Detroit Water and Sewerage Department

Wastewater Master Plan

DWSD Project No. CS-1314

Conceptual Design for a Future Wastewater Treatment Plant

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Conceptual Design for a Future Wastewater Treatment Plant

1. Background

The purpose of this memorandum is to identify process alternatives for 2040 and beyond for the Detroit Wastewater Treatment Plant. According to the preliminary findings of the 50-year Detroit Wastewater Master Plan, the current plant will be adequate until at least 2020. In that decade, plant capacity will be reevaluated and the process of rebuilding the plant should begin. The plant was built in 1940, and some units will be over 100 years old by 2040.

Providing for the long term can be challenging. The plant is landlocked in an urban setting, and the adjacent community has historically been opposed to plant expansion. Because of that opposition, this memorandum focuses on processes that require a smaller footprint than the processes currently used.

This analysis does not consider disinfection or solids handling. Disinfection (using chlorination and followed by dechlorination) is provided east of Jefferson Avenue and is thus not constrained by limitations of the site. In addition, the disinfection facilities are new and should be useful for the entire planning period.

Sludge is now disposed of by incineration and landfilling. Disposal by Minergy has been planned, but it is possible that that plan will not go forward. In the future, depending on its quality, sludge could be reused after digestion and drying. A separate memorandum was prepared on sludge disposal. A comparison of the advantages and disadvantages of the various sludge treatment alternatives is recommended. These alternatives could be studied in more detail when DWSD is considering biosolids treatment alternatives. The figure included at the end of this section includes land set aside on-site for digestion/drying facilities. This alternative would facilitate an end to incineration at the WWTP. Digestion/drying is one of the treatment technologies discussed in the sludge disposal technical memorandum. If an alternative biosolids treatment is selected, it could be located in the same general area.

This memorandum discusses constraints that need to be addressed, identifies and describes reasonable process options, estimates area required, and presents a potential scenario for the future.

2. Constraints

Constraints that need to be evaluated in reviewing process options include:

- Flows and loads
- Permit requirements
- Existing major features

- Cost and availability of consumables

This section examines the constraints in turn.

2.1 Future Flows and Loads

Table 1 presents estimates of current and future flows. The current flows include flows from the Western Township Utility Authority (WTUA), whose flows will be diverted to the Ypsilanti wastewater treatment plant. Current flow from the WTUA to DWSD averages about 27 mgd. With flow from WTUA removed, flow to the plant in 2040 is predicted to be in the same range as current flow rates.

Table 1. Comparison of current and future flows

Condition	Flow (mgd)	
	Current (2000)	Future (2040)
Average dry-weather flow	605	629
Average flow	724	750
Peak-month dry-weather flow	683	714
Peak-month flow	885	912
Peak hour wet weather flow (approximate)	1,520	1,700
Peak-hour dry-weather flow	812	836

Sources and Notes:
Technical Memorandum "Peak Hour Flows at the WWTP" (12 February 20003)
Notes:
Draft Technical Memorandum "Flow Needs for DWSD Customers Through 2050" (20 January 2003)
Flows do not include sidestreams and other recycled flows, which are now about 60 mgd.

It is expected that influent concentrations in the future will remain about the same as current ones. The concentrations will be affected by improvements to control infiltration and inflow, by changes in industrial flow, and by increased use of garbage grinders. But at the level of accuracy of this report, changes are not expected to be significant. The concentrations are shown in Table 2.

Table 2. Median influent concentrations from October 1996 through September 2001

Pollutant	Concentration (mg/L)
TSS	163
TVSS	119
TS	681
FOG	18
$CBOD_5$	112

Table 2. Median influent concentrations from October 1996 through September 2001

Pollutant	Concentration (mg/L)
	341
TP	3.7
TSP	1.1
NH_4-N	12
Org-N	8
TKN	17
Fe	2.3
Zn	0.224

Source: Table II of "Review of Detroit Wastewater Treatment Plant," May 31, 2003.

2.2 Permit Requirements

The Detroit Water and Sewerage Department and the Michigan Department of Environmental Quality are negotiating new discharge permits. It is expected that flows up to 930 mgd, including sidestreams and other recycled flows, will continue to require secondary treatment; flows exceeding 930 mgd will continue to require only primary treatment. All flows will be disinfected by chlorination and dechlorinated before discharge.

