SECTION 13.0
CHEMICAL PHOSPHORUS REMOVAL ALTERNATIVES

13.1 INTRODUCTION

The sources and quantities of phosphorus in domestic wastewaters vary significantly depending upon factors such as industrial contributions, non-point source run-off and use of phosphate-bearing detergents. Municipal wastewaters may contain phosphorus concentrations in the range of 4 to 15 mg/L as P. The usual forms of phosphorus found in wastewater include orthophosphate, polyphosphate, and organically-bound phosphorus. Orthophosphate is the only form available for biological metabolism. Polyphosphate must be converted to orthophosphate by the relatively slow process of hydrolysis prior to availability for biological uptake. The concentration of organically-bound phosphorus in domestic wastewater is usually of minor importance; however, this form of phosphorus can be a significant constituent of industrial wastewater.

The removal of phosphorus from wastewater involves the incorporation of phosphorus into suspended solids and the subsequent removal of these solids. Phosphorus can be incorporated into either biological solids or chemical precipitates. Microorganisms utilize phosphorus during their metabolism. Approximately 10 to 30 percent of the influent phosphorus is removed during secondary biological treatment in a conventional activated sludge process. In treatment plants specifically designed for biological nutrient removal, uptakes in excess of this range are achievable as will be discussed in Section 14.0. The following sub-sections, however, cover chemical removal of phosphorus and its implementation issues for the City of Winnipeg Water Pollution Control Centres.

13.2 CHEMICAL PHOSPHORUS REMOVAL – PROCESS DESCRIPTION

In this method of phosphorus removal, chemicals added to the wastewater react with the phosphates to form insoluble precipitates. The advantages and disadvantages of chemical phosphorus removal can be summarized as:

- Advantages:
  - Reliable process has been applied successfully in many full-scale plants since the 1970's.
  - Controls required for phosphorus removal are fairly simple and straightforward.
  - Relatively easy to install at existing facilities.
  - Biosolids (sludge) produced can be processed in same manner as in non-phosphorus removal systems.

  - Addition of chemicals to the primary treatment system can reduce organic loading on the secondary treatment processes by 25-35 percent.
  - Effluent phosphorus levels can be controlled by chemical dosage to achieve maximum efficiency levels.

- Disadvantages:
  - Chemical costs are high.
  - Chemical equipment (handling, storage, feeding system) must be installed.
  - Significantly more biosolids (sludge) is generated than with wastewater treatment processes without chemical addition; may overload existing biosolids handling equipment; higher biosolids treatment and disposal costs.
  - When chemicals are added to the secondary treatment system, the additional biosolids produced will cause higher solids loading rates on the final clarifiers. This can be a problem in systems designed to operate in a nitrifying (ammonia removal) or a total nitrogen removal mode where the SRT must necessarily be high.

13.3 CHEMICAL ALTERNATIVES

Chemicals used for phosphorus precipitation include metal salts and lime, with metal salts being the most common. A variety of metal salts can be used for the removal of phosphorus from municipal wastewater. The most common chemicals are aluminum sulphate (alum, $Al_2(SO_4)_3 \cdot 14H_2O$) and ferric chloride ($FeCl_3$). Ferrous sulphate, ferric sulphate, and ferrous chloride solutions are also used. Systems with metal salts addition can achieve 80 to 95 percent total phosphorus removal. For an effluent limit of 1 mg/L total phosphorus, metal salts addition with conventionally designed clarifiers can suffice. To consistently meet phosphorus discharge limits of less than 1 mg/L, filtration of the secondary effluent is often required. In many cases, anionic polymers are used in addition to the mineral salts to assist in solids separation.

The reactions between phosphorus and metal salts are complex. The typical reactions of alum and ferric chloride with phosphorus can be described as follows:

Alum: $Al_2(SO_4)_3.14H_2O + 2PO_4^{3-} \longrightarrow 2AlPO_4 \text{ (precipitate)} + 3SO_4^{2-} + 14H_2O$

Ferric Chloride: $FeCl_3 + PO_4^{3-} \longrightarrow FePO_4 \text{ (precipitate)} + 3Cl^-$

The optimum pH for phosphorus removal using alum is in the range of 5.5 to 6.5. Because alum usage results in a small depression in pH and most treatment systems operate at near neutral pH, the addition of alum almost automatically results in a pH in the suitable range. The optimum pH range for iron precipitation of phosphorus is between 4.5 to 5, although significant phosphorus removal occurs at pH values of about 7.

On the basis of reaction stoichiometry, one mole (594 g) of alum will react with 2 moles (190 g) of phosphate containing 62 g of phosphorus to form 2 moles (244 g) of $AlPO_4$. Thus, the weight ratio of alum to phosphorus is 594 to 62, or 9.6:1. In the case of ferric chloride, 162.3 g of $FeCl_3$ will react with 95 g of PO_4 to form 150.8 g $FePO_4$, resulting in a weight ratio of 5.2:1 of $FeCl_3$ to P. In practice, however, the quantities of the chemicals required are higher than the stoichiometry predictions due to competing reactions. In general, the amount of chemicals required varies significantly depending upon the wastewater characteristics such as influent phosphorus concentration, pH, alkalinity, quantity and nature of suspended solids, ionic constituents, and the effluent phosphorus limit to be achieved. As a result, it is often advisable to undertake jar tests and/or pilot-plant studies prior to actual design to determine the type and the amount of chemicals most suitable for the conditions under study. The dose rate and type of chemical also impact the quantity and quality of the sludge produced.

Lime is another chemical that can be used to remove phosphorus from wastewater. The process is basically a water softening process in which the quantity of lime required is dependent on the alkalinity of the wastewater rather than on the phosphorus content. Lime removal systems are either a single-stage low lime process (pH<10) which can achieve 1 mg/L effluent phosphorus levels or a two-stage high-lime process that raises the pH to 11-11.5 and is used to achieve very low (<1 mg/L) effluent total phosphorus concentrations.

The use of lime for phosphorus removal is not very common because of the following factors:

- A substantial increase in the mass of sludge to be handled compared to that from the use of metal salts
- Operation and maintenance problems associated with the handling, storage and feeding of lime
- Higher capital cost
- Potential for scaling on ultraviolet (UV) lamps if it is dosed prior to a UV effluent disinfection system

13.4 CHEMICAL APPLICATION POINTS

The most common points for addition of aluminum and iron salts are as follows:

1. Addition immediately upstream of the primary clarifier. The advantages of addition to primary treatment include greater opportunity for adequate mixing and flocculation, and reduced loadings to downstream biological processes as a result of improved BOD and SS removal. This option requires good mixing and flocculation in order to ensure optimum results. With proper design, 70 to 90 percent phosphorus removal can be achieved in primary treatment. The major disadvantage of chemical addition to primary treatment is that incomplete phosphorus precipitation may result because of the presence of phosphorus forms other than orthophosphate (polyphosphate and organically-bound phosphorus) that are not easily precipitated. In addition, a greater mass of waste sludge will be generated, resulting in greater loadings on the biosolids management systems.
2. Addition to the bioreactors or to the mixed liquor channel between the bioreactors and the final clarifiers. This alternative has considerable flexibility in the point of chemical addition, allowing modifications of the injection point to ensure use of the best available conditions for coagulation and flocculation to occur. The addition of a small amount of coagulant aid such as anionic polyelecrolytes may be necessary before the final clarifier to assist in removing dispersed metal-phosphate floc. A typical polymer dose when used as a coagulant aid is 0.1 to 0.25 mg/L.
3. Addition at multiple points. This is an efficient and cost-effective means of chemical addition for phosphorus control. Advantages include overall reduction in chemical usage and operational flexibility. This option is often recommended in design of the new facilities.
4. Addition to a tertiary chemical treatment and clarification stage (justified only for very stringent effluent discharge standards, such as for reuse).

