>179,183</sup>. Extraction procedures have been used to assess the availability of metals in soils treated with chemical sludge to plants<sup>184</sup>. The levels of extractable metals in soils amended with sludges from plants adding iron and alum salts were increased the same as in soils amended with non-chemical sludge. Sludge from lime treatment caused small increases. In a study of the effects of slope (2% and 6%) on runoff quality from plots treated with iron-containing sludge, phosphorus, nitrogen, COD, and metals losses were low, with higher losses occurring on the 6% slope<sup>179</sup>. Canadian studies of chemical sludge application to crops demonstrated that the heavy metal uptake by vegetation<sup>46,47,91</sup> or leaching from the soils<sup>47</sup> was minimal and within acceptable limits.

A prime concern in the use of pickle liquors is the build-up of heavy metals in the sludge. Addition of pickle liquor to an Ontario plant did not increase

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heavy metals in the effluent, but the waste sludge contained higher concentrations of cadmium, chromium, copper, manganese, nickel,lead, zinc, arsenic, and mercury compared to the sludge generated with no pickle liquor addition<sup>166</sup>. Preliminary research has been reported on the acid extraction of phosphates and metals from raw and dewatered chemical sludges in order to make them more amenable to disposal methods requiring lower concentrations of either component<sup>186</sup>. However, in one case biological-chemical sludge resulting from pickle liquor addition at the Jones Island, Milwaukee plant has been sold as a commercial fertilizer for many years<sup>24</sup>.

A laboratory study shows that lime, alum and iron salts used to chemically treat wastewater have little effect on the degradation of the sludges when applied to acidic soils, but have a great influence on the liming potential of the sludge. Degradation of the iron and aluminum sludges was increased by adding lime to raise the pH to 7.4, demonstrating that the degradation of these sludges was more 'related to soil pH than the presence of treatment chemicals<sup>98</sup>. Some research has been done on the use of water treatment plant lime sludges for liming farmland<sup>137</sup>. New England farmers using lime-stabilized (to reduce pathogens) wastewater sludges report reduced soil liming requirements and satisfactory crop growth<sup>149</sup>. No differences in bacteria type or concentrations have been found between leachates from sludge treated land and untreated land<sup>47</sup>. Nitrogen conversion to ammonia and nitrate and nitrate movement through soils treated with chemical sludges has been described<sup>179,182</sup>. The concentrations of nitrate present in leachate from crop soils treated for two years with chemical sludges were less than the allowable concentration in drinking water<sup>47</sup>. Total phosphorus concentrations were generally 0.2 mg/L.

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Surveys of sludge disposal practices at Ontario wastewater treatment plants practicing chemical treatment determined that a predominate means of disposal was on farmland, practiced by 63% of the plants<sup>164</sup>. A similar percentage (69%) of plants practicing chemical treatment in five states bordering the Great Lakes used land application at a means of final sludge disposal. Other means of disposal are landfill, incineration, public distribution or hauling by a contractor, and lagoons (Table 4).

#### Phosphorus Removal in Lagoons

Wastewater treatment lagoons are used to serve small populations where the necessary land area is available. Treatment consists essentially of storage of wastewater allowing suspended solids to settle and bacteria levels to reduce. Photosynthesis by plants and algae is also responsible for some removal of soluble BOD and nutrients from lagoon wastewaters. The lagoon contents are normally discharged semi-annually or annually to streams or rivers which dilute the discharges, although some continually discharge.

Lagoons do not usually treat a large percentage of the total sewage flow in an area. For example, in 1981 there were 106 lagoons in the State of Michigan which discharged to surface waters which treated approximately 1% of the total municipal sewage flow for the state<sup>73</sup>. While this state-wide total flow is small, the impact on the waters adjacent to any particular lagoon may be significant.

Technology for chemical treatment of lagoon contents has been developed <sup>32,74,75,76,114,,148,164,165,189,191</sup>. Chemical treatment with alum or ferric chloride of the contents of seasonal retention lagoons in Canada has typically resulted in effluents containing less than 1 mg P/L total phosphorus <sup>74,76,148</sup>. Phosphorus resolubilization does not appear to occur in lagoons after ferric chloride or alum addition, even under anaerobic conditions<sup>76</sup>. Lime has not been effective in the treatment of lagoon contents <sup>164,189</sup>. The

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initial pH obtained by continuous lime treatment of one lagoon's influent sewage was not maintained over the detention time of the lagoon resulting in resolubilization of the phosphorus<sup>76</sup>. Phosphorus resolubilization has also occurred in seasonal lagoons after batch lime treatment<sup>74</sup>. In addition, lime treatment required more labor and the hydrated lime used at the lagoon caused many mechanical breakdowns due to scaling<sup>76</sup>. In a U.S. study of chemical addition to a lagoon, although effluent total phosphorus concentrations of 1 mg P/L were not consistently achieved, 85% of the influent phosphorus was removed<sup>114</sup>. In Sweden, wastewater treatment lagoons practicing chemical treatment achieved an average effluent total phosphate concentration of 0.93 mg P/L in 1976<sup>77</sup>. By 1979, 65 lagoons and aerated treatment cells discharging either continuously or seasonally were practicing chemical treatment in the Province of Ontario, Canada<sup>147</sup>.

Suspended solids and BOD are also reduced by chemical addition to seasonal lagoons<sup>74,114,164,165,191</sup>. Effluent BOD and suspended solids concentrations less than 20 mg P/L can be produced consistently<sup>74,148</sup>. Effluent suspended solids and BOD concentrations were not effected by continuous chemical addition (ferric chloride, alum, and lime) to sewage entering lagoons that continuously discharge<sup>32,76</sup>. Batch chemical treatment with alum or ferric chloride reduced the wastewater pH by approximately 1 unit, but not below 6.5<sup>74</sup>. Batch treatment with lime raised the pH approximately 2 units<sup>74</sup>. Batch treatment with ferric chloride alum, or lime had no effect on nitrite, nitrate, or ammonia concentrations in the lagoons<sup>74</sup>. Alum addition increases the sulfate concentration of sewage<sup>74,76</sup>. Total coliforms and feral coliforms have been noted to be reduced by 98% or more by batch treatments of seasonal lagoons using ferric chloride, alum or lime<sup>74</sup>.

