Module 12: Detention Pond Design for Water Quality Improvement

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Presentation Contents
- Small-scale settling devices
- Different types of stormwater ponds
- Wet pond performance and design approach
- Wet pond problems and ways to overcome them
- Example design calculations for wet detention ponds

Common Stormwater Controls
- Public works practices (drainage systems, street and catchbasin cleaning)
- Sedimentation
- Infiltration/biofiltration
- Critical source area controls
- Public education

NURP (1983) found particulates reduced by between 0% (for small ponds and large drainage areas) and 90+% for large ponds. For well designed ponds BOD and COD removals were 70%, and heavy metals between 60 – 95%.

Oliver (1981) reported 88% reductions in SS and 54% and 60% reductions for COD and total phosphorus.

Yousef (1986) found 85% removal of soluble nutrients due to plant uptake.
Retro-fitted Catchbasin with Sump Tested at Ocean County, NJ

Dimensions of Optimally-Designed Catchbasin

Box Plots - Catchbasin with Sump

Dimensions of Optimally-Designed Catchbasin

PEAK HYDRAULIC EVENT CONDITION

Stromecenter Corp.
Sedimentation

- Dry detention ponds
- Wet detention ponds
- Wetlands

Wet Basins

Caltrans, San Diego, California

Extended Detention Ponds

Caltrans, San Diego and Los Angeles, California
**Wet Detention Pond Advantages**

- Very good control of particulate pollutants
- Opportunity to utilize biological processes
  - Protozoa as bacteria predators
  - Aquatic plants enable higher levels of nutrient removal
- Outfall ponds capture and treat all storm sewer discharges
  - Wet weather stormwater runoff
  - Dry weather baseflows
  - Snowmelt
  - Industrial spills
  - Illegal discharges

**Typical Dry Detention Pond, with Pilot Channel**

**Unusual Dry Detention Pond Located on Hillside to Meet Peak Flow Rate Criterion**
Dry Detention Pond Forebay for Stormwater Pump Station, Los Angeles, CA

Scour and Sediment Transport in Dry Detention Ponds

Large Corrugated Pipes used for Underground Detention Below Parking Area

Wet Detention Facility at Shopping Center, Birmingham, AL
Wet Detention Facility at Shopping Center, Dayton, OH

Wet Detention Facility at Convention Center, Orlando, FL

Wet Detention Facility at Industrial Park, Birmingham, AL

Wet Detention Facility at Apartments, Lake Oswego, OR (Part of Treatment Train)
Wet Detention Facility at Residential Area, Birmingham, AL

Advertising for New Wet Ponds, Austin, TX

Wetlands for Stormwater Control

Wetlands in Malmo, Sweden (under construction and mature)

Watch your step Eric!
Inlet for Wetland in Malmo, Sweden for Treatment of CSOs and Stormwater

Mature Wetlands and Wet Detention Pond Facility, Malmo, Sweden

New Wetlands being Planted by Volunteers, Malmo, Sweden
Necessary Harvesting of Aquatic Plants from Wetland used for Treatment of Municipal Wastewater

Observed Wet Pond Performance (when constructed and operated according to best guidance)

- Suspended solids: 70 to 95%
- COD: 60 to 70%
- BOD\textsubscript{5}: 35 to 70%
- Total Kjeldahl nitrogen: 25 to 60%
- Total phosphorus: 35 to 85%
- Bacteria: 50 to 95%
- Copper: 60 to 95%
- Lead: 60 to 95%
- Zinc: 60 to 95%

Pond Problems

- Safety
- Nuisance conditions
- Maintenance
- Poorly known site conditions
- Critters

Safety of Detention Ponds

Numerous design features to maximize pond safety:
- Side slopes
- Depth
- Safety ledge
- Accessibility
- Outlet structure protection
- etc.
Children are Attracted to Urban Waters

Deep Water Too Close To Shore

Thin Ice Near Shore

Frequent Maintenance and Adjustments to Outlets may be Needed
Sometimes the pond wins!

Wet Ponds Located in Areas of Karst Geology may have Sinkholes

Ponds can be attractive and in some areas they actually encourage contact recreation, but water quality is usually poor. Birds and other wildlife are also frequently attracted to ponds.

However, they may be mutually exclusive uses.
Other critters also attracted to ponds (no geese at this pond!)

