Watershed Hydraulic Analyses and Detention Pond Design

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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 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

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

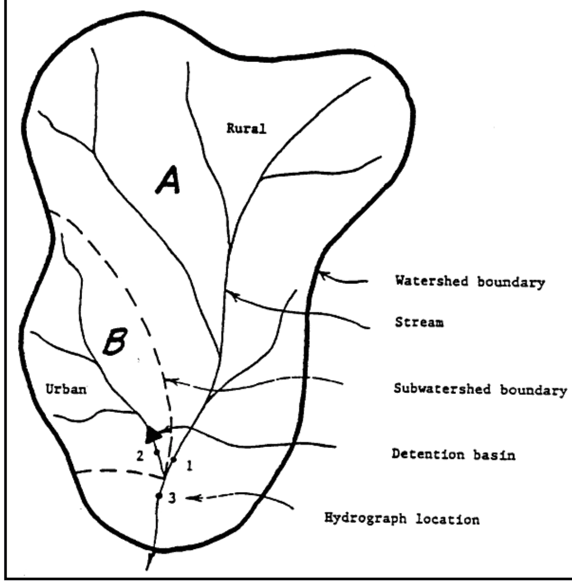
Wet Detention Facility at Apartments, Lake Oswego, OR (Part of Treatment Train)

Wet Detention Facility at Residential Area, Birmingham, AL

Advertising for New Wet Ponds, Austin, TX

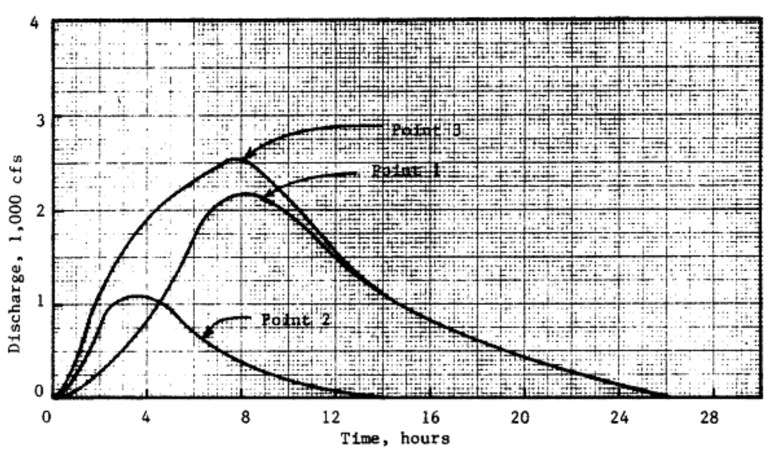
Basinwide Hydraulic Analyses

- Basinwide analyses are needed to identify the most suitable locations and sizes for flood control detention ponds
- If just follow “pre” and “post” development peak flow rate criterion (the peak flow rate after development must be no larger than the peak flow rate before development for a specific design storm), worse conditions are likely to occur at downstream areas
- WinTR-55 is the easiest and cheapest tool available to perform a basinwide hydraulic analysis to ensure that hydrographic interferences will not occur.

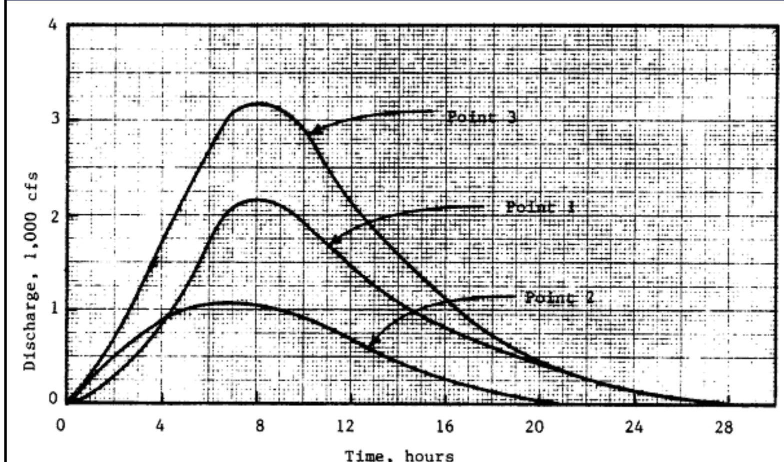


Developing subwatershed requiring detention pond

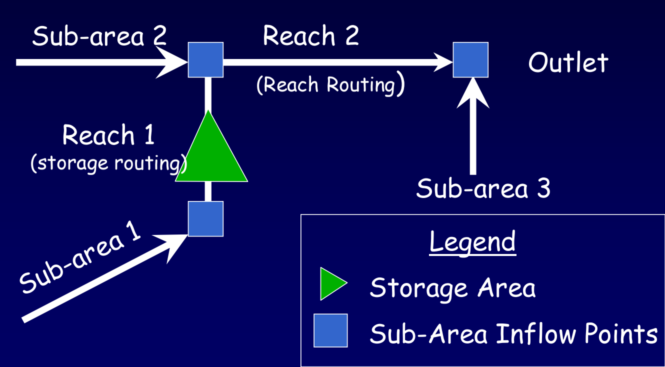
Predevelopment hydrographs from upstream area and from developing subarea



Final hydrographs from subareas and total area with detention pond to meet predevelopment peak flow criterion

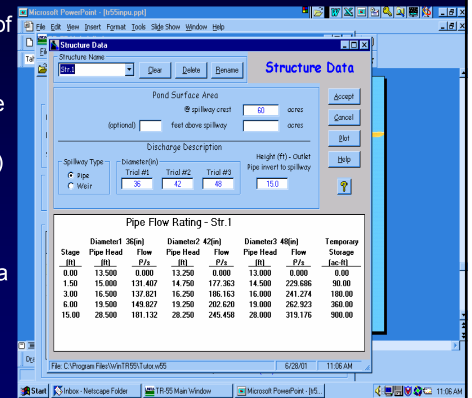


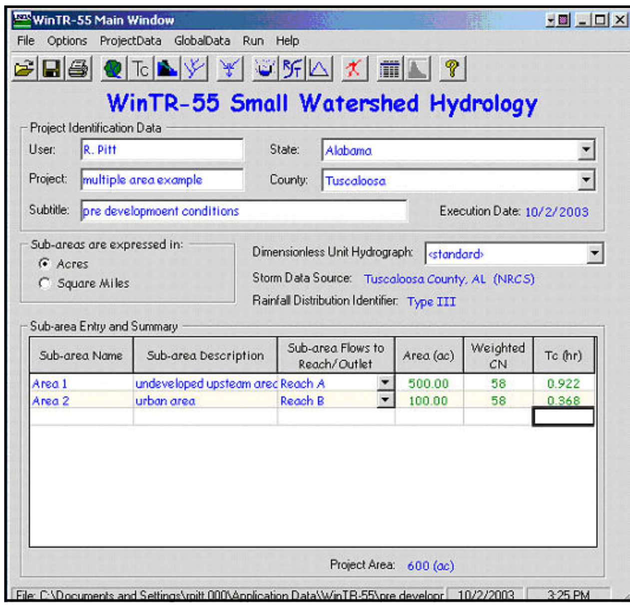
WinTR-55 Schematic Example



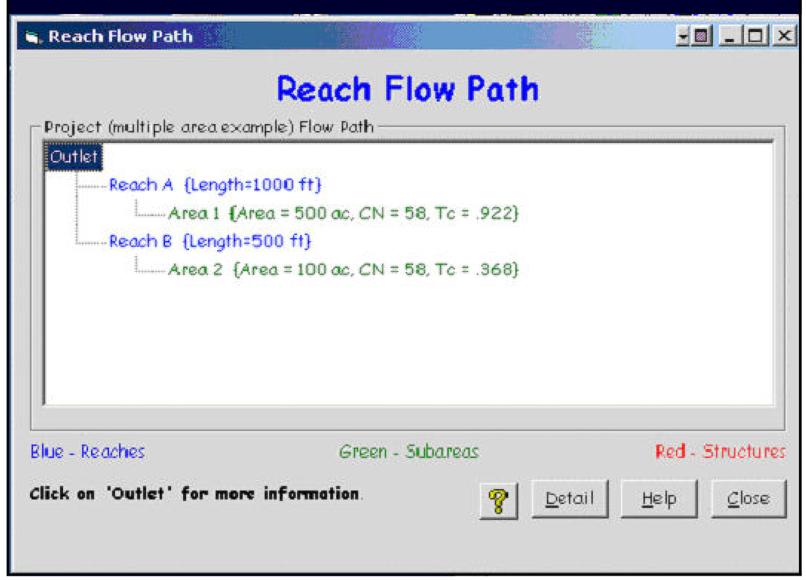
WinTR-55 Structure Data Window

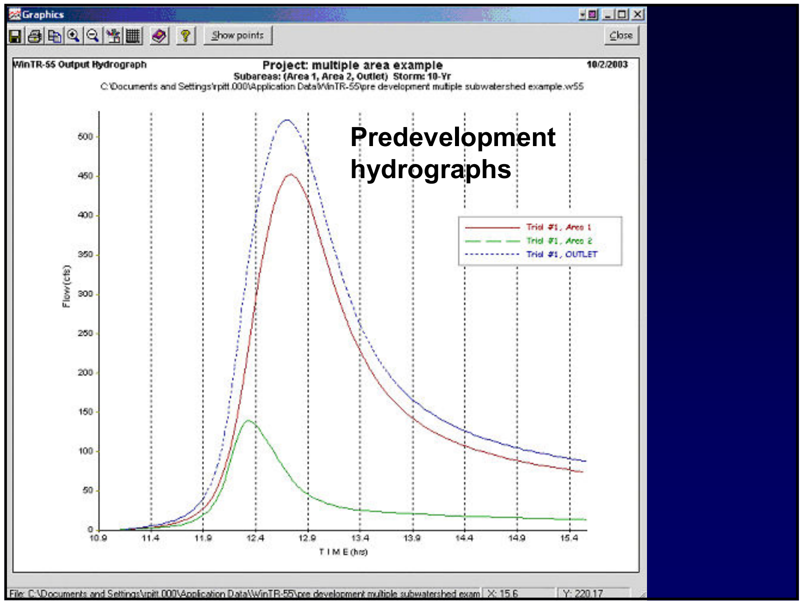
- Entry, editing and/or viewing of a pond's surface area, structure outlet type and dimensions, and rating can be found on this window.
- Up to three outlet sizes (trials) may be defined for each structure.
- If the temporary structure storage or hydraulics require a complex rating, use another method like TR-20 or Sites.