13.5 CHEMICAL PHOSPHORUS REMOVAL ALTERNATIVES FOR THE CITY OF WINNIPEG

For chemical phosphorus removal, selection of the type of chemical to be used in each treatment plant and the point of application of the chemical must be made. The evaluation of chemicals must take into consideration the following:

- Cost of chemicals
- Amount of sludge production
- Impact on other treatment units
- Operational and maintenance impacts

Lime has not been considered at this stage because of the operational and maintenance problems, the possible scaling on UV lamps, and the high quantity of sludge production which will increase the cost of sludge handling and disposal significantly.

Ferric chloride, although a common chemical for phosphorus removal, has not been considered at this stage because typically it is more costly than alum in the Prairie Provinces.

As a result, alum was selected as the preferred chemical for phosphorus removal in all the three treatment plants for the purposes of this study.

13.6 IMPACT OF PHOSPHORUS REMOVAL ON OTHER PARTS OF THE TREATMENT PLANTS

The impact of chemical phosphorus removal on the existing plants depends upon the point of application of the chemical and the amount of excess sludge that is produced.

With regard to the point of application of alum, two alternatives were evaluated for each of the treatment plants: a) application of alum to the primary treatment system, and b) application of alum to the secondary treatment system. Each of these alternatives will affect the existing liquid-treatment line as follows:

1. Alum addition to the primary treatment system. In this option, chemicals will be added immediately upstream of the primary clarifiers. Addition of alum to primary treatment will increase the removal efficiency of the primary clarifiers for suspended solids (60-75 percent) and BOD (40-65 percent). As a result, the loads to the secondary treatment system will decrease. This will enhance biological treatment performance and will reduce the tankage requirement if nitrification is to be considered. It will also reduce the oxygen consumption as well as loading to the final clarifiers. Addition of alum to the primary treatment system, however, typically generates more sludge overall than addition to the secondary treatment system.
2. Alum addition to the secondary treatment system. In this application, alum will be added to the mixed liquor channel between the biological reactors and the final clarifiers. As discussed earlier, chemicals can be added at a variety of different points in the treatment process, but, because polyphosphates and organic phosphorus are less easily removed than orthophosphate, adding the chemicals after the secondary reactors (where organic phosphorus and polyphosphate are transformed into orthophosphate) usually results in the best removal. Some additional nitrogen removal may also occur because of better settling due chemical addition. This option, however, will increase the solids loading on the final clarifiers. It also increases the inert content of the MLSS. As a result, additional reactors and/or final clarifiers are often

required to compensate for the higher inert solids content of MLSS and higher loading rates.

The chemical phosphorus removal process generates a considerable amount of sludge due to the precipitates. The excess sludge will increase the cost of sludge handling, treatment and disposal.

The details of the chemical phosphorus removal options considered for each of the City's treatment plants, the selected alternatives, the sludge quantities and the other related issues such as impact on the existing systems are discussed separately in the subsequent sections. All the evaluations are mass-balance based and are calculated using year 2041-maximum month flows and loads. In the evaluation of chemical phosphorus removal options, no consideration was given to ammonia removal through nitrification.

The general procedure to determine optimal chemical phosphorus removal alternatives included:

1. Evaluation of a year 2041 base-line condition for each treatment plant (no chemical addition). In this option, the performance of the existing systems (existing tankage) was evaluated using the maximum month flow and maximum month load for the year 2041.
2. Evaluation of maximum month 2041 conditions with the addition of alum to the primary treatment system and determination of the operational and performance limitations. If necessary, the plant tankage was increased to the capacities required to achieve acceptable levels of operational and performance criteria.
3. Evaluation of maximum month 2041 conditions with the addition of alum to the secondary treatment system and determination of operational and performance limitations. If necessary, the plant tankage was increased to the capacities required to achieve acceptable levels of operational and performance criteria.

13.7 NORTH END WATER POLLUTION CONTROL CENTRE (NEWPCC)

The year 2041 annual average and the maximum month flows and loads to the NEWPCC are shown in Table 13.1. Maximum month flows and loads were used in evaluation of chemical phosphorus removal alternatives.

Table 13.1: NEWPCC – Year 2041 Flows and Loads

Parameter	Annual Average	Maximum Month
Flow (ML/d)	286	418
COD Load (kg/d)	107,153	150,130
BOD Load (kg/d)	53,578	75,070
TSS Load (kg/d)	66,348	128,490
TKN Load (kg/d)	9,795	12,490
Total Phosphorus Load (kg/d)	1,398	1,990

The phosphorus removal alternatives investigated for the NEWPCC included three main scenarios: the base-line condition, adding alum to the primary treatment system, and alum dosage to the secondary treatment system. Assumptions made for primary removal efficiencies and the operational criteria associated with each option are summarized in Table 13.2. The assumed Al:P dosage ratios are 1.7 for dosing into the primary treatment and 1.6 for dosing into the secondary treatment plant.

Option 1 in Table 13.2 is the base line evaluation in which the performance of the existing system was investigated under the year 2041 flows and loads without any addition of chemical for phosphorus removal. In options 2 and 3, alum was added to the primary and secondary treatment systems respectively. As the operational parameters such as MLSS, MLVSS/MLSS, SOR, and SLR (shown in Table 13.2) indicate, the existing tankage capacity in the NEWPCC appears to be adequate for chemical phosphorus removal regardless of alum dosage to either the primary or the secondary systems. However, the final clarifiers are the most critical bottleneck in the existing secondary treatment system. A solids loading rate (SLR) of 115 kg/m^2-d is as a result from the addition of alum to the secondary treatment system. Although within the acceptable range as per current final clarifier design practice, this loading rate will likely be problematic for these particular final clarifiers. To decrease the loading rate, the SRT can be reduced from two days to 1.5 days, which will reduce the SLR from 115 kg/ m^2-d to 85 kg/ m^2-d. This is presented as option 4 in Table 13.2, and is used as the preferred substitute for option 3 in the subsequent discussions.