Existing Ponds can be Modified for Improved Performance

- Change outlet device
- Reshape pond
- Add internal berms to prevent short-circuiting

Modification of Outlet for Improved Performance

Modification of Pond Outlet at Epcot Center, Orlando, FL
Design Suggestions to Enhance Pollutant Control and to Minimize Problems
Composite list from literature and experience

- Locate and size ponds to minimize hydraulic interferences.
- Keep pond shape simple to minimize short-circuiting.
- Slope ground leading to pond between 5 and 25%.
- Use shallow perimeter shelf as a safety ledge.
- Plant dense emergent vegetation on shelf.
- Plant thick vegetation barrier around pond perimeter.
- Provide at least 3 ft. of permanent pool depth for scour protection.
- Provide at least 2 more feet as sacrificial storage.

Design Suggestions (cont.)

- Use sub-surface outlets to minimize clogging and to retain floatables.
- Discourage water contact recreation and consumptive fishing.
- Stock mosquito eating fish.
- Minimize water level fluctuations to reduce mosquito problems.
- Place rocks at inlet and outlet areas to minimize scour.
- Use anti-seep collars around outlet pipes to minimize piping.
- Provide trash and safety racks, plus baffles on outlets.
- Provide emergency spillway.
Use of Sedimentation in Conjunction with other Controls

- Effluent can be directed to infiltration or wetland area.
- Sedimentation is a common pre-treatment option for filtration and chemical treatment.
- Sedimentation can better handle large flows and serves to protect downstream more “fragile” devices, such as wetlands or infiltration areas.
Percolation Ponds

- Can incorporate sedimentation with infiltration
- Usually in areas of shallow groundwater
- Concern about possible groundwater contamination, especially in industrial areas
Special Stormwater Control Considerations in Areas having Harsh Winters

• Snowmelt can contribute the majority of the annual pollutant loads from urban areas
• Summer runoff is typically only considered in the design of stormwater controls
• Cold weather hinders all stormwater control processes (such as infiltration, settling, and plant uptake)
• Deicing salts are a special threat to urban groundwater quality

Stormwater Design Considerations for Cold Climates

• “Oversize” wet ponds to accommodate reduced settling rates (can be one-half of the summer rates)
• Protect sediment from scour during snowmelt
• “Oversize” infiltration areas due to reduced soil infiltration rates, but substantial infiltration does occur under snowpacks during long winters
• Divert snowmelt from infiltration areas
• Do not rely on wetlands and other controls utilizing plants during long dormant season
• Follow good snow removal practices
• Reduce the use of deicing salts
• Prevention is especially important in design of land development
Particulate Settling

- Ideal Settling – Particle path is vector sum of particle velocity through pond and settling (upflow) velocity
  
  - $L$ – Pond Length
  - $D$ – Outlet Depth
  - $V$ – Water Velocity through Pond
  - $v$ – Settling Velocity
  - $Q_{out}$ – Outflow from Pond
  - $A$ – Pond Surface Area

\[
\frac{V}{v} = \frac{L}{D} \quad v = \frac{Q_{out}}{A}
\]

Pages 23-25 of detention pond design.pdf

Measured Particle Sizes, Including Bed Load Component, at Monroe St. Detention Pond, Madison, WI

The Monroe St. detention pond in Madison has been monitored by the WI DNR and USGS for many years. The data have been used to verify the wet detention pond routines in WinSLAMM and Detpond.
Retrofitted to result in 90% SS control, the long-term monitored results were 87%.

### Wet Pond Design Criteria for Water Quality

- Surface area should have a minimum area based on land use and desired pollutant control
- Pond freeboard storage equal to runoff associated with 1.25 inches of rain for the land use and development
- Select outlet device to obtain desired pollutant control for all pond stages
- Incorporate special features for harsh winters and snowmelt loads, if needed

### 1. Pond Area as a Percentage of Drainage Area

<table>
<thead>
<tr>
<th>Land Use</th>
<th>5 micrometer</th>
<th>20 micrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Totally paved</td>
<td>2.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Industrial</td>
<td>2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Commercial</td>
<td>1.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Institutional</td>
<td>1.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Residential</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Open space</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Construction</td>
<td>1.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
2. Design of Wet Detention Ponds (cont.)