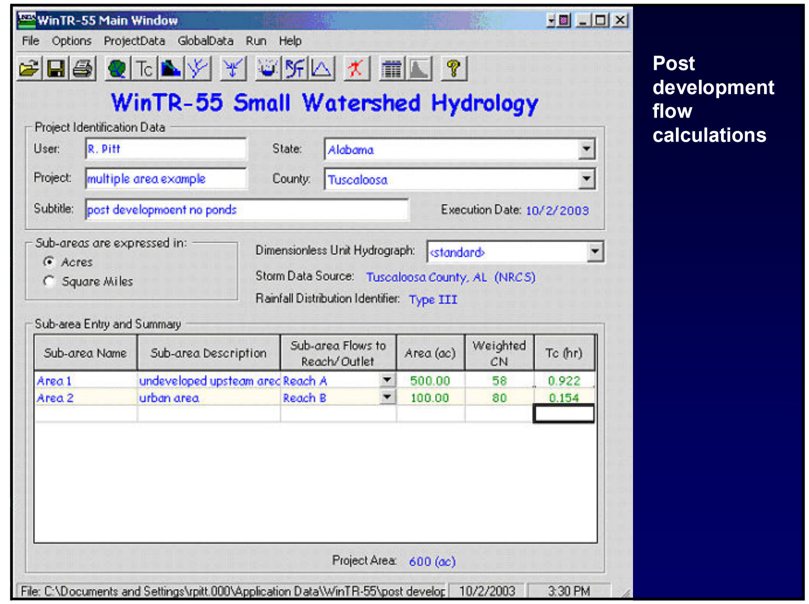


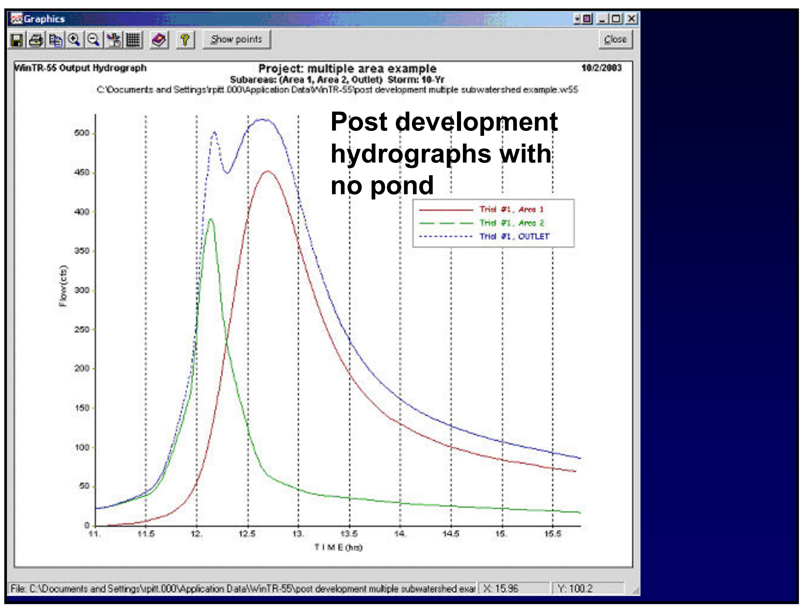


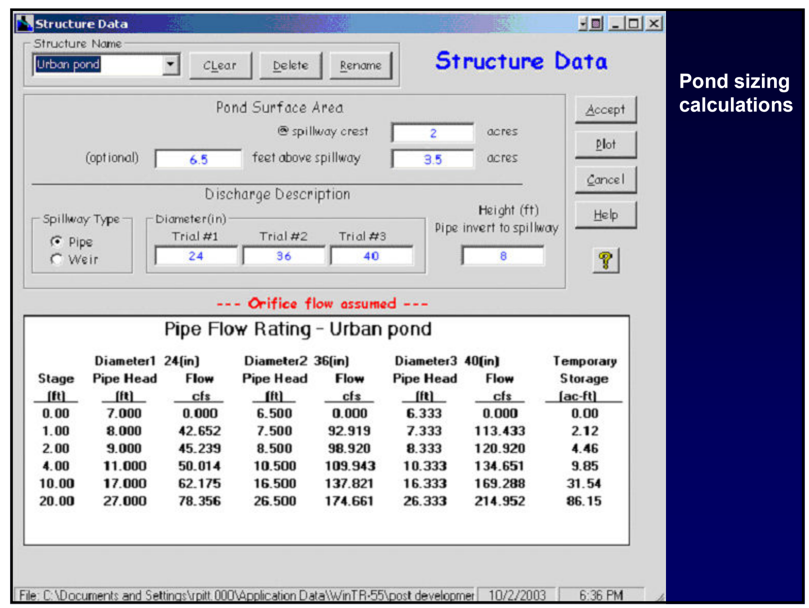
Pre-development flow calculations

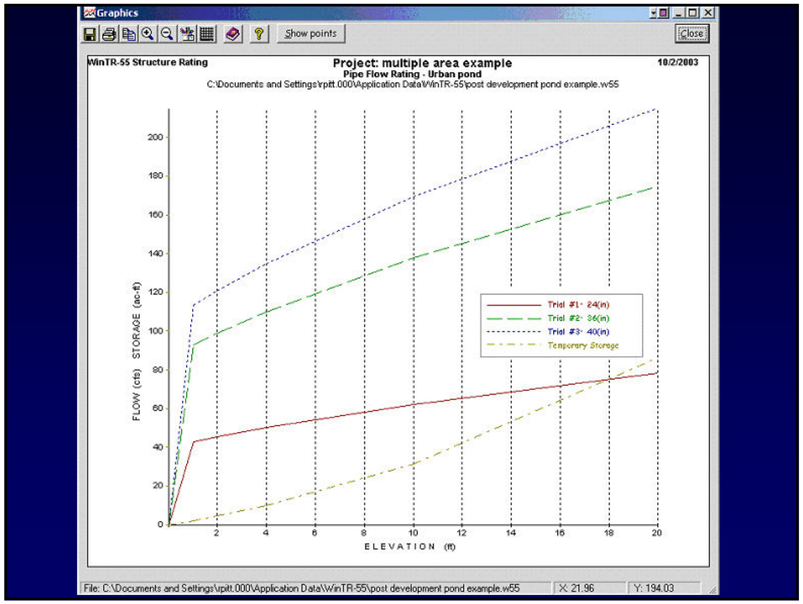


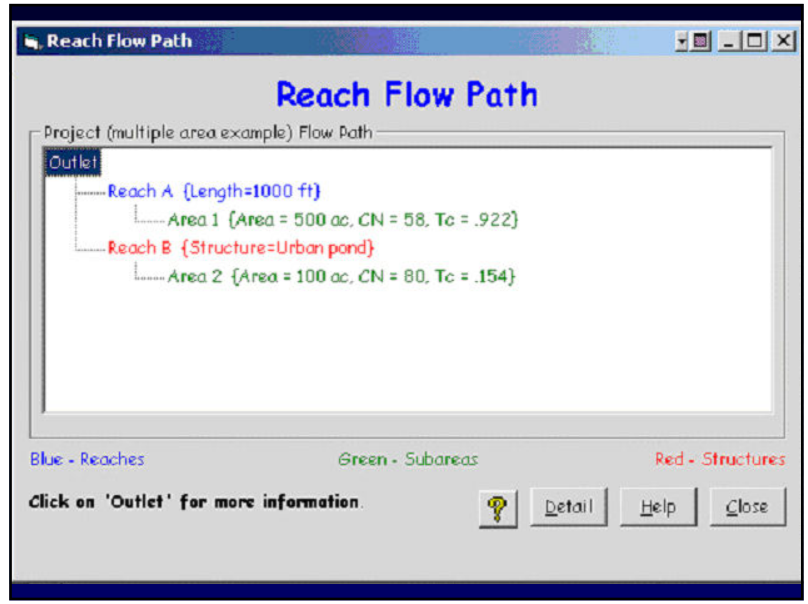

Graphics
Show points
Close
WinTR-55 Output Hydrograph
Project: multiple area example
Subareas: (Area 1, Area 2, Outlet) Storm: 10-Yr
10/2/2003
Predevelopment hydrographs
Trial #1, Area 1
Trial #1, Area 2
Trial #1, OUTLET
Flow(cfs)
T I M E (hrs)

