Proposed Design for a Cost-Effective and Energy-Efficient Wastewater Treatment System

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1 Introduction

A cost-effective and energy-efficient wastewater treatment system is proposed for a proposed estate by developer HOPE. The proposed treatment system is expected to provide tertiary level treatment for all wastewater generated from the estate's residential, institutional, commercial, and industrial developments. Effluent from the plant is expected to comply with Singapore's Trade Effluent Regulation (1976) standards for *discharge into controlled watercourses*.

2 Background

The client, HOPE, intends to develop an estate on a newly acquired piece of land. The proposed types and sizes of developments are given in Table 1.

Type of development	Land area allocated (ha)
Single family dwellings	350
Low-rise apartments	450
High-rise apartments	900
Commercial	3200
Industrial	400
School	150
Total	5450

Table 1: Proposed types of development and land area allocated in estate.

The Environmental Regulatory Agency's requirements are as follows:

- All wastewater generated is to be treated to meet the Singapore Trade Effluent Standards (1976)
- All new treatment system are to cater to climate changes

3 Key considerations

3.1 Design assumptions

3.1.1 Nature of sewer system

The estate's sewer system is assumed to have separate and independently operating public sewers and storm drains. All wastewater from the public sewer will be treated by the proposed treatment system. Stormwater is assumed to be carried away by the storm drains into a nearby receiving body of adequate assimilation capacity.

3.1.2 Industrial wastewater disposal

Industries are assumed to have treated their wastewaste to meet Singapore's Trade Effluent Regulation (1976) standards for *discharge into public sewers*.

3.2 Operational considerations

3.2.1 Flowrate and loading estimates at carrying capacity

Table 2 shows the estimated population and flowrate values at the estate's carrying capacity. Data is assumed to be based on similar nearby developments.

Land use	Land area allocated (ha)	Population density[a] (capita/ha)	Population	Per capita flowrate[b] (L/capita/d)	Area flowrate[b] (m^3/ha/d)	Design average flowrate (m^3/d)
Single-family	350	50	17500	320	16	5600
Low-rise	450	150	67500	260	39	17550
High-rise	900	300	270000	200	60	54000
Residential total	1700		355000			77150
Commercial	3200	150	480000	50	7.5	24000
Industrial	400	100	40000	150	15	6000
School	150	400	60000	100	40	6000
Other total	3750		580000			36000
Grand Total	5450					113150

[a]Population density is assumed to be estimated from similar nearby developments. Here it is deduced with information from (Metropolitan Design Center, 2005).
[b]Per capita and area flowrates are assumed to be estimated from similar nearby developments. Here they are based on typical values found in (Tchobanoglous et al., 2003).

Table 2: Estimation of design average flowrate.

3.2.2 Startup and initial transition period

In the initial months of treatment system operations, influent flowrates are expected to be to be well below design flowrates and rise steadily over time. Loading during this period is expected to undergo significant variablility due to major construction activities. The treatment system has to cater for this variability.

3.2.3 Odour management

Wastewater when gathered in large quantities is inherently odorous. Moreover, treatment processes themselves may produce odourous substances. The design should incorporate odour reduction technologies.

3.3 Cost effectiveness and energy efficiency

3.3.1 Modular design and progressive construction

Flowrates during the initial transition period are expectied to be well below design flowrates. Thus, the full capacity of the treatment system does not need to be realised at the start of operations. This allows the treatment system to be construction in a progressive manner.

Cost-effectivesness is improved as the construction period can be lengthened, and the plant can operate close to optimum levels even in the initial transition period. To facilitate this, the treatment system will be designed in a modular fashion.