The pond freeboard storage should be equal to the runoff associated with 1.25 inches rain for the land use and development type. The following is an example:

<table>
<thead>
<tr>
<th>Example site</th>
<th>Land Area (acres)</th>
<th>Pond WQ Volume Factor</th>
<th>Pond WQ Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paved area</td>
<td>0.6</td>
<td>1.1 inches</td>
<td>0.66 ac-in</td>
</tr>
<tr>
<td>Undeveloped area (clayey soils)</td>
<td>3.8</td>
<td>0.3</td>
<td>1.14</td>
</tr>
<tr>
<td>Construction site (clayey soils)</td>
<td>27.6</td>
<td>0.6</td>
<td>16.56</td>
</tr>
<tr>
<td>Total</td>
<td>32.0</td>
<td></td>
<td>18.36 ac-in (1.53 ac-ft)</td>
</tr>
</tbody>
</table>

3. The “dead” storage is needed to prevent scour of previously deposited material and should be at least 3 ft deep over the sediment. Sediment storage volume is also needed and can be estimated using RUSLE for the construction site.

4. Selection of Outlet Control Device (this example for two small V-notch weirs)

<table>
<thead>
<tr>
<th>Head (ft)</th>
<th>Flow (cfs)</th>
<th>22.5° Storage (ac-ft)</th>
<th>Reqd. area (acres)</th>
<th>Flow (cfs)</th>
<th>30° Storage (ac-ft)</th>
<th>Reqd. area (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.1</td>
<td>&lt;0.01</td>
<td>0.01</td>
<td>0.1</td>
<td>&lt;0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.03</td>
<td>0.1</td>
<td>0.7</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>1.5</td>
<td>1.4</td>
<td>0.1</td>
<td>0.2</td>
<td>1.9</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>2.8</td>
<td>0.3</td>
<td>0.5</td>
<td>3.8</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>3</td>
<td>7.8</td>
<td>1.2</td>
<td>1.4</td>
<td>11</td>
<td>1.6</td>
<td>1.8</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>3.3</td>
<td>2.8</td>
<td>22</td>
<td>4.4</td>
<td>3.8</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>7.2</td>
<td>4.9</td>
<td>38</td>
<td>9.6</td>
<td>6.6</td>
</tr>
<tr>
<td>6</td>
<td>44</td>
<td>14</td>
<td>7.7</td>
<td>60</td>
<td>18</td>
<td>10</td>
</tr>
</tbody>
</table>
$V_s = 1.53 \text{ acre-ft}$
$V_r = 7.5 \text{ acre-ft}$
and $V_s/V_r = 0.20$

for type II or III rain categories:
$q_o/q_i = 0.72$

if the calculated peak discharge rate entering the pond ($q_i$) = 8.7 cfs, the resulting peak discharge rate leaving the pond, $q_o$, (through the water quality primary outlet plus the emergency spillway) is therefore: $0.72 \times 8.7 = 6.3$ cfs

Rain and watershed characteristics for the emergency spillway design:
- $P = 8$ inches
- $CN = 86$; therefore the $I_a = 0.0366$
- $Q = 6.2$ inches and $I_a/P = 0.041$
- Area ($A_m$) = 0.021 mi$^2$ (13.2 acres)
- $T_c = 20$ min (0.3 hr)

The peak unit discharge rate from the tabular hydrograph method is 498 csm/in, and the peak discharge is therefore:

$$Q_{\text{peak}} = (498 \text{ csm/in})(0.021 \text{ mi}^2)(6.2 \text{ in}) = 63.7 \text{ ft}^3/\text{sec}$$

Also, the volume of runoff for this event is:

$$V_r = [(6.2 \text{ in})(13.2 \text{ ac})]/12 \text{ in/ft} = 6.82 \text{ ac-ft}$$
The maximum desired discharge rate for this pond (for both the water quality outlet plus the emergency spillway) is given as 46.5 ft$^3$/sec.

The ratio of the outlet to the inlet flow rate is therefore: $q_o/q_i = 46.5/63.7 = 0.73$

The ratio of the storage volume ($V_s$) to the runoff volume ($V_r$), for Type II rains is 0.2, for this ratio of outlet to inlet peak flow rates. Therefore the storage for the pond to meet this peak discharge rate goal is: $V_s = 0.2 \times (6.82 \text{ acre-ft}) = 1.34 \text{ acre-ft}$

Example Sizing of Wet Detention Pond

- the basic pond area,
- the “live” storage volume,
- the pond side slopes, top surface area, and “dead storage” volume,
- the selection of the primary discharge device,
- the additional storage volume needed for the emergency spillway,
- the sizing of the emergency spillway, and
- the sacrificial storage volume for sediment accumulation.