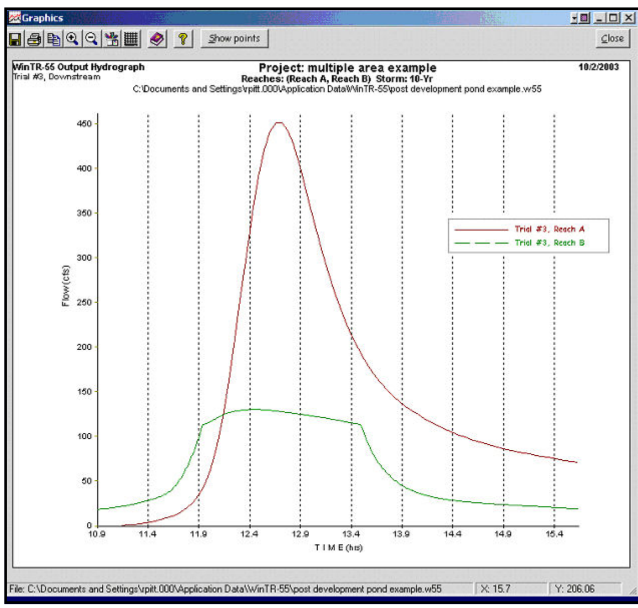

WinTR-55 Main Window
File Options ProjectData GlobalData Run Help
WinTR-55 Small Watershed Hydrology
Project Identification Data
User: R. Pitt
State: Alabama
Project: multiple area example
County: Tuscaloosa
Subtitle: post development no ponds
Execution Date: 10/2/2003
Sub-areas are expressed in:
Acres
Square Miles
Dimensionless Unit Hydrograph: <standard>
Storm Data Source: Tuscaloosa County, AL (NRCS)
Rainfall Distribution Identifier: Type III
Sub-area Entry and Summary
Sub-area Name | Sub-area Description | Sub-area Flows to Reach/Outlet | Area (ac) | Weighted CN | Tc (hr)
Area 1 | undeveloped upsteam area | Reach A | 500.00 | 58 | 0.922
Area 2 | urban area | Reach B | 100.00 | 80 | 0.154
Project Area: 600 (ac)
10/2/2003
3:30 PM
Post development flow calculations


Graphics
Show points
Close
WinTR-55 Output Hydrograph
Project: multiple area example
Subareas: (Area 1, Area 2, Outlet) Storm: 10-Yr
10/2/2003
Post development hydrographs with no pond
Trial #1, Area 1
Trial #1, Area 2
Trial #1, OUTLET
Flow(cfs)
T I M E (hrs)


Structure Data
Structure Name
Urban pond
Clear
Delete
Rename
Structure Data
Pond Surface Area
@ spillway crest 2 acres
(optional) 6.5 feet above spillway 3.5 acres
Discharge Description
Spillway Type
Pipe
Weir
Diameter(in)
Trial #1 24
Trial #2 36
Trial #3 40
Height (ft) Pipe invert to spillway 8
Accept
Plot
Cancel
Help
--- Orifice flow assumed ---
Pipe Flow Rating - Urban pond
Diameter1 24(in) | Diameter2 36(in) | Diameter3 40(in)
Stage (ft) | Pipe Head (ft) | Flow cfs | Pipe Head (ft) | Flow cfs | Pipe Head (ft) | Flow cfs | Temporary Storage (ac-ft)
0.00 | 7.000 | 0.000 | 6.500 | 0.000 | 6.333 | 0.000 | 0.00
1.00 | 8.000 | 42.652 | 7.500 | 92.919 | 7.333 | 113.433 | 2.12
2.00 | 9.000 | 45.239 | 8.500 | 98.920 | 8.333 | 120.920 | 4.46
4.00 | 11.000 | 50.014 | 10.500 | 109.943 | 10.333 | 134.651 | 9.85
10.00 | 17.000 | 62.175 | 16.500 | 137.821 | 16.333 | 169.288 | 31.54
20.00 | 27.000 | 78.356 | 26.500 | 174.661 | 26.333 | 214.952 | 86.15
10/2/2003
6:36 PM
Pond sizing calculations







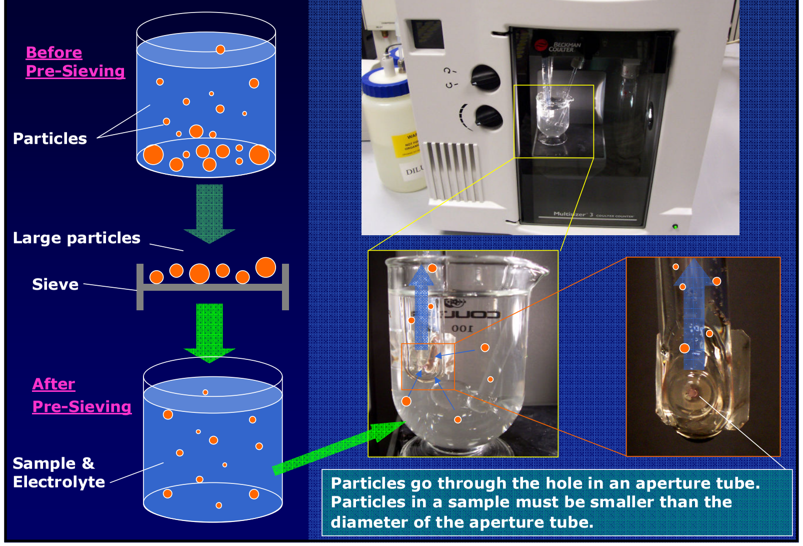
The maximum total flow rate is about 450 plus 120 = 570 cfs, compared to a maximum of about 520 cfs without detention.

Treatability Testing and the Development of Stormwater Control Design Criteria

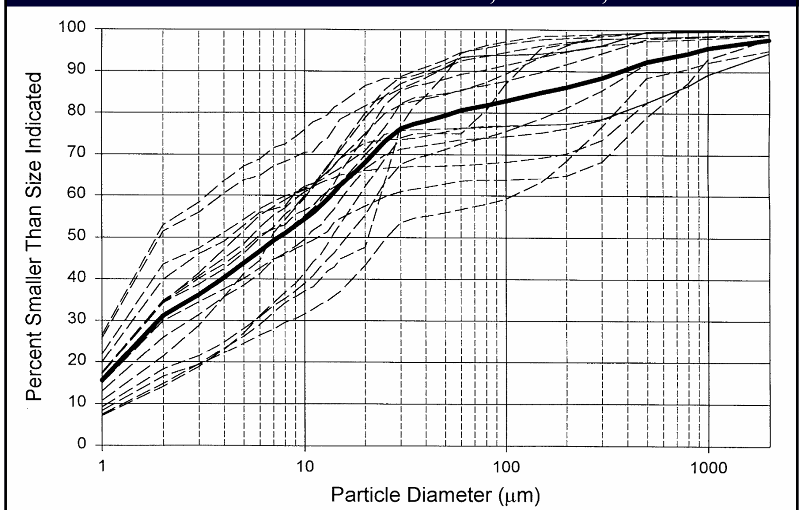
- Particle sizes and settling rates
- Relative toxicity after different unit processes
- Laboratory-scale and field pilot-scale tests
- Full-scale tests

Pond Performance Dependent on Particle Characteristics

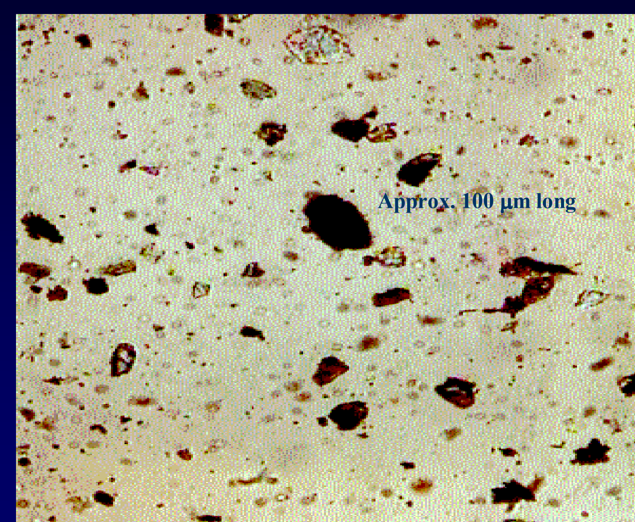
Coulter Counter analysis

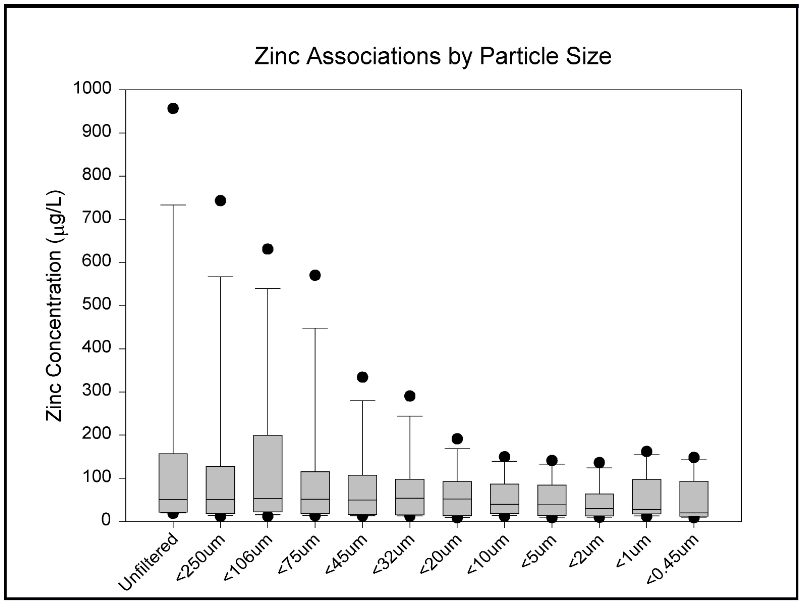


Measured Particle Sizes, Including Bed Load Component, at Monroe St. Detention Pond, Madison, WI

