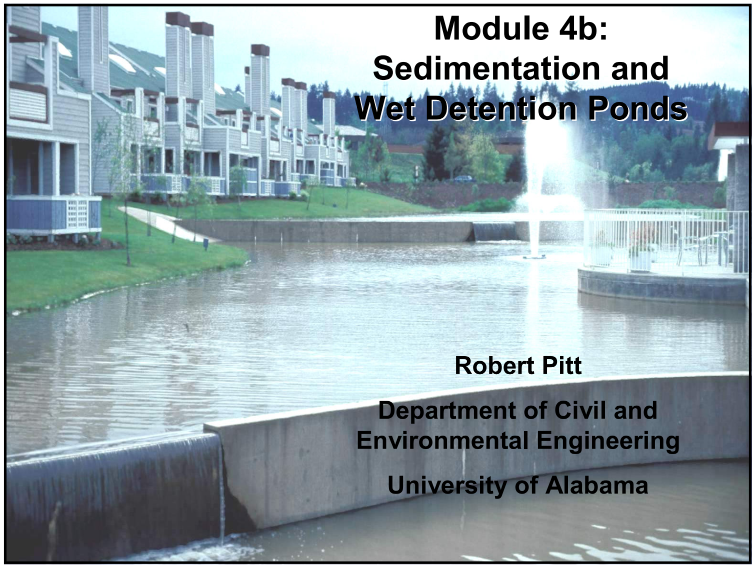
Module 4b: Sedimentation and Wet Detention Ponds



Robert Pitt

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University of Alabama

Presentation Contents

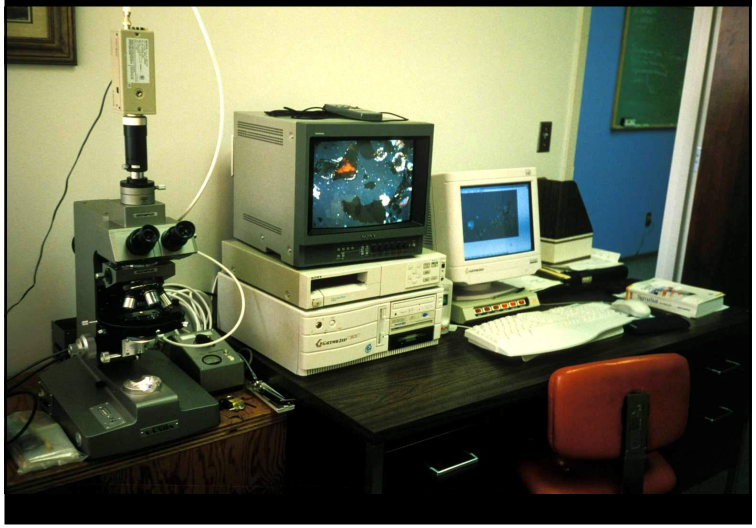
- Stormwater treatability and enhancements to improve stormwater control
- Small-scale settling devices
- Stormwater ponds
- Use of sedimentation with other unit processes and the development of other control practices
- Chemical-assisted sedimentation
- Example design calculations for wet detention ponds
- Modeling wet detention facilities with WinSLAMM

Treatability Testing and the Development of Stormwater Control Design Criteria

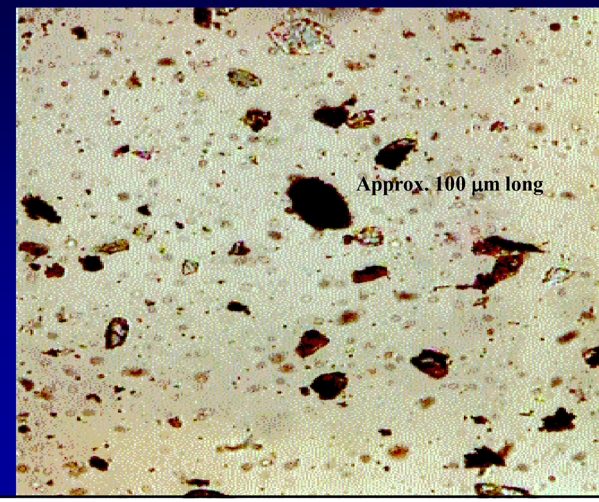
- Particle sizes and settling rates
- Relative toxicity after different unit processes
- Laboratory-scale and field pilot-scale tests
- Full-scale tests

Particle Size Analyses Using Cascading Sieves

Particle Size Analyses Using Video Microscope and Computer

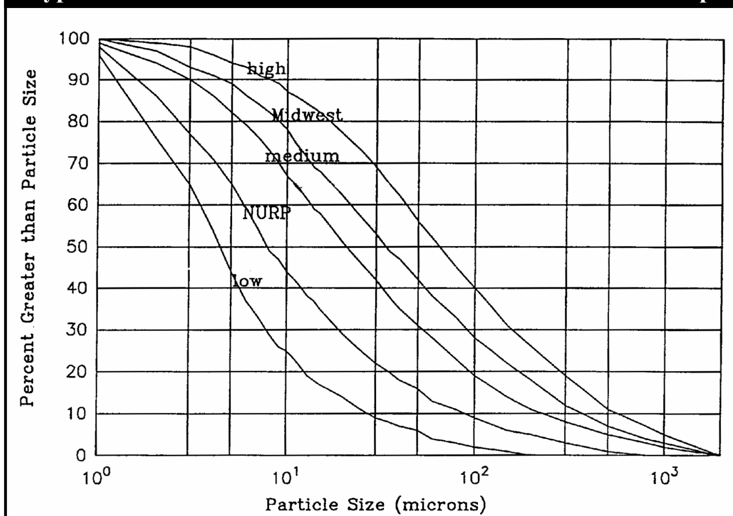


Micrograph of Road Surface Sediment Washoff

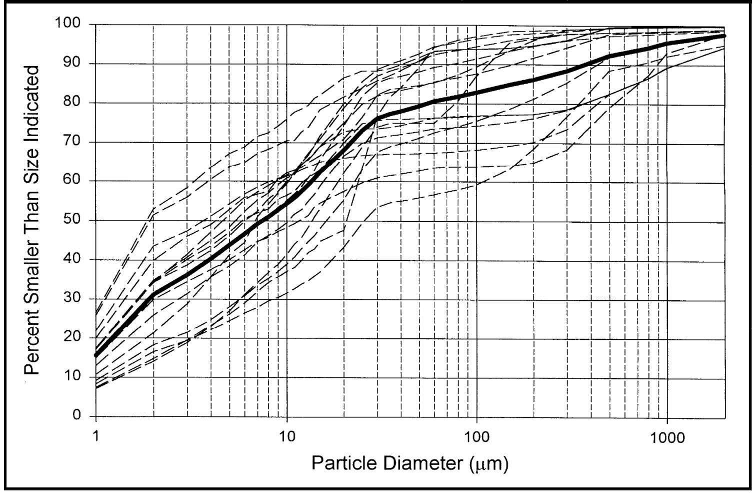


Particle Size Analyses Using Coulter Counter Multi-Sizer 2

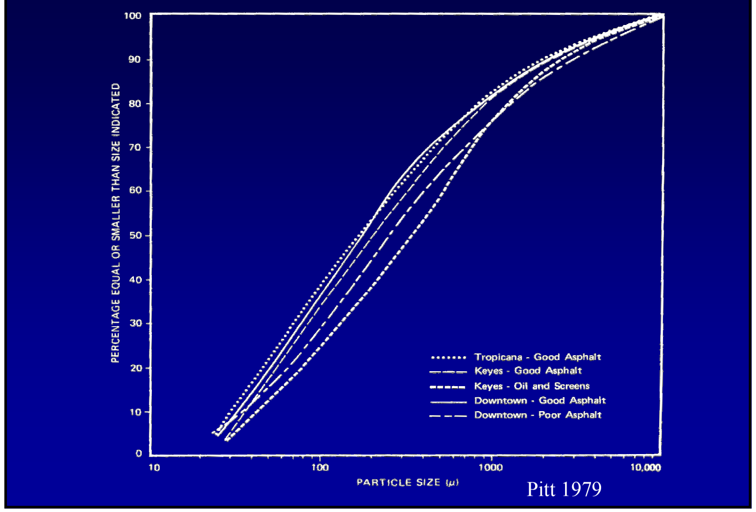
Typical Stormwater Particle Size Distributions for Outfall Samples