An early study of chemical addition directly into the aerated cell of a lagoon facility determined such means of phosphorus removal was impractical due to excessive sludge build-up<sup>32</sup>. The process has subsequently been carried out in a

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batch-type operation and by continuous addition of coagulant to the ponds raw sewage entering aerated lagoons and conventional stabilization ponds with minimal capital or operational expense<sup>74,76,164,165</sup>. The amount of chemical required is about the same as required by other treatment systems and can be determined by jar tests without the need for full-scale tests<sup>164</sup>.

The accomplishments of this process are significant when compared to the ease by which it is carried out. The batch treatment technique for lagoons that discharge seasonally involves addition of the chemicals from the shoreline or from a boat and mixing of the chemicals using a motorboat <sup>74,165</sup>. The process can be carried out in 1.5 to 2.0 man-hours per acre for liquid chemical addition , 13 to 24 man-hours per acre for dry chemical addition<sup>148,74,189</sup>. Design considerations have been described<sup>148,74,189</sup>. Discharges of the lagoon contents is recommended within 8 to 10 days after batch treatment due to a deterioration in quality that occurs after two weeks<sup>164,165</sup>. Batch treatment has also proven effective for lagoons with continuous discharge<sup>74,76</sup>. The build-up of chemical precipitates on the lagoon bottom is very small<sup>148</sup>, less than 1 centimeter (cm) per application<sup>74</sup>. Chemicals can also be continuously added to the influent raw sewage or to one cell of a multicell lagoon<sup>76,114</sup>.

#### Selection of Chemical and Point of Addition

Table 5 lists coagulants and coagulant aids available for wastewater treatment.

Chemical treatment systems do not usually require much in the way of skills on the part of wastewater treatment plant operators<sup>84</sup>. The process is simple. A solution of a metal salt, generally an iron or alumnimum salt, or lime can be pumped into an existing treatment tank. Simple laboratory tests can assist the operator in selecting the proper chemical and chemical dose <sup>26,32,99,164,165,188</sup>.

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Due to variabilities in wastewater characteristics and treatment facilities, the laboratory tests are a necessary phase of any chemical treatment program. Generally, dosages predicted in laboratory jar tests are greater (15-25%) than those actually needed during plant operation<sup>164</sup>. Jar tests at one plant overestimated the alum dose required for phosphorus removal by 500 percent<sup>177</sup>. One explanation for the discrepancies between doses determined by jar tests and full-plant operations is that the former do not take into account the phosphorus removal capabilities of recycled sludge containing precipitating chemicals. For example, recycling of alum-containing sludge allowed one plant to reduce alum usage  $57\%^{177}$ . With recyle, it has been reported that some plants were able to reduce alum consumption by one-third<sup>57</sup>. Therefore, chemical doses at plants recycling sludge tend to decline after an initial start-up period<sup>87</sup>. Treatment plant studies have shown that recycling of sludge causes phosphorus to continue to be removed 4 to 8 days after metal salt addition is stopped<sup>176,178</sup>.

A program for jar testing and full scale treatability tests has been described<sup>164,165</sup>. Precautions to be taken in designing for chemical treatment have been summarized<sup>167,192</sup>. By enhancement of wastewater treatment plant operation, chemical treatment can be a time and money savings process<sup>82,84</sup>. Automatic metering equipment is not needed at small plants. For instance, in full-scale plant studies, changing the flow of chemical two to eight times per day to match the hydraulic load was sufficient<sup>16,32,79,87,150,190</sup>.

Jar test data have indicated that the correlation between influent phosphorus concentrations and the chemical dose needed to achieve a desired effluent concentration when metal salts are used, is poor and not suitable for controlling chemical addition<sup>32,26,180</sup>. Dosing chemicals proportional to the influent phosphorus load has been observed to provide no benefit<sup>190</sup>. The chemical dosage required to achieve an effluent total phosphorus concentration of 1 mg P/L using

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metal salts is not proportional to the influent phosphorus concentration due to side, or competing, reactions which exert a chemical demand  $^{170,57}$ . Generally, every 1% decrease in influent phosphorus would reduce the chemical dose 0.4 to  $0.6\%^{170}$ .

When lime is used, the residual soluble phosphorus concentration is pH dependent<sup>51</sup>. The chemical dose required to achieve a desired pH and effluent phosphate concentration when lime is used is primarily dependent on the alkalinity of the wastewater<sup>63,117,123</sup>. At final pH values 10, total phosphate residuals are insensitive to the initial concentration of phosphorus<sup>51</sup>. The effect of initial orthophosphate concentration on the lime dose required to achieve a desired effluent concentration has been described elsewhere<sup>51</sup>. Equations for predicting lime dosage based on Canadian field studies have been reported<sup>91</sup>.

Full-plant trials determine the compatability of the chemical with the treatment process, proper dosing locations, settling characteristics, and resulting sludge production. These trials have led to many different choices of chemicals and dosing points at wastewater treatment plants. Of the 134 operators of major ( 1MGD) Canadian and U. S. treatment plants in the lower Great Lakes responding to a survey, 104 (80%) indicated that they practiced chemical treatment<sup>80,161</sup>. Reported chemical usage was as follows: aluminum salts - 48%; iron salts - 50%; and lime -  $2\%^{161}$ . Only 5% (5 plants) utilized a tertiary process to remove phosphorus. The most frequent approaches utilized metal salt addition to the primary or secondary stages, i.e., aluminum salt addition to the secondary, iron addition to the primary, and iron addition to the secondary, in order of decreasing frequency. Overall 55% were treating for phosphorus removal using simultaneous precipitation  $^{119}$ . Swedish plants using chemical treatment primarily utilize post-precipitation (74%), where the chemical is added in a separate stage after biological treatment<sup>4</sup>. Alum is used in 85-95% of the Swedish plants practicing chemical treatment<sup>13</sup>. Almost all plants in Switzerland

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practicing chemical treatment use the simultaneous precipitation method and 90-95% use ferric-iron salts<sup>5</sup>.

One report states that iron salts must be in the ferric form before a reaction with soluble orthophosphate can take  $place^{26}$ . Therefore, ferrous salts, usually as ferrous sulfate or ferrous chloride in pickle liquor, should not be used in the primary stages of treatment. Retention times (2-3 hours) and oxygen supplies (0.15g 0/g Fe<sup>+2</sup>) in secondary processes are reported to be adequate to convert the ferrous ion to ferric ion and, therefore, allow ferrous salts to be successfully used<sup>26,164,165</sup>. A survey of chemical treatment practices in Ontario, Canada determined that the most compatible dosing point for aluminum and ferric salts was the aereation tank effluent immediately prior to the point of discharge to the final clarifiers<sup>26</sup>. Plants utilizing ferrous salts add the chemical at the beginning of the aeration tank, for the previously explained reasons. It was concluded on the basis of the survey that "[T]he chemical compatibility with raw sewage [of aluminum and iron salts] at most wastewater treatment plants throughout the province was exceptional."