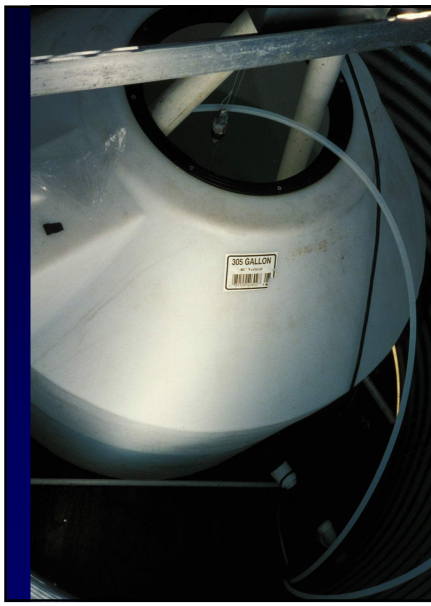


Micrograph of Road Surface Sediment Washoff



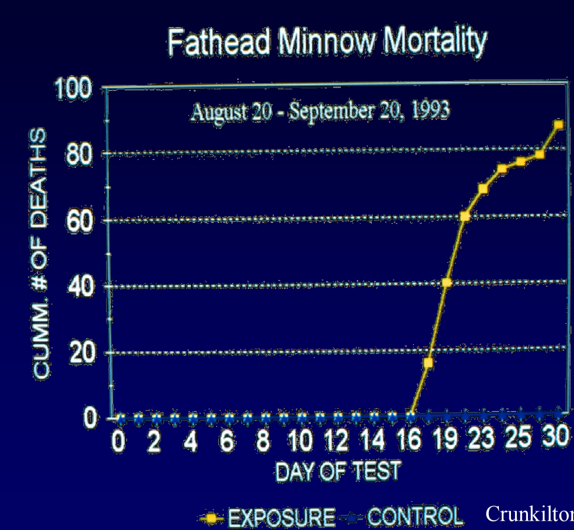


Lincoln Creek Side-Stream Toxicity Tests (UW Steven's Point, USGS, and WI DNR Tests)



Pilot-Scale Wet Detention Pond used at Lincoln Creek Side-Stream Toxicity Test Facility to Measure Reduction in Toxicity due to Removal of Stormwater Particulates

Interior of Side-Stream Toxicity Test Facility



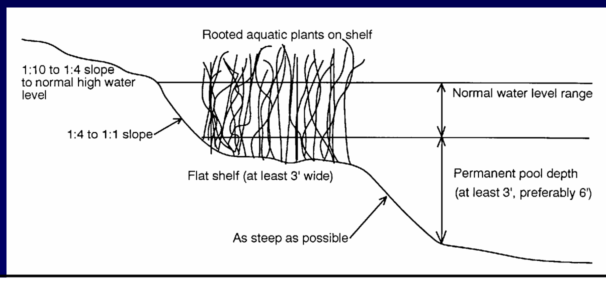
Crunkilton, *et al.* (1996)

Design Suggestions to Enhance Pollutant Control and to Minimize Problems

- 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.

Wet Detention Pond Design Guidelines to Minimize Potential Problems

- Proper pond side slopes are very important to improve safety and aesthetics and to minimize mosquito problems and excessive rooted plant growths.
  - An underwater shelf near the pond edge needs to be planted with rooted aquatic plants to prevent children's access to deep water, to improve pond aesthetics, to increase pollutant removals through biochemical processes, and to improve aquatic habitat.
  - If waterfowl are desired users, then no more than ½ of the pond perimeter should be heavily planted.
  - The following general dimensions for pond side slopes are suggested:



Wet Detention Pond Design Guidelines to Minimize Potential Problems

- Outlet structures should be designed for low outflows during low pond depths to maximize particulate retention.
- Place underwater dams or deeper sediment trapping forebays near pond inlets to decrease required dredging areas.
- Provide a drain to completely de-water the pond for easier maintenance.
- Protect the inlet and outlet areas from scour erosion and cover the inlets and outlets with appropriate safety gratings.
- Provide an adequate emergency spillway.
- Minimize water elevation changes to discourage mosquito problems.

Pond Problems

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

Deep Water Too Close To Shore

Thin Ice Near Shore

Children are Attracted to Urban Waters

Frequent Maintenance and Adjustments to Outlets may be Needed

Wet Ponds Located in Areas of Karst Geology may have Sinkholes

Bob Kort photo

Existing Ponds can be Modified for Improved Performance

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

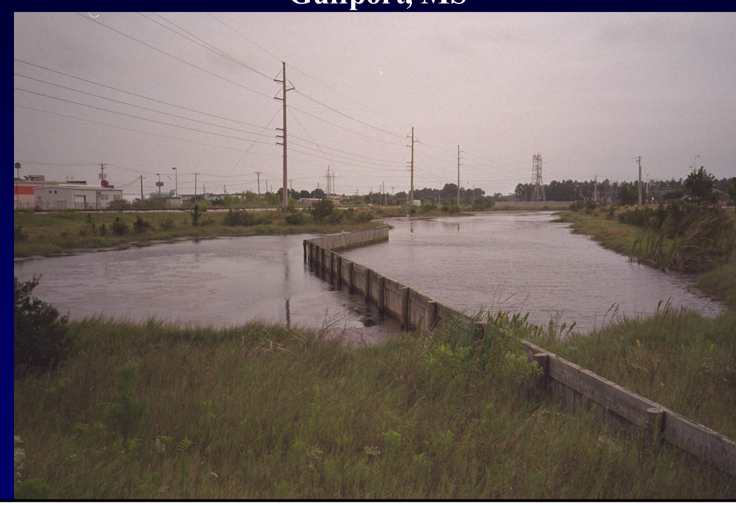
Modification of Outlet for Improved Performance

Modification of Pond Outlet at Epcot Center, Orlando, FL

Re-building Pond (Re-shaping and Dredging), Moscow, Russia

Infiltration Swale in Office Park Area, Downstream of Wet Pond, Lake Oswego, OR, Part of Treatment Train

Berm Located in Pond to Minimize Short-Circuiting, Gulfport, MS



Estimating Storage Requirements of the Detention Pond

- The detention basin is the most widely used measure for controlling peak discharge.
- It is generally the least expensive and most reliable of the measures that have been considered.
- It can be designed to fit a wide variety of sites and can accommodate multiple-outlet spillways to meet requirements for multi-frequency control of outflow.

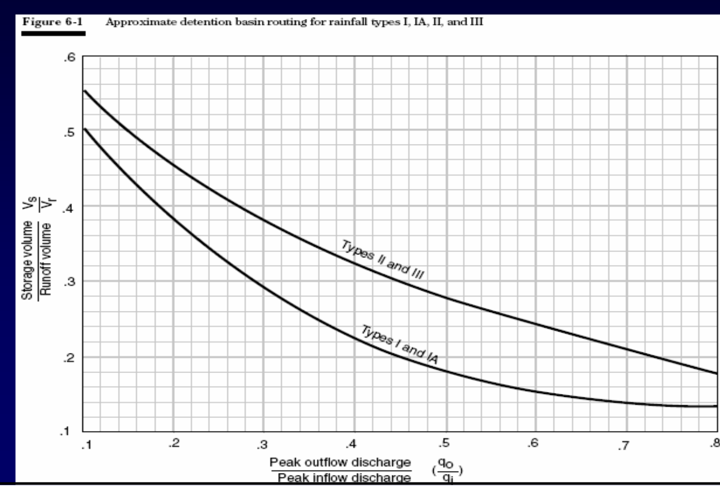
Estimating the Effects of Storage (Based on Chapter 6 of TR-55)

- Hydrologic routing procedures can be used to estimate the effect on hydrographs.
  - Both the TR-20 (SCS 1983) and DAMS2 (SCS 1982) computer programs provide accurate methods of analysis.
- This chapter contains a manual method for quick estimates if the effects of temporary detention on peak discharges.
  - The method is based on average storage and routing effects for many structures.