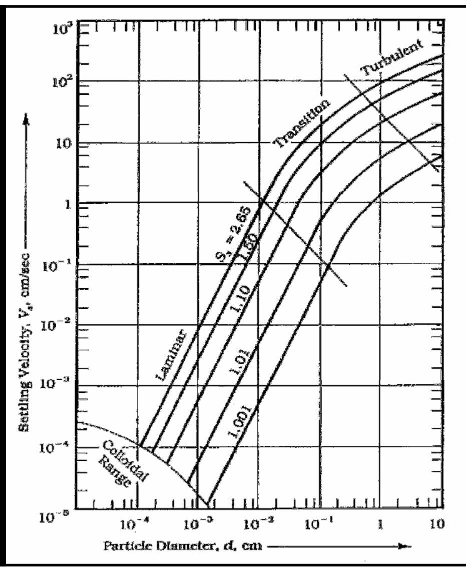
Measured Particle Sizes, Including Bed Load Component, at Monroe St. Detention Pond, Madison, WI



Particle Size Distribution of Street Dirt

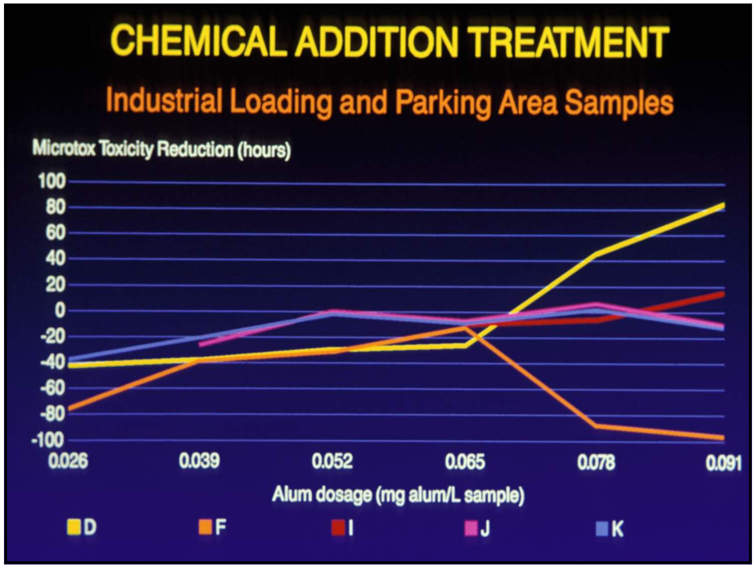


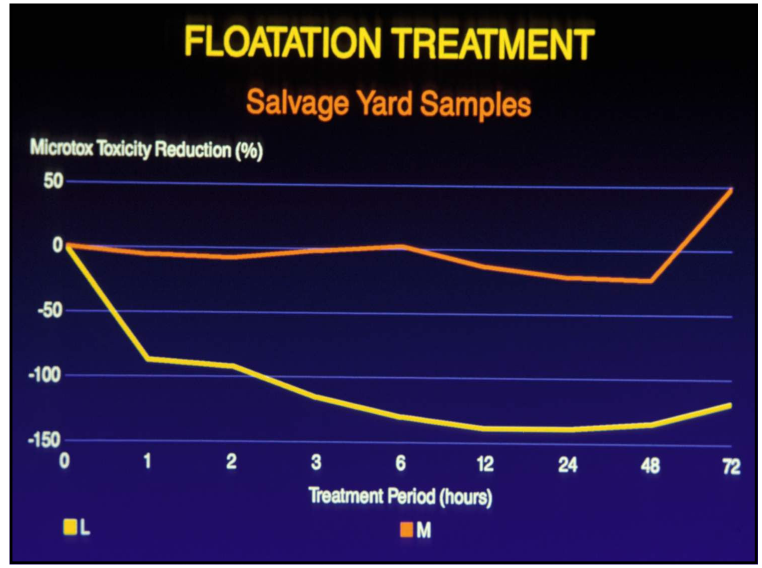
Pitt 1979

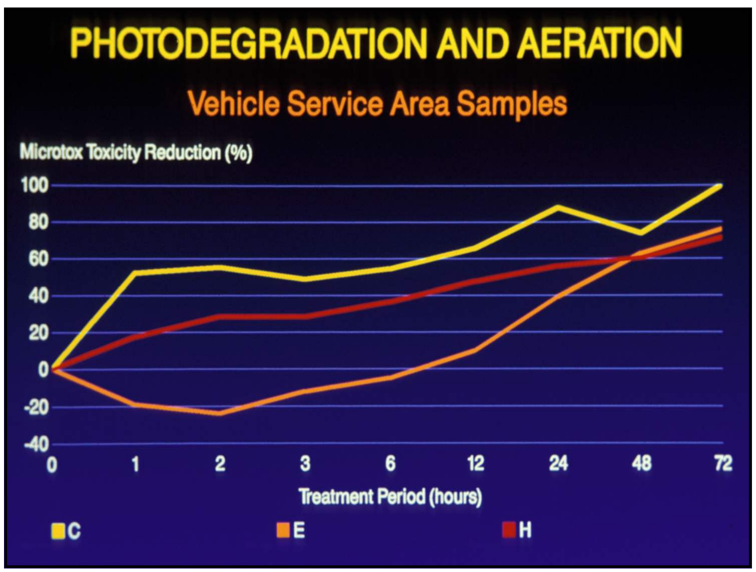


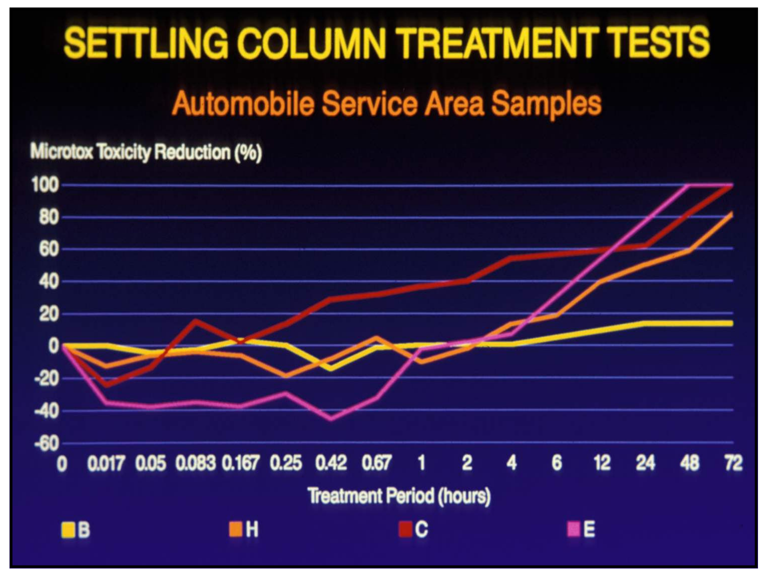
Particle Settling Rates; Stoke's and Newton's Laws

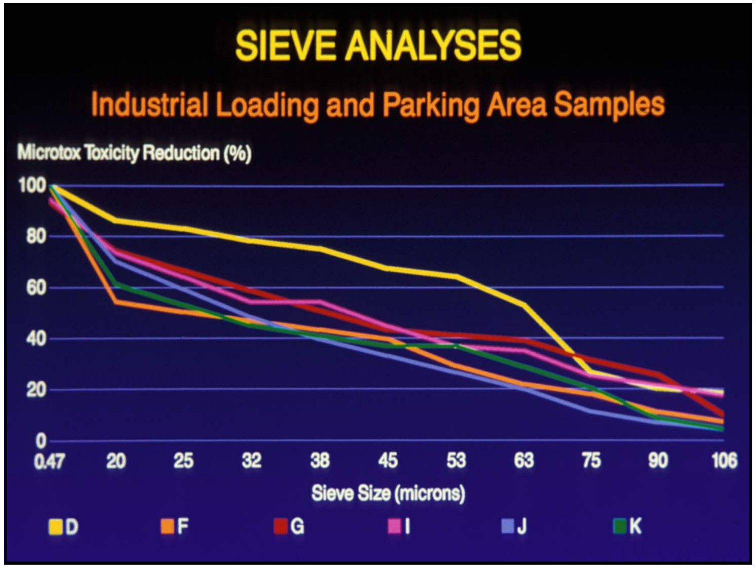
Azur's Microtox Unit used for Relative Toxicity Measurements


CHEMICAL ADDITION TREATMENT
Industrial Loading and Parking Area Samples
Microtox Toxicity Reduction (hours)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0.026
0.039
0.052
0.065
0.078
0.091
Alum dosage (mg alum/L sample)
D
F
I
J
K

