Module 6: Sediment Pond Project Example

The following is an example showing the steps that should be taken when designing a sediment pond for a construction site.

Example Sizing of Sediment Pond at Construction Site
This example problem considers the sizing of all the major components of a sediment pond at a construction site:

- 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.

Consider the following site information:
The pond performance goal is 90% suspended-solids removal. The pond needs to safely pass the flows from the 25-yr storm. The area is characterized by clayey soils. The following are the areas associated with each land use in the drainage area:

- paved areas: 0.2 acres
- undeveloped areas: 1.2 acres
- construction area: 32 acres
- total site area: 33.4 acres

Basic pond area and “live” storage volume calculations:

<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 (acre-inches of runoff)</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>

Pond side slopes and top surface area:

1) If 3 ft deep:

   Top area:
\[
\frac{(0.49 \text{ acres} + X) \cdot 3 \text{ ft}}{2} = 1.65 \text{ ac} - \text{ft}
\]

\[X = 0.61 \text{ acres}\]

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 = \(\frac{3 \text{ ft}}{(92-82 \text{ ft})} = \frac{3 \text{ ft}}{10 \text{ ft}} = 0.3 = 30\%\) too steep

2) If 1 ft deep:

Top area:

\[
\frac{(0.49 \text{ acres} + X) \cdot 1 \text{ ft}}{2} = 1.65 \text{ ac} - \text{ft}
\]

\[X = 2.81 \text{ acres}\]

at 2.81 acres:
\[ \pi r^2 = 122,400 \text{ ft}^2 \]

\[ r = 197 \text{ ft} \]

at 0.49 acres, \( r = 82 \text{ ft} \)

side slope = \( 1 \text{ ft}/(197-82 \text{ ft}) = 1 \text{ ft}/115 \text{ ft} = 0.012 = 1.2\% \) too shallow

3) If 2 ft deep:

Top area:

\[ \frac{(0.49 \text{ acres} + X)2 \text{ ft}}{2} = 1.65 \text{ ac} - \text{ ft} \]

\[ X = 1.16 \text{ acres} \]

at 1.16 acres:

\[ \pi r^2 = 50,530 \text{ ft}^2 \]

\[ r = 126 \text{ ft} \]

at 0.49 acres, \( r = 82 \text{ ft} \)

side slope = \( 2 \text{ ft}/(126-82 \text{ ft}) = 2 \text{ ft}/44 \text{ ft} = 0.045 = 4.5\% \) suitable, but on the low side

Selection of primary outlet device:
At the top of the live storage volume, this pond will have provided 2 ft of stage and 1.16 acres of maximum pond area.

According to Tables 6-2 to 6-4, a 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. A 30° V-notch weir would require only 0.7 acres, while a 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.

Sacrificial storage volume:
Calculate the sediment loss for the complete construction period for the site area draining to the pond. Chapter 4 describes how to calculate the sediment loss for different phases of the construction period and for different areas of the site. For a simple analysis, assume the following typical site conditions:

\[ R = 350 \]

\[ LS = 1.28 \text{ (based on typical slope lengths of 300 ft at 5\% slope)} \]

\[ k = 0.28 \]
C = 0.24 (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)

The calculated unit area erosion loss for this construction period is therefore: \((350)(1.28)(0.28)(0.24) = 30\) 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, assuming the conventional conversion factor of tons x 1.02 = yd³ for a loam soil.

The pond water surface is approximately 0.5 acres. With a three-foot-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, resulting in a bottom pond area of 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:

\[ \frac{(0.35 \text{ acres} + X)3 \text{ ft}}{2} = 0.8 \text{ acres} \]

\[ X = 0.18 \text{ acres} \]

at 0.18 acres, \( r = 50 \text{ ft} \)

side slope = 3 ft/(70-50 ft) = 3 ft/20 ft = 0.15 = 15%

Selection of emergency spillway:
TR-55 can be used to estimate the peak flood flow rate that the emergency spillway must accommodate. Since these ponds are generally temporary, the design storm is usually smaller than for permanent stormwater ponds (which are commonly designed as high as controlling the 100-year event). Also, temporary ponds usually do not include an attenuated flow rate goal, like permanent ponds. These flow rate goals for permanent ponds need to be based on comprehensive basin-wide hydraulic analyses to be effective. Therefore, this example will only consider the capacity of the emergency spillway to meet the design storm flow rate. The design storm for this pond will be the 25-year event (one that has a 4% probability of occurring in any one year). The time of concentration of this small watershed was previously calculated to be 12 minutes. The watershed characteristics affecting the peak flow rate are therefore:
- Watershed area: construction area (32 acres), paved area (0.2 acres), and undeveloped area (1.2 acres) = 33.4 acres = 0.052 mi²
- Clayey (hydrologic soil group D) soils
- 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 12 minute time of concentration (from the local IDF curve, Figure 3-4): 6.6 inches/hour (Type III rain)

Since the undeveloped area has such a comparatively low CN (greater than a difference of 5) from the others, and it is a very small fraction of the site, it will be ignored for these calculations. The flows from the undeveloped area will be very low and will enter the pond after the flows from the other areas. If the undeveloped area was a significant fraction of the watershed area, it should be examined as a separate subwatershed and the resulting hydrographs combined. The weighted curve number is therefore estimated to be:

$$CN_w = \left(\frac{32}{32.2}\right)(94) + \left(\frac{0.2}{32.2}\right)(98) = 94$$