3.3.2 Minimising land area requirements

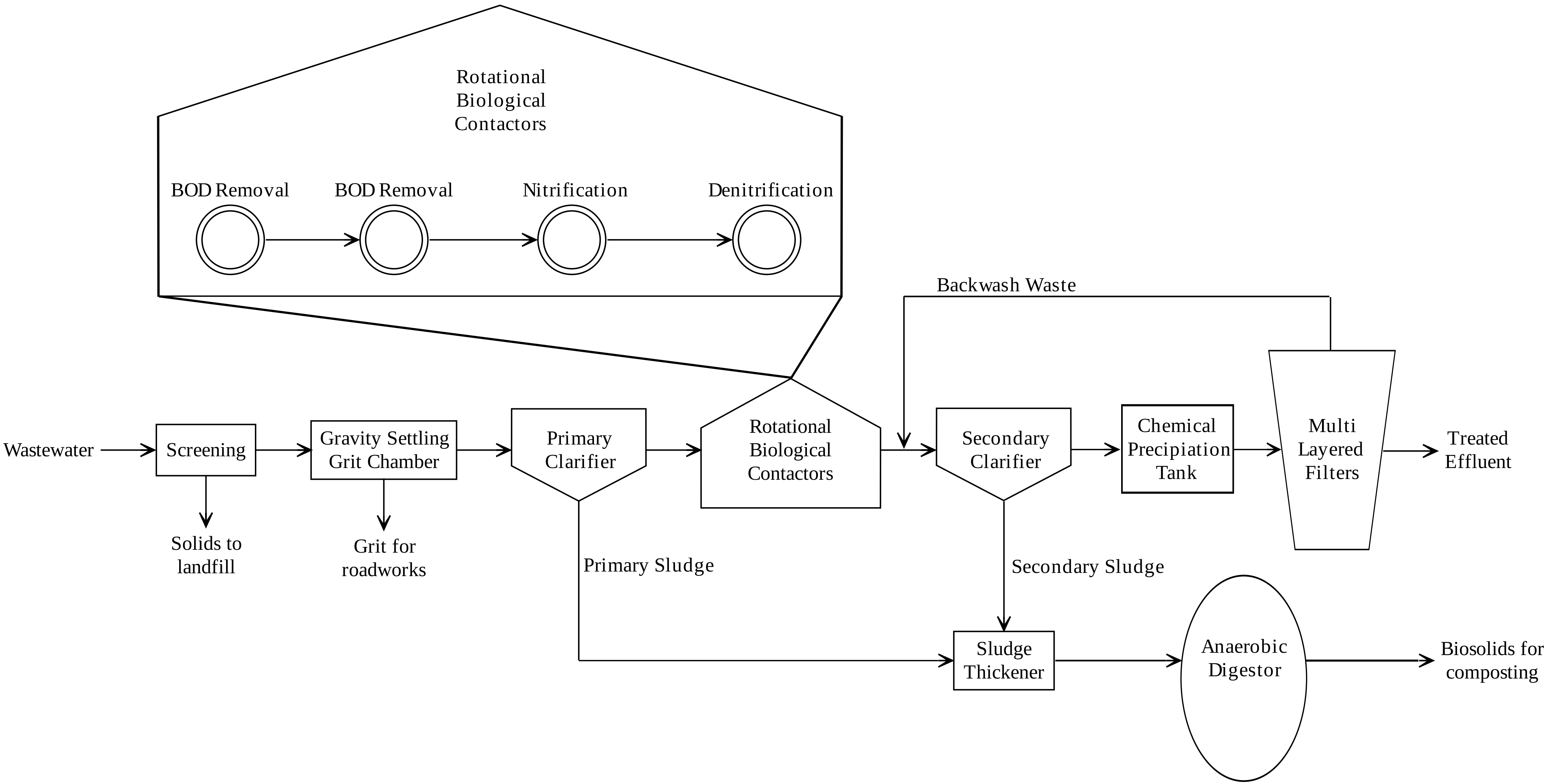
Treatment technologies that are compact and have small land requirements will be favoured.

3.3.3 Reducing aeration requirements

Experience has shown that aeration systems typically account for about 40–60% of electricity usage in wastewater treatment systems. To improve energy efficiency, the treatment system will be designed to significantly reduce aeration requirements.

3.3.4 Energy production from sludge handling

The scale of the treatment system allows anaerobic digestion to be performed in a cost-effective manner. The design will utilise biogas output from anaerobic sludge digestion to fulfil part of the treatment system's energy requirements.