Estimating the Effects of Storage (Based on Chapter 6 of TR-55)

- The “Approximate Detention Basin Routing” figure (next slide) relates two ratios: peak outflow to peak inflow discharge (q_o/q_i) and storage volume runoff volume (V_s/V_r) for all rainfall distributions.
  - The relationships in the figure were determined on the basis of single stage outflow devices. Some were controlled by pipe flow, others by weir flow. Verification runs were made using multiple stage outflow devices, and the variance was similar to that in the base data. The method can therefore be used for both single- and multiple-stage outflow devices.
  - The only constraints are that (1) each stage requires a design storm and a computation of the storage required for it and (2) the discharge if the upper stage(s) includes the discharge of the lower stage(s).
  - When combined with the Tabular Hydrograph method, the procedure’s usefulness is increased. Its principal use is to develop preliminary indications of storage adequacy and to allocate control to a group of detention basins. It is also adequate, however, for final design of small detention basins.

Estimating the Effects of Storage
(Based on Chapter 6 of TR-55)



Estimating the Effects of Storage: Input Requirements

- The figure is used to estimate storage volume (V_s) required or peak outflow discharge (q_o).
- The most frequent application is to estimate V_s, for which the required inputs are runoff volume (V_r), q_o, and peak inflow discharge (q_i).
- To estimate q_o, the required inputs are V_r, V_s, and q_i.

Estimating the Effects of Storage: Estimating V_s

- Use worksheet 6a to estimate V_s, storage volume required, by the following procedure.

1. Determine q_o. Many factors may dictate the selection of peak outflow discharge. The most common is to limit downstream discharges to a desired level, such as predevelopment discharge. Another factor may be that the outflow device has already been selected.
2. Estimate q_i by either the graphical peak discharge or tabular hydrograph methods. Do not use peak discharges developed by other procedure.
   1. When using the Tabular Hydrograph method to estimate q_i for a subarea, only use peak discharge associated with $T_t = 0$.

Estimating the Effects of Storage: Estimating V_s

3. Compute q_o/q_i and determine V_s/V_r from figure 6-1.
4. Q (in inches) was determined when computing q_i in step 2, but now it must be converted to the units in which V_s is to be expressed—most likely, acre-feet or cubic feet. The most common conversion of Q to V_r is expressed in acre-feet:

$$V_r = 53.33Q(A_m)$$

Where V_r = runoff volume (acre-ft)
Q = runoff (in)
A_m = drainage area (mi^2), and
53.33 = conversion factor from in-mi^2 to acre-ft.

Estimating the Effects of Storage: Estimating V_s

5. Use the results of steps 3 to 4 to compute V_s:

$$V_s = V_r\left(\frac{V_s}{V_r}\right)$$

Where V_s = storage volume required (acre-ft).

6. The stage in the detention basin corresponding to V_s must be equal to the stage used to generate q_o.
   1. In most situations a minor modification of the outflow device can be made. If the device has been preselected, repeat the calculations with a modified q_o value.

Estimating the Effects of Storage: Estimating q_0

- Use worksheet 6b to estimate q_o, required peak outflow discharge, by the following procedure.

1. Determine V_s. If the maximum stage in the detention basin is constrained, set Vs by the maximum permissible stage.
2. Compute Q (in inches) by the procedures in chapter 2, and convert it to the same units as V_s (see step 4 in "estimating V_s").
3. Compute V_s/V_r and determine q_o/q_i from figure 6-1.
4. Estimate q_i by the procedures in chapters 4 or 5. Do not use discharges developed by any other method. When using Tabular method to estimate q_i for a subarea, use only the peak discharge associated with T_t = 0.

Estimating the Effects of Storage: Estimating q_0

5. From steps 3 to 4, compute q_o:

$$q_0 = q_i \left(\frac{q_0}{q_i} \right)$$

6. Proportion the outflow device so that the stage at q_o is equal to the stage corresponding to V_s. If q_o cannot be calibrated except in discrete steps (i.e., pipe sizes), repeat the procedure until the stages for q_o and V_s are approximately equal.

Detention Pond Size Estimation: Example

- A development is being planned in a 75-acre (0.1170 mi^2) watershed that outlets into an existing concrete-lined channel designed for present conditions. If the channel capacity is exceeded, damages will be substantial. The watershed is in the type II storm distribution region.
- The present channel capacity, 180 cfs, was established by computing discharge for the 25-year frequency storm by the Graphical Peak Discharge method.
- The developed-condition peak discharge (q_i) is 360 cfs, and runoff (Q) is 3.4 inches. Since outflow must be held to 180 cfs, a detention basin having that maximum outflow discharge (q_o) will be built at the watershed outlet.
- How much storage (V_s) will be required to meet the maximum outflow discharge (q_o) of 180 cfs, and what will be the approximate dimensions of a rectangular weir outflow structure?

Detention Pond Size Estimation: Example

- How much storage (V_s) will be required to meet the maximum outflow discharge (q_o) of 180 cfs, and what will be the approximate dimensions of a rectangular weir outflow structure?
- Figure 6-2 shows how worksheet 6a is used to estimate required storage (V_s = 5.9 acre-ft) and maximum stage (E_{max} = 105.7 ft). The rectangular weir was chosen for its simplicity; however, several types of outlets can meet the outflow device proportion requirement. Most hydraulic references, along with considerable research data that are available, provide more guidance on variations of outlet devices that can be summarized here.
- An outlet device should be proportioned to meet specific objectives. A single-stage device was specified in this example because only one storm was considered. A weir is suitable here because of the low head. The weir crest elevation is 100.00 ft. Using V_s = 5.9 acre-ft (figure 6-2, step 9) and the elevation-storage curve, the maximum stage (E_{max}) is 105.7 ft.

Detention Pond Size Estimation: Example

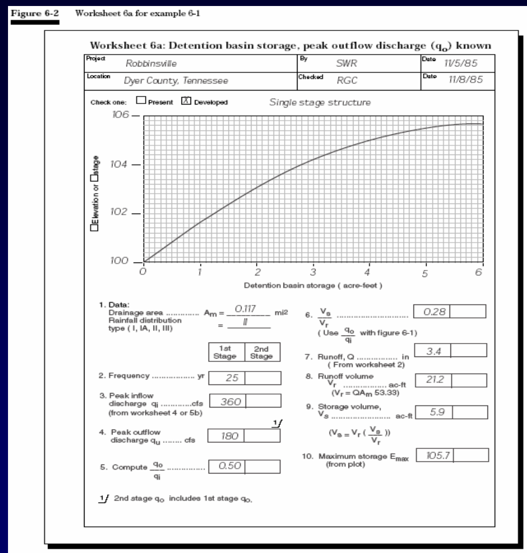


Figure 6-2 Worksheet 6a for example 6-1

Worksheet 6a: Detention basin storage, peak outflow discharge (q_o) known

Project	Robbinsville	By	SWR	Date	11/5/85
Location	Dyer County, Tennessee	Checked	RGC	Date	11/8/85

Check one: ☐ Present ☒ Developed — Single stage structure

1. Data: Drainage area .... A_m = 0.117 mi2; Rainfall distribution type (I, IA, II, III) = II

	1st Stage	2nd Stage
2. Frequency .... yr	25	
3. Peak inflow discharge q_i .... cfs (from worksheet 4 or 5b)	360	
4. Peak outflow discharge q_o .... cfs	180	1/
5. Compute $\frac{q_o}{q_i}$	0.50	
6. $\frac{V_s}{V_r}$ .... (Use $\frac{q_o}{q_i}$ with figure 6-1)	0.28	
7. Runoff, Q .... in (From worksheet 2)	3.4	
8. Runoff volume V_r .... ac-ft ($V_r = QA_m$ 53.33)	21.2	
9. Storage volume, V_s .... ac-ft ($V_s = V_r (\frac{V_s}{V_r})$)	5.9	
10. Maximum storage E_{max} (from plot)	105.7	

1/ 2nd stage q_o includes 1st stage q_o.

Detention Pond Size Estimation: Example

- How much storage (V_s) will be required to meet the maximum outflow discharge (q_o) of 180 cfs, and what will be the approximate dimensions of a rectangular weir outflow structure?
- The rectangular weir equation is:
  - **$Q_o = 3.2 L_w H_w^{1.5}$**

Where q_o = peak outflow discharge (cfs)
L_w = weir crest length (ft)
H_w = head over weir crest (ft)

- H_w and q_o are computed as follows:
  $H_w = E_{max}$ – weir crest elevation = 105.7 - 100.0 = 5.7 ft.

Detention Pond Size Estimation: Example

- Since q_o is known to be 180 cfs, solving for L_w yields

$$L_w = \frac{q_0}{3.2 H_w^{1.5}}$$

$$L_w = \frac{180\, ft^3/\sec}{3.2(5.7\, ft)^{1.5}} = 4.1\, ft$$

- In summary, the outlet structure is a rectangular weir with crest length of 4.1 ft, H_w = 5.7 ft, and q_o = 180 cfs corresponding to a V_s = 5.9 acre-ft.

Estimating the Effects of Storage: Limitations

- This routing method is less accurate as the q_o/q_i ratio approaches the limits shown in the figure.
- The curves in the figure depend on the relationship between available storage, outflow device, inflow volume, and shape of the inflow hydrograph.
  – When storage volume (V_s) required is small, the shape of the outflow hydrograph is sensitive to the rate of the inflow hydrograph.
  – Conversely, when V_s is large, the inflow hydrograph shape has little effect on the outflow hydrograph. In that case, the outflow hydrograph is controlled by the hydraulics of the outflow device and the procedure yields consistent results.
  – When the peak outflow discharge (q_o) approaches the peak flow discharge (q_i) parameters that affect the rate of rise of a hydrograph, such as rainfall volume, curve number, and time of concentration, become especially significant.
- The procedure should not be used to perform final design if an error in storage of 25 percent cannot be tolerated.
  – The figure is biased to prevent undersizing of outflow devices, but it may significantly overestimate the required storage capacity.
  – More detailed hydrograph development and routing will often pay for itself through reduced construction costs.