Table 13.2: NEWPCC – Chemical Phosphorus Removal Options

Option	Al:P Ratio*	Primary Treatment (% Removal)			SRT (d)	MLVSS/ MLSS	MLSS (mg/L)	SOR (MM) (m^3/m^2-d)	SLR (MM) (kg/m^2-d)
		TSS	BOD	TKN					
1. Base line Condition	-	55	35	10	2	0.88	2254	32	85
2. Al to Primary **	1.7	70	45	10	2	0.85	1932	32	73
3. Al to Secondary	1.6	55	35	10	2	0.65	3033	32	**115**
4. Al to Secondary **	1.6	55	35	10	1.5	0.65	2316	32	86.5

* Al:P Weight Ratio. Additional 35 percent safety factor was included to compensate Al requirements in excess of the theoretical stoichiometric predictions

** Preferred phosphorus removal options

The preferred phosphorus removal options for the NEWPCC and tankage requirements are shown in Table 13.3. As shown in this table, whether the chemical is added to the primary treatment or secondary treatment, the implementation of chemical phosphorus removal in NEWPCC does not require any extra tankage capacity in the liquid-treatment line.

Table 13.3: NEWPCC – Chemical Phosphorus Removal Options

Option	Tankage Requirement	Dimension of New Tankage
Base-line Condition	Existing	None required
Al to Primary Treatment	Existing	None required
Al to Secondary Treatment	Existing	None required

The final effluent characteristics and the sludge production rates under maximum month flow and load conditions for each of the selected phosphorus removal options are presented in Table 13.4. Application of chemical phosphorus removal (either through primary clarifiers or secondary clarifiers) will provide a high level of treatment for the NEWPCC. With chemical phosphorus removal, an effluent total phosphorus content of less than 1 mg/L can be achieved. Without chemical phosphorus removal, the final effluent phosphorus concentration would be approximately 3.9 mg/L.

Table 13.4: NEWPCC – Phosphorus Removal Options – Effluent Characteristics and Maximum Month Sludge Production

Option	Estimated Final Characteristics (mg/L)				Primary Sludge Production			WAS Production			Total Sludge Production			
	BOD_5	TSS	TKN	Total-P	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	IS (kg/d)	%TSS
Base-line	5	5	25.7	3.9	70,978	56,782	80	33,965	29,723	87.5	104,943	86,505	18,438	4
Al to primary	5	5	26.1	0.2	103,342	72,268	70	29,110	24,881	85.5	132,452	97,149	35,303	4
Al to secondary	5	5	26.0	0.3	70,978	56,782	80	46,531	30,541	65.5	117,509	87,323	30,186	4

WAS = Waste Activated Sludge

The average and maximum month production of sludge is summarized in Table 13.5. Annual average solids production increases over the base-line condition by approximately 23 percent with the addition of alum to the primary treatment and by about 14 percent by alum dosage to the secondary system. Addition of alum to the primary treatment system produces a higher quantity of sludge than addition to the secondary system.

Table 13.5: NEWPCC - Annual Average and Maximum Month Sludge Productions

Option	Annual Average Sludge Production		Maximum Month Sludge Production	
	(kg/d)	(m^3/d)	(kg/d)	(m^3/d)
Base-line Condition	60,238	1,506	104,943	2,624
Al to Primary	73,867	1,847	132,452	3,311
Al to Secondary	68,772	1,719	117,509	2,938

Taking all of the above into consideration, the selected chemical phosphorus removal option for the NEWPCC is Option 4 in Table 13.2 – addition of alum to the secondary treatment system and operation of the secondary treatment system at a 1.5 day SRT. This option will generate the least amount of excess sludge and does not require the construction of additional mainstream treatment tankage.

13.8 SOUTH END WATER POLLUTION CONTROL CENTRE (SEWPCC)

The predicted year 2041 annual average and maximum month flows and loads to the SEWPCC are summarized in Table 13.6.

Table 13.6: SEWPCC – Year 2041 Flows and Loads

Parameter	Annual Average	Maximum Month
Flow (ML/d)	87	150
COD Load (kg/d)	48,920	91,530
BOD Load (kg/d)	24,460	47,210
TSS Load (kg/d)	29,790	61,845
TKN Load (kg/d)	3,150	4,840
Total Phosphorus Load (kg/d)	560	940

Several phosphorus removal options, described in Table 13.7, were evaluated for the SEWPCC. The shaded areas in this table show the operational limitations associated with some of the alternatives. The evaluated options for the SEWPCC included the base-line condition, alum addition to the primary clarifiers, and alum addition to the secondary clarifiers. The assumed Al:P dosage ratios are 1.7 for dosing into the primary treatment system and 1.6 for dosing into the secondary treatment system.

For the base-line condition, chemicals were not used. This option represents the treatment plant performance under the year 2041 flow and load conditions without the incorporation of any phosphorus removal alternatives. Even under the base-line condition, the existing final clarifiers will be subject to an unacceptably high solids loading rate (refer to Table 13.7; SLR = 206 kg/m^2-d). A new final clarifier similar in size to the largest existing clarifier (diameter of 45.7 m and SWD of 4.6 m) is required to prevent deterioration of the effluent quality.

In option 2, alum is added to the primary treatment system. This option, although resulting in an effluent phosphorus concentration of less than 1 mg/L, generated a high solids loading rate (185 kg/m^2-d) to the final clarifiers. The existing final clarifiers are the limiting factor with this option. A new final clarifier with dimensions similar to the existing largest clarifier would be required to prevent the risk of effluent impairment under the maximum month flow and load conditions. This is presented as option 3 in Table 13.7. With addition of one new final clarifier, adequate capacity will be provided for a reliable performance.

It was found that phosphorus removal through addition of alum to the secondary treatment system requires much more tankage capacity than the alternative option of phosphorus removal in the primary clarifiers. In option 4 in Table 13.7, alum would be dosed to the secondary treatment and the operational performance was evaluated with two new bioreactors. The existing final clarifier capacity limits the optimal performance of this option during maximum month flows and loads conditions. The maximum month condition produces a solid loading rate of 175 kg/m^2-d which is too high for the existing final clarifiers. A new final clarifier (similar in dimensions to the largest existing clarifier) will eliminate the limitation and provide satisfactory operational criteria. This is shown as option 5 in Table 13.7.

Table 13.7: SEWPCC – Phosphorus Removal Options

Option	Al:P Ratio*	Primary Treatment (% Removal)			SRT (d)	MLVSS/ MLSS	MLSS (mg/L)	SOR (MM) (m^3/m^2-d)	SLR (MM) (kg/m^2-d)
		TSS	BOD	TKN					
1. Base line Condition	-	65	50	10	1.5	0.91	3998	44	206
2. Al to Primary (existing tankage)	1.7	75	55	10	1.5	0.90	3610	**44**	**185**
3. Al to Primary** (1 new final clarifier)	1.7	75	55	10	1.5	0.90	3610	29	125
4. Al to Secondary (2 new bioreactors)	1.6	65	50	10	1.5	0.70	3450	**44**	**175**
5. Al to Secondary** (2 new bioreactors and 1 new clarifier)	1.6	65	50	10	1.5	0.70	3450	30	118

* Al:P Weight Ratio. Additional 35 percent safety factor was included to compensate Al requirements in excess of the theoretical stoichiometric predictions

** Preferred phosphorus removal options

The preferred phosphorus removal alternatives as well as the base line condition and the associated tankage requirements are summarized in Table 13.8. It is clear that more tankage is required in the option using alum addition to the secondary treatment system than if alum were added to the primary treatment system.