Because lime removal of phosphorus is based on elevation of the wastewater's pH, lime cannot be used in the secondary stages of treatment due to the detriment that the pH elevation would have on the biomass<sup>26,164</sup>. Therefore, lime is typically added prior to the primary clarifier or after the secondary stage in a third, separate stage<sup>26,164</sup>. Lime addition to the primary stage has been demonstrated to be an effective step in reclaiming municipal wastewater for industrial use<sup>135</sup>. A pilot scale study of lime addition to a primary stage concluded that subsequent trickling filter performance was not adversely affected by pH levels required for effective phosphorus removal, approximately 9.5<sup>138</sup>. The previously mentioned Ontario survey found that, generally, the use of lime resulted in operational problems wherever it was used<sup>26</sup>. Considerable maintenance problems with mixing and feeding equipment were reported and lime addition had high manpower requirements. Some plants reported mechanical failure

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of equipment. The major disadvantages to lime treatment have been determined in Ontario studies to be 1) operators find lime more difficult to handle than metal salts, 2) plant designers have had difficulty in developing a low maintenance lime system for wastewater treatment, and 3) only the low-lime process (pH 9.5-10.0) is directly compatible with conventional secondary plants; effluent from a high-lime process would require neutralization (recarbonation) prior to biological treatment<sup>165</sup>. The potential adverse effects of lime and lime sludge on biological units has been also noted by others<sup>61,117</sup>. Lime addition to primary clasifiers may require subsequent adjustment of pH to maintain it within acceptable limits for downstream biological units. However, one plant study of lime addition to a primary stage followed by biological nitrification demonstrated that in-process generation of carbon dioxide by oxidation is sufficient to reduce the pH of the wastewater, provided enough oxygen is present, and thereby avoid a separate recarbonation stage<sup>135</sup>.

Plant trials can include tests of polymer additions. Polymers are used to improve the settling properties of suspended solids, reportedly allowing a reduction in metal salt requirements<sup>101,40,99,57</sup>. The relationship between polymer additions and suspended solids removals have been described elsewhere<sup>127</sup>.

Full plant trials also lead to a cost-efficient dosing method. Dosing according to flow to flow has been recommended to minimize chemical use<sup>167,180</sup>. One plant has reported that dosing according to the mass of phosphorus entering the plant is more cost-efficient than dosing according to flow<sup>122</sup>.

Table 6 summarizes chemical doses reported at treatment plants in the Province of Ontario. Generally, higher doses of metal salts were reported at primary plants than secondary plants<sup>12,26</sup>. Chemical addition to aeration units appears to allow lower doses of metal salts to be used to achieve 1 mg P/L total soluble phosphorus than addition to raw wastewater<sup>2,175</sup>. Some possible explanations for these differences have been described<sup>12</sup>. For example, approximately 200 mg/L of alum is required for chemical addition to raw wastewater, whereas only

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50-100 mg/L of alum is needed for addition to the final effluent<sup>2</sup>. It has also been noted that municipal wastewaters having high industrial contributions have more variable phosphorus removal than primarily domestic wastewaters<sup>32</sup>.

Chemical treatment converts phosphate to a solid material of the type wastewater treatment plants are designed to remove. Proper clarifier overflow rates are essential for solids removal, including insolubilized phosphorus<sup>33,92</sup>. Wastewater treatment plant personnel who have been trained to operate a plant successfully with respect to achieving suspended solids limitations have the training for carrying out chemical treatment satisfactorily.

#### Availability and Safety of Chemicals Used for Chemical Treatment

The chemicals commonly used-lime, iron salts, aluminum salts, and organic flocculants-have met the very high and stringent standards necessary for chemicals used to treat drinking water supplies. These chemicals have been widely used for this purpose for many years.

One option available with the use of lime is the ability to recover the lime from the sludge for reuse in the treatment process<sup>134</sup>, <sup>136</sup>, <sup>139</sup>, <sup>141</sup>. Generally this would be practical only at larger plants<sup>141</sup>.

It has been proposed that alum from water treatment plants be recovered by acidulation and be used for wastewater treatment<sup>29</sup>. The recovered alum could be delivered to the treatment plant by truck or pipeline. If the existing sewer lines can withstand low pH's and have velocities sufficient to keep solids in suspension, recovered alum can be added to an interceptor sewer near the water treatment plant. Laboratory tests indicate that recoverd of alum from wastewater treatment plant sludges may be economical<sup>173</sup>. Preliminary investigations have also been conducted on the recovery of iron from incinerated sludges for reuse in phosphorus removal<sup>185</sup>.

The increase in dissolved solids in effluents resulting from chemical treatment is minimal. Assuming average total phosphorus concentrations of 7.5 mg P/L in the wastewater plant influent and 1.0 mg P/L in the effluent, 31 mg SO $_{a}$ /L

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of sulfate would be added to the wastewater effluent by alum addition. Ferric chloride addition would add 22 mg Cl/L of chloride to the wastewater. Secondary activated sludge effluent has been reported to have sulfate and chloride concentrations of 185 mg SO<sub>4</sub>/L and 179 mg Cl/L<sup>78</sup>. Therefore, chemical treatment will typically result in an effluent having sulfate and chloride concentrations below the recommended maximum limits for these constituents in drinking water (250 mg/l for both)<sup>78</sup>.

All of these chemicals are readily available. There are over 100 manufacturers of inorganic coagulants<sup>6,56</sup> which are derived from some of the most abundant elements in the earth's crust. Listings of U.S. supplies of inorganic chemicals are published elsewhere<sup>71</sup>. An overview organic flocculants and a listing of U.S. suppliers has also been published elsewhere<sup>158</sup>.

#### Costs for Achieving a 1 mg P/L Limitation

Chemical treatment of wastewater is an operation-intensive rather than capital-intensive process. A chemical treatment system is simple to design. In many cases the required storage and chemical feeding equipment can be designed and installed by the treatment plant engineer.