The only substantive change for concentrations of contaminants allowed in plant effluent is the introduction of a requirement for acute toxicity (Toxicity Unit Acute of 3). A TU_A of 3 means that a mixture of one-third effluent and two-thirds dilution water is not acutely toxic to 50% of the test organisms. This requirement is not expected to require a change in treatment process. The toxicity reduction evaluation that is required in the discharge permit might show otherwise, but ammonia could be the cause for toxicity. For the purpose of this analysis, we have examined alternatives that minimize potential toxicity problems by controlling effluent ammonia concentrations. It is assumed that a goal of 1 mg/L for ammonia nitrogen might be appropriate to address future toxicity issues, unless other pollutant parameters such as trace metals or organics are identified as contributing to the effluent toxicity. In this case, further control of these pollutants might be required by adjusting Local Limits in the Industrial Pretreatment Program. The discharge requirements are shown in Table 3.

Table 3. Monthly effluent concentrations allowed in discharge permit

Constituent	Concentrations		
	Current permit	Proposed permit	Future permit
PRIMARY EFFLUENT (for flows exceeding 930 mgd, including recycles)			
CBOD (mg/L)	100	100	100
TSS (mg/L)	100	100	100
Phosphorus (mg/L)	2.5	2.5	2.5
SECONDARY EFFLUENT			
CBOD (mg/L)	25	25	25
TSS (mg/L)	30	30	30
Phosphorus (mg/L)	1.0	1.0	1.0
Ammonia nitrogen (mg/L)			1
Acute toxicity (TU_A)		3.0	3.0
ALL EFFLUENTS			
Fecal coliform (cts/100 mL)	200	200	200

2.3 Constraints from Existing Major Features

The existing major facilities have to be recognized in any planning effort. The limited area of the Jefferson Avenue site might require the use of compact treatment processes. Some of the most-compact treatment processes have not been used at any scale approaching the size of the Detroit plant, but, in the future, there might be adequate experience that they would be applicable.

There are two influent pumping stations and two intermediate pumping stations. For some of the treatment processes discussed below, head loss would not increase, and the pumping stations would be adequate. For others, such as for biological aerated filters, head loss is substantially higher, and additional pumping would be required.

The locations of treatment facilities have to recognize the major piping. For example, any new works for primary treatment or equivalent would best remain in the south side of the treatment plant, because that is where the pipes from the headworks terminate. Similarly, secondary treatment would probably remain in the general location of existing facilities, considering the locations of pipes delivering primary effluent to the intermediate pumping stations and of the outfalls.

The area available in the locations of existing treatment processes is of interest in long-term planning. Approximate areas are shown on Table 4.

Table 4. Approximate area taken up by existing facilities.

Process	Area (Acres)
Pumping and headworks	4.8
Primary clarifiers	32.3
Aeration tanks	13.9
Secondary clarifiers	38.8
Gravity thickeners	6.0
Sludge complexes 1 and 2	3.8

Age and condition of facilities could be important factors in deciding on a long-term plan. For this evaluation, we have assumed, however, that equipment could be maintained indefinitely, replaced with similar equipment, or replaced with other types of equipment.

Capacities of existing facilities are shown on Table 5. Capacities are adequate for anticipated flows.

Table 5. Liquid-treatment capacities

Facility	Firm capacity (mgd)	Net Firm capacity[(1)] (mgd)
Raw-wastewater pump stations	1,800[(2)]	1,700[(2)]
Primary clarifiers	1,800	1,700
Intermediate lift pumps	1,050	950
Aeration decks	1,050	950
Secondary clarifiers	930	830

Notes:

1) The net firm capacity allows for 100 mgd of in-plant recycle flow, which would reduce the plant's capacity to treat raw wastewater flows from the collection system.
2) Contract PC-744 contains provisions to upgrade raw wastewater pumps. The final pump station capacity will be at least 1,800 mgd (1,700 mgd net); however the exact capacity is not yet known.