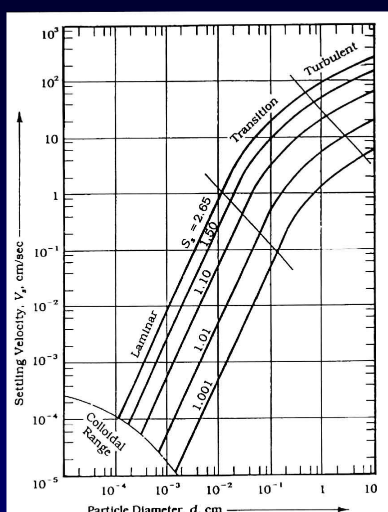
Basic Wet Detention Pond Design Guidelines

- Engineering design guidelines (covering such things as foundations, fill materials, embankments, gratings, anti-seep collars, and emergency spillway construction), such as published by the U.S. Natural Resources Conservation Service, the Bureau of Reclamation, and the Army Corps of Engineers must be followed.
- Pond size is dictated mostly by desired particle size control and water outflow rate.
- A target for the worst-case control of 5 µm will remove all particles greater than 5 µm under almost all conditions and will result in a long-term median removal of about 2 µm. This control goal corresponds to about 90% suspended solids reductions in urban runoff. A worst-case goal of 20 µm control will result in about 65% suspended solids reductions.

Wet Detention Ponds for Sediment Control

- The upflow-velocity concept can be used to predict the performance of wet ponds for capturing sediment.
- Effectiveness based on the amount of runoff and the particle size distributions.

Particle Settling Rates

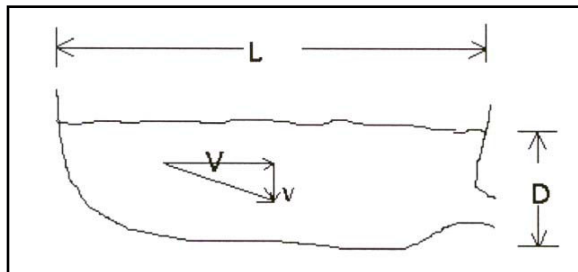


2 µm particle ⇒ 2 x 10^{-4} cm/s or 5.8 days for 1 meter

20 µm particle ⇒ 2 x 10^{-2} cm/s or 1.4 hours for 1 meter

200 µm particle ⇒ 2 cm/s or 50 sec for 1 meter

2000 µm (2 mm) particle ⇒ 20 cm/s, or 5 sec for 1 meter



$$v = \frac{Q_{out}}{A}$$

Q_{out} = pond outflow rate (cubic feet per second),
A = pond surface area (square feet: pond length times pond width), and
v = upflow velocity, or critical particle settling velocity (feet per second)

Design of Wet Detention Ponds: Example

1. The wet pond should have a minimum surface corresponding to land use and desired pollutant control. The following is an example of how initial size guidance values can be used:

	Land Area (acres)	Pond Size Factor	Resulting Pond Surface Area (acres)
Paved area	0.6	3%	0.018
Undeveloped area	3.8	0.6%	0.023
Construction area	27.6	1.5%	0.414
Total	32.0		0.455

Pond Area as a Percentage of Drainage Area Type

	5 micron	20 micron
Totally paved	2.8	1.0
Industrial	2.0	0.8
Commercial	1.7	0.6
Institutional	1.7	0.6
Residential	0.8	0.3
Open space	0.6	0.2
Construction	1.5	0.5

If an area contains infiltration devices, pond surface area is accordingly smaller.

Design of Wet Detention Ponds: Example

2. 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:

	Land Area (acres)	Pond WQ Volume Factor	Pond WQ Volume
Paved area	0.6	1.1 inches	0.66 ac-in
Undeveloped area (clayey soils)	3.8	0.3	1.14
Construction site (clayey soils)	27.6	0.6	16.56
Total	32.0		18.36 ac-in (1.53 ac-ft)

Runoff Depth Corresponding to 1.25 Inches of Rain

Based on Small Storm Hydrology (Pitt 1987)

	Sandy Soil	Clayey Soil
Freeways	0.35	0.40
Totally paved	1.1	1.1
Industrial	0.85	0.9
Commercial	0.75	0.85
Schools	0.2	0.4
Low density residential	0.1	0.3
Medium density residential	0.15	0.35
High density residential	0.2	0.4
Developed parks	0.5	0.6
Construction sites	0.5	0.6

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.

Design of Wet Detention Ponds: Example

4. The selection of the outlet devices for the wet detention pond must be based on the desired pollutant removal at different pond stages. An emergency spillway is also needed to safely handle the largest design rains. The following is an example for a 30° V-notch weir that will provide 5 micrometer control:

Head Over Weir Invert (ft)	Flow (cfs)	Minimum surface area (acres)
0.5	0.1	0.02
1.0	0.7	0.1
1.5	1.9	0.3
3	11	1.8
6	60	10

Weir Equation

$$Q = CLH^{3/2}$$

Where C = weir coefficient (see table)
L = weir length

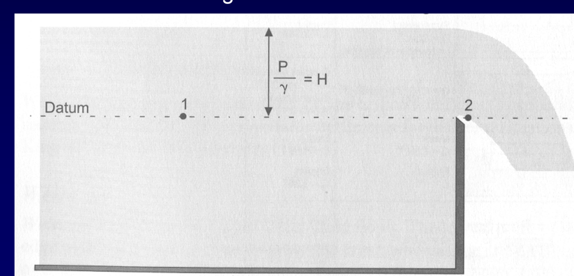
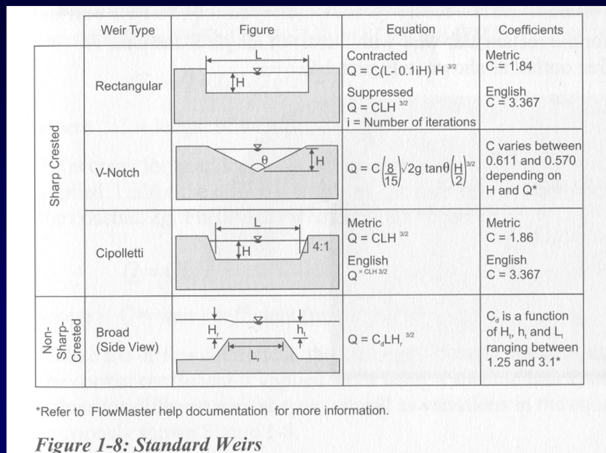


Figure 1-9: Weir Example

Weirs



	Weir Type	Figure	Equation	Coefficients
Sharp Crested	Rectangular		Contracted $Q = C(L - 0.1iH)H^{3/2}$ Suppressed $Q = CLH^{3/2}$ i = Number of iterations	Metric C = 1.84 English C = 3.367
Sharp Crested	V-Notch		$Q = C\left(\frac{8}{15}\right)\sqrt{2g}\tan\theta\left(\frac{H}{2}\right)^{5/2}$	C varies between 0.611 and 0.570 depending on H and Q*
Sharp Crested	Cipolletti		Metric $Q = CLH^{3/2}$ English $Q^{+CLH^{3/2}}$	Metric C = 1.86 English C = 3.367
Non-Sharp-Crested	Broad (Side View)		$Q = C_dLH_r^{3/2}$	C_d is a function of H_r, h_r and L_r ranging between 1.25 and 3.1*

*Refer to FlowMaster help documentation for more information.

Figure 1-8: Standard Weirs

Correlations between Outlet Structure, Particle Control and Pond Surface Area

	60° V-notch weir			90° V-notch weir		
Head (ft)	Discharge (cfs)	Min. surface acres for:		Discharge (cfs)	Min. surface acres for:	
		5 µm	20 µm		5 µm	20 µm
0.5	0.25	0.044	0.004	0.45	0.08	0.006
1	1.4	0.25	0.02	2.4	0.42	0.03
1.5	3.9	0.69	0.06	6.7	1.2	0.1
2	8.0	1.4	0.11	14	2.5	0.2
3	22	3.9	0.32	40	7.1	0.6
4	45	7.9	0.65	81	14	1.2

Introduction to the Storage-Indication Method

- The pond routing calculation procedure is based on the Natural Resources Conservation Service Technical Release-20 (TR-20) procedures (SCS 1982), as presented by McCuen (1982). The reservoir routing subroutine in TR-20 (RESVOR) is based on the storage equation:

$$I - O = \frac{\Delta S}{\Delta T}$$

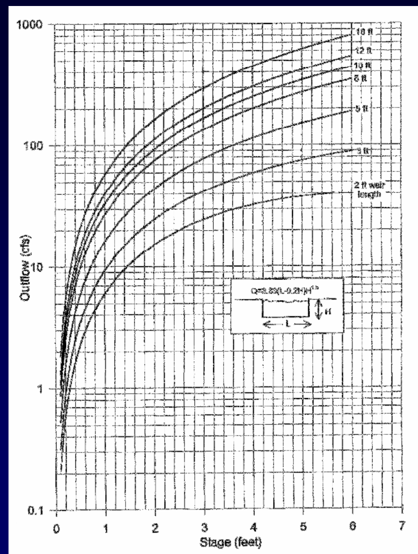
where I is the pond inflow and O is the pond outflow.