An average <u>capital cost for chemical storage and feed systems</u> at U.S. plants of \$1.32 per capita per year was calculated in an economic analysis of chemical treatment based on data from four plants<sup>146</sup>. Capital costs for chemical treatment equipment were surveyed at 64 plants in Ontario, Canada and found to average much less. It was estimated on the basis of costs observed at these 64 plants that chemical treatment equipment (exclusive of sludge handling facilities) for a typical 1.3 MGD wastewater treatment plant costs approximately \$25,000<sup>26</sup>. Based on a typical design population for such a plant (13,000 people), this cost is equivalent to \$0.18 per design capita per year (see footnote 6 in Table I for method of calculation). It was noted in the Canadian survey that as the size of

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the plant increased, the cost per million gallons of design capacity decreased. In a study of fourteen U.S. trickling filter plants practicing chemical treatment, it was determined that physical alterations for the storage, dosing, and mixing of chemicals are simple and can be provided at a low cost<sup>107</sup>.

Plants have purchased tanks and chemical feed equipment for interim treatment which will ultimately become part of a permanent facility when enlargements have been completed. This avoids wastage of funds and enables the plants to start chemical treatment in a matter of days<sup>12</sup>.

The capital costs of chemical storage and feed facilities for chemical treatment have been reported for 15 U.S. wastewater treatment plants (Table 7). The reported costs range from \$0.01 to \$2.47 per design capita per year, with an arithmetic mean of \$0.56 per design capita per year. This average cost is about one-half of the cost previously reported<sup>146</sup>.

<u>Chemical storage and feed system, operating and maintenance costs</u> for chemical treatment are composed mostly of the costs for the necessary chemicals. An economic analysis based on data from four plants determined these costs to average \$3.01 per capita per year at U.S. plants<sup>146</sup>. A survey of 21 Ontario wastewater treatment plants indicated that the average cost for chemicals required for chemical treatment was equivalent to \$1.49 per capita per year. The costs ranged between \$4.41 and \$136.85 per million gallons wastewater (equivalent to \$0.16 and \$4.99 per capita per year, respectively). Operational costs in addition to chemical costs (e.g., energy, manpower) were about \$2,300 per year for a 1 MGD plant (\$0.23 per capita per year) and about \$7,700 per year for a 10 MGD plant (\$0.08 per capita per year)<sup>26</sup>.

One method of minimizing chemical operating costs is to use waste pickle liquor (ferrous sulfate, a waste by-product of the steel industry, as a source of iron. This material, which is usually available at little or no cost, is utilized

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at many plants in the U.S., including some of the largest (e.g., Milwaukee<sup>24</sup>, Detroit<sup>118</sup>). Pickle liquor use has been shown not to cause any deleterious effects to activated sludge or plant physical facilities<sup>24</sup>. Another area of investigation is the reuse of water treatment sludge, typically alum sludge, to remove phosphorus in wastewater treatment plants<sup>29</sup>. Wastewater treatment costs could be reduced by recovering alum from water treatment plant. Alternately, the recovered alum to a nearby wastewater treatment plant. Alternately, the recovered alum could be added directly to a nearby sewer going to the wastewater treatment plant, thereby providing an extended time period for the alum to insolubilize phosphorus. In some cases, operation and maintenance costs for chemical treatment may be reduced by operating the chemical treatment system only during the summer, when algal productivity is greatest<sup>30</sup>.

Based on data from 46 wastewater treatment plants in the United States, chemical treatment operating costs range between \$0.00 and \$10.89 per capita per year (see Table 8). Excluding U.S. plants using pickle liquor, the costs range from \$0.28 to \$10.89 per capita per year. For this latter group, the average (arithmetic) cost was \$4.74 per capita per year, about 50% larger than reported in in an earlier economic analysis of U.S. plants<sup>146</sup> and at the high end of the range of costs reported at Canadian plants<sup>26</sup>. The chemical costs at plants using pickle liquor can be substantially less, often zero. Some examples are shown in Table 8.

<u>Capital costs associated with the handling and disposal of chemical sludge</u> are often zero, since the additional sludge produced by chemical treatment can be processed by the same equipment used to handle conventional sludge if capacity is adequate. In such an instance, operation and maintenance costs may be increased due to the need to operate the existing equipment longer. Such was the case at two Minnesota plants<sup>15</sup>.

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An economic analysis has estimated the capital costs associated with the handling and disposal of chemical sludge at U.S. plants to be \$1.64 per capita per year based on data from four plants<sup>146</sup>.

Michigan Department of Natural Resources staff estimated the total costs for chemical treatment at six wastewater treatment plants (Alma, Bedford Township. Delta Township, East Lansing, Port Huron, and Three Rivers)<sup>28</sup>. The average annual per capita capital and operation and maintenance costs for chemicals, both metal salts and flocculants, and sludge handling and disposal were determined for the plants. To estimate sludge handling and disposal costs for chemical sludge at the plants, the Michigan Department of Natural Resources staff attributed 20% of the cost of handling all of a wastewater treatment plant's sludge to handling and disposal of the chemical sludge formed by chemical treatment<sup>28</sup>. However, extensive data from fifteen Canadian secondary wastewater treatment plants has shown that sludge volumes increase 35% when chemical treatment is implemented<sup>91,99</sup>. Therefore, it is more accurate to assume that 26% (i.e., 35% (100% + 35%)) of the total sludge produced at the six Michigan plants is chemical sludge. Sludge handling and disposal capital costs were reported for five of the six Michigan plants. They are presented in Table 9, adjusted on the basis of the 26% figure.

Table 9 summarizes the capital costs observed at two Minnesota plants and the estimated capital costs at five Michigan plants. The capital costs range from \$0.00 to \$1.27 per design capita per year. The average (arithmetic) capital cost was \$0.50 per design capita per year, significantly lower than previously reported<sup>146</sup>.

Although chemical treatment may not require capital expenditures for additional sludge handling capacity at the time of implementation, sludge handling capacity held in reserve for future sewage flows would be consumed. Therefore, a conservative estimate of the capital costs for sludge handling and disposal should include the costs for the used capacity.

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The capital costs for the four plants reporting such costs ranged from \$0.61 to \$1.27 per design capita per year (Table 9). The average (arithmetic) capital cost was \$0.88 per design capita per year, about one-half of the cost previously reported.

<u>Chemical sludge handling and disposal, operation and maintenance costs</u> have been estimated through a survey of 21 Ontario plants. The survey determined that the average cost to handle additional sludge produced during chemical treatment is \$4.65 per million gallons of sewage treated, equivalent to about \$0.17 per capita per year. The maximum observed cost (\$17.93 per million gallons) is equivalent to \$0.65 per capita per year<sup>26</sup>. The cost has been estimated based on operations at four U.S. plants to average \$1.80 per capita per year<sup>146</sup>.