Table 13.8: SEWPCC – Chemical Phosphorus Removal Options

Option	Tankage Requirement	Dimension of New Tankage
Base-line Condition	Existing +1 New Final Clarifier	Diameter = 45.7 m SWD = 4.6 m
Al added to Primary	Existing +1 New Final Clarifier	Diameter = 45.7 m SWD = 4.6 m
Al added to the Secondary	Existing +2 New Bioreactors + 1 New Clarifier	30m x 10m x 5.4 m Diameter = 45.7 m SWD = 4.6 m

The effluent characteristics and the details of sludge production resulting from each of the above selected phosphorus removal options are presented in Table 13.9. An effluent total phosphorus concentration of 4.8 mg/L is estimated for the base-line condition at the SEWPCC. With either of the selected chemical phosphorus removal options, the effluent phosphorus concentration will be reduced to levels below 1 mg/L.

Table 13.9: SEWPCC - Phosphorus Removal Options – Effluent Characteristics and Maximum Month Sludge Production

Option	Estimated Final Characteristics (mg/L)				Primary Sludge Production			WAS Production			Total Sludge Production			
	BOD_5	TSS	TKN	Total-P	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	IS (kg/d)	%TSS
Base-line	5	5	26.6	4.8	40,924	32,739	80	17,273	15,760	91	58,197	48,499	9,698	4
Al to primary	5	5	27.0	0.2	53,023	37,778	71	15,596	14,088	90	68,619	51,866	16,753	4
Al to secondary	5	5	27.0	0.5	40,924	32,739	80	22,359	15,760	70	63,283	48,499	14,784	4

WAS = Waste Activated Sludge

Sludge production will be increased as the result of the implementation of chemical phosphorus removal, as presented in Table 13.10. This table shows annual average and maximum month rates of sludge production with and without phosphorus removal application. The excess sludge will require additional holding tank capacity prior to hauling of the sludge to the NEWPCC and increase the hauling costs.

The annual average sludge production will increase by 17 percent (4,731 kg/d) with chemical phosphorus removal in the primary clarifiers and by 11 percent (3,062 kg/d) when alum is dosed to the secondary treatment system. Addition of alum to the primary system will generate more sludge than its addition to the secondary treatment system. In terms of daily tanker requirements for sludge hauling, approximately 35 tankers per day will be required for hauling the sludge generated in the year 2041 with no phosphorus removal option. This number increases to 41 tankers per day for the chemical phosphorus removal in the primary clarifiers and to 39 tankers per day for chemical phosphorus removal in the secondary system. The calculations were based on sludge solids content of 4 percent and a hauling capacity of 20 m^3 per truck load.

Table 13.10: SEWPCC - Annual Average and Maximum Month Sludge Production and Hauling Requirements

Option	Annual Average Sludge Production		Maximum Month Sludge Production		Average Hauling Requirement (No. of Trucks/d)
	(kg/d)	(m^3/d)	(kg/d)	(m^3/d)	
Base-line Condition	27,793	695	58,197	1,455	35
Al to Primary	32,524	813	68,619	1,716	41
Al to Secondary	30,855	771	63,283	1,582	39

Taking all of the above discussion into consideration, the selected chemical phosphorus removal option for the SEWPCC is Option 3 in Table 13.7 – addition of alum to the primary treatment system. In this option, no additional mainstream treatment tankage will be required other than a fourth final clarifier that would have been required to accommodate the growth in the SEWPCC sewer catchment by 2041 in any event.

13.9 WEST END WATER POLLUTION CONTROL CENTRE (WEWPCC)

The annual average and maximum month raw wastewater flows and loads to the WEWPCC for the year 2041 are tabulated below in Table 13.11.

Table 13.11: WEWPCC – Year 2041 Flows and Loads

Parameter	Annual Average	Maximum Month
Flow (ML/d)	34.8	60
COD Load (kg/d)	12,060	15,030
BOD Load (kg/d)	6,030	7,155
TSS Load (kg/d)	7,610	12,115
TKN Load (kg/d)	1,110	1,300
Total Phosphorus Load (kg/d)	190	220

As with the NEWPCC and the SEWPCC, three scenarios have been evaluated. These options as well as the assumed removal rates in the primary clarifiers for TSS, BOD and TKN are tabulated in Table 13.12. The baseline condition (option 1) assumes no chemical phosphorus removal. The other two options (options 2 and 3) are based on alum dosing into the primary clarifiers and alum dosing into the secondary treatment plant, respectively. The assumed Al:P ratios for the WEWPCC are 1.7 for dosing into the primary clarifiers and 1.6 for dosing into the secondary treatment plant.

Table 13.12: WEWPCC - Phosphorus Removal Options

Option	Al:P Ratio*	Primary Treatment (% Removal)			SRT (d)	MLVSS/ MLSS	MLSS (mg/L)	SOR (MM) (m^3/m^2-d)	SLR (MM) (kg/m^2-d)
		TSS	BOD	TKN					
1. Base line Condition	-	65	35	10	6	0.81	1,893	42	118
2. Al to Primary** (existing tankage)	1.7	70	45	10	6	0.78	1,640	42	102
3. Al added to Secondary (existing tankage)	1.6	65	35	10	**4**	**0.62**	**1,802**	42	111
4. Al added to Secondary** (2 new final clarifiers)	1.6	65	35	10	10	0.56	3,865	21	121

* Al:P Weight Ratio. Additional 35 percent safety factor was included to compensate Al requirements in excess of the theoretical stoichiometric predictions

** Preferred phosphorus removal options

The baseline scenario will operate at a maximum month SRT of six days. The final clarifiers will operate at a SOR of 42 m^3/m^2-d and a SLR of 118 kg/m^2-d, both under maximum month conditions. Operating at a 6 day SRT, the plant will tend to nitrify in the summer and not nitrify during winter.

Dosing alum into the primary clarifiers reduces the loads to the secondary treatment plant, enabling a slight reduction in MLSS concentration and final clarifier solids loading rate (SLR). Dosing into the secondary treatment plant increases the MLSS concentration and the SLR on the clarifiers. To maintain an acceptable SLR on the final clarifiers requires a reduction in the SRT to four days. This causes the MLSS to reduce to approximately 1,800 mg/L. However due to alum dosing, the active biomass component in the MLSS is reduced to 62 percent. In order to increase the active biomass inventory and to avoid the transition between nitrifying and non-nitrifying conditions that results in unstable plant operating conditions, an SRT of 10 days was chosen to allow for year-round nitrification. Under these conditions, two new clarifiers, each of 30 m diameter would be required (option 4). The details of the selected phosphorus removal options for the WEWPCC and the tankage requirements are shown in Table 13.13.

Table 13.13: WEWPCC – Chemical Phosphorus Removal Options

Option	Tankage Requirement	Dimension of New Tankage
Base-line Condition	Existing	None required
Al added to Primary	Existing	None required
Al added to Secondary	Existing + 2 New Final Clarifiers	Diameter = 30 m SWD = 4 m

Table 13.14 presents the details of effluent quality and sludge production for each of the selected phosphorus removal alternatives, and for the base line condition. For the base line, the effluent total phosphorus concentration will be approximately 3 mg/L. Application of either selected phosphorus removal alternatives will reduce effluent phosphorus concentrations to below 1 mg/L.