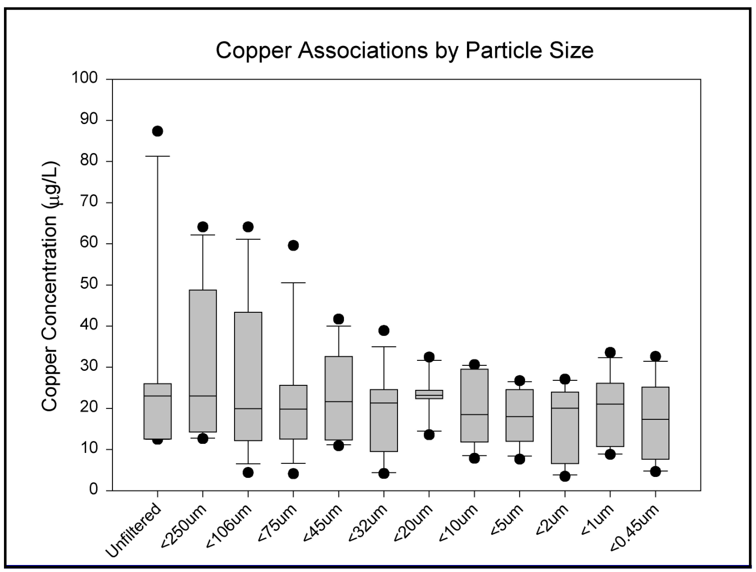

FLOATATION TREATMENT
Salvage Yard Samples
Microtox Toxicity Reduction (%)
50
0
-50
-100
-150
0
1
2
3
6
12
24
48
72
Treatment Period (hours)
L
M

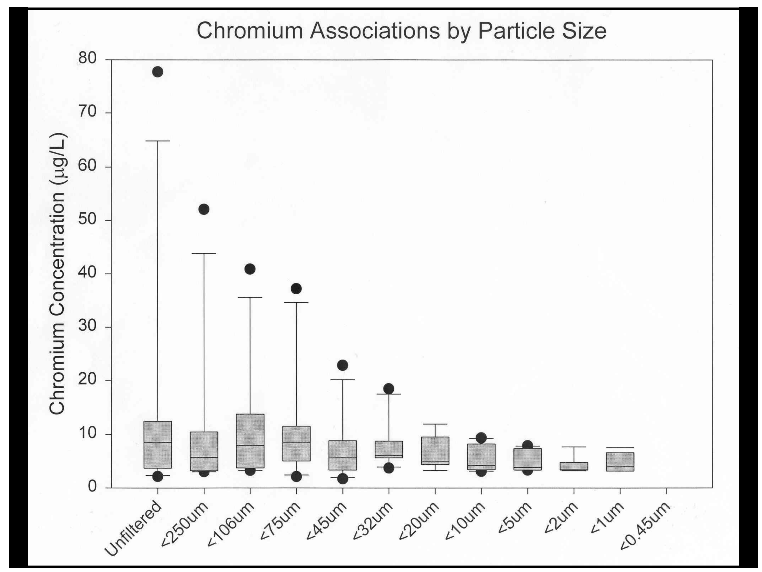

PHOTODEGRADATION AND AERATION
Vehicle Service Area Samples
Microtox Toxicity Reduction (%)
100
80
60
40
20
0
-20
-40
0
1
2
3
6
12
24
48
72
Treatment Period (hours)
C
E
H

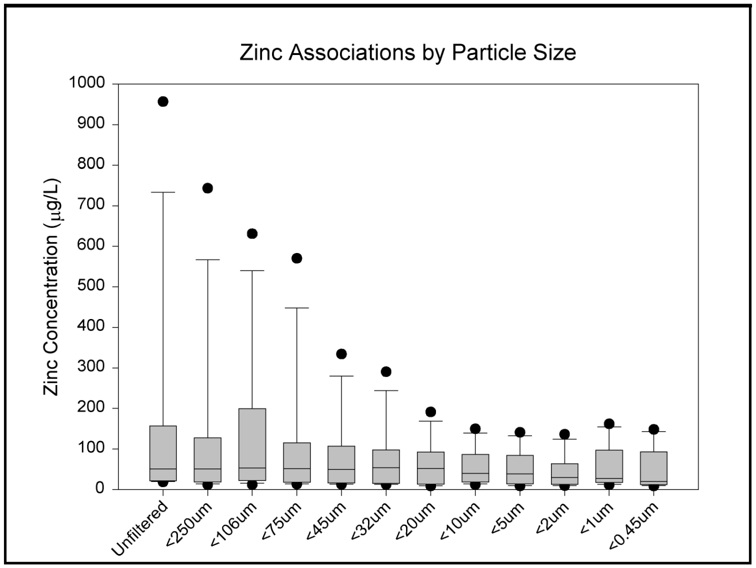

SETTLING COLUMN TREATMENT TESTS
Automobile Service Area Samples
Microtox Toxicity Reduction (%)
100
80
60
40
20
0
-20
-40
-60
0
0.017
0.05
0.083
0.167
0.25
0.42
0.67
1
2
4
6
12
24
48
72
Treatment Period (hours)
B
H
C
E



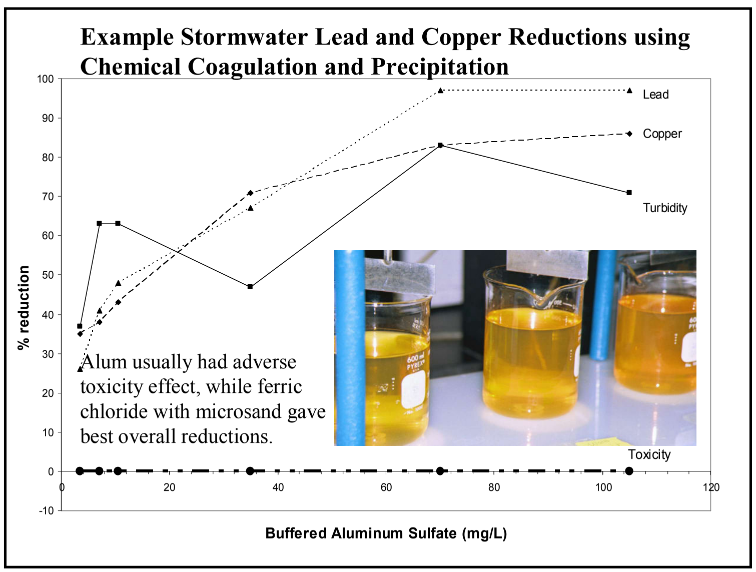
Atomic Adsorption Spectrophotometer (AAS) With Graphite Furnace, Used for Ultra Low Level Measurements of Heavy Metals







Gas Chromatograph/Mass Spectrophotometer (GC/MSD) used for Organic Toxicant Trace Analyses



Stormwater Toxicant Control

- Toxicant removal mechanisms include sedimentation, biodegradation, volatilization, sorption onto soil particles, and chemical oxidation and hydrolysis
- These processes are available in many urban runoff controls, but modifications should be made in their designs to increase their toxicant removal efficiencies

Stormwater Toxicant Control, cont.

- The most effective treatment processes included:
- settling for at least 24 hours (40 to 90% reductions),
- screening through 40 micrometer sieves (20 to 70% reductions), and
- aeration and or photo-degradation for at least 24 hours (up to 80% reductions).

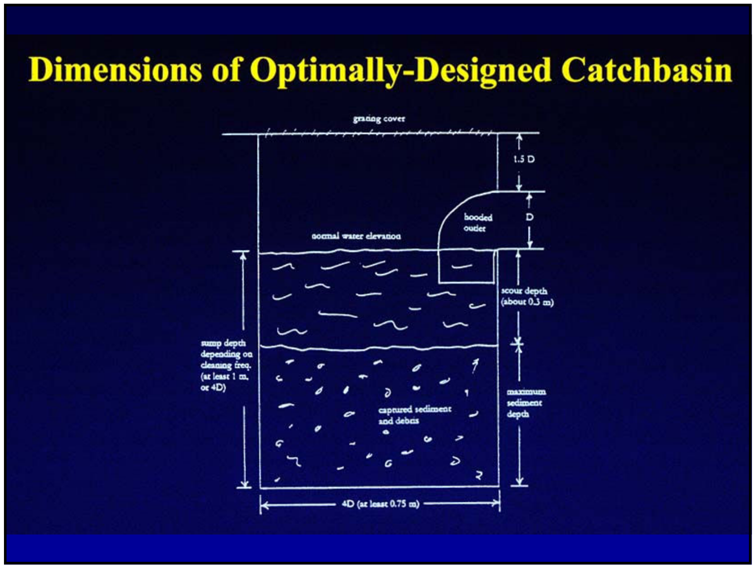
Design Modifications to Enhance Control of Toxicants in Wet Detention Ponds