The length ($L_w$ in feet) of a rectangular weir, for a given stage ($H_w$ in feet) and desired outflow rate ($q_o$ in ft$^3$/sec) can be expressed as:

$$L_w = \frac{q_o}{3.2H_w^{1.5}}$$

The desired $q_o$ for the rectangular weir is $46.5 - 2.2 = 44.3$ ft$^3$/sec. If the maximum stage for the emergency spillway is 1 ft, then length for the emergency spillway is:

$$L_w = \frac{44 \text{ ft}^3/\text{sec}}{3.2(1^1)^{1.5}} = 13.8 \text{ ft}$$

The basic pond area and “live” storage volume

The following are the areas associated with each surface in the drainage area:
- paved areas: 0.2 acres
- undeveloped areas: 1.2 acres
- construction area: 32 acres
- total site area: 33.4 acres

<table>
<thead>
<tr>
<th>Site Subarea</th>
<th>Pond Surface Area (acres)</th>
<th>Pond “Live” Volume, runoff from 1.25 inches of rain fall (acres-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>paved area (0.2 acres)</td>
<td>3% of 0.2 acres = 0.006 acres</td>
<td>1.1 inches x 0.2 acres = 0.22 ac-in</td>
</tr>
<tr>
<td>undeveloped area (1.2 acres)</td>
<td>0.6% of 1.2 acres = 0.007 acres</td>
<td>0.3 inches x 1.2 acres = 0.36 ac-in</td>
</tr>
<tr>
<td>construction area (32 acres)</td>
<td>1.5% of 32 acres = 0.48 acres</td>
<td>0.6 inches x 32 acres = 19.2 ac-in</td>
</tr>
<tr>
<td>Total:</td>
<td>0.49 acres</td>
<td>19.8 ac-in = 1.65 ac-ft</td>
</tr>
</tbody>
</table>
1) If 3 ft deep:
Top area:
\[
\frac{0.49 \text{ acres} + X \text{ ft}}{2} = 1.65 \text{ ac} - \text{ ft}
\]
\[X = 0.61 \text{ acres}\]

at 0.61 acres:
\[\pi r^2 = 26,570 \text{ ft}^2\]
\[r = 92 \text{ ft}\]

at 0.49 acres:
\[\pi r^2 = 21,340 \text{ ft}^2\]
\[r = 82 \text{ ft}\]

side slope = 3 ft/(92-82 ft) =
3 ft/10 ft = 0.3 = 30% too steep

Therefore try different pond depths and calculate diameters and slopes:

If 1 ft deep; top area = 2.81 acres and r = 197 ft and side slope = 1.2% too shallow

If 2 ft deep; top area = 1.16 acres and r = 126 ft and side slope = 4.5% suitable, but on the low side

etc.....

The “pond sizer” spreadsheet does this (and evaluates different outlet devices) for you.

**the selection of the primary discharge device**

At the top of the live storage volume, this pond will have 2 ft of stage and 1.16 acres maximum pond area:

- 45° V-notch weir requires at least 1.0 acres of pond surface at 2 feet of stage in order to provide about 90% control of sediment.
- 30° V-notch weir would require only 0.7 acres,
- 60° V-notch weir would require 1.4 acres.

None of the rectangular weirs would be suitable, as the smallest 2 ft weir requires at least 2.6 acres at 2 feet of stage.

The 45° weir is closest to the area available and is therefore selected for this pond.

Another suitable outlet structure would be an 18” drop tube structure which requires at least 1.1 acres.

**the sacrificial storage volume for sediment accumulation**

Using RUSLE, calculate the sediment loss for the complete construction period for the site area draining to the pond:

\[
R = 350
\]
\[
LS = 1.28 \text{ (based on typical slope lengths of 300 ft at 5% slope)}
\]
\[
k = 0.28
\]
\[
C = 0.24 \text{ (assuming that 5 of the 32 acres of the construction area is being actively worked with a C=1, and the other 27 acres of the construction area is effectively protected with a C=0.1)}
\]
\[
A = (350)(1.28)(0.28)(0.24) = 30 \text{ tons per acre per year.}
\]

Since the construction period is for one year and the active construction area is 32 acres, the total sediment loss is estimated to be about 960 tons. For a loam soil, this sediment volume is about 980 yd³, or 0.8 acre-ft. At least 1 or 2 ft should be used for stabilized areas.
The pond water surface is about 0.5 acres. With a three feet deep dead storage depth to minimize scour, the surface area at the bottom of this 3 ft scour protection zone (and the top of the sediment storage zone), can be about 0.35 acres (about 25% underwater slope).