Table 13.14: WEWPCC - Phosphorus Removal Options - Effluent Characteristics and Maximum Month Sludge Production

Option	Estimated Final Characteristics (mg/L)				Primary Sludge Production			WAS Production			Total Sludge Production			
	BOD_5	TSS	TKN	Total-P	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	VS (%)	TSS (kg/d)	VS (kg/d)	IS (kg/d)	%TSS
Base-line	5	5	18.7	3.0	8,268	6,614	80	3,239	2,632	81.3	11,507	9,246	2,261	4
Al to primary	5	5	18.9	0.4	10,189	7,123	70	2,806	2,200	78.4	12,995	9,323	3,672	4
Al to secondary	5	5	18.7	0.6	8,268	6,614	80	3,697	2,237	56.4	12,235	8,851	3,384	4

WAS = Waste Activated Sludge

The annual average and maximum month daily sludge production for each option are tabulated in Table 13.15, below. This indicates that when dosing alum into the primary clarifiers, the total sludge production increases by 13 percent compared to the baseline. Dosing into the secondary treatment plant results in a lesser increase, 6 percent greater than the baseline. Chemical phosphorus removal increases the sludge volume being hauled to the NEWPCC. Based on sludge solids content of 4 percent and the tanker capacity of 20 m^3/tanker, the number of hauling trucks required per day, as shown in Table 13.15, would be 9, 11, and 10 for the base line option, alum dosing to the primary clarifiers, and alum dosing to the secondary clarifiers, respectively.

Table 13.15: WEWPCC - Annual Average and Maximum Month Sludge Productions and Hauling Requirements

Option	Annual Average Sludge Production		Maximum Month Sludge Production		Average Hauling Requirement (No. of Trucks/d)
	(kg/d)	(m^3/d)	(kg/d)	(m^3/d)	
Base-line Condition	7,225	181	11,507	288	9
Al to Primary	8,321	208	12,995	325	11
Al to Secondary	8,045	201	12,235	306	10

Taking all of the above discussion into consideration, the selected chemical phosphorus removal option for the WEWPCC is Option 2 in Table 13.2 – addition of alum to the primary treatment system. In this option, no additional mainstream treatment train tankage would be required.

13.10 SLUDGE PROCESSING

13.10.1 Sludge Digestion

At present, the primary and secondary biosolids from each of the NEWPCC, SEWPCC and WEWPCC are co-thickened in the primary clarifiers at each plant. Co-thickened sludge is removed from the primary clarifiers at between 2 and 5 percent concentration, with an average of approximately 3.5 percent. The sludges from the SEWPCC and the WEWPCC are transported by road tanker to the NEWPCC. At the NEWPCC all biosolids are stabilized in the anaerobic digesters located on the south side of the property. Table 13.16 summarizes approximate current daily biosolids production in each of the three treatment plants and the number of trucks required to haul sludge from the SEWPCC and WEWPCC to the NEWPCC.

Table 13.16: Current Biosolids Production and Hauling Requirements

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Biosolids flow	m^3/d	1500	408	164	2,072
TSS concentration	%	3.6	3.3	3.6	3.5
VSS/TSS	%	69	75	73	70
Total biosolids TSS	kg/d	54,000	13,460	5,900	73,360
Biosolids hauling	No. of 20 m^3 truck/d	-	21	9	-

The existing digesters at the NEWPCC and their mode of operation are shown in Table 13.17. Anaerobic digestion occurs in six 33.6 m diameter digesters (No.9 to No.14). The total volume of these primary digesters is approximately 42,000 m^3. These digesters operate at between 35°C and 38°C and provide a solids retention time of 20 to 24 days. Mixing is provided by a gas mixing system; each digester has an 11.25 kW gas compressor supplying a "gas cannon" system. The sludge from these six digesters overflows into four 26 m diameter digesters (No. 5 to No.8). These four units operate as holding tanks for the dewatering process, filling and drawing to buffer sludge generation fluctuations and centrifuge operation changes. Recycle pumps provide mixing within these tanks. There are also four 18 m diameter digesters (No. 1 to No. 4). One of these tanks operates as an emergency overflow for the operating digesters. The remaining three units are not in service.

Table 13.17: NEWPCC Anaerobic Digesters

Digester No.	Diameter (m)	Total Volume (m^3)	Mixing	Function
1,2,3, and 4	18.0	15,000	Not in Service	One is used for emergency overflow Others not in service
5,6,7, and 8	26.0	21,000	Recirculation Pumps	Holding tanks prior to dewatering
9,10,11,12, 13, and 14	33.6	42,000	Gas Canons	Primary digesters

The City has experienced severe struvite formation in the dewatering facility, which has led to some operational difficulties. The implementation of chemical phosphorus removal will increase the phosphorus content of the sludge. However, phosphorus will be in its insoluble form not available for struvite formation unless the conditions in the digesters (e.g. high pH) encourage its solubilization. This is unlikely because anaerobic digesters usually operate at a neutral pH range. The addition of alum also tends to reduce pH slightly. As a result, chemical phosphorus removal is expected to have little impact on struvite formation in the digesters or the piping system. However, each plant is unique with regard to struvite formation; hence, consideration of potential problems and mitigation techniques must be evaluated on a plant-specific basis prior to implementation.

13.10.2 Year 2041 - Baseline Condition

The biosolids quantities for this condition are listed in Table 13.18. As described previously, this option does not include for nitrification or nutrient removal. It has been assumed that the co-thickened sludge can be thickened to an average concentration of 4 percent by careful management of the primary clarifiers.

Table 13.18: Maximum Month Biosolids Production – Base Line Condition

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	104,943	58,197	11,507	174,647
Total sludge VSS	kg/d	86,505	48,499	9,246	144,250
Total sludge ISS	kg/d	18,438	9,698	2,261	30,397
VSS/TSS	%	82	83	80	83
TSS concentration	%	4	4	4	4
Biosolids flow	m^3/d	2,624	1,455	288	4,367

The loading to the existing digesters will be approximately 3.5 $kgVS/m^3/d$ during maximum month. The recommended values for loading of high-rate anaerobic digesters are in the range of 1.6 to 4.8 $kgVS/m^3/d$. The risk of process upset and souring of the digesters increases with high loading rates. The SRT in the existing six digesters at maximum month sludge flow will be approximately 10 days. This is too low and will require modifications to the sludge management and treatment strategy. A desirable SRT at maximum month flow is 14 days. To achieve this level, either of the following two options could be included:

- Provide additional primary digester capacity but continue to co-thicken to 4 percent. The required total digestion capacity could be achieved by utilizing the existing primary digesters and construction of three new digesters (each at 33.6 m diameter and SWD of 7.6 m). This would give a total digester capacity of approximately 63,000 m^3, providing an SRT of 14.5 days at maximum month sludge production. The existing 26 m diameter digesters would be used as holding tanks, as at present. The 18 m diameter digesters could be used as an emergency overflow for the operating digesters. The tankage requirements are summarized in Table 13.19.