The capacities shown provide for facilities out of service.

From technical memorandum "Review of the Detroit Wastewater Treatment Plant," prepared by CH2M HILL (May 31, 2003)

2.4 Costs and Availability of Consumables

Major consumables include power and chemicals such as ferric chloride. It is assumed that changes in cost or availability will not affect the selection of future processes.

3. Treatment Options

Treatment options can be classified in these groups:

- Settling
- Biological treatment
- Combined biological treatment and separation of biomass
- Treatment of wet-weather flows

3.1 Settling

A major decision regarding primary clarification is whether to continue the use of iron salts or not. The most significant benefits of adding iron salts are:

- Operation at higher overflow rates decreases the area required for primary clarifiers.
- Increased removal of suspended solids and BOD reduces the load on, and required size, of the biological treatment system,
- The iron salts react with and remove phosphorus, and
- The iron salts react with sulfide in the raw sewage and decrease odor generation.

Disadvantages of addition of iron salts include cost, the increase in solids produced, and the decrease in volatile solid percentage of solids produced.

On the whole, iron addition has been advantageous. It is expected that iron salts will continue to be added far in the future unless their cost becomes prohibitive or a change in sludge processing forces reconsideration.

Should there be a need to improve the primary or secondary sedimentation processes, stacked clarifiers and plate settlers would provide the same settling efficiency, but with far less area. Two-level stacked clarifiers required about 55% of the footprint of conventional single-level rectangular clarifiers. Plate settlers require about one-sixth of the area for conventional rectangular clarifiers. All these units are sized on the basis of surface area. Surface areas of alternative technologies are set equal to the overflow rates for the current primary and secondary clarifiers.

3.2 Biological Treatment

The area required for activated sludge treatment could be reduced by using deeper tanks or by changing the process. With depths of 30 feet, the existing aeration tanks are close to the deepest, if not the deepest, tanks in the United States. There are some deeper tanks in Europe, but deeper tanks are unusual. So, the depth of the aeration tanks is sufficient for conventional technology.

Worldwide, there are a few examples of "deep-shaft" technology, with shafts over 350 feet deep. At large depths, solubility of nitrogen is very high, and the nitrogen is released in clarifiers. Flotation-type clarifiers thus have to be used, rather than conventional clarifiers. Deep-shaft aeration has been applied only in special cases.

The process itself can be made more space efficient by implementing the step-feed process or by adding media to the process tanks. The space efficiency of step feed increases with increased number of stages, but at a diminishing rate. Four stages provide a reasonable balance between space efficiency and complexity. With four stages, area required decreases by about 30%. Systems with media added to aeration tanks are called "hybrid" systems. The media is added to provide sites for organisms to grow as a film. Hybrid systems add materials such as ropes, sponges, and fixed or neutrally buoyant plastic material. With the added media, the concentration of biomass can be increased by about one-third compared with suspended-growth systems, resulting in decreased volume and surface area.

3.3 Combined Biological Treatment and Separation of Biomass

If even more space needs to be saved at the treatment plant, processes that combine the features of activated-sludge treatment (biological treatment and separation of biomass) into a single unit could be incorporated. These processes include membrane bioreactors (MBRs), biological aerated filters, sequencing batch reactors (SBRs), and fluidized-bed reactors. Membrane bioreactors have not been used at facilities larger than about 10 mgd, but they offer great potential for decreasing area required. Because the membranes separate biomass from mixed liquor, secondary clarifiers are not required. Also, mixed liquor can be much more concentrated. In conventional activated sludge systems, the concentration of mixed liquor is limited by solids-flux consideration. The common MLSS operating condition for membrane bioreactors is in the range of 10,000 mg/L. In estimating space required for MBRs, we estimated that the volume occupied by the membranes would be about 10% of the total area.

Biological aerated filters (BAFs) are being evaluated for Hong Kong as a means of decreasing footprint required for secondary treatment. These units have much higher headloss than activated sludge, and additional pumping capacity would be required.

Karmasin et al (2003) found that SBRs require more area than the alternatives above, even when the SBRs are stacked in two levels. Potentially the most space efficient of all processes, fluidized-bed reactors have been found practical only for denitrification, and no research is ongoing to improve applications to nitrification.