Wastewater treatment plant data from eight plants in the United States indicates that operational costs associated with chemical sludge handling and disposal range between \$0.83 and \$4.45 per capita per year (see Table 10). The average (arithmetic) cost is \$2.01 per capita per year, similar to the cost estimated in an earlier analysis<sup>146</sup>. The cost figures for the Michigan plants listed in Table 10 were estimated by Michigan Department of Natural Resources staff and were adjusted in the same manner as the sludge capital costs to reflect current estimates of sludge quantities attributable to chemical treatment.

<u>The total cost of chemical treatment</u> can be estimated by summing the averages of the annual per capita costs presented in Tables 7, 8, 9 and 10 for the various cost categories. The average (arithmetic) total cost of removing phosphates from all municipal sources including human wastes, focd, industries, institutions, and laundry detergents is estimated to be \$8.19 per capita per year at plants using virgin chemicals (i.e., not using waste pickle liquor), distributed as follows:

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## COSTS FOR CHEMICAL TREATMENT OF MUNICIPAL WASTEWATER

#### Dollars per capita per year

Chemical Storage and Feed System Costs

Capital Costs	\$0.56
Operation Costs	\$4.74

Sludge Handling and Disposal Costs

Capital Costs	\$0.88
Operation Costs	\$2.01
Total	\$8.19

All of the treatment plants in Table 7 through 10 utilized metal salts for chemical treatment and received phosphates from household laundry detergents, as well as from other municipal sources.

Some cost data are available on lime use. Capital costs for lime addition to wastewater and lime recovery from the sludge for reuse were estimated for a 7.5 MGD plant to be \$205 per million gallons, equivalent to \$7.47 per capita pOer year<sup>136</sup>. Operation and maintenance costs for lime addition and handling of chemical sludge were \$225 per million gallons, equivalent to \$8.21 per capita per year. therefore, the total cost for lime addition was \$430 per million gallons, equivalent to \$15.68 per capita per year.

Enhanced Biological and Biological-Chemical Removal of Phosphorus

In recent years treatment systems that enhance the biological uptake of phosphorus have been developed  $^{126,142}$ . These systems incorporate an anaerobic zone in the treatment process during which the microorganisms in the mixed liquor release phosphorus. Subsequently, the microorganisms are introduced to an aerobic zone in which they take up phosphorus in quantities in excess of their nutritional needs, up to 6% of their biomass  $^{142}$ . Biomass in conventional secondary treatment systems typically contain 2% phosphorus.

The phosphorus-rich sludge that settles in these systems can be processed in several ways. In the Phostrip process the sludge forms a side-stream which enters an anaerobic unit to cause phosphorus release from the microorganisms. The microorganisms settle and are returned to the main treatment stream leaving a phosphorus-rich solution which is then treated with lime to remove phosphorus<sup>142</sup>.

The A/O and Bardenpho Systems waste the phosphorus-rich sludge. To achieve the excess phosphorus uptake by the biomass, a soluble BOD to phosphorus ratio of about 10 to 1 ris best for the A/O System<sup>142</sup>. The Bardenpho System operates best on a soluble BOD to phosphorus ratio of 20 to 1 or greater<sup>142</sup>. The phosphorus-rich sludge from one plant using the A/O System is marketed as a fertilizer, providing income to the plant<sup>142</sup>.

The Phostrip Process appears to be capable of achieving a 1 mg P/L effluent total phosphorus concentration. The other two systems may require metal salt 'addition and/or filtration to achieve this concentration<sup>142</sup>. The production of a mixed liquor biomass rich in phosphorus in all three processes requires that attention be paid to the suspended solids content of the effluent in meeting a limitation on total phosphorus<sup>142</sup>.

All three systems have operational and design options that can provide nitrogen removal<sup>142</sup>. Retro-fitting existing treatment plants can be accomplished using these systems, but case-by-case analysis is necessary due to the specific wastewater characteristics required by each<sup>142</sup>.

Some cost comparisons have been made between these systems (i.e., the Phostrip and Bordenpho processes) and conventional chemical treatment<sup>126,143</sup>, 144,145. However, full-plant operating experience is limited for all three systems<sup>142</sup>.

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## Types of Plants in the Gre Practicing Chemical

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STATE/ PROVINCE		AS	<u> </u>	HR	SA	EA	CS	P0	TF	OD	R
Illinois <sup>151</sup>		1							1		
Indiania <sup>152</sup>		36				13	1		8	2	
Michigan <sup>73</sup>	3	20	8		1	5	3	1	33		
Minnesota <sup>153</sup>		6					3	1	6		
New York <sup>154</sup>	2	10				3		4	3		
0hio <sup>129</sup>	5	19			3	4	15	2	7		
Ontario <sup>147</sup>	22	72		3		27	6		2	8	

Key:				
P	=	Primary	OD	=
AS	=	Conventional Activated Sludge	RBC	=
СМ	=	Complete Mix Activated Sludge	MU	=
HR	=	High Rate Activated Sludge	LS	=
SA	=	Step Aeration Activated Sludge	LC	=
EA	=	Extended Aeration	AL	=
CS	=	Contact Stabilization	L/AL	=
P0	=	Pure Oxygen Activated Sludge	F	Ξ
TF	=	Trickling Filter	С	=

Percent Removals of Metals From Chemically-Treated Wastewaters Reported in the Literature

References:	22,68,25	23	67	25,31	25,68	23,58,67
Zinc	1-99	+392-49***	92-98	83-90	60	+1-85
Vanadium	55-86	+10-14			93	7
Titanium	92-92				84	
Tin	91-92		<b>a</b> )		95	
Thallium	33-54		×		36	
Stontium		4-11				
Sodium		+9-0				0
Silver	75-99	+262		92	94	
Silicon	· · ·	+40-13				+7
Selenium	36-53	20-38			66-68	9
Potassium		+1				2
Nickel	25-97	22-37	63-96	93	10	0-27
Molybdenum	0-4	+100	9-18		66	0-26
Mercury	0-88	35-52		+15	92	+23
Manganese	31-99	76-80		87-93	10	31-33
Magnesium		52-80	•			2
Lead	23-96	11-46	90-97	95-97	95	18-97
Iron	99	12-43			• -	43-52
Cyanide			23			3/
Copper	70-99	5-30	79-98	84-87	83	37-90
Cobalt	47-97	+57-+40*	88-99		27	+4-0
Chromium(VI)	20-61		0	35	60	23
Chromium(III)	93-99	86-79	15-99	95	96	65-99
Calcium		+26/-+64*		<b>AF</b>	00	+24**
Cadnium	43-99	0-53	94	91	85	19-2/
Boron	*		0	01	0.5	+0-0
Bismuth	90-92	2-6	0		83	16.0
Beryllium	93-98				93	90
Barium	80-87	+12-+5*		37-98	96	12
Arsenic(V)	75	45-81	52-98	80	90	33-94
Arsenic(III)			0-35			0
Antimony	21-61					•
Aluminum	17-26	47				+407
	······································	• .				
	High Lime	Salts	Lime	Salts	Salts	Alum
		Plus Iron	Low	Iron	Iron	
		High Lime		Lime Plus		
:				Low		

NOTE: Chromium and arsenic data from reference 31 and chromium data from reference 58 not included because the valencies were not identified.