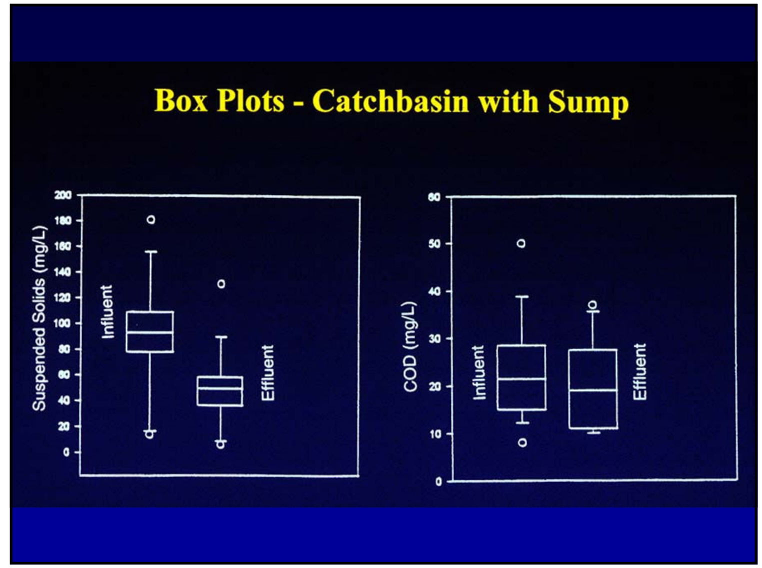
- Settling of fine particulates
- Photo-degradation (enhanced vertical circulation, but not complete mixing that can scour sediments)
- Aeration
- Floatation (subsurface discharges) to increase trapping of floating litter

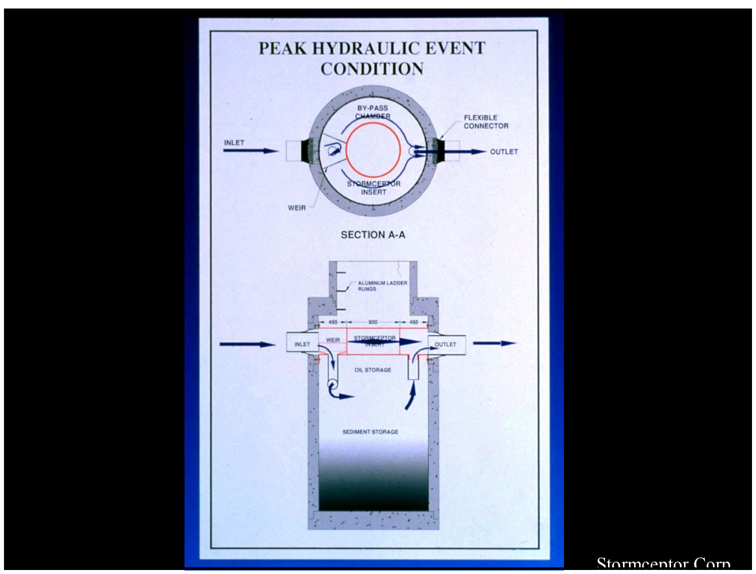
Common Stormwater Controls

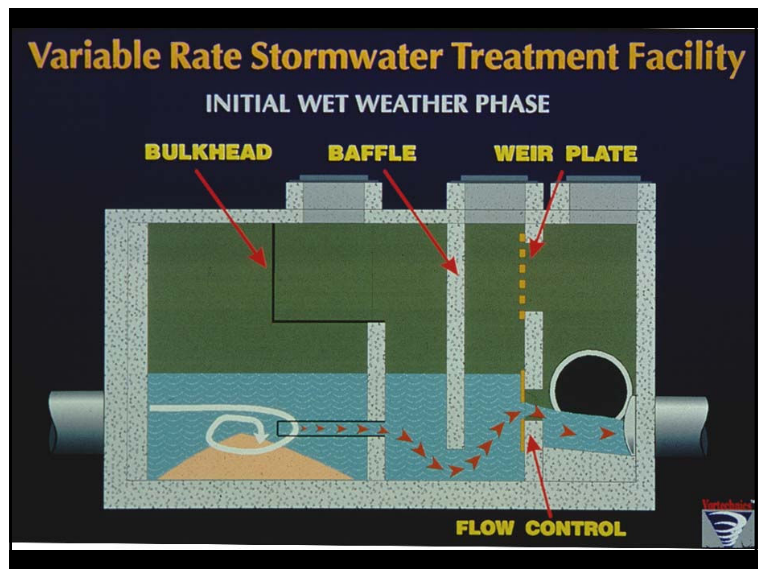
- Public works practices (drainage systems, street and catchbasin cleaning)
- Sedimentation
- Infiltration/biofiltration
- Critical source area controls
- Public education

Retro-fitted Catchbasin with Sump Tested at Ocean County, NJ


Dimensions of Optimally-Designed Catchbasin
grating cover
1.5 D
D
hooded outlet
normal water elevation
scour depth (about 0.3 m)
sump depth depending on cleaning freq. (at least 1 m, or 4D)
captured sediment and debris
maximum sediment depth
4D (at least 0.75 m)


Box Plots - Catchbasin with Sump
Suspended Solids (mg/L)
0
20
40
60
80
100
120
140
160
180
200
Influent
Effluent
COD (mg/L)
0
10
20
30
40
50
60
Influent
Effluent


PEAK HYDRAULIC EVENT CONDITION
BY-PASS CHAMBER
FLEXIBLE CONNECTOR
INLET
OUTLET
STORMCEPTOR INSERT
WEIR
SECTION A-A
ALUMINUM LADDER RUNGS
INLET
WEIR
OUTLET
OIL STORAGE
SEDIMENT STORAGE
Stormceptor Corp.


Variable Rate Stormwater Treatment Facility
INITIAL WET WEATHER PHASE
BULKHEAD
BAFFLE
WEIR PLATE
FLOW CONTROL

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

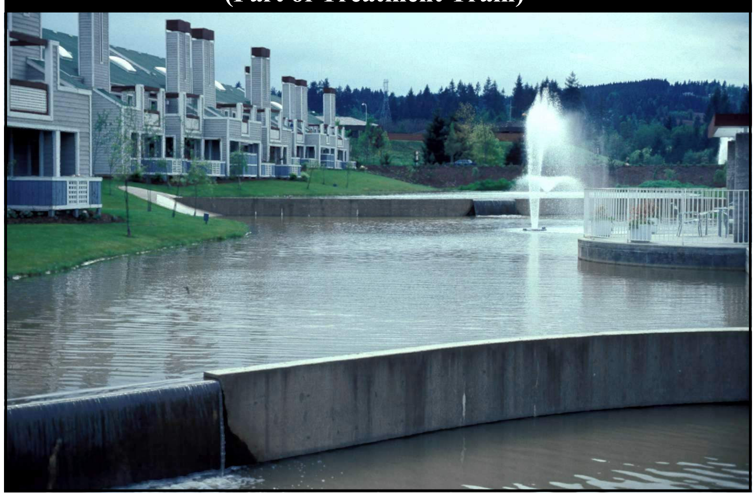
Wet Detention Facility at Shopping Center, Birmingham, AL

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)

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


New Wetlands being Planted by Volunteers, Malmo, Sweden


Necessary Harvesting of Aquatic Plants from Wetland used for Treatment of Municipal Wastewater

Lemna Systems

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

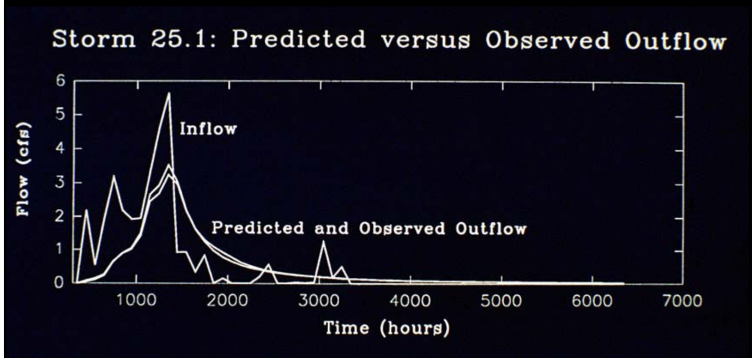
- Suspended solids: 70 to 95%
- COD: 60 to 70%
- BOD_5: 35 to 70%
- Total Kjeldahl nitrogen: 25 to 60%
- Total phosphorus: 35 to 85%
- Bacteria: 50 to 95%
- Copper: 60 to 95%
- Lead: 60 to 95%
- Zinc: 60 to 95%