3.4 Treatment of Wet Weather Flows

At the Detroit Wastewater Treatment Plant, flows exceeding the capacity of the activated sludge system now receive primary treatment and disinfection. In the future, stricter standards might require additional treatment. One option would be to process these flows by ballasted flocculation. Ballasted flocculation adds a coagulant (usually ferric chloride) and "microsand" (grain size from 0.075 mm to 0.3 mm in diameter) to screened, degritted wastewater. The mixture is flocculated and then

settled in plate settlers. The sludge is passed through a cyclone, where the microsand is recovered. Chemical requirements are high (25 to 35 mg/L as ferric ion), but removals are outstanding. BOD removal is about 60 to 70% and TSS removal is about 85 to 90%.

Ballasted flocculation could treat degritted, screened flows, and replace primary treatment for some wet-weather flow. In a possible scenario, the rectangular clarifiers would be abandoned and primary treatment would be accomplished in the six circular primary clarifiers. Capacity of the six primary clarifiers is estimated to be about 1,080 mgd, which exceeds peak dry-weather flow. The rectangular tanks are a continuing source of issues with sludge-collector maintenance, grease collection, etc. Some of the rectangular tanks could be converted to ballasted flocculation, and the remaining space could be used for other processes. A possible use of the remaining space could be for grit handling to replace the grit handling facilities in Pumping Station 1.

4. Area Requirements

Table 6 provides preliminary estimates of land area required to meet requirements in the current and proposed permits and in a potential future permit. The table is divided into five sections (primary settling, biological treatment, secondary settling, combined secondary treatment, and wet weather).

Table 6. Land area required for treatment (acres)

	Current and proposed permits	Future permit
PRIMARY SETTLING		
Current	32.3	32.3
Stacked clarifiers	11.7	11.7
Plate settlers	4.4	4.4
BIOLOGICAL TREATMENT		
Current	13.9	40.9
Step-feed	-	28.6
Hybrid system	10.4	30.7
SECONDARY SETTLING		
Current	38.3	38.3
Stacked clarifiers	13.9	13.9
Plate settlers	5.2	5.2
COMBINED SECONDARY TREATMENT		
Current[1]	52.2	79.2
Membrane bioreactors	3.9	11.4
Biological aerated filters	8.5	16.7
WET WEATHER		
Ballasted flocculation	4.6	4.6

[1] Sum of biological treatment and secondary settling above.

Values for current operations listed in the column "Current and proposed limits" are from Table 4. In the column "Future permit," the values for biological treatment and for combined secondary treatment are changed, to reflect the additional volume required for nitrification. Primary settling and secondary settling requirements are unchanged. With the stricter permit, the area required for aeration tanks similar to the existing ones would be roughly tripled, because of the increased SRT required to achieve nitrification. With essentially no space available for additional treatment on site, building aeration tanks similar to the existing ones is not reasonable. Changing operation to step feed or adding media to produce a hybrid system still greatly increases the area required. So, changes to the biological process alone would not be sufficient.

There would be enough space, however, with expanded aeration tanks, if stacked rectangular clarifiers or plate settlers replace the circular settling tanks. The space constraints can be easily met with biological aerated filters or membrane bioreactors. The addition of BAFs is included in the example discussed below.

5. Planning for the Future

Based on the results presented in Table 6, several scenarios could evolve between now and the year 2040 depending on:

- Which permit conditions are imposed
- Which sludge treatment process is selected and
- Whether new sludge processing facilities are located at the current plant site, or off-site.

As an example, the following scenario in Table 7 is one of many that could evolve. This one represents the worst-case treatment requirement, under which nitrification is required and wet-weather flows must be treated. The scenario uses the circular clarifiers and about half of the rectangular clarifiers for primary treatment, replaces activated sludge with biological aerated filters, treats excess wet-weather flows with ballasted flocculation, and provides additional facilities for sludge processing. It also provides for new facilities for sludge processing, including new anaerobic digesters and thermal drying facilities, plus additional capacity for gravity thickening primary sludge.