\*Increases attributed to the chemicals added (e.g. - calcium increase with lime addition) or contaminants in the chemicals (e.g., barium in lime, cobalt in iron salt).

\*\*Calcium increase due to small amount of lime being added.

\*\*\*Zinc increase attributed to the galvanized coating on the recarbonation
 basin.

# Effect of Metal Salt Addition on Sludge at Canadian Wastewater Treatment Plants $^{\rm Plants}$

		Percen	t Change	Mean Percent Solids		
	Number	<u>in Tota</u> Dry	1 Sludge	Before Chemical	After Chemical	
Type of Plant	<u>of Plants</u>	Weight	Volume	Treatment	Treatment	
Activated Sludge	15	+26	+35	4.5	4.2	
Primary	7	+40	+60	6.0	5.3	

#### Summary of Final Sludge Disposal Methods Used at Facilities Practicing Chemical Treatment in Illinois, Indiana, Michigan, New York and Ohio\*

State	Land Application	<u>Landfill</u>	Incineration	Public Distribution or Hauled by <u>Contractor</u>	Lagoon	<u>Other</u>	Not <u>reported</u> .
Illinois <sup>151</sup>	9			1			5
Indiana <sup>152</sup>	49	7		3	5		6
Michigan <sup>73</sup>	76**	50	5	14		6	6
New York <sup>154</sup>	8	13	11				1
Ohio <sup>129</sup>	58	19	6	1	4	5	2
Total	200	89	22	19	9	11	20
Percent of Plants Reporting (N=290)	69%	31%	8%	7%	3%	4%	

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\* Table shows number of plants. Some plants use more than one disposal method. \*\*52 Agricultural application; 24 non-agricultural application Wastewater Coagulants<sup>115,165,117</sup>

Aluminum sulfate (alum) (dry or liquid) Aluminum chloride (waste liquid) Sodium aluminate (dry or liquid) Ferrous sulfate (dry or as waste-pickle liquor) Ferris sulfate Ferric chloride (liquid, manufactured or waste product) Lime (dry or slurry by-product) Carbide Lime (by-product of acetylene production) Polyelectrolytes (coagulant acid) Sodium silicate (coagulant aid)

## CHEMICAL DOSAGE SUMMARY FOR PERMANENT OPERATION

## Province of Ontario, Canada

Level of Treatment	Point of Addition	Chemical Dosed	Number of Plants Dosed with Each Chemical	Range (mg/l)	Chemical Dosage Mean (mg/l)
Primary	Raw Sewage	Lime	3	167-200	185
		Alum	1	100	100
		Iron Salts (as Fe+++)	9	6-30	16
Secondary	Raw Sewage	Lime	2	40-100	70
		Alum	0	-	-
e		Iron Salts (as Fe+++)	0	· <b>_</b>	-
	Secondary	Lime	0	-	-
		Alum	15	30-150	65
		Iron Salts (as Fe+++)	32	2-30	11

Source: Reference 26, Table 6

#### TABLE 7 Chemical Storage and Feed System

#### CAPITAL COSTS

Treatment Plant (State)	Population Served	Capita <u>Year</u>	I Costs	Updated Capital - Cost <sub>5</sub> 1983 \$	Design Flow (MGD)	Actual Flow <u>(MGD)</u> 1	Design <mark>3</mark> Population	Updated Costs 1983:\$/design capita/yr	References
Stillwater(MN)	12.500	1973	22,500	46,700	3.0	2.1	17,900	0.25	15
Bayport(MN)	4,200	1973	22,500	46,700	0.65	0.5	5,500	0.80	15
Milwaukee-			<b>,</b>						
Jones Is-		•							•
land (MN)	1,000,000	1970	85,000	262,100	200	171.9	1,163,500	0.02	24
Richardson(TX)	13,500	1970	38,000	114,700	2.4	1.6,	20,300	0.53	79,130
Alma(MI)	8,240	1973	40,200	83,400	2.5	2.12	9,800	0,80	14,28,73
Delta Town-	-					2			
ship(MI)	17,000	1972	115,000	267,300	4.0	1.74	40,000	0.63	14,28,73
East Lan-						2			
sing(MI)	80,000	1972	162,000	376,600	8.0	9.92	64,600	0.55	14,28,73
Port Huron(MI)	40,000	1972	467,000	1,085,600	20	19.3	41,500	2.57	14,28,73
Three Rivers(MI	) 7,500	1970	45,200	199,200	2.0	1.3(197	5) 11,500	1.64	14,28,73
		1975	35,500			2			
Sandusky(OH)	40,000	1974(est.)	31,000	57,000	12.5	10.62	47,200	0.11	12,14,129
Michigan						2			
City(IN)	39,369	1974(est.)	74,000	136,000	1.5	8.84	67,100	0.19	12,14,128, 130
Kaukauna (WI)	13,300	1973(est.)	21.000	43,600	4.1	2.5	21,800	0.19	12.89.130
Leesburg(FL)	13,000	1974(est.)	22,500	41,400	3.3	2.2	19,500	0.20	12.130
Columbus(IN)	27,141	1974(est.)	11,000	20,200	8.6	7.9	29,500.	0.06	12,130
Maumee(OH)	14,890	1974(est.)	1,000	1,800	NR	2.52	14,8904	0.01	12,14,130
					Arith	metic Mean		0.56	
				Po	pulation	(Design)-w	eighted Mear	n 0.58(with	out Milwaukee)

Range Number of Plants 0.56 0.58(without Milwaukee) 0.17(with Milwaukee) 0.01-2.47 15 ¢

#### Notes:

- 1. Actual flows corresponding as close as possible to years for which populations served figures are available.
- 2. Actual flow estimated based on overall rate of change in flow rate at each plant over the 1975-81 time period.
- 3. Calculated as, design population = (population served + actual flow) x design flow.
- 4. Due to unavailability of design flow or population estimates for the Maumee (OH) plant, the cost is based on the population served.
- 5. Updated to first quarter 1983 costs using the EPA Small City Conventional Treatment (SCCT) Index, except for Milwaukee cost which was updated using the EPA Large City Advanced Treatment (LCAT) Index. See Appendix II.
- 6. Calculated as, 1983 \$/design capita/yr = Updated capital cost (1983 \$) x 0.09439 (present worth factor based

on 20 years at 7% interest) + design population (capita).