Wet Pond Design Criteria for Water Quality

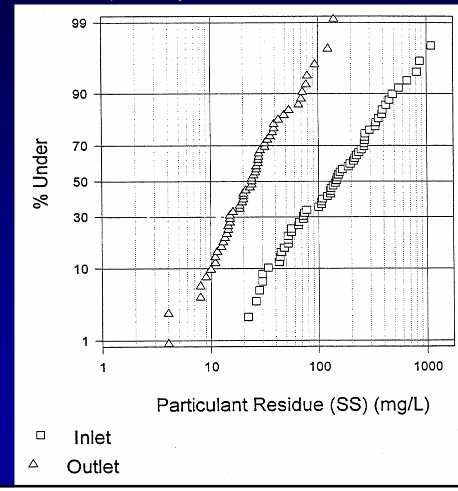
- Surface area should have a minimum area based on land use and desired pollutant control
- Pond freeboard storage equal to runoff associated with 1.25 inches of rain for the land use and development
- Select outlet device to obtain desired pollutant control for all pond stages
- Incorporate special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

Pond Area as a Percentage of Drainage Area

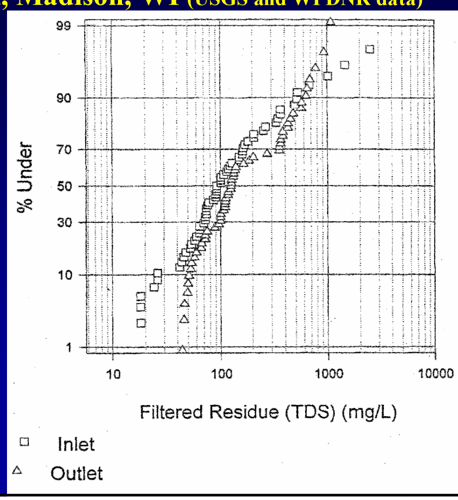
	5 micrometer	20 micrometer
Totally paved	2.8	1.0
Industrial	2.0	0.8
Commercial	1.7	0.6
Institutional	1.7	0.6
Residential	0.8	0.3
Open space	0.6	0.2
Construction	1.5	0.5



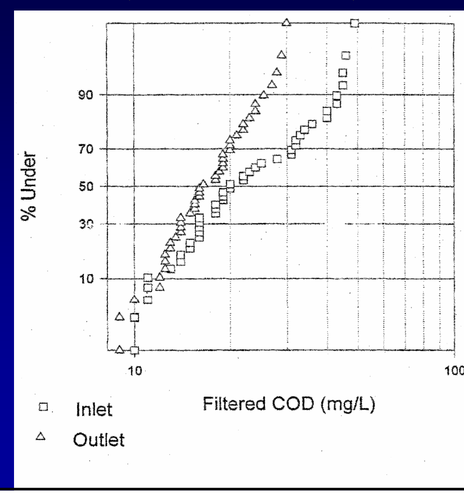
Suspended Solids Control at Monroe St. Detention Pond, Madison, WI (USGS and WI DNR data)



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)

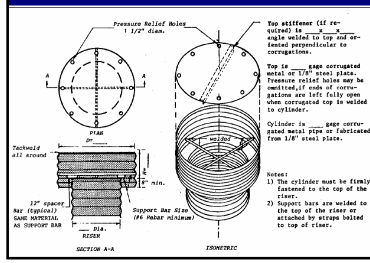


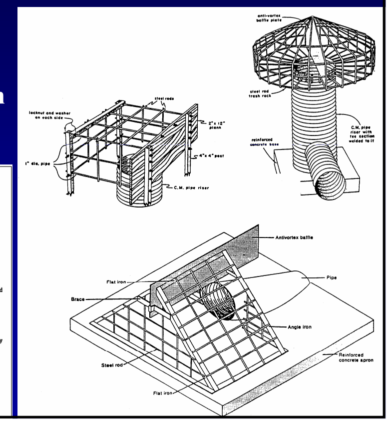
Pond Problems

- 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.





Deep Water Too Close To Shore

Thin Ice Near Shore

Steve Auger photo

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

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

Bob Kort photo

Other critters also attracted to ponds

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

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

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

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.

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

Wet Pond after Oil and Grease Trap and Step Aerator, Austin, TX

Settling Pond after Alum Injection, Orlando, FL

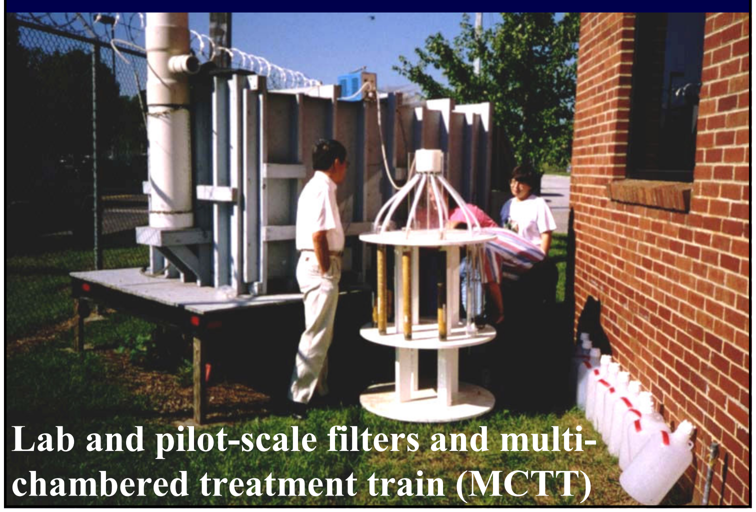
Dry Pond to Equalize Flows before Sand Filter, Austin, TX

Equalizing Dry Pond to Control SSO Problems, Moody, AL

Development of other Control Devices

- Multiple treatment processes can be incorporated into other stormwater treatment units sized for various applications.
  - Gross solids and floatables control (screening)
  - Capture of fine solids (settling or filtration)
  - Control of targeted dissolved pollutants (sorption/ion exchange)

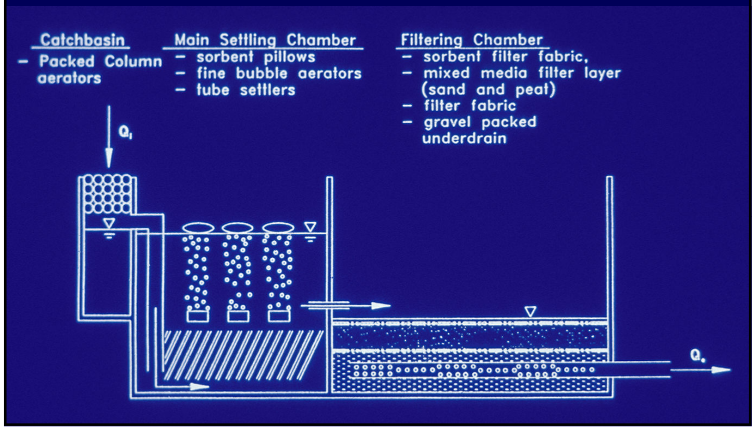
Pilot-Scale Treatment Tests using Filtration, Carbon Adsorption,UV Disinfection, and Aeration



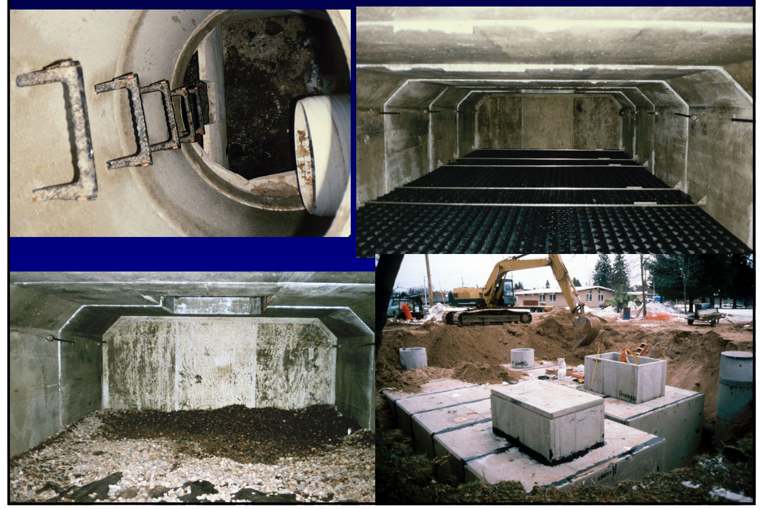
Lab and pilot-scale filters and multi-chambered treatment train (MCTT)

Pilot-scale filters examining many different media.

