Design parameter

Design population 200,000 people
Avg per capita consumption 350 L/day
Recovery by wastewater Plant 90% (90% of water consumption is WWTP influent)
Peaking factor 2.0 (peak hourly flow during heavy rainfall is 2 times the average hourly dry weather flow)
Temp 20 °C

Design of Primary clarifier based on average flow
Design of AS based on average flow
Design of Secondary clarifier based on both peak and average flow

Average flow 63000000 L/day 63000 m3/day
Peak flow 126000000 L/day 126000 m3/day

Wastewater characteristic

BOC5 250 mg/L
SS 250 mg/L
NH3-N 30 mg/L

Assumptions

Wastewater has been screened
Grit has been removed
No BOD and SS during screening and grit removal
Use "10 State Standards" as criteria for overflow rates, weir loading rates, side water depths, detention time, etc.
Two or more tanks are needed for each unit process, but no spare tank
Tank is circular in shape

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>7.62</td>
</tr>
<tr>
<td>50</td>
<td>15.24</td>
</tr>
<tr>
<td>75</td>
<td>22.86</td>
</tr>
<tr>
<td>150</td>
<td>45.7</td>
</tr>
</tbody>
</table>

Odor concern—no flow EQ basin is needed

Primary tanks remove
BOD 35%
SS 60%

Discharge limit
BOD5 25 mg/L
SS 25 mg/L
NH3-N 2 mg/L

BOD5 of SS in effluent = 0.6 mg BOD/mg SS

MLSS no more than 3000 mg/L
MLSS = 1.18 MLVSS

HRT of aeration tank 4 hrs at least
Primary clarifier

Based on "10 State Standard"

The overflow rate is 41 m3/m2-day (average flow)
61 m3/m2-day (peak flow)

The weir loading rate not to exceed 186 m3/m-day

Side water depth 2.1 m at least

Tank surface area requirement
= flow rate/overflow rate

Average: = 63000 m3/day / 41 m3/m2-day
1537 m2

Peak: = 126000 m3/day / 61 m3/m2-day
2066 m2

Tank weir length area requirement
= flow rate/weir loading rate rate

Peak: = 126000 m3/day / 186 m3/m2-day
677 m

Tank size determination

<table>
<thead>
<tr>
<th>Diameter (m)</th>
<th>Area (m2)</th>
<th>Weir length (m)</th>
<th># of tank required</th>
<th># of tank adjusted</th>
<th>Resulting weir length (m)</th>
<th>Resulting weir length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>single</td>
<td>double</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.62</td>
<td>45.6</td>
<td>23.9</td>
<td>45.9</td>
<td>45</td>
<td>1077</td>
<td>2155</td>
</tr>
<tr>
<td>15.24</td>
<td>182.4</td>
<td>47.9</td>
<td>95.8</td>
<td>11.3</td>
<td>575</td>
<td>1149</td>
</tr>
<tr>
<td>22.86</td>
<td>410.4</td>
<td>71.8</td>
<td>143.6</td>
<td>5.0</td>
<td>431</td>
<td>862</td>
</tr>
<tr>
<td>30.47</td>
<td>729.2</td>
<td>95.7</td>
<td>191.4</td>
<td>2.8</td>
<td>287</td>
<td>547</td>
</tr>
<tr>
<td>45.7</td>
<td>1640.3</td>
<td>143.6</td>
<td>287.1</td>
<td>1.3</td>
<td>144</td>
<td>287</td>
</tr>
</tbody>
</table>

# of tank required = Area required at peak (2066 m2) / tank area

Choose: 6 circular tanks with 22.86 m-diameter (75 ft) with double weir

Overflow rate = 126000 m3/day / (410.4 m2 x 6) = 51 m3/m2-day PEAK OK

Weir loading rate = 126000 m3/day / (862 m2) = 146 m3/m-day PEAK OK

Detention time = Total volume / flow rate = with side water depth = 2.1 m

BOD5 = 250 mg/L x (1-0.35) = 162.5 mg/L

TSS = 250 mg/L x (1-0.60) = 100 mg/L

Primary sludge production = 250 mg/L x 0.6 x 126000 m3/day x 1000 m3/L x kg/10^6 mg
= 10900 Kg/day
Kinetic parameter determination