Table 7. Worst-Case Treatment Requirement – Imposition of Nitrification and Wet-Weather Requirements

Unit Process	Existing Process		Future Process	
	Process	Area (acres)	Process	Area (acres)
Primary treatment	Combination of existing round and rectangular clarifiers	32.3	Circular clarifiers	19.4
			Half of Rectangular Clarifiers (for BAF recycle treatment)	4.4
Secondary treatment	Air and oxygen activated sludge systems	52.3	Biological aerated filters	16.7
			Future BAFs (if needed)	3
Wet-weather flows (flows exceeding 930 mgd)	Treatment in existing primary clarifiers	0	Ballasted flocculation	4.6
Additional sludge thickening	NA	NA	Additional thickening and storage facilities	2
New sludge processing facilities	NA	NA	Possibly digesters and drying	20
TOTAL		84.6		62.7

Table 7 indicates that this scenario allows for improved treatment (nitrification plus treatment excess wet-weather flows) and new sludge processing facilities within the Jefferson Avenue site. Figure 1 illustrates a potential arrangement for these facilities.

The potential imposition of nitrogen limits and treatment for wet weather flows may require that decisions be made now regarding capital improvements that will facilitate the future implementation of facilities for nitrification, treatment of excess wet-weather flows, and new sludge facilities at the plant site.

Selection of new facilities should not be based only on footprint required. Other factors, including costs, reliability, simplicity, and ease of operation of operation also have to be considered.

6. References

Karmasin, B. M., S. H. Lo, A. B. Pincince, and R. D. Reardon (2003). " Sizing large, compact wastewater treatment plants." Manuscript submitted for consideration for presentation at conference of International Water Association.

Pincince, A. B, R. D. Reardon and S. H. Lo. (2002) "Design of Compact Wastewater Treatment Plants." Proceedings of International Conference on Wastewater Treatment & Technologies for Highly Urbanized Coastal Cities. Hong Kong Polytechnic University.

7. Basis of Estimates

This section summarizes the basis for estimates in Table 6.

Current Areas

Estimated by drawing outlines around structures on a site plan and calculating the approximate areas enclosed.

Stacked Clarifiers

Based on stacked clarifiers at Stonecutters Island Sewage Treatment Works in Hong Kong.

Tank surfaces 210 feet long by 23 feet wide.

Tank surfaces multiplied by area factor of 1.4 to allow for galleries, etc.

Plate Settlers

Based on plate settlers at Ulu Pandan Treatment Plant in Singapore.

Area factor of 2.65.

Aeration Tanks

For future, SRT of 10 days, vs. current SRT of 2.5 days.

Net yield less by 12%.

Step Feed

From Figure 2 of Pincince et al (2002)

Hybrid Systems

Based on increase of one-third in biomass concentration.

Membrane Bioreactors

MLSS of 10,000 mg/L, vs. current concentration of 2,500 mg/L

10% of total volume required for membrane equipment.

Biological Aerated Filters

Criterion	BOD removal	Nitrification
Loading (kg BOD/m^3/d)	4.6	
Loading (kg N/m^3/d)		1.2
Velocity (m/hr)	8	8
Net yield (g TSS/g BOD)	0.6	0.73
Reactor depth (m)	4	4

BOD of primary effluent = 100 mg/L, from discharge permit for primary effluent.

TKN of primary effluent = 14 mg/L .

Ballasted Flocculation

Based on Acheres plant in France.

Provides for capacity equal to difference between pumping capacity (1,752 mgd) and secondary-treatment capacity (930 mgd)

Sludge Production

Table 5 of memorandum "Future Solids Processing Requirements—A Summary of the 'Evaluation of WWTP Under Preferred Plan Conditions' Study Results for DWSD Solids Master Plan under PC-744

Drying and Digestion

Digesters based Deer Island Treatment Plant in Boston. Dryers based on Fore River Sludge Drying and Pelletizing Facilities.

Thickeners for Primary Sludge

Allows for two new gravity thickeners.

8. Conceptual Construction Sequence

Background

For the example discussed in Section 5, a conceptual construction sequence has been proposed to delineate how the modifications/additions to the WWTP treatment processes could be made.