Multi-Chambered Treatment Train (MCTT) developed during EPA research to protect groundwater during infiltration, (Pitt, *et al.* 1999)



Minocqua, WI, MCTT (2.5 acre commercial parking)



Milwaukee, WI, Ruby Garage Public Works Maintenance Yard (0.25 acre)

Wisconsin Full-Scale MCTT Test Results

(median % reductions and median effluent quality)	Milwaukee (15 events)	Minocqua (7 events)
Particulate Solids	98 (<5 mg/L)	85 (10 mg/L)
Phosphorus	88 (0.02 mg/L)	>80 (<0.1 mg/L)
Copper	90 (3 µg/L)	65 (15 µg/L)
Lead	96 (1.8 µg/L)	nd (<3 µg/L)
Zinc	91 (<20 µg/L)	90 (15 µg/L)
Benzo (b) fluoranthene	>95 (<0.1 µg/L)	>75 <0.1 µg/L)
Phenanthrene	99 (<0.05 µg/L)	>65 (<0.2 µg/L)
Pyrene	98 (<0.05 µg/L)	>75 (<0.2 µg/L)

Upflow filter insert for catchbasins

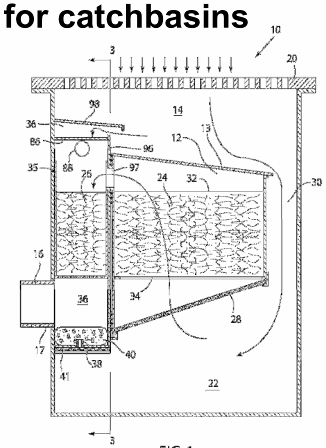


FIG. 1

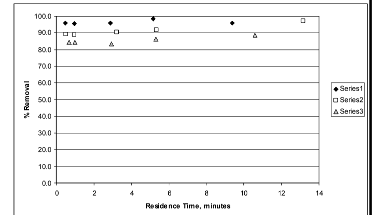
Upflow Filter™ patented

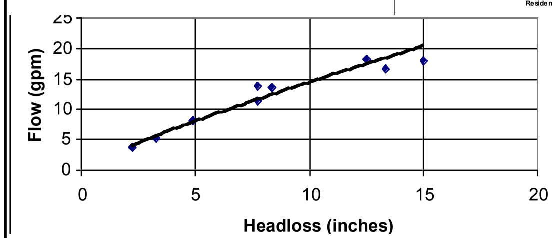
Main features of the MCTT can be used in smaller units.

The Upflow Filter™ uses sedimentation (22), gross solids and floatables screening (28), moderate to fine solids capture (34 and 24), and sorption/ion exchange of targeted pollutants (24 and 26).

Successful flow tests using prototype unit and mixed media as part of EPA SBIR phase 1 project. Phase 2 tests are being currently conducted, including ETV.

80 to 90% removal of dissolved zinc using sand/peat upflow filtration



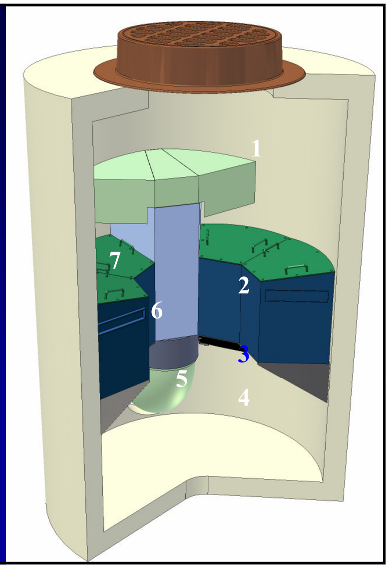


15 to 20 gpm/ft²obtained for most media tested

UpFlow Filter™

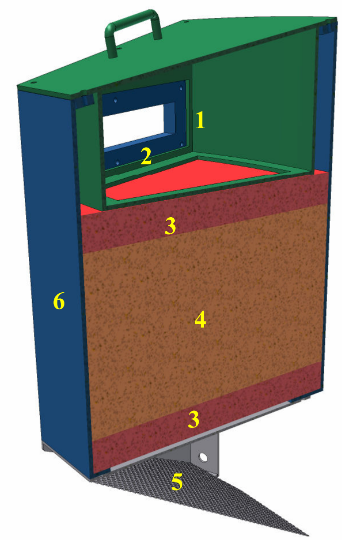
Components:

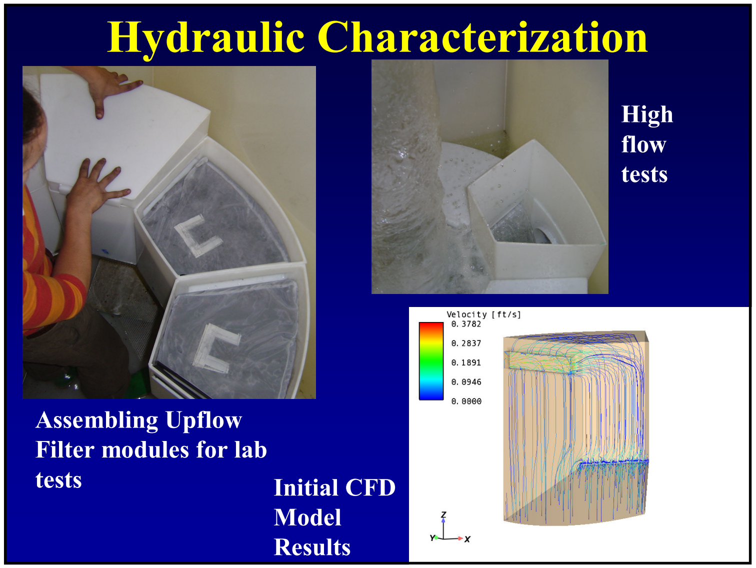
1. Access Port
2. Filter Module Cap
3. Filter Module
4. Module Support
5. Coarse Screen
6. Outlet Module
7. Floatables Baffle/Bypass



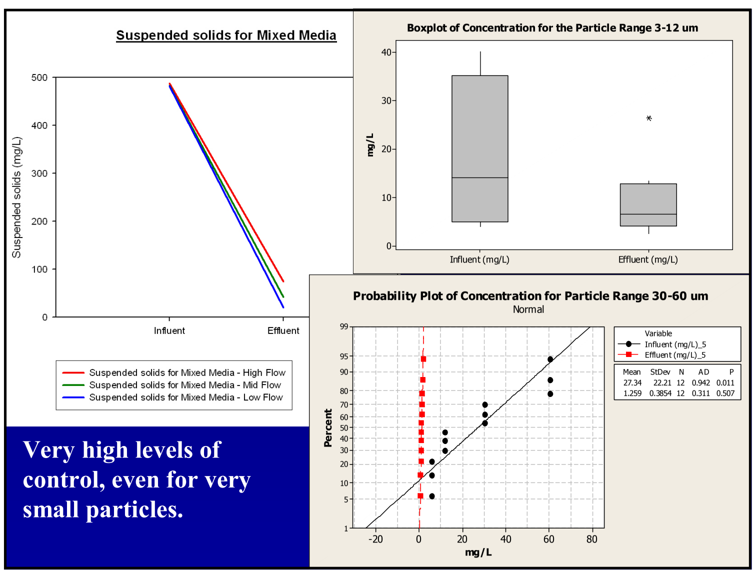
Upflow Filter Components

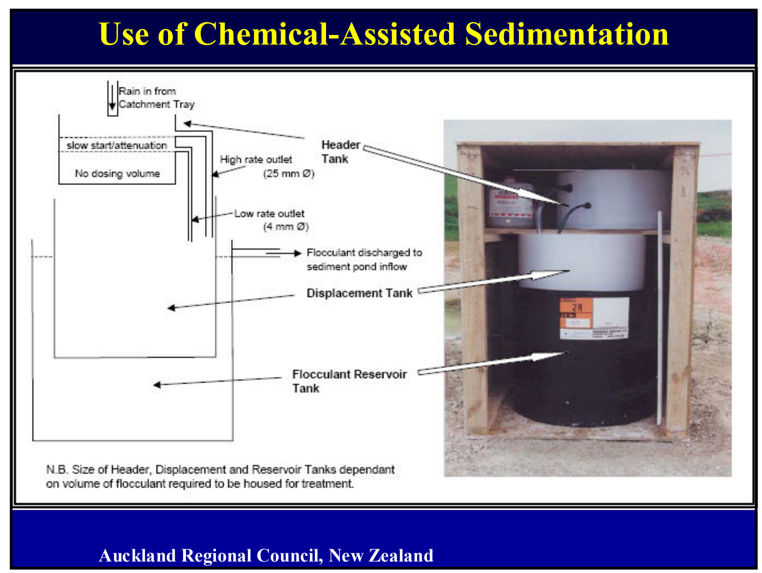
1. Module Cap/Media Restraint and Upper Flow Collection Chamber
2. Conveyance Slot
3. Flow-distributing Media
4. Filter Media
5. Coarse Screen
6. Filter Module




Hydraulic Characterization
High flow tests
Assembling Upflow Filter modules for lab tests
Initial CFD Model Results
Velocity [ft/s]
0.3782
0.2837
0.1891
0.0946
0.0000


EPA-funded SBIR2 Field Test Setup, Tuscaloosa, AL


Suspended solids for Mixed Media
Suspended solids (mg/L)
Influent
Effluent
Suspended solids for Mixed Media - High Flow
Suspended solids for Mixed Media - Mid Flow
Suspended solids for Mixed Media - Low Flow
Boxplot of Concentration for the Particle Range 3-12 um
mg/L
Influent (mg/L)
Effluent (mg/L)
Probability Plot of Concentration for Particle Range 30-60 um
Normal
Percent
mg/L
Variable
Influent (mg/L)_5
Effluent (mg/L)_5
Mean StDev N AD P
27.34 22.21 12 0.942 0.011
1.259 0.3854 12 0.311 0.507
Very high levels of control, even for very small particles.