<table>
<thead>
<tr>
<th>$S_0$, mg/L as BOD</th>
<th>$S$, mg/L as BOD</th>
<th>$\Theta = \Theta_0$, hr</th>
<th>$\Theta = \Theta_0$, d</th>
<th>$X$, mg VSS/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>10.3</td>
<td>144</td>
<td>6</td>
<td>64</td>
</tr>
<tr>
<td>250</td>
<td>18.4</td>
<td>96</td>
<td>4</td>
<td>69</td>
</tr>
<tr>
<td>250</td>
<td>27.6</td>
<td>72</td>
<td>3</td>
<td>81</td>
</tr>
<tr>
<td>250</td>
<td>32.6</td>
<td>48</td>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>250</td>
<td>44.2</td>
<td>36</td>
<td>1.5</td>
<td>92</td>
</tr>
<tr>
<td>250</td>
<td>90</td>
<td>24</td>
<td>1</td>
<td>74</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$S_0-S$, mg/L</th>
<th>$X$, mg VSS/L</th>
<th>$X(\Theta_0-S)$, 1/d</th>
<th>1/$S$, L/mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>238.7</td>
<td>334</td>
<td>1.6</td>
<td>0.097</td>
</tr>
<tr>
<td>231.6</td>
<td>276</td>
<td>1.2</td>
<td>0.054</td>
</tr>
<tr>
<td>222.2</td>
<td>243</td>
<td>1.1</td>
<td>0.036</td>
</tr>
<tr>
<td>217.4</td>
<td>160</td>
<td>0.7</td>
<td>0.031</td>
</tr>
<tr>
<td>205.8</td>
<td>138</td>
<td>0.7</td>
<td>0.023</td>
</tr>
<tr>
<td>160</td>
<td>74</td>
<td>0.5</td>
<td>0.011</td>
</tr>
</tbody>
</table>

$X \Theta_0/(S_0-S) = Ks/k \times 1/S + 1/k$

$Kw/k = 13.017$

$1/k = 0.4131$

$k = 2.421$ day$^{-1}$

$K_s = 31.511$ mg/L

$1/\Theta_0 = (S_0-S) \times X \Theta_0, d^{-1}$

<table>
<thead>
<tr>
<th>$1/\Theta_0$, $d^{-1}$</th>
<th>(So-S) \times X \Theta_0, $d^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.167</td>
<td>0.6</td>
</tr>
<tr>
<td>0.250</td>
<td>0.8</td>
</tr>
<tr>
<td>0.333</td>
<td>0.9</td>
</tr>
<tr>
<td>0.500</td>
<td>1.4</td>
</tr>
<tr>
<td>0.667</td>
<td>1.5</td>
</tr>
<tr>
<td>1.000</td>
<td>2.2</td>
</tr>
</tbody>
</table>

$1/\Theta_0 = Y (S_0-S) \times \Theta_0 - kd$

$kd = 0.189$ day$^{-1}$

$Y = 0.068$ mg VSS/mg BOD

$\mu_m = kY = 1.327$ day$^{-1}$

$0.055$ hr$^{-1}$

$y = 13.017x + 0.4131$

$y = 0.548x - 0.1888$
**Activated sludge System**

**Operating parameters**
BOD₅ of SS in effluent = 25 mg/L x 0.6 = 15 mg/L
So, design target BOD₅ has to be = 25-15 = 10 mg/L

\[ S = \frac{K_s (1 + K_d \Theta_c)}{\Theta_c (\mu_m-K_d)-1} = \frac{31.511 (1+0.189\Theta_c)}{\Theta_c (1.327-0.189)-1} \]

\[ \Theta_c = 7.65 \text{ days} \quad \text{Solid retention time} \]

MLVSS = 3000 / 1.18 \quad = \quad 2542 \text{ mg/L}

\[ X = \frac{\Theta_c Y (S_o - S)}{\Theta (1+K_d \Theta_c)} = \frac{7.65 (0.548)(162.5-10)}{\Theta (1+0.189\times7.65)} = 2542 \]

\[ \Theta = 0.103 \text{ day} \quad 2.472 \text{ hrs} \quad \text{Hydraulic retention time} \]