## Chemical Storage a

## OPERATING AND MAI

Treatment Plant (State)	Population Served	Type 7 of Plant <sup>7</sup>	Effluent Phosphorus Concentration (mg/L)	Chemical Used
Grand Haven(MI) <sup>1</sup>	15,000	AS	1.1	Pickle Liqu
Waldorf(MD)	8,000	L	2.5	Alum
Alpena(MI)	15,200	AS	0.7 <sup>11</sup>	FeCl <sub>3</sub> ,alum <sup>6</sup>
Ann Arbor(MI)	92,260	AS	2.7 <sup>11</sup>	FeC1 <sub>3</sub>
Cadillac (MI)	8,020	AS	1.3 <sup>11</sup>	FeC1 <sub>3</sub>
Delta Twshp.(MI)	5,205	AS	1.0 <sup>11</sup>	FeC1 <sub>3</sub>
East Lansing(MI)	67,000	AS	1.0 <sup>11</sup>	FeC13
Escanaba(MI)	13,260	AS	2.6 <sup>11</sup>	FeCl <sub>3</sub> ,polyme
Midland(MI)	35,800	TF	$0.9^{11}$	FeCl <sub>3</sub> ,polyme
Three Rivers(MI)	7,350	AS	0.8 <sup>11</sup>	Alum
Warren(MI)	162,120	AS	1.2 <sup>11</sup>	Alum
Chapel Hill(NC) <sup>2</sup>	26,119 <sup>10</sup>	TF	2.3(0.2) <sup>5</sup>	Alum
Richardson(TX)	13,500	TF	(NR)	Alum
Lima(OH)	53,000	Т	0.73	FeCl <sub>3</sub> ,polyme

TABLE	8 (	Continued)
INDLL	0	0011011100

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Roanoke(VA)	200,000	Т	0.39 <sup>3</sup>	FeCl <sub>3</sub> , pickle liquo
Danbury(CT) <sup>8</sup>	35,000	TF	1.2	FeC1 <sub>3</sub>
Appleton(WI)	61,400	AS	2.3	FeC1 <sub>3</sub>
Ashland(WI)	9,200	AS	0.60	Alum
Brookfield (WI)	28,000	AS	1.1	Pickle liquor
Cedarburg(WI)	9,000	AS	0.72	Alum
Fond du Lac(WI)	36,000	AS	1.02	Alum
Grand Chute(WI)	4,000	ÂS	2.29	Alum
Heart of the Valley (WI)	27,300	AS	0.43	Alum
Kenosha(WI)	87,000	AS	0.80	Pickle Liquor
Kiel(WI)	3,000	AS	4.8	FeC1 <sub>3</sub>
Manitowoc(WI)	33,000	TF	1.9	Alum
Menomonee Falls 1,2 & 3 (WI)	16,000	TF,AS,AS	1.0	Pickle Liquor
Milwaukee- Jones Island(WI)	736,000	AS	0.42	Pickle Liquor
Milwaukee- South Shore(WI)	433,000	AS	1.06	Pickle Liquor

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TABLE 8 (Continued)			

11022 - (				• 7	1078
Oconto(WI)	4,600	AS	0.74	Alum	1970
Oshkosh(WI)	50,250	AS	0.51	Pickle liquor	1978
Bacino(WI)	93,000	AS	1.1	Pickle liquor	1978
	7 053	AS+F	0.51	Pickle liquor	1978
Ripon(WI)	12,000	۵S	0.52	FeCl <sub>3</sub>	1978
Shawano Lake(WI)	12,000	٨٥	0.63	Alum	1978
Two Rivers(WI)	14,400	AD	1 47	Pickle liquor	1978
Waukesha(WI)	50,600	11	1.4/		1978
Maumee(OH)	60,000	(NR)	1	ATUIII	1078
Mentor(OH)	62,000	Т	2.31	Alum	1970
Sandusky(OH)	60,300	Т	0.84	Alum,polymer	19/8
	383,800	Т	2.11	FeCl <sub>3</sub> ,polymer	1978
Munt Vennen(OU)	15.000	AS	(NR)	Alum,polymer	1978
Mount vernon(on)	12,500	AS	0.4	Alum	1976-7
Stillwater(MN)	12,500	٨٥	0.5	Alum	1976-7
Bayport(MN)	4,200	AD	0.0 <sup>12</sup>	FeCl. polvmer	1975-7
Alma(MI)	8,240	AS	0.4	10013,00.9.00	

,

TABLE 8 (Continued)

Bedford Twshp.(MI)	6,500	AS	(NR)	FeCl <sub>3</sub> ,polymer	•
Port Huron(MI)	36,831	AS	1.1	Alum,polymer	1

Notes:

1. Lime from tannery wastes entering the plant in the influent wastewater.

- 2. Based on plant trials using one-half of the plant.
- 3. Before filtration.
- 4. EPA cost indices for alum and ferric chloride used to update costs to f 1983. Pickle liquor costs were updated using the ferric chloride cost
- 5. Number in parentheses is effluent soluble phosphorus concentration, mg/
- 6. Relatively small amount of alum used. Therefore, costs were updated us ferric chloride index.
- 7. Type of Treatment: AS = Activated Sludge, L = Lagoon, TF = Trickling Fi RBC = Rotating Biological Contactors, T = Tertiary, F = Filtration
- 8. Based on four-month full-plant trial.
- 9. Milwaukee-South Shore plant actually profited by chemical addition sinc paid to take waste pickle liquor.
- 10. From 1970 U.S. Census.
- 11. Mean of 1976-77.
- 12. Mean of 1975-76
- (NR) = Not Reported.