Use of Chemical-Assisted Sedimentation
Rain in from Catchment Tray
slow start/attenuation
No dosing volume
High rate outlet (25 mm Ø)
Header Tank
Low rate outlet (4 mm Ø)
Flocculant discharged to sediment pond inflow
Displacement Tank
Flocculant Reservoir Tank
N.B. Size of Header, Displacement and Reservoir Tanks dependant on volume of flocculant required to be housed for treatment.
Auckland Regional Council, New Zealand

Polyaluminum Chloride (PAC) was a more suitable choice, especially for clayey soil conditions, than alum and other tested coagulants.

The overall suspended solids treatment efficiency of PAC-treated ponds has been between 90 – 99 % for ponds having good physical designs. Lower treatment efficiencies have occurred where there have been problems with decants not operating properly, or physical problems such as multiple inflow points, high inflow energy, and poor separation of inlets and outlets.

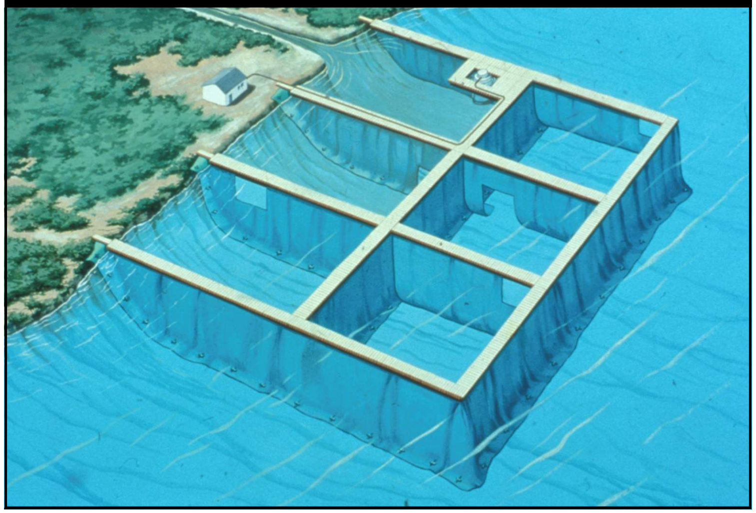
Example Performance Data for PAC-assisted Settling

Pond	Inflow		Outflow		SS Reduction
	Flow (L/sec)	SS (mg/L)	Flow (L/sec)	SS (mg/L)	(%)
Mason's Rd	3	26,300	3	144	99.4
Mason's Rd	2	5,100	2	40	99.2
OVR E	15	1,639	8	51	96
OVR E	2	749	2	56	92
23800E	8	14,800	6	966	93
23800E	1	18,700	2	67	99
B1 Gully	0.3	4,300	0.4	3	99.9
B1 Gully	0.5	16,900	3.0	59	99.6

Flow-Balancing Method (FBM)

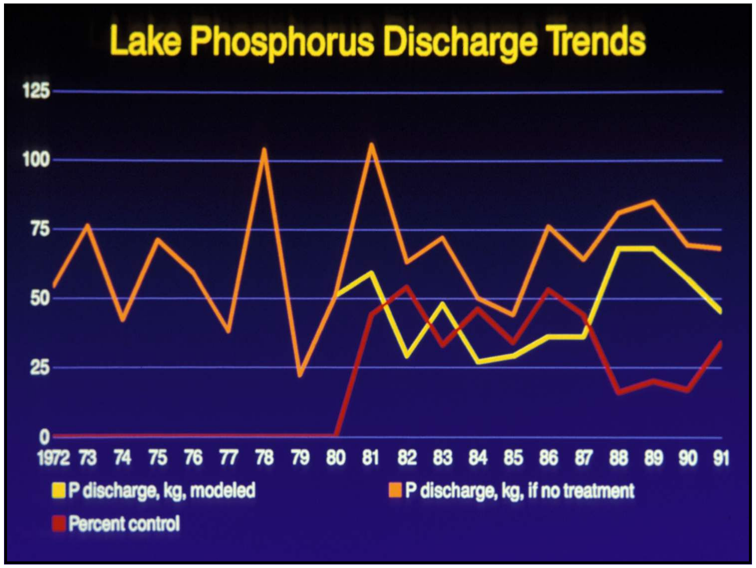
- Developed by Karl Dunkers, Taby, Sweden
- Sedimentation facility placed directly in water.
- Usually for pumpback systems to treatment facilities

Drawing of FBM in Place (Karl Dunker, Taby, Sweden)



FBM Chamber at Lake Ronningesjon, Taby Sweden (Karl Dunker)

Ferric Chloride Treatment Unit at Lake Ronningesjon, Taby Sweden (Karl Dunker)

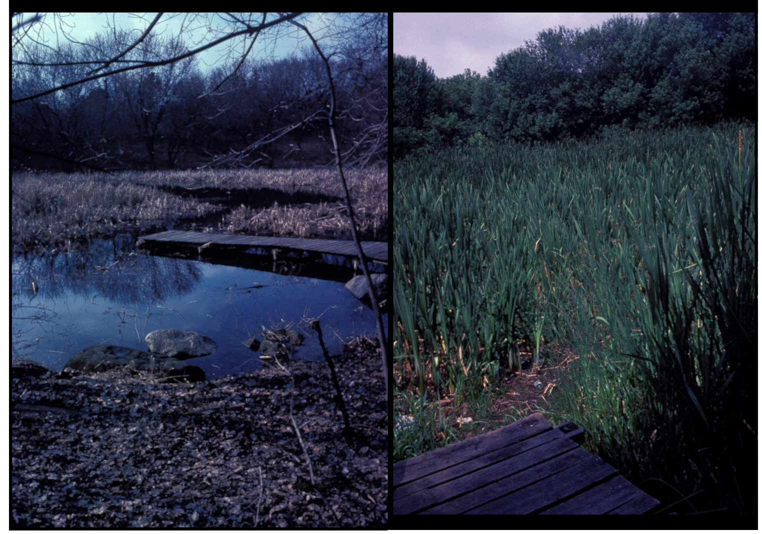


Percolation Ponds

- Can incorporate sedimentation with infiltration
- Usually in areas of shallow groundwater
- Concern about possible groundwater contamination, especially in industrial areas

Watertable Percolation Pond, Berlin, Germany

Watertable Percolation Pond, Madison, WI



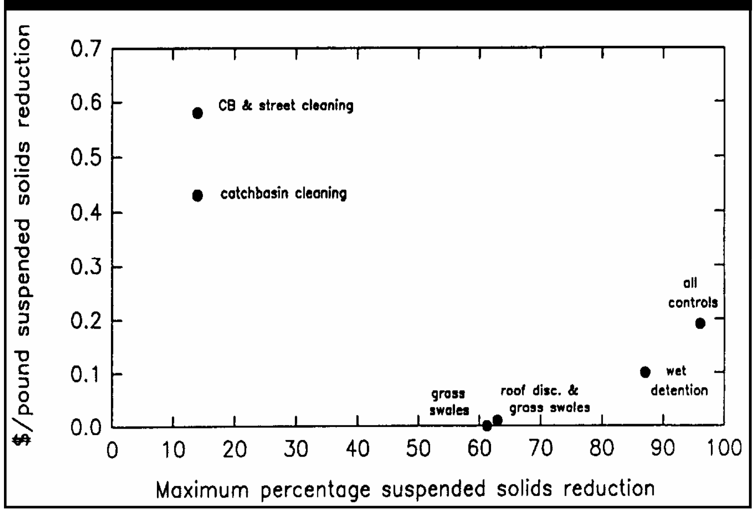
Special Stormwater Control Considerations in Areas having Harsh Winters

- 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

Cost-Benefit Analysis for Various Stormwater Controls, SLAMM



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.