City recommend 4 hour HRT, so we use 4 hour HRT (0.166 days)

\[ X = \frac{7.65 (0.548)(162.5-10)}{0.166 (1+0.189\times7.65)} = \frac{1575 \text{ mg/L}}{\text{MLVSS}} \quad \text{less than 2542} \quad \text{OK} \]

**Aeration tank sizing**
\[ \Theta = \frac{V}{Q} \]

\[ V = \Theta Q = 0.166 \text{ day}^{-1} \times 63000 \text{ m}^3/\text{day} = 10458 \text{ m}^3 \]

say 10500 m³

Use 4 tanks of 25 m (L) x 10.5 m (W) x 10 m (Depth) at 2525 m³ each

**Return sludge**

\[ X' \text{ (or MLSS)} = 1.18 \times 1575 = 1859 \text{ mg/L} \]

SVI @ 20°C approximately = 200 mg/L

\[ X'r \text{ (or return sludge MLSS)} = \frac{10^6}{\text{SVI}} = 5000 \text{ mg/L} \]
Return sludge rate (Qr)

\[
\frac{Q_r}{Q} = \frac{X'}{X_t - X} = \frac{1859}{5000 - 1859} = 0.59
\]

\[Q_r = 0.59 \times 63000 = 37170 \text{ m}^3/\text{day}\]

Sludge waste rate (Qw)

\[
\frac{V X}{Q_w X_r} = \Theta_c
\]

\[X_r = X'/1.18 = 5000/1.18 = 4237\]

\[Q_w = \frac{10500 \times 1575}{7.65 \times 4237} = 510 \text{ m}^3/\text{day}\]

Sludge production rate (Px)

\[
Y_{obs} = \frac{Y}{1 + K_d \Theta_c} = \frac{0.548}{1 + 0.180 \times 7.85} = 0.224
\]

\[P_x = Y_{obs} Q \ (So-S) = 0.224 \times 63000 \text{ m}^3/\text{day} \times (152.5 \text{ mg/L - 10 mg/L}) \times 1000 \text{ L/m}^3 \times \text{kg/10}^6 \text{ mg} = 2152 \text{ kg/day}\]

Oxygen requirement

\[
O_2 \text{ req} = \frac{Q \ (So-S) \times 1000 \text{L/m}^3 \times \text{kg/10}^6 \text{ mg}}{f} - 1.42 P_x
\]

\[f = \text{BOD5/BODL} = 0.6
\]

\[= \frac{63000 \times (162.5 - 10) \times 1000 \text{L/m}^3 \times \text{kg/10}^6 \text{ mg}}{0.6} - 1.42 \times 2152 = 12957 \text{ kg/day}\]
Nitrification

Oxygen requirement

\[
O_2 \text{ req} = \frac{Q \times (S_o-S) \times 1800 \text{L/m}^3 \times x \text{kg}/10^6 \text{mg}}{f} - 1.42 \text{mg} + 4.57 \frac{Q \times (\text{No-N}) \times 1000 \text{L/m}^3 \times x \text{kg}/10^6 \text{mg}}{f}
\]

\[f = \frac{\text{BOD}_5}{\text{BOD}_L} = 0.6\]

\[= \frac{63000 \times (182.5 - 10) \times 1000 \text{L/m}^3 \times x \text{kg}/10^6 \text{mg}}{0.6} - 1.42 \times 2152 + 4.57 \times 63000 \times (30 - 2) \times 1000 \text{L/m}^3 \times x \text{kg}/10^6 \text{mg}\]

\[= 20730 \text{ kg/day Oxygen requirement from CBOD and NBOD}\]

or \[20730/12857 = 1.6 \text{ times more than that of CBOD alone}\]

Alkalinity requirement

\[\text{ALK req} = Q \times 7.14 \times (\text{No-N}) \times 1000 \text{ L/m}^3 \times x \text{kg}/10^6 \text{mg}\]

\[= 63000 \times 7.14 \times (30 - 2) \times 1000 \text{ L/m}^3 \times x \text{kg}/10^6 \text{mg}\]

\[= 12145 \text{ kd/day as CaCO}_3\]
Secondary clarifier

Based on "10 State Standard"