The Ia for this curve number (from Table 3-16) is 0.128 inches. The 24-hour, 25-year rain has a total rain depth (P) of 6.9 inches (from Table 3-3). The Ia/P ratio is therefore: 0.128/6.9 = 0.019, which is much less than 0.1. 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 (from Figure 3-11). The $A_mQ$ value (area in square miles times the direct runoff in inches) for this site is: (0.052 mi²)(6.2 inches) = 0.32 mi²-in. This value is multiplied by the csm value to obtain the peak runoff rate for this design storm: (0.32 mi²-in)(565 csm/in) = 182 ft³/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 for this weir plus the spillway, the 45° V-notch weir will have 3 feet of stage. The V-notch weir will discharge 16 ft³/sec at this stage (from Table 6-2). 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 presented earlier:

$$L_w = \frac{q_o}{(3.2)(H_w)^{2.5}} = \frac{166 ft^3/sec}{(3.2)(1)^{2.5}} = 52 ft$$

This may be large for this pond, so 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 presented earlier:
\[ L_w = \frac{q_o}{(3.2)(H_w)^{\frac{3}{2}}} = \frac{149\text{ ft}^3/\text{sec}}{(3.2)(2)^{\frac{3}{2}}} = 16\text{ ft} \]

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:**
This pond therefore has the following shape, and outlet structures:

<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 Detpond) (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 “dead” 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>
<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>

In summary, this pond has a total of 3 acre-ft of live storage, plus the needed 0.8 acre-ft for sediment storage. The following table summarizes the results of modeling the pond using WinDETPOND (www.WinSLAMM.com). This example shows the expected pond performance for a variety of rain
depths, ranging from very small rains to larger events. The maximum pond stages reflect the maximum depth of water in the pond during these events (out of the total 10 feet available). The pond has very high levels of control (using the “medium” particle size distribution) for most events.

<table>
<thead>
<tr>
<th>Rain Depth (in)</th>
<th>Maximum Pond Stage (ft)</th>
<th>Event Inflow Volume (ac-ft)</th>
<th>Peak Reduction Factor (Fraction)</th>
<th>Event Flushing Ratio</th>
<th>Flow-weighted Particle Size (µm)</th>
<th>Particulate Solids Removed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>6</td>
<td>0</td>
<td>0.98</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0.05</td>
<td>6</td>
<td>0</td>
<td>0.97</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>0.1</td>
<td>6</td>
<td>0.001</td>
<td>0.96</td>
<td>0.007</td>
<td>0.1</td>
<td>99.9</td>
</tr>
<tr>
<td>0.25</td>
<td>6.02</td>
<td>0.14</td>
<td>0.96</td>
<td>0.02</td>
<td>0.2</td>
<td>99.8</td>
</tr>
<tr>
<td>0.5</td>
<td>6.07</td>
<td>0.043</td>
<td>0.95</td>
<td>0.041</td>
<td>0.3</td>
<td>99.7</td>
</tr>
<tr>
<td>0.75</td>
<td>6.14</td>
<td>0.085</td>
<td>0.95</td>
<td>0.041</td>
<td>0.4</td>
<td>99.6</td>
</tr>
<tr>
<td>1</td>
<td>6.21</td>
<td>0.134</td>
<td>0.93</td>
<td>0.064</td>
<td>0.5</td>
<td>99.5</td>
</tr>
<tr>
<td>1.5</td>
<td>6.36</td>
<td>0.263</td>
<td>0.88</td>
<td>0.126</td>
<td>0.8</td>
<td>98.9</td>
</tr>
<tr>
<td>2</td>
<td>6.51</td>
<td>0.435</td>
<td>0.83</td>
<td>0.209</td>
<td>1.2</td>
<td>97.2</td>
</tr>
<tr>
<td>2.5</td>
<td>6.78</td>
<td>0.785</td>
<td>0.74</td>
<td>0.377</td>
<td>1.9</td>
<td>94.4</td>
</tr>
<tr>
<td>3</td>
<td>7.05</td>
<td>1.236</td>
<td>0.65</td>
<td>0.593</td>
<td>2.7</td>
<td>91.4</td>
</tr>
<tr>
<td>4</td>
<td>7.52</td>
<td>2.325</td>
<td>0.53</td>
<td>1.115</td>
<td>4.4</td>
<td>84.8</td>
</tr>
</tbody>
</table>

The continuous simulation feature of WinDETPOND allows the user to predict the overall pond performance based on actual rain records. The following table summarizes the pond performance for a 30-year period of rain (3,346 events, ranging from 0.01 to 13.6 inches). During these 30 years, the expected maximum pond stage was 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 approximately 92%. Therefore, this pond is likely over-designed for these conditions and could be somewhat reduced in area and depth.

<table>
<thead>
<tr>
<th>Maximum Pond Stage (ft)</th>
<th>Event Inflow Volume (ac-ft)</th>
<th>Peak Reduction Factor (Fraction)</th>
<th>Event Flushing Ratio</th>
<th>Flow-weighted Particle Size (µm)</th>
<th>Particulate Solids Removed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>8.1</td>
<td>23</td>
<td>0.99</td>
<td>11</td>
<td>6.8</td>
</tr>
<tr>
<td>Average</td>
<td>6.2</td>
<td>0.10</td>
<td>0.64</td>
<td>0.05</td>
<td>n/a</td>
</tr>
<tr>
<td>Flow-weighted Average</td>
<td>n/a</td>
<td>n/a</td>
<td>0.62</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Median</td>
<td>6.1</td>
<td>0.012</td>
<td>0.87</td>
<td>0.0057</td>
<td>0.39</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.22</td>
<td>0.54</td>
<td>0.40</td>
<td>0.26</td>
<td>0.57</td>
</tr>
<tr>
<td>COV</td>
<td>0.035</td>
<td>5.1</td>
<td>0.63</td>
<td>5.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>