The construction sequence development has taken into account the constraints identified for the treatment analyses. For reference, the resultant constraints and assumptions of our analyses are tabulated below.

The conceptual construction sequence was developed considering three key goals. The first was to minimize operational impacts during construction as well as the temporary loss of existing treatment capacity. The second was the placement of proposed facilities, which were carefully considered to maximize the use of property currently owned by DWSD. It is important to note that, as described below, additional land will be needed for a portion of the new unit processes. The third was to avoid the use of substantial temporary treatment unit processes during construction.

Conceptual Construction Sequence

The conceptual construction sequence summarized below provides one possible sequence, which the Contractor could use to construct the facilities. However, the Contractor may select an alternate sequence, which addresses the construction constraints and facilitates project completion within the project schedule.

Below is a general conceptual sequence of construction:

Isolate a fraction (approximately 50%) of the rectangular primary clarifiers from the process stream and demolish or modify to facilitate the addition of a ballasted flocculation unit process. The proposed location of the unit process is shown on Figure 1.

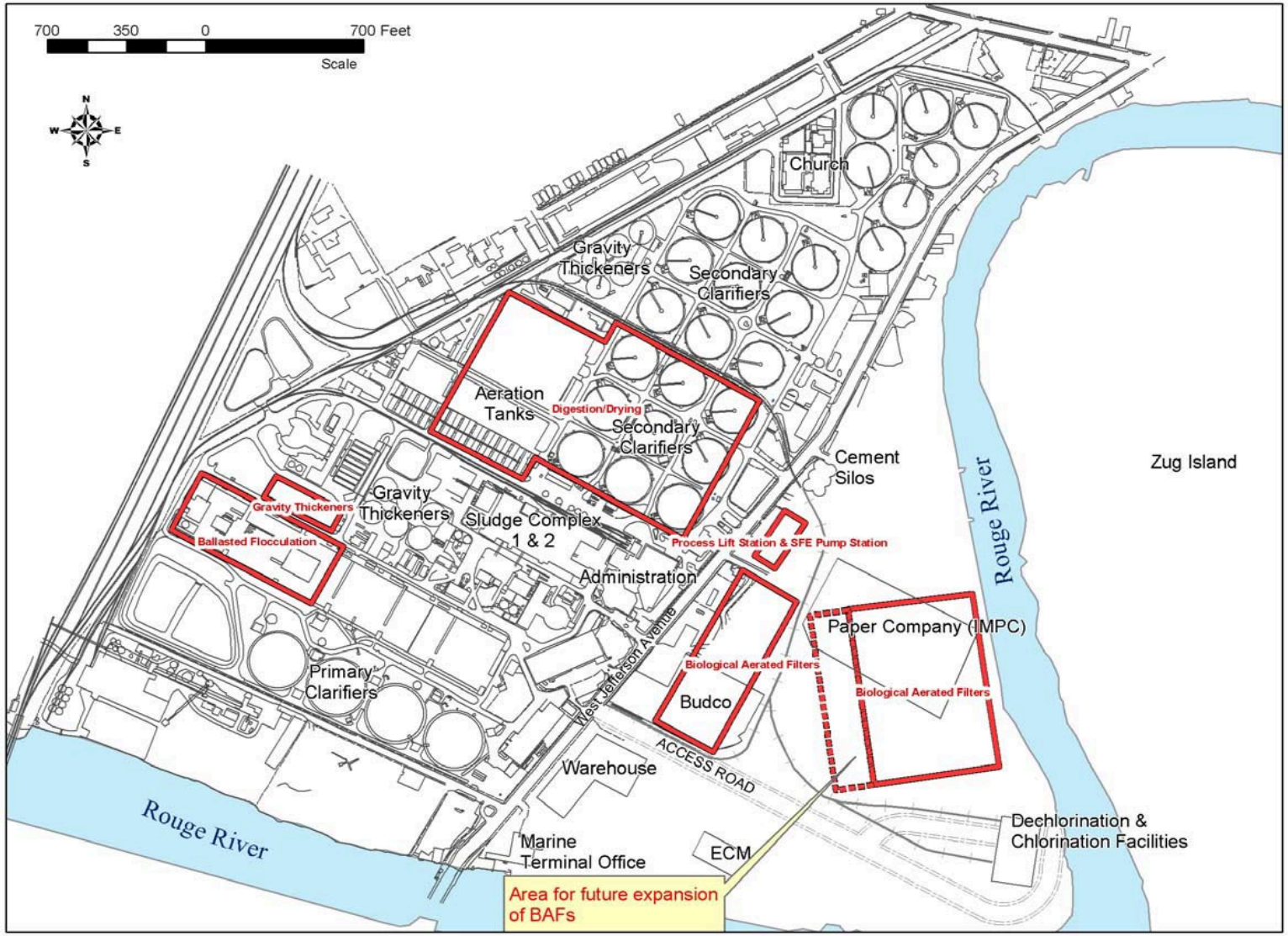

Figure 1. Possible Future WWTP Unit Process Layout

Note: Siting of the potential facilities shown outside the existing property line is only for general reference. Optimal location of new facilities has not yet been determined.

Construct ballasted flocculation unit process and all associated support systems.

Note:

1. During this initial period of construction, the peak primary treatment plant capacity will be reduced. However, after the ballasted flocculation system is on-line all excess wet-weather flows (above 930 mgd) would be treated by this new unit process.

2. A portion of the remaining rectangular clarifiers will be needed to treat the recycle flow associated with the biological aerated filters (BAFs discussed below). This recycle flow could be on the order of 1/5 to 1/6 of the plant flow.

There may be an option in which the BAFs, the associated lift station and supporting systems could be constructed prior to the ballasted flocculation process. This option could facilitate treatment of the flows, which would typically be processed by the portion of the rectangular clarifiers that would be removed to construct ballasted flocculation. This would result in the elimination of long-term loss of plant capacity during construction. In order to consider the viability of this option further, an assessment of other possible capacity limitations to convey the flow to the secondary plant would need to be investigated. In addition, a temporary flow split would be required to split the primary effluent between the existing aeration basins and the BAFs.