Table 13.19: Tankage Requirements for Sludge Digestion Without Pre-thickening - Base Line Condition

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC
Anaerobic Primary Digesters	No.	9	-	-
Existing Primary Digesters	No.	6	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.5	-	-
Depth	m	7.6	-	-
New Digesters	No.	3	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.6	-	-
Depth	m	7.6	-	-

- Pre-thicken the sludges generated by the NEWPCC and the SEWPCC. Gravity consolidation alone would be unable to guarantee the production of sludge with solids concentration consistently greater than 3.5 percent. Thickening to 6 percent solids could be achieved using gravity belt thickeners. Thickening could be undertaken on the sludge after mixing of the primary and secondary sludges. Alternately, there could be dedicated streams, one for primary sludge and one for secondary sludge.

  Pre-thickening reduces the cost of sludge hauling and sludge processing as the daily volume of sludge to be hauled and processed will be reduced. The number of daily sludge truck loads from the SEWPCC will drop from approximately 35 to approximately 23 based on annual average production of sludge. With pre-thickening, the daily total volume of sludge to be digested will be approximately 2,947 m^3/d (maximum month conditions). To provide an SRT of 14 days, a total digestion volume of 41,250 m^3 will be required. This volume is provided by the existing primary digesters that have a total volume of 42,000 m^3. Sludge characteristics and major equipment and tankage requirements for this option are tabulated in Table 13.20. A careful appraisal of the existing gas mixing system would be required to ascertain its ability to adequately mix the thicker sludge. It may prove necessary to increase the intensity of mixing by additional mixing equipment.

Table 13.20: Pre-thickened Sludge, Equipment, and Digestion Tankage Requirements - Base Line Condition

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	104,943	58,197	11,507	174,647
TSS concentration	%	6	6	4	5.9
Sludge flow	m^3/d	1,750	970	288	2,948
Gravity belt thickener					
Number	No.	4	3	-	7
Width	m	3	3	-	-
Daily operation	hr/d	24	24	-	24
Anaerobic Digesters	-	Existing	-	-	Existing

Whichever option is eventually selected, a detailed analysis of the digester ancillary equipment is required to ensure that there is sufficient capacity for handling the increased sludge and biogas volumes. The review would need to include the biogas system, flaring equipment, heat exchangers and boilers.

Assuming 50 percent removal of VSS in the digesters, the maximum month digested sludge load will be 102,521 kg/d. Assuming a digester feed of 4 percent, i.e., the worst case scenario, the output will be at approximately 2.35 percent. The digested sludge flow will be approximately 51 L/s.

13.10.3 Year 2041 - Alum Dosing into the Primary Treatment

Chemical removal of phosphorus in the primary clarifiers of the treatment plants is projected to produce sludges with characteristics shown in Table 13.21.

Table 13.21: Maximum Month Sludge Production – Primary Sludge Phosphorus Removal

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	132,452	68,619	12,995	214,066
Total sludge VSS	kg/d	97,149	51,866	9,323	158,338
Total sludge ISS	kg/d	35,303	16,753	3,672	55,728
VSS/TSS	%	73	76	72	74
TSS concentration	%	4	4	4	4
Sludge flow	m^3/d	3,311	1,715	325	5,352

Compared to the baseline condition, this option produces approximately 23 percent more sludge. The options for sludge treatment are as follows:

- Digestion of sludge as produced (4 percent solids). This will require the addition of five new primary digesters at the NEWPCC, each with approximate volume of 7,000 m^3. The total volume of the new reactors and the existing primary digesters will be 77,000 m^3. This volume will provide an SRT of 14.4 days during maximum month conditions. The tankage requirements are shown in Table 13.22.

Table 13.22: Tankage Requirements for Sludge Digestion Without Pre-thickening - Phosphorus Removal in Primary Clarifiers

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC
Anaerobic Primary Digesters	No.	11	-	-
Existing primary digesters	No.	6	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.6	-	-
SWD	m	7.6	-	-
New Digesters	No.	5	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.6	-	-
SWD	m	7.6	-	-

- Thickening of sludges generated in the NEWPCC and SEWPCC to 6 percent. Thickening will reduce hauling costs associated with transportation of sludge from the SEWPCC to the NEWPCC. However, it does not reduce the total volume of sludge sufficiently to provide an SRT of 14 days at maximum month sludge loads in the existing six primary digesters. While thickening to 7 percent would provide sufficient retention in the existing six digesters, it becomes more difficult to mix the thicker concentration of sludge within the digesters. This likely would result in a loss of performance in the digestion system.

  Assuming the thickening of the sludges to 6 percent, the total sludge flow to the digestion system would be 3,677 m^3/d. In order to provide the required minimum SRT of 14 days at maximum month loads, additional digester capacity is required. This could be achieved by constructing two new primary digesters each with a diameter of 33.6 m and SWD of 7.6 m (similar in dimensions to the existing primary digesters). These new reactors will provide a total volume of approximately 14,000 m^3 which provides an SRT of 15 days under the maximum month conditions. Equipment and tankage are summarized in Table 13.23. The existing 26 m diameter digesters and the 18 m diameter digesters will be used as holding tanks and emergency overflow (as at present), respectively. Again, a careful check of the existing equipment is required to ensure their adequate capacity. This would include checking the mixing system, pumps, the biogas handling, and all related equipment.

Table 13.23: Pre-thickened Sludge, Equipment and Digestion Tankage Requirements for Phosphorus Removal in Primary Clarifiers

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	132,452	68,619	12,995	214,066
TSS concentration	%	6	6	4	5.8
Sludge flow	m^3/d	2,208	1,144	325	3,677
Gravity belt thickener					
Number	No.	5	3	-	8
Width	m	3	3	-	-
Daily operation	hr/d	24	24	-	24
Anaerobic Primary Digesters:	No.	8			8
Existing primary digesters	No.	6	-	-	6
Volume (each)	m^3	7,000	-	-	-
Diameter	m	33.6	-	-	-
Depth	m	7.6	-	-	-
New Digesters	No.	2	-	-	2
Volume (each)	m^3	7,000	-	-	-
Diameter	m	33.6	-	-	-
Depth	m	7.6	-	-	-

Assuming 50 percent removal of VSS, the maximum month digested sludge load will be 134,897 kg/d. Assuming a digester feed of 4 percent, i.e., worst case, the output will be at approximately 2.5 percent. The digested sludge flow will be approximately 62 L/s.

13.10.4 Year 2041- Alum Dosing into Secondary Treatment

The characteristics of sludges produced at the three WPCCs resulting from alum addition to the secondary treatment are presented in Table 13.24.

Table 13.24: Maximum Month Biosolids Production – Secondary Sludge Phosphorus Removal

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	117,509	63,283	12,235	193,027
Total sludge VSS	kg/d	87,323	48,499	8,851	144,673
Total sludge ISS	kg/d	30,186	14,784	3,384	48,354
VSS/TSS	%	74	77	72	75
TSS concentration	%	4	4	4	4
Biosolids flow	m^3/d	2,938	1,582	306	4,826

Compared to the baseline condition, this option produces approximately 11 percent more biosolids. The options for biosolids treatment are as follows:

- Digestion of sludge as produced (at 4 percent solids) without application of thickening process. The additional tankage requirement for this option is illustrated in Table 13.25.