The sacrificial storage zone can be about 3 ft deep also, and the bottom pond area would be about 0.18 acre, as shown in the following calculations:
Top of sacrificial storage area is 0.35 acres, at 0.35 acres:
\[ \pi r^2 = 15,250 \text{ ft}^2 \]
\[ r = 70 \text{ ft} \]

Therefore, the area of the bottom of the sacrificial storage area needed to provide 0.8 acre-ft of storage, if 3 feet deep can be approximated by:
\[ \frac{(0.35 \text{ acres} + X) \text{ ft}}{2} = 0.8 \text{ acre-ft} \]
\[ X = 0.18 \text{ acres} \]

at 0.18 acres, \( r = 50 \text{ ft} \)
side slope = 3 ft/(70-50 ft) = 3 ft/20 ft = 0.15 = 15%

**the additional storage volume needed for the emergency spillway**

Therefore, this example will only consider the capacity of the emergency spillway to meet the design storm flow rate, the 25-year event. Other watershed characteristics are:

- watershed area: construction area (32 acres), paved area (0.2 acres), and undeveloped area (1.2 acres) = 33.4 acres = 0.052 mi\(^2\)
- clayey (hydrologic soil group D) soils (weighted curve number = 94)
- time of concentration (Tc): 12 minutes (0.2 hours). Since the pond is at the bottom of this watershed, there is no “travel time” through down-gradient subwatershed areas.
- rain intensity for a “25-year” rain for the Birmingham, AL, area, with a 15 minute time of concentration (from the local IDF curve): 6.6 inches/hour (type III rain)

Therefore the tabular hydrograph table to be used would be Exhibit III, corresponding to a Tc of 0.2 hour. The top segment of “csm/in” (cubic feet per second per square mile of watershed per inch of direct runoff) values are therefore used, corresponding to Ia/P values of 0.1, or less. The top row is also selected as there is no travel time through downstream subwatersheds. Examining this row, the largest value is 565 csm/in, occurring at 12.3 hours. The amount of direct runoff for a site having a CN of 94 and a 24-hr rain depth of 6.9 inches is 6.2 inches. The AmQ value (area in square miles times the direct runoff in inches) for this site is: (0.052 mi\(^2\))(6.2 inches) = 0.32 mi\(^2\)-in. This value is multiplied by the csm value to obtain the peak runoff rate for this design storm: (0.32 mi\(^2\)-in)(565 csm/in) = 182 ft\(^3\)/sec.
The first trial for an emergency spillway will be a rectangular weir, with one foot of maximum stage. At the one foot of stage on this weir, the 45° V-notch weir will have 3 feet of stage. The V-notch weir will discharge 16 ft³/sec at this stage. Therefore, the rectangular weir will need to handle: 182 – 16 ft³/sec = 166 ft³/sec. The rectangular weir can be sized from the rectangular weir equation:

\[ L_w = \frac{q_w}{(3.2)^2} = \frac{166 \text{ ft}^3/\text{sec}}{(3.2)(1)^2} = 52 \text{ ft} \]

This may be large for this pond, so another alternative is to try for a rectangular weir having 2 ft of maximum stage.

Another alternative is to try for a rectangular weir having 2 ft of maximum stage. At this elevation (4 ft total), the 45° V-notch weir will discharge 33 ft³/sec. Therefore, the rectangular weir will need to handle: 182 – 33 ft³/sec = 149 ft³/sec. The rectangular weir can be sized from the rectangular weir equation:

\[ L_w = \frac{q_w}{(3.2)^2} = \frac{149 \text{ ft}^3/\text{sec}}{(3.2)(2)^2} = 16 \text{ ft} \]

This is a suitable length, but does result in an additional foot of pond depth. For this example, the 52 foot long weir is selected.