After completion of acceptance testing, place the ballasted flocculation system on-line.

After completion of the ballasted flocculation system, construct additional gravity thickeners, as necessary, for the treatment of primary sludge. Please refer to Figure 1 for the proposed thickener location near the existing primary sludge gravity thickeners. If necessary, the thickener construction could be performed simultaneously with the BAF and process lift station construction described below.

Construct new process lift station, biological aerated filters and all associated support facilities. The proposed location of these facilities includes an area east of West Jefferson Avenue across from the administration building and a portion of the area currently occupied by the secondary clarifiers (see Figure 1 for details).

The lift station and BAF construction could begin at the same time as the ballasted flocculation construction, if desired, to reduce the overall construction schedule.

This proposed location for the lift station and BAFs would necessitate the purchase of additional land (approximately 22 acres). The intent is to locate facilities in this area to minimize disruption of the railroad spur, which serves the chlorination/dechlorination facilities. This location was selected to minimize

operational disruption of the secondary plant during construction of the BAFs. In addition, this location was looked upon favorably since it is between the secondary plant and the new disinfection facilities, which will reduce the required process flow piping.

A new SFE pumping station will also be required because secondary effluent will no longer be available at the current location. The SFE pumping station will be located downstream of the BAFs.

An evaluation of the optimum location for the process lift station is suggested. Ultimately a location west of West Jefferson Avenue may be selected in order to minimize the installation of relatively deep pipe and to minimize the length of duct banks serving this station.

After completion of acceptance testing, place the process lift station, SFE pumping station and BAFs on-line.

In order to provide room for the anaerobic digesters, sludge drying facilities and all supporting facilities, demolish the process lift stations, aeration basins and a portion of the secondary clarifiers. All of the secondary clarifiers could be demolished as part of this work as well as the associated gravity thickeners, if desired. However, the units located closest to the aeration basins (Nos. 1 – 10) need to be demolished first to facilitate construction of solids handling system improvements.

Construct the anaerobic digesters and sludge drying facilities. After acceptance testing has been completed, place these systems on-line. After the digestion/drying facilities are on-line, the incinerators and supporting systems could be decommissioned and demolished.