- The difference between the inflow and outflow must be equal to $\Delta S/\Delta T$, the change in pond storage per unit of time.
- Must develop a storage-indication curve to relate pond outflow against pond storage at that outflow plus ½ of the outflow times the time increment. When the pond outflow hydrograph is developed, the upflow velocity procedure described earlier can be used to estimate pond pollutant removal and peak flow rate reduction performance.

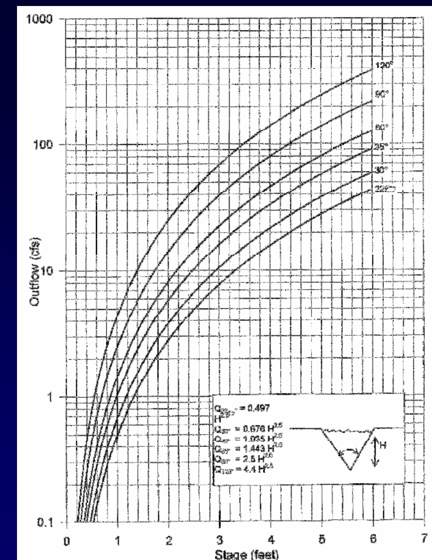
Outflow Rates from Discharge Control Devices

- The first step in using the storage-indication method is to determine the stage-discharge relationship for the pond.
- This relationship (the rating curve) is the pond outflow rate (expressed in cubic feet per second, or cfs) for different pond water surface elevations (expressed in feet).
- The figures are approximate rating curves for several common outlet control weir types for water surface elevation ranges up to six feet above the weir inverts.
- For most applications, other stage-discharge rating curves will need to be developed and used, especially for commonly used broad crested weirs or culverts.

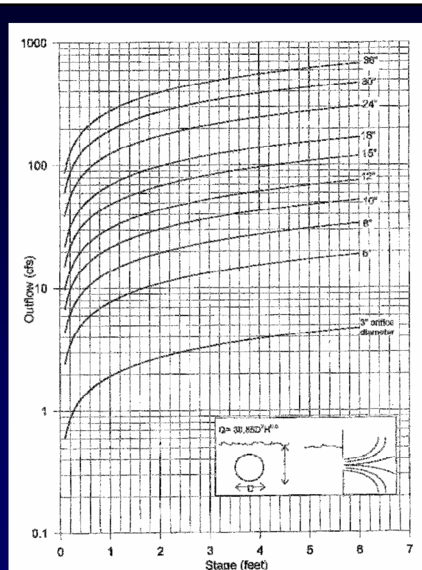
Approximate Rating Curves of Rectangular Weirs



Approximate Rating Curves of V-notch Weirs

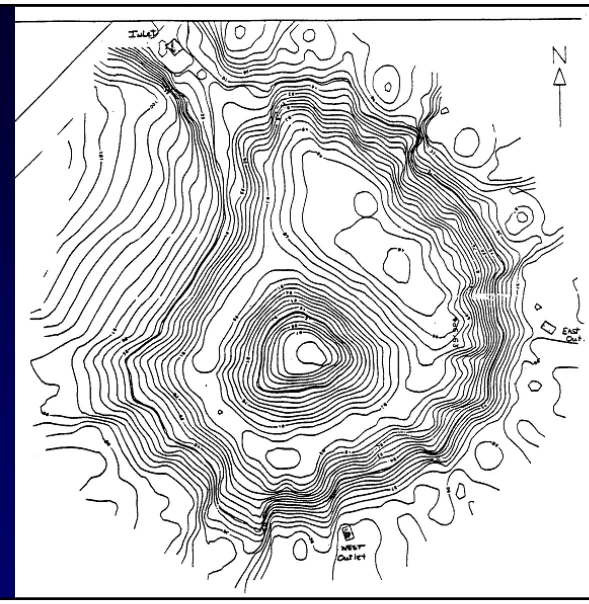


Approximate Rating Curves of Orifices



Stage-Area and Storage-Indication Curve Development

- The relationship between the pond stage and the surface area for the pond under study is also needed in order to calculate the storage volume available for specific pond stages.
- The figure is an example stage-area curve developed from topographic maps of the Monroe Street detention pond in Madison, Wisconsin. The normal pond wet surface is at 13 feet (arbitrary datum) and the emergency spillway is located at 16 feet, for a resultant useable stage range of three feet.



Stage-Area and Storage-Indication Curve Development: Monroe St. Detention Pond

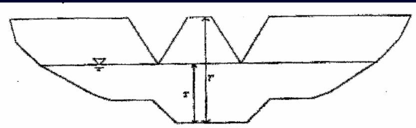
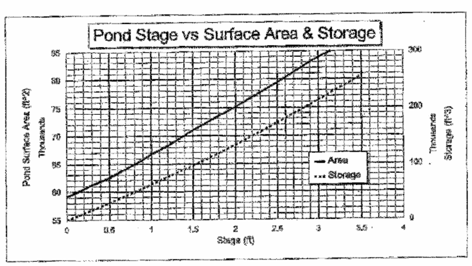


Diagram of Example Pond with Two 90 Degree V-Notch Weirs



Stage-Area and Storage-Indication Curve Development

- The table shows the calculations used to produce the storage-indication figure for the Monroe St. pond.
- This example assumes some pond modifications: two 90° V-notch weirs, with a maximum stage range increased to 3.5 feet available before the emergency spillway is activated.
- The storage calculations assume an initial storage value of zero at the bottom of the V-notch weirs (13.0 feet). The time increment used in these calculations is ten minutes, or 600 seconds.
- The storage-indication curve shown as the figure is therefore a plot of pond outflow (cfs) verses pond storage plus 300 (½ of 600 seconds) times the outflow rate. The storage-indication figure must also include the stage verses outflow and storage versus outflow curves.

Stage-Area and Storage-Indication Curve Development

- Calculation Equations:

Using two 90° V-notch weirs:

$Q = 2(2.5H^{2.5})$

$S + \frac{1}{2} O \Delta t = S + O (\frac{1}{2} \Delta t) = S + 300 (O)$

$\Delta t = 600$ seconds

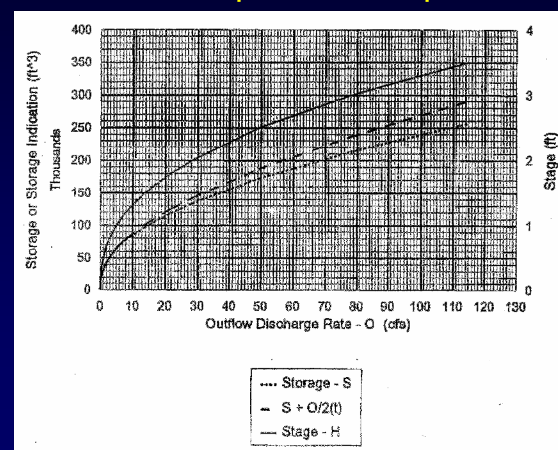
Calculation of Storage-Indication Relationships for Example Pond

Datum Stage (H) (ft)	Discharge Rate (O) (cfs)	Surface Area (ft²)	Storage (S) (ft²)	S + ½ OΔt
0	0	59,100	0	0
0.1	0.016	59,800	5,980	5,985
0.2	0.09	60,500	12,100	12,130
0.3	0.25	61,250	18,375	18,450
0.4	0.51	61,850	24,740	24,890
0.5	0.88	62,520	31,260	31,520
0.6	1.4	63,300	37,980	38,400
0.7	2.1	64,200	44,940	45,570
0.8	2.9	65,000	52,000	52,870
0.9	3.8	65,800	59,200	60,340

Calculation of Storage-Indication Relationships for Example Pond

Datum Stage (H) (ft)	Discharge Rate (O) (cfs)	Surface Area (ft²)	Storage (S) (ft²)	S + ½ OΔt
1.0	5.0	66,767	66,770	68,270
1.2	7.9	68,300	82,000	84,370
1.5	14	71,000	107,000	111,200
1.8	22	73,500	130,000	136,600
2.0	28	75,148	150,300	158,700
2.5	49	79,400	200,000	214,700
3.0	78	83,928	251,800	275,200
3.5	115	87,500	306,300	340,800

Calculation of Storage-Indication Relationships for Example Pond



Storage-Indication Calculation Procedure

- The next table shows the calculations necessary to develop the pond outflow hydrograph for a triangular inflow hydrograph resulting from a 1.5 inch, 3-hour rain.
- Columns A through J of this table (to develop the outflow hydrograph and pond surface area) need to be calculated by rows (horizontally).
- It should be noted that columns C through F are offset between the indicated time values and not for the specific times shown in column A. All of the starting values (time zero) in columns B (the beginning inflow rate), G (the beginning outflow rate), H (the pond storage volume above the normal wet pond water surface elevation), and I (the pond stage) are zero for this example.