### Final pond profile and expected performance

<table>
<thead>
<tr>
<th>Pond Depth (ft from bottom of pond, the datum)</th>
<th>Surface Area at Depth (acres)</th>
<th>Pond Storage below Elevation (calculated by Delpond) (acre-ft)</th>
<th>Pond slope between this elevation and next highest noted elevation</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>the pond bottom (datum) must be 0 acres for the routing calculations</td>
</tr>
<tr>
<td>0.1</td>
<td>0.18</td>
<td>-</td>
<td>15%</td>
<td>the area close to the bottom can be the calculated/desired pond bottom area. This is the bottom of the sacrificial storage area for the sediment</td>
</tr>
<tr>
<td>3</td>
<td>0.35</td>
<td>0.8</td>
<td>25%</td>
<td>this is the top of the sacrificial storage area for the sediment</td>
</tr>
<tr>
<td>6</td>
<td>0.49</td>
<td>2.0</td>
<td>4.5%</td>
<td>this is the bottom of the &quot;dead&quot; storage area, at least 3 feet above the pond bottom (this is 6 feet above the absolute bottom, but is 3 feet above the top of the maximum sediment accumulation depth)</td>
</tr>
</tbody>
</table>

### Final pond profile (continued)

<table>
<thead>
<tr>
<th>Pond Depth (ft from bottom of pond, the datum)</th>
<th>Surface Area at Depth (acres)</th>
<th>Pond Storage below Elevation (calculated by Delpond) (acre-ft)</th>
<th>Pond slope between this elevation and next highest noted elevation</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>1.16</td>
<td>3.7</td>
<td>4.5%</td>
<td>this is the bottom (invert) of the water quality outlet structure (and live storage volume), a 45° V-notch weir</td>
</tr>
<tr>
<td>9</td>
<td>1.5</td>
<td>5.0</td>
<td>4.5%</td>
<td>this is the top of live storage volume, and the bottom of the emergency spillway, a 52 ft long rectangular weir</td>
</tr>
<tr>
<td>10</td>
<td>1.8</td>
<td>6.7</td>
<td>-</td>
<td>1 foot of freeboard above maximum expected water depth, the top of the pond</td>
</tr>
</tbody>
</table>
The pond performance for a 30 year period of rain (3,346 events, ranging from 0.01 to 13.6 inches) was calculated using Detpond. During these 30 years, the expected maximum pond stage is slightly more 8 ft. The emergency spillway was used a total of four times in this period. The flow-weighted particulate solids removal rate was about 92%.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>8.1</td>
<td>23</td>
<td>11</td>
<td>6.8</td>
<td>100</td>
</tr>
<tr>
<td>Average</td>
<td>6.2</td>
<td>0.10</td>
<td>0.05</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Flow-weighted Average</td>
<td>n/a</td>
<td>n/a</td>
<td>1.4</td>
<td>2.6</td>
<td>92</td>
</tr>
<tr>
<td>Median</td>
<td>6.1</td>
<td>0.012</td>
<td>0.0057</td>
<td>0.39</td>
<td>99.6</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.22</td>
<td>0.54</td>
<td>0.26</td>
<td>0.57</td>
<td>1.9</td>
</tr>
<tr>
<td>COV</td>
<td>0.035</td>
<td>5.1</td>
<td>5.1</td>
<td>1.1</td>
<td>0.019</td>
</tr>
</tbody>
</table>

Therefore, this pond is likely over-designed for these conditions and could be somewhat reduced in area and depth.

**Appropriate Combinations of Controls**

- No single control is adequate for all problems
- Only infiltration reduces water flows, along with soluble and particulate pollutants. Only applicable in conditions having minimal groundwater contamination potential.
- Wet detention ponds reduce particulate pollutants and may help control dry weather flows. They do not consistently reduce concentrations of soluble pollutants, nor do they generally solve regional drainage and flooding problems.
- A combination of biofiltration and sedimentation practices is usually needed, at both critical source areas and at critical outfalls.

### relative effectiveness of controls

<table>
<thead>
<tr>
<th>Control</th>
<th>Cost</th>
<th>Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inappropriate discharge</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Erosion control</td>
<td>Low to mod.</td>
<td>Low to moderate</td>
</tr>
<tr>
<td>Floatable and litter control</td>
<td>Low to mod.</td>
<td>Low to high</td>
</tr>
<tr>
<td>Oil&amp;water separators</td>
<td>Moderate</td>
<td>Very low</td>
</tr>
<tr>
<td>Critical source control</td>
<td>High</td>
<td>Low to high</td>
</tr>
<tr>
<td>Low impact development</td>
<td>Low to mod.</td>
<td>Moderate to high</td>
</tr>
<tr>
<td>Public education</td>
<td>Low to mod.</td>
<td>??????</td>
</tr>
<tr>
<td>Wet detention ponds</td>
<td>Mod. To high</td>
<td>Usually high</td>
</tr>
</tbody>
</table>