#### Chemical Sludge Handling and Disposal

#### CAPITAL COSTS

Treatment Plant (State)	Population <u>Served</u>	Cap Year	ital Costs\$	Updated Capital Cost 1983 \$ <sup>2</sup>	Design Flow (MGD)	Actual Flow <u>(MGD)</u>	Design Population	Updated Costs: 1983\$/desigg <u>capita/yr</u>	References
Stillwater (MN)	12,500	1973	0	0	3.0	2.1	17,900 <sup>1</sup>	0.00 -	15
Bayport (MN)	4,200	1973	0	0	0.65	0.5	5,500 <sup>1</sup>	0.00	15
Alma (MI)	8,240	1973	0	0		NR	17,200	0.00	28,73
Delta Town- ship(MI)	17,000	1972	208,000(est.)	483,500	4.0	NR	36,000	1.27	28,73
East Lansing(MI)	67,000	1972	301,860(est.)	701,700	8.0	NR	109,000	0.61	28,73
Port Huron(MI)	40,000	1972	335,660(est.)	780,200	2.0	NR	81,700	0.90	28,73
Three Rivers(MI)	7,500	1970	26,000(est.)	78,400	2.0	NR	10,000	0.74	28,73
			All plants:		Arithmet Populati Range Number o	ic Mean on(Design) f Plants	-weighted Mean	0.50 0.70 0.00 - 1.2 7	7
	Plants	Reporting	Capital Costs:		Arithmet Populati Range Number o	ic Mean on (Desigr weighted M f Plants	n)- Iean	0.88 0.82 0.61-1.27 4	

#### Notes:

1.

Calculated as, design population = (population served + actual flow) x design flow. Updated to first quarter 1983 costs using EPA Small City Conventional Treatment (SCCT) Index. See Appendix II. 2.

Calculated as, 1983 \$/design capita/yr = Updated capital cost (1983 \$) x 0.0943 (present worth factor based on 20 years at 7% interest) + design population (capita) 3.

#### Chemical Sludge Handling and Disposal

## OPERATION AND MAINTENANCE COSTS

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Treatment	Population		O&M Co	Costs: 1983			
Plant (State)	Served	Year	\$/Year	<pre>\$/capita/year</pre>	<pre>\$/capita/yr<sup>1</sup></pre>	<u>Reference</u>	
Stillwater (MN)	12,500	1973	21,900	1.75	4.45	15	
Bayport (MN)	4,200	1973	4,000	0.95	2.42	15	
Alma (MI)	8,240	1975 <b>-76</b>	7,800(est.)	0.95	1.71	28	
Bedford Township (MI)	6,500	1975	5,928(est.)	0.91	1.89	28	
Delta Township (MI)	17,000	1975	26,000(est.)	1.53	2.86	28	
East Lansing (MI)	80,000	1976	38,331(est.)	0.48	0.83	28	
Port Huron (MI)	40,000	1976	17,514(est.)	0.44	0.76	28	
Three Rivers (MI)	7,500	1976	5,200(est.)	0.69	1.19	28	
			Arithmetic N	lean	2.01		
			Population-w	veighted Mean	1.40		
	•	Range			0.83-4.45		
			Number of Pl	lants	8		

Note: 1. Updated to first quarter 1983 costs using EPA Annual Operation and Maintenance Escalation Index. See Appendix II.

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#### APPENDIX I

## ABBREVIATIONS

mg/l equivalent to MGD equivalent to gal/cap/day equivalent to BOD equivalent to \$/cap/yr equivalent to milligrams per liter Million Gallons per Day gallons per capita per day Biological Oxygen Demand dollars per capita per year

#### APPENDIX II

#### EPA COST INDICES

Small City Conventional Treatment (SCCT) Index for Construction Costs	Large City Advanced Treatment (LCAT) Index <u>for Construction Costs</u>	Alum Index	Ferric <u>Choride Index</u>	Operation and Maintenance Escalation Index
NA	NA	1.00	1.00	1.00
NA	NA	1.08	1.00	1.03
NA(53.1 est.)	NA(58.0 est.)	1.08	1.00	1.09
NA(64.1 est.)	NA(69.1 est.)	1.16	1.00	1.16
NA(73.2 est.)	NA(80.1 est.)	1.16	1.14	1.23
NA(83.2 est.)	NA(91.2 est.)	1.26	1.14	1.30
93.2	102.3	1.26	1.14	1.38
105.2	116.3	1.52	1.32	1.64
109.2	118.8	2.10	1.42	1.88
116.2	127.2	2.32	1.42	2.03
124.6	136.1	2.55	1.46	2.18
137.5	149.5	2.75	1.57	2.35
153.8	167.7	2.98	1.69	2.59
165.2	180.1	3.54	2.15	2.94
177.9	195.0	4.43	2.58	3.28
184.6	202.7	5.18	2.91	3.50
193.4	213.1	5.18	2.91	3.51
	Small City Conventional Treatment (SCCT) Index for Construction Costs NA NA NA(53.1 est.) NA(64.1 est.) NA(73.2 est.) NA(73.2 est.) 93.2 105.2 105.2 109.2 116.2 124.6 137.5 153.8 165.2 177.9 184.6 193.4	Small City Conventional Treatment (SCCT) Index for Construction Costs    Large City Advanced Treatment (LCAT) Index for Construction Costs      NA    NA      NA    NA      NA    NA      NA(53.1 est.)    NA(58.0 est.)      NA(64.1 est.)    NA(69.1 est.)      NA(73.2 est.)    NA(80.1 est.)      NA(83.2 est.)    NA(91.2 est.)      93.2    102.3      105.2    116.3      109.2    118.8      116.2    127.2      124.6    136.1      137.5    149.5      153.8    167.7      165.2    180.1      177.9    195.0      184.6    202.7      193.4    213.1	Small City Conventional Treatment (SCCT) Index for Construction CostsLarge City Advanced Treatment (LCAT) Index for Construction CostsAlum IndexNANA1.00 NAIndexNANA1.00 NANA(53.1 est.)NA(58.0 est.)1.08 NA(64.1 est.)NA(64.1 est.)NA(69.1 est.)1.16 NA(73.2 est.)NA(83.2 est.)NA(80.1 est.)1.16 NA(91.2 est.)93.2102.31.26 105.2105.2116.31.52 109.2116.2127.22.32 2.32124.6136.12.55 137.5137.5149.52.75 153.8165.2180.13.54 4.43177.9195.04.43 2.13.1193.4213.15.18	$\begin{array}{c c c c c c c c c c c c c c c c c c c $

#### Notes:

1. Annual Index values are averages of available quarterly values. Value for 1983 is for the first quarter of 1983, the last reported value. 1969-72 index values are estimates based on overall rate of change over the 1973-83 period.

2. NA = Not Available

Source: Reference 131.