Table 13.25: Tankage Requirement for Sludge Digestion without Pre-thickening Phosphorus Removal in Secondary Clarifiers

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC
Anaerobic Primary Digesters:	No.	10	-	-
Existing primary digesters	No.	6	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.6	-	-
SWD	m	7.6	-	-
New Digesters	No.	4	-	-
Volume (each)	m^3	7,000	-	-
Diameter	m	33.6	-	-
SWD	m	7.6	-	-

- Thickening of the NEWPCC and the SEWPCC sludges to 6 percent prior to digestion will not reduce the volume sufficiently to provide an SRT of 14 days at maximum month sludge loads in the existing digesters. Assuming the thickening of NEWPCC and SEWPCC sludges to 6 percent, the total sludge flow to the digestion plant would be 3,319 m^3/d. This flow requires a new additional digester similar in size to the existing primary digesters. With the new digester, the total volume will be adequate to meet requirements for sludge flows and loads during maximum month conditions. The existing 26 m and 18 m diameter digesters will be used for purposes similar to present usage. As indicated before, a careful appraisal of the equipment is required. Equipment and tankage requirements for this option are shown in Table 13.26.

Table 13.26: Pre-thickened Sludge, Equipment and Digestion Tankage Requirement for Phosphorus Removal in Secondary Clarifiers

Parameter	Unit	NEWPCC	SEWPCC	WEWPCC	Total
Total sludge TSS	kg/d	117,509	63,283	12,235	193,027
TSS concentration	%	6	6	4	5.8
Sludge flow	m^3/d	1,958	1,055	306	3,319
Gravity belt thickener					
Number	No.	5	3	-	8
Width	m	3	3	-	-
Daily operation	hr/d	24	24	-	24
Anaerobic Primary Digesters:	No.	7	-	-	7
Existing primary digesters	No.	6	-	-	6
Volume (each)	m^3	7,000	-	-	-
Diameter	m	33.6	-	-	-
Depth	m	7.6	-	-	-
New Digesters	No.	1	-	-	1
Volume (each)	m^3	7,000	-	-	-
Diameter	m	33.6	-	-	-
Depth	m	7.6	-	-	-

Assuming 50 percent removal of VSS, the maximum month digested sludge load will be 120,691 kg/d. Again assuming a digester feed of 4 percent, the output will be approximately 2.5 percent. The digested sludge flow will be approximately 56 L/s.

13.11 DEWATERING

13.11.1 Existing plant

The existing plant consists of six Penwalt Sharples PM 76000 centrifuges. When operating, a centrifuge will run 24 hours per day, 7 days per week. Generally one centrifuge is used on the weekends and two or three are used on the weekdays. Sludge at 2.0 to 2.5 percent is fed at 12 to 16 L/s to each centrifuge. The cake produced is in the range 23 to 32 percent. Centrate is returned to the head end of the treatment plant.

The maximum sludge flows, as identified above, assume 4 percent digester feed concentration and 50 percent VSS removal. Each centrifuge is assumed to have a capacity of 14 L/s. The centrifuges are assumed to produce a cake of 28 percent with a density of 1.1 kg/L. The increased level of inert material in the cake, due to phosphorus precipitation, is expected to marginally improve the performance of the centrifuges in terms of cake concentration. However for this evaluation, a value of 28 percent has been assumed for all options. A summary of the information related to the operation of dewatering system and the characteristics of the thickened sludge is presented in Table 13.27.

Table 13.27: Digested Sludge Dewatering

Parameter	Unit	Baseline Condition	Primary Clarifier Phosphorus Removal	Final Clarifier Phosphorus Removal
Sludge Flow	L/s	51	62	56
No. of centrifuges on-line	-	3.7	4.5	4.0
Cake produced	tonnes/day	366	482	431
Cake produced	m^3/d	333	438	392

For all cases, there is at least one standby centrifuge available during maximum month sludge load. For the option where alum is dosed into the primary clarifiers, 4.5 centrifuges are required. If two of the six centrifuges were out of operation, the plant would be unable to handle the maximum month loads. A risk analysis is required to ascertain whether this level of redundancy is sufficient. If not, additional centrifuge capacity may be required.

13.11.2 Hauling Requirements

Table 13.28 summarizes the existing and the year 2041 situations for the number of trucks hauling from the SEWPCC and WEWPCC to the NEWPCC and also from the NEWPCC to the biosolids application site. The calculations were based on the annual average sludge production in each treatment plant and the following assumptions:

- TSS in Thickened sludge = 6 percent
- TSS in digested sludge = 2.5 percent
- VSS reduction in anaerobic digesters = 50 percent
- TS in dewatered biosolids = 28 percent
- Dewatered biosolids density = 1.1 kg/L

Table 13.28: Annual Average Hauling Requirements

Parameter	Unit	NEWPCC to Land Application Site	SEWPCC to NEWPCC	WEWPCC to NEWPCC	Total
Current					
Total sludge TSS	kg/d	54,000	13,460	5,900	73,360
Sludge flow	m^3/d	1,500	408	164	2,072
Sludge hauling	trucks/d	-	21	8	29
Dewatered biosolids	tonnes/d	170	-	-	170
Dewatered biosolids volume	m^3/d	155	-	-	155
Biosolids hauling	trucks/d	8			8
Total hauling	**trucks/d**				**37**

Table 13.28: Annual Average Hauling Requirements (continued)

Parameter	Unit	NEWPCC to Land Application Site	SEWPCC to NEWPCC	WEWPCC to NEWPCC	Total
Year 2041					
Base Line					
Total sludge TSS	kg/d	60,238	27,793	7,225	95,256
VSS/TSS	%	82	83	80	82.5
Total sludge VSS	kg/d	49,654	23,160	5,805	78,619
Total sludge ISS	kg/d	10,584	4,633	1,420	16,637
TSS (No Thickening)	%	4	4	4	4
TSS (With Thickening)	%	6	6	6	6
Sludge flow (No Thickening)	m^3/d	1,506	695	181	2,382
Sludge Flow (with Thickening)	m^3/d	1,004	463	181	1,648
Sludge hauling (No Thickening)	trucks/d	-	35	9	44
Sludge hauling (With Thickening)	trucks/d	-	24	9	33
Digested biosolids	kg/d	55,947	-	-	55,947
Dewatered biosolids	tonnes/d	200	-	-	200
Dewatered biosolids volume	m^3/d	182	-	-	182
Biosolids hauling	trucks/d	10	-	-	10
Total hauling (No thickening)	**trucks/d**				**54**
Total hauling (With thickening)	**trucks/d**				**43**
Phosphorus Removal in Primary Clarifiers					
Total sludge TSS	kg/d	73,867	32,524	8,321	114,712
VSS/TSS	%	73	76	72	74
Total sludge VSS	kg/d	54,181	24,582	5,969	84,732
Total sludge ISS	kg/d	19,686	7,942	2,352	29,980
TSS (No Thickening)	%	4	4	4	4
TSS (With Thickening)	%	6	6	6	6
Sludge flow (No Thickening)	m^3/d	1,847	813	208	2,868
Sludge Flow (with Thickening)	m^3/d	1,231	542	208	1,981
Sludge hauling (No Thickening)	trucks/d	-	41	11	52
Sludge hauling (With Thickening)	trucks/d	-	28	11	39
Digested biosolids	kg/d	72,346	-	-	72,346
Dewatered biosolids	tonnes/d	259	-	-	259
Dewatered biosolids volume	m^3/d	236	-	-	236
Biosolids hauling	trucks/d	12	-	-	12
Total hauling (No thickening)	**trucks/d**				**64**
Total hauling (With thickening)	**trucks/d**				**51**