The hydraulic loading is 49 m³/m²-day (peak and average flow)

for conventional AS

The weir loading rate not to exceed 186 m³/m/day

Side water depth  3.7 m at least

**Tank surface area requirement**

= flow rate/overflow rate

Average:  63000 m³/day / 49 m³/m²-day  1286 m²

Peak:  126000 m³/day / 49 m³/m²-day  2571 m²

**Tank weir length area requirement**

= flow rate/weir loading rate rate

Average:  63000 m³/day / 186 m³/m²-day  339 m

Peak:  126000 m³/day / 186 m³/m²-day  677 m

**Tank size determination**

<table>
<thead>
<tr>
<th>Diameter m</th>
<th>Area m²</th>
<th>Weir length (m)</th>
<th># of tank required</th>
<th># of tank adjusted</th>
<th>Resulting weir length</th>
<th>677 m required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>single</td>
<td>double</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.62</td>
<td>45.6</td>
<td>23.9</td>
<td>47.9</td>
<td>55.4</td>
<td>57</td>
<td>1365</td>
</tr>
<tr>
<td>15.24</td>
<td>182.4</td>
<td>47.9</td>
<td>95.8</td>
<td>14.1</td>
<td>15</td>
<td>718</td>
</tr>
<tr>
<td>22.86</td>
<td>410.4</td>
<td>71.8</td>
<td>143.6</td>
<td>6.3</td>
<td>7</td>
<td>503</td>
</tr>
<tr>
<td>30.47</td>
<td>729.2</td>
<td>95.7</td>
<td>191.4</td>
<td>3.5</td>
<td>4</td>
<td>383</td>
</tr>
<tr>
<td>45.7</td>
<td>1640.3</td>
<td>143.6</td>
<td>287.1</td>
<td>1.6</td>
<td>2</td>
<td>287</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter m</th>
<th>Area m²</th>
<th>Weir length (m)</th>
<th># of tank required</th>
<th># of tank adjusted</th>
<th>Resulting weir length</th>
<th>339 m required</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>single</td>
<td>double</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.2</td>
<td>28</td>
<td>670</td>
<td>1341</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.0</td>
<td>7</td>
<td>335</td>
<td>670</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>3</td>
<td>215</td>
<td>431</td>
<td>YES-double</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.8</td>
<td>2</td>
<td>191</td>
<td>303</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>1</td>
<td>144</td>
<td>287</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Choose: 7 circular tanks with 22.86 m-diameter (75 ft) with double weir
Design criteria

Surface loading rate

\[
\text{rate} = \frac{126000 \text{ m}^3/\text{day}}{(7 \times \text{area of each tank})} = 43.9 \text{ m}^3/\text{m}^2\text{-day}\]  
\[
\text{rate} = \frac{63000 \text{ m}^3/\text{day}}{(7 \times \text{area of each tank})} = 21.9 \text{ m}^3/\text{m}^2\text{-day}\]

Solid loading rate

\[
\text{rate} = \frac{1859 \text{ mg/L} \times 126000 \text{ m}^3/\text{day} \times 1000 \text{ L/m}^3 \times \text{kg}/10^6 \text{ mg}/(7 \times \text{area of each tank})} = 81.5 \text{ kg/m}^2\text{-day}\]  
\[
\text{rate} = \frac{1859 \text{ mg/L} \times 63000 \text{ m}^3/\text{day} \times 1000 \text{ L/m}^3 \times \text{kg}/106 \text{ mg}/(7 \times \text{area of each tank})} = 40.8 \text{ kg/m}^2\text{-day}\]

less than 244 kg/m²-day OK

Weir loading rate

\[
\text{rate} = \frac{126000 \text{ m}^3/\text{day}}{\text{weir length (or 1005 m)}} = 125.3 \text{ m}^3/\text{m}\text{-day}\]  
\[
\text{rate} = \frac{63000 \text{ m}^3/\text{day}}{\text{weir length}} = 62.7 \text{ m}^3/\text{m}\text{-day}\]

less than 186 m³/m·day OK

Detention time

\[
\text{Detention time} = \frac{\text{Total volume}}{\text{flow rate}} = 2.0 \text{ hrs}\]  
\[
\text{Detention time} = \frac{\text{side water depth}}{3.7\text{m}} = 4.0 \text{ hrs}\]

PEAK

OK