Storage-Indication Calculation Procedure

- Column A shows the times at ten minute increments for five hours (300 minutes) since the start of the runoff.
- Column B is the pond inflow hydrograph (instantaneous flow rates at each time increment).
- The inflow runoff rates can be estimated using WinTR-55 for a design storm, or by any other method, or from an observed hydrograph.

Storage-Indication Calculation Procedure

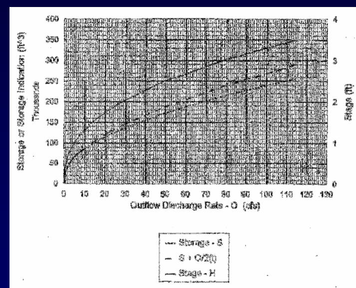
- Column C shows the average runoff rates (cfs) for the two adjacent time increments.
- Column D shows the incremental incoming runoff volume (cubic feet) for each time increment (average inflow runoff rate, from column C, times the increment time, or 600 seconds).
- Column E shows the previous storage volume minus one-half of the outflow rate times the time increment (one-half of the outflow volume).
  - The first value shown in this column (for the increment 0 to 10 minutes) is zero because the previous storage and outflow rate values (for time 0) are both 0: 0 - 1/2 (0) (600) = 0 - 0 = 0.
  - The second value in column E (for the time increment 10 to 20 minutes) is: 3,000 - 1/2 (0.01) (600) = 3,000 - 3 = 2,997.
  - Before this second value in column E can be calculated, the previous outflow rate (O) and pond storage (S) values (for time 10 minutes) must be calculated.

Storage-Indication Calculation Procedure

- Column F is the Column E value plus the Column D value (increment inflow).
  - The first value shown in Column F is therefore equal to the first value shown in Column D (2700 for this example).
  - The second value in column F (for the time increment 10 to 20 minutes) is 8,100 + 2,997 = 11,100.

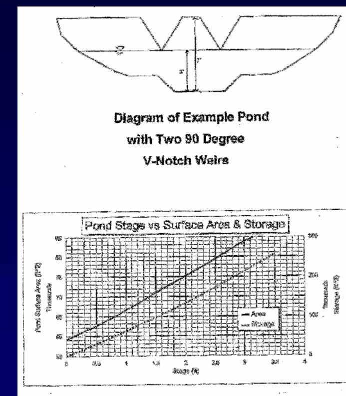
Storage-Indication Calculation Procedure

- Column G (pond outflow rate, O) and column H (pond storage, S) also start as 0 values at time 0.
  - Later values in these columns are obtained from the storage-indication curve, using the column F value for the previous time increment.
  - The 2,700 value in column F (representing S + 1/2 (O) (dt)) is used in Figure 5 to obtain a corresponding pond outflow rate of about 0.01 cfs and a pond storage volume of about 3,000 cubic feet.



Storage-Indication Calculation Procedure

- The stage values in column I are obtained from the stage-discharge curve using the corresponding outflow rates from column G.
- The pond surface area values are obtained from the stage-area curve, using the corresponding stage values from column I.



Storage-Indication Calculation Procedure

A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
0	0					0	0	0	59,000
		4.5	2,700	0	2,700				
10	9					0.01	3,000	0.1	60,000
		13.5	8,100	2,997	11,100				
20	18					0.09	12,100	0.2	60,400
		22.5	13,500	12,073	25,600				
30	27					0.51	24,740	0.4	62,000
		31.5	18,900	24,590	43,490				

Storage-Indication Calculation Procedure

A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
40	36					1.0	44,000	0.7	64,100
		40.5	24,300	43,700	68,000				
50	45					5.1	66,770	1.0	66,800
		50.0	30,000	65,240	95,240				
60	55					10	95,000	1.4	70,000
		59.5	35,700	93,500	129,200				
70	64					19	125,000	1.8	73,500
		68.5	41,100	119,300	160,400				

Storage-Indication Calculation Procedure

A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
80	73					30	155,000	2.1	76,000
		77.5	46,500	146,000	192,500				
90	82					41	180,000	2.3	77,800
		86.5	51,900	167,700	219,600				
100	91					52	205,000	2.6	80,200
		95.5	57,300	189,400	246,700				
110	100					63	225,000	2.8	81,800
		95.5	57,300	206,100	263,400				

Storage-Indication Calculation Procedure

A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
120	91					71	240,000	2.9	82,700
		86.5	51,900	218,700	270,600				
130	82					77	250,000	3.0	83,700
		77.5	46,500	226,900	273,400				
140	73					78	250,000	3.0	83,800
		68.5	46,100	226,600	267,700				
150	64					73	245,000	2.9	82,700
		59.5	35,700	223,100	258,800				

Storage-Indication Calculation Procedure

A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
160	55					69	240,000	2.8	81,800
		50.0	30,000	219,300	249,300				
170	45					65	230,000	2.7	81,800
		40.5	24,300	210,500	234,800				
180	36					58	220,000	2.6	80,200
		31.5	18,900	202,600	221,500				
190	27					52	205,000	2.5	79,400
		22.5	13,500	189,400	202,900				

Storage-Indication Calculation Procedure

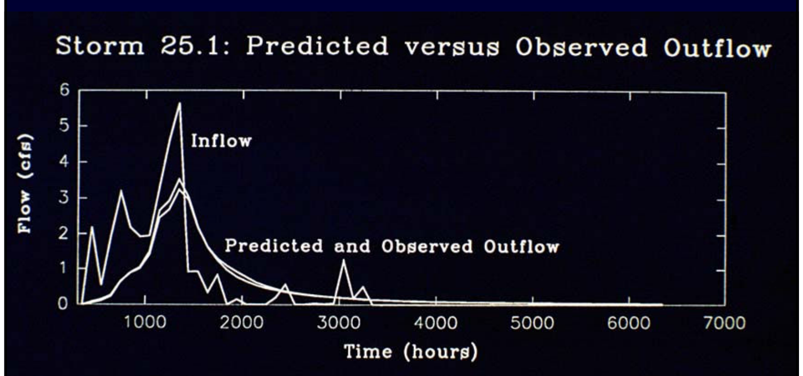
A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
200	18					44	185,000	2.4	78,600
		13.5	8,100	171,800	180,000				
210	9					36	170,000	2.2	76,900
		4.5	2,700	159,200	162,000				
220	0					29	152,000	2.0	75,200
		0	0	143,300	143,300				
230	0					22	135,000	1.8	73,500
		0	0	128,400	128,400				

Storage-Indication Calculation Procedure

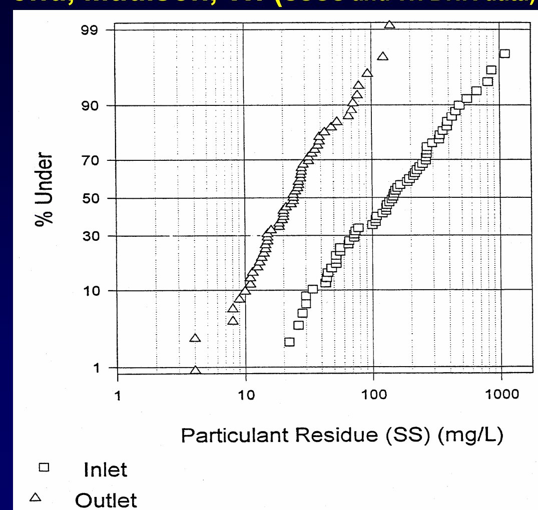
A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
240	0					18	125,000	1.7	72,700
		0	0	119,600	119,600				
250	0					16	115,000	1.6	71,900
		0	0	110,200	110,200				
260	0					13	105,000	1.5	71,000
		0	0	101,100	101,100				
270	0					11	100,000	1.4	70,000
		0	0	96,700	96,700				

Storage-Indication Calculation Procedure

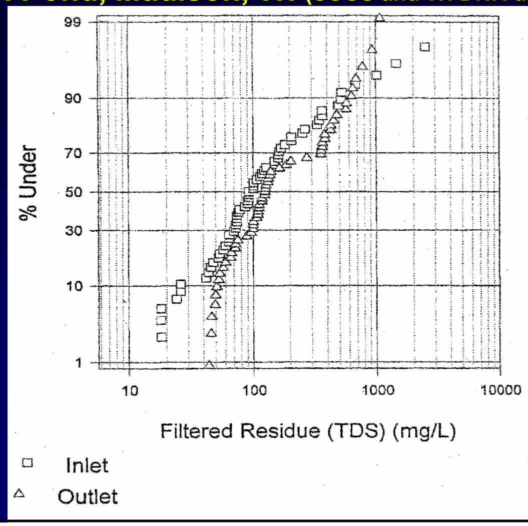
A	B	C	D	E	F	G	H	I	J
Time (min)	Inflow (cfs)	Avg. inflow for incre-ment	Avg. inflow volume (C x time period)	Previous storage minus incre-mental outflow S-0.5(O)Δt	Previous storage plus incre-mental outflow S-0.5(O)Δt	Outflow O (cfs)	Storage S (ft²)	Pond Stage (ft)	Pond Surface Area (ft²)
280	0					10	95,000	1.3	69,200
		0	0	92,000	92,000				
290	0					9	90,000	1.3	69,200
		0	0	87,300	87,300				
300	0					8	85,000	1.2	68,500
		0	0	101,100	101,100				
	Maxi mum = 100 cfs		Total = 660,000			Max. = 78 Total = 981			



Suspended Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)



Total Dissolved Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)



COD Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)