Table 13.28: Annual Average Hauling Requirements (continued)

Parameter	Unit	NEWPCC to Land Application Site	SEWPCC to NEWPCC	WEWPCC to NEWPCC	Total
Phosphorus Removal in Final Clarifiers					
Total sludge TSS	kg/d	68,772	30,855	8,045	10,7672
VSS/TSS	%	74	77	72	
Total sludge VSS	kg/d	51,104	23,647	5,820	80,571
Total sludge ISS	kg/d	17,668	7,208	2,225	27,101
TSS (No Thickening)	%	4	4	4	4
TSS (With Thickening)	%	6	6	6	6
Sludge flow (No Thickening)	m^3/d	1,719	771	201	2,691
Sludge Flow (with Thickening)	m^3/d	1,146	515	201	1,862
Sludge hauling (No Thickening)	trucks/d	-	39	10	49
Sludge hauling (With Thickening)	trucks/d	-	26	10	36
Digested biosolids	kg/d	67,387	-	-	67,387
Dewatered biosolids	tonnes/d	241	-	-	241
Dewatered biosolids volume	m^3/d	220	-	-	220
Biosolids hauling	trucks/d	11	-	-	11
Total hauling (No thickening)	**trucks/d**				**60**
Total hauling (With thickening)	**trucks/d**				**47**

13.12 BIOSOLIDS LAND APPLICATION

The City of Winnipeg currently applies the digested, dewatered biosolids to agricultural land in the surrounding areas. The current biosolids program was implemented in the early 1990s and has been given the name "WinGro". The WinGro program has been licensed under CEC Order 1089RR.

The use of chemical phosphorus removal will increase the concentration of phosphorus and aluminum in the biosolids. At present, the key criterion for land application is the maximum application rate of 56 tonnes per hectare dry weight. The levels of phosphorus and aluminum are not parameters used in defining the land application rate. If the existing licensing arrangements are still in place at the time of implementing chemical phosphorus removal, there would be no effect on the application rate. The increased biosolids production rate will obviously require a larger area of agricultural land in comparison to the baseline option.

The City's biosolids application licence is to be reviewed by Manitoba Conservation later in 2001. Two of the concerns relate to metal loading rates and nutrient loading rates. Should the licence be altered to limit loading rates based on metal and nutrient loading rates, the use of chemical phosphorus removal may necessitate a reduction in the application rate. This in turn would lead to a further increase in the area of agricultural land being required for application. The aluminum concentration is generally not an issue in other jurisdictions when considering land application. Therefore it is likely that the phosphorus content of the biosolids will be more of an issue than aluminum content.

13.13 SUMMARY OF FINDINGS – CHEMICAL PHOSPHORUS REMOVAL

The preferred means of chemical phosphorus removal at the three Winnipeg Water Pollution Control Centers for 2041 flow and load conditions are as follows:

- For the NEWPCC -- Addition of alum to the secondary treatment system and operation of the HPO plant at an SRT of 1.5 days. No new mainstream treatment tankage would be required.
- For the SEWPCC -- Addition of alum to the primary treatment system. It is assumed that the new final clarifier required to accommodate growth in the SEWPCC sewer catchment by the year 2041 would be constructed whether or not chemical phosphorus removal is implemented for the mainstream treatment train.
- For the WEWPCC -- Addition of alum to the primary treatment system. No new mainstream treatment tankage would be required.

Biosolids production at the three plants for 2041 average annual and maximum month loading conditions are summarized in Table 13.29.

Table 13.29: Summary of Biosolids Production Rates for 2041 Loadings Conditions

Plant	Annual Average (kg/d)				Maximum Month (kg/d)			
	WE	SE	NE	Total	WE	SE	NE	Total
Baseline	7,225	27,793	60,238	95,256	11,507	58,197	104,943	174,647
Chemical * Phosphorus Removal	8,321	32,524	68,772	109,617	12,995	68,619	117,509	199,123

* For WEWPCC and SEWPCC, alum is added to primary treatment systems
For NEWPCC, alum is added to secondary treatment system

Generated at a solids concentration of 4 percent, the projected 2041 sludge production will require an additional three primary digesters, each of a size similar to the six existing primary digesters, at the NEWPCC to accommodate the baseline (no chemical addition) conditions. To accommodate the projected 2041 sludge production if chemical phosphorus removal were to be implemented, an additional one to two primary digesters of similar size would be required beyond that necessary for the baseline condition.

The installation of pre-thickening of the mixed primary and secondary sludges using gravity belt thickeners at the NEWPCC and SEWPCC will substantially reduce the additional digestion capacity requirements. Five 3 m wide gravity belt thickeners would be required for the NEWPCC and three 3 m wide gravity belt thickeners would be required for the SEWPCC, each operating on a 24-hour schedule. These numbers would provide sufficient duty plus one standby unit at each plant for 2041 maximum month loading conditions at each plant. Due to the relatively small amount of sludge generated at the WEWPCC, no pre-thickening would be done there. Pre-thickening would reduce the additional primary sludge digestion requirements at the NEWPCC to one unit with a diameter of 33.5 m and SWD of 7.6 m. For the purposes of this study, it is assumed that pre-thickening would be implemented.

Table 13.30 compares the projected annual average 2041 base case (no chemical addition) total truck haulage requirements to the corresponding haulage requirements for the implementation of chemical phosphorus removal, assuming that pre-thickening is employed at the SEWPCC and NEWPCC. It is noted that the implementation of chemical phosphorus removal will result in an increase of about 12 percent in the total truck haulage requirements.

Table 13.30: Summary of Projected 2041 Truck Haulage Requirements With and Without the Implementation of Chemical Phosphorus Removal (Per Day)

Item	WEWPCC (Unthickened Biosolids)	SEWPCC (Thickened Biosolids)	NEWPCC (Dewatered Biosolids to Land Application Site including WE & SE Biosolids)	Total Truck Haulage
Base Case (No Chemical Phosphorus Removal)	9	24	10	43
Chemical Phosphorus Removal	12	26	11	49

13.14 ESTIMATED COSTS

The cost estimating approach set out in Section 2.4 has been used to develop representative estimates of the total cost of ownership of the facilities required to implement Chemical Phosphorus Removal at the three WPCCs. The details of the estimates are presented in Appendix A. The 95 percent confidence limit estimates are summarized in Table 9.15.

Table 13.31: Summary of Estimated Costs - Chemical Phosphorus Removal

	NEWPCC	SEWPCC	WEWPCC
Capital Cost	$22,500,000	$10,200,000	$1,700,000
Operating & Maintenance Cost	$2,630,000	$1,100,000	$315,000
Net Present Worth Cost (4 % Discount Rate)	$76,400,000	$33,200,000	$8,000,000