Rotational
Biological
Contactors
BOD Removal
BOD Removal
Nitrification
Denitrification
Backwash Waste
Wastewater
Screening
Gravity Settling
Grit Chamber
Primary
Clarifier
Rotational
Biological
Contactors
Secondary
Clarifier
Chemical
Precipiation
Tank
Multi
Layered
Filters
Treated
Effluent
Solids to
landfill
Grit for
roadworks
Primary Sludge
Secondary Sludge
Sludge
Thickener
Anaerobic
Digestor
Biosolids for
composting

4 Rationale for the proposed treatment system

4.1 Pre-treatment

Large solids can damage treatment equipment. Grit can abrade surfaces of treatment equipment, accumulate in pipes and tanks, and interfere with subsequent treatment processes. Grease forms a layer on the wastewater surface and prevents dissolving of atmospheric oxygen into the wastewater stream. Pre-treatment removes large solids, grit and floatables such as grease from the influent stream.

4.1.1 Mechanical bar screens

Screening removes large solids and floatables such as branches, twigs, rags and cigarette butts, etc. Mechanical bar screens were chosen as they are cost-effective for a treatment system of this size.

Other options considered:

- Hand-cleaned bar screens

4.1.2 Aerated grit chambers

Aerated grit chambers were chosen for the following reasons:

- They are compact and occupy less space
- Aeration removes odours, and facilitated subsequent BOD removal
- The air bubbles dislodge organics from grit particles, allowing direct disposal of grit in landfills
- Skimmers can be employed for grease removal
- Greater control over particle settling can be achieved

Other options considered:

- Gravity settling grit chambers

4.2 Primary treatment

Primary treatment removes a portion of the SS and the BOD from the wastewater stream. This reduces loading on subsequent secondary treatment systems.

After primary treatment, 99% of grit, 70% of suspended solids (SS) and 20–40% of BOD is expected to have been removed.

4.2.1 Primary clarifiers

Primary clarifiers were chosen as they are provide sufficient removal of SS and BOD while being cost-effective and energy-efficient. Detention time can be varied based on variations in loading and flowrates. Chemical additives can also be added if necessary.

Other options considered:

- Floatation systems

4.3 Secondary treatment

Secondary treatment removes most of the SS and BOD from the wastewater stream. Nitrogen removal is also included in this design. After secondary treatment, effluent SS and BOD concentration is expected to be about 15–30 mg/L.

4.3.1 Rotating biological contactors

Rotating biological contactors (RBCs) were chosen as they are compact, and proven technology. RBC units can be arranged in series to promote specialization of bacteria, enhancing both BOD and nitrogen removal. RBCs are also cost-effectiveness and energy-efficiency as they usually do not require aeration. The modular nature of RBCs allows for more units to be added if required.

Other options considered:

- Activated-sludge process
- Trickling filters
- Stabilization lagoons
- Anaerobic contact process

4.3.2 Secondary clarifiers

Secondary clarifiers remove waste sludge from the effluent stream after biological treatment. Secondary clarifies were chosen for the same reasons as primary clarifiers (see section 4.2.1).

Other options considered:

- Floatation systems

4.4 Tertiary treatment

Tertiary treatment removes phosphorous and other trace constituents. Effluent is expected to meet Singapore's Trade Effluent Standards (1976) for *discharge into controlled watercourses* after tertiary treatment.

4.4.1 Chemical precipitation tanks

The chemical precipitation tanks facilitate mixing of chemicals such as coagulants and neutralizing agents with the influent stream. This facilitates the subsequent filtration process.

4.4.2 Multi layered filters

When used with upstream coagulation, filtration can remove almost all remaining SS, nitrogen and phosphorus. Multi layered filters are chosen as they can function for a longer time than sand filters before backwash is necessary, and are more cost effective than filters with only activated carbon.

- Sand filters
- Activated carbon filters

4.5 Sludge handling

4.5.1 Sludge thinckeners

Sludge thickeners remove water from the sludge stream. This reduces hydraulic loading on the digesters, making them more efficient in energy production per kg sludge processed.

4.5.2 Anaerobic digestors

Anaerobic digestion was chosen as it is both energy efficient and cost-effective for a treatment plant of this size. Removal of 40–60% of organic solids is expected, reducing solid waste output. The biogas produced from the anaerobic digestion process can be used to fulfil part of the treatment system's energy requirements.

References

Metropolitan Design Center, College of Architecture and Landscape Architecture, U. o. M. (2005). Housing types. Originally prepared for the Northwest Corridor Development Approach.

Tchobanoglous, G., Burton, F. L., Stensel, H. D., and Metcalf & Eddy, Inc. (2003). *Wastewater Engineering: Treatment and Reuse*. McGraw-Hall Professional, 4 edition.