Conclusions – relative effectiveness of controls

	Cost	Effectiveness
Inappropriate discharge	**Low**	**High**
Erosion control	**Low to mod.**	**Low to moderate**
Floatable and litter control	**Low to mod.**	**Low to high**
Oil&water separators	**Moderate**	**Very low**
Critical source control	**High**	**Low to high**
Low impact development	**Low to mod.**	**Moderate to high**
Public education	**Low to mod.**	**?????**
Wet detention ponds	**Mod. To high**	**Usually high**

Design of Wet Detention Ponds

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:

Example site	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 areas contain infiltration controls then less area needed

Design of Wet Detention Ponds (cont.)

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:

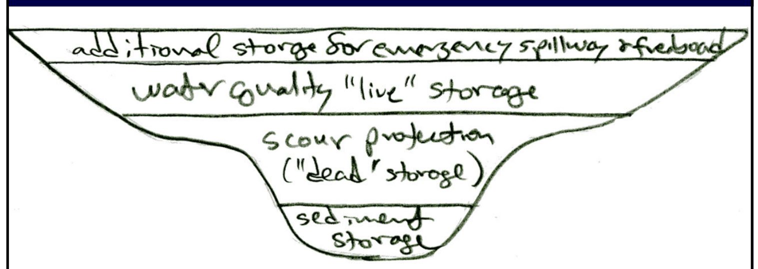
Example site	Land Area (acres)	Pond WQ Volume Factor	Pond WQ Volume
Paved area	0.6	1.1 inches	0.66 ac-in
Undeveloped area (clayey soils)	3.8	0.3	1.14
Construction site (clayey soils)	27.6	0.6	16.56
Total	32.0		18.36 ac-in (1.53 ac-ft)

Runoff Depth Corresponding to 1.25 Inches of Rain

Based on small storm hydrology

	Sandy	Clayey
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

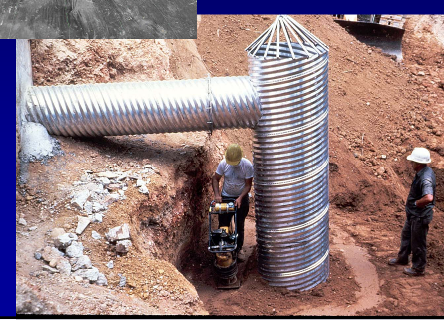
Pitt 1987



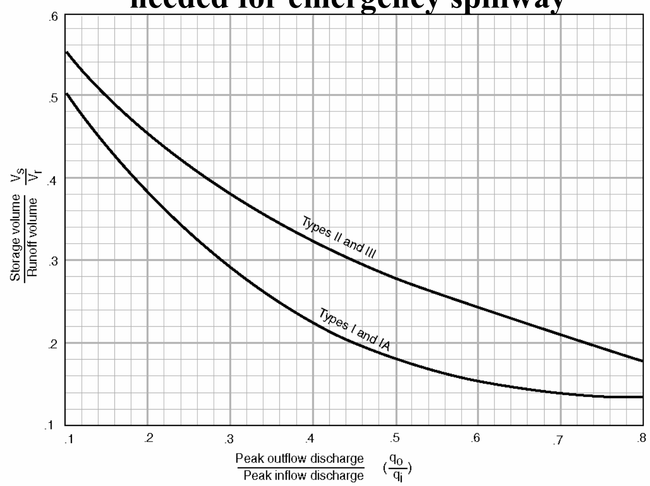
3. The "dead" storage is needed to prevent scour of previously deposited material and should be at least 3 ft deep over the sediment. Sediment storage volume is also needed and can be estimated using RUSLE for the construction site.

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

Head (ft)	Flow (cfs)	22.5° Storage (ac-ft)	Reqd. area (acres)	Flow (cfs)	30° Storage (ac-ft)	Reqd. area (acres)
0.5	0.1	<0.01	0.01	0.1	<0.01	0.02
1	0.5	0.03	0.1	0.7	0.05	0.1
1.5	1.4	0.1	0.2	1.9	0.2	0.3
2	2.8	0.3	0.5	3.8	0.3	0.7
3	7.8	1.2	1.4	11	1.6	1.8
4	16	3.3	2.8	22	4.4	3.8
5	28	7.2	4.9	38	9.6	6.6
6	44	14	7.7	60	18	10



SCS TR-55 plot used to size additional freeboard needed for emergency spillway



Vs = 1.53 acre-ft
Vr = 7.5 acre-ft
and Vs/Vr = 0.20

for type II or III rain categories:
qo/qi = 0.72

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

Rain and watershed characteristics for the emergency spillway design:

- P = 8 inches
- CN = 86; therefore the Ia = 0.0366
- Q = 6.2 inches and Ia/P = 0.041
- Area (Am) = 0.021 mi^2 (13.2 acres)
- Tc = 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_{peak} = (498 csm/in)(0.021 mi^2)(6.2 in) = 63.7 ft^3/sec

Also, the volume of runoff for this event is:
V_r = [(6.2 in)(13.2 ac)]/12 in/ft = 6.82 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 ft3/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 (6.82 acre-ft) = 1.34 acre-ft

The length (LW in feet) of a rectangular weir, for a given stage (HW in feet) and desired outflow rate (qo 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:

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

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.

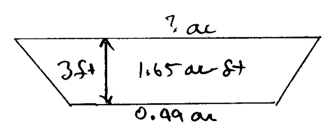
the basic pond area and "live" storage volume

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

Site Subarea	Pond Surface Area (acres)	Pond "Live" Volume, runoff from 1.25 inches of rain fall (acre- inches of runoff)
paved area (0.2 acres)	3% of 0.2 acres = 0.006 acres	1.1 inches x 0.2 acres = 0.22 ac-in
undeveloped area (1.2 acres)	0.6% of 1.2 acres = 0.007 acres	0.3 inches x 1.2 acres = 0.36 ac-in
construction area (32 acres)	1.5% of 32 acres = 0.48 acres	0.6 inches x 32 acres = 19.2 ac-in
Total:	0.49 acres	19.8 ac-in = 1.65 ac-ft

pond side slopes, top surface area, and "dead storage" volume

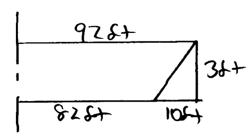
1) If 3 ft deep:
Top area:



$$\frac{(0.49acres + X)3\,ft}{2} = 1.65ac - ft$$

$$X = 0.61acres$$

at 0.61 acres: $\pi r^2 = 26{,}570\,ft^2$ r = 92 ft
at 0.49 acres: $\pi r^2 = 21{,}340\,ft^2$ r = 82 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 (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)
A = (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 yd^3, 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:

$\pi r^2 = 15{,}250\, ft^2$ r = 70 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:

$$\frac{(0.35acres + X)3\,ft}{2} = 0.8ac - ft$$

$$X = 0.18acres$$

at 0.18 acres, r = 50 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)

- Ia for this curve number is 0.128 inches.
-24-hour, 25-year rain has a total rain depth (P) of 6.9 inches.
-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. 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 mi2-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 ft^3/sec at this stage. Therefore, the rectangular weir will need to handle: 182 – 16 ft^3/sec = 166 ft^3/sec. The rectangular weir can be sized from the rectangular weir equation :

$$L_w = \frac{q_o}{(3.2)(H_w)^{1.5}} = \frac{166\,ft^3/\sec}{(3.2)(1)^{1.5}} = 52\,ft$$

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

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:

$$L_w = \frac{q_o}{(3.2)(H_w)^{1.5}} = \frac{149\,ft^3/\sec}{(3.2)(2)^{1.5}} = 16\,ft$$

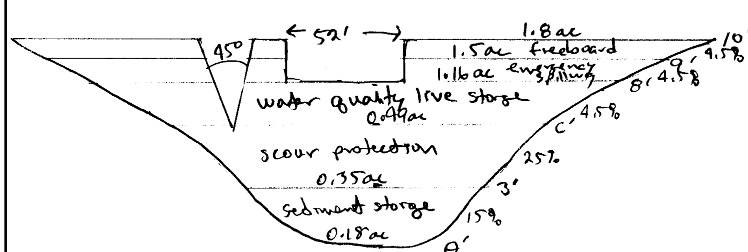
This is a suitable length, but does result in an additional foot of pond depth. For this example, the 52 foot long weir is selected.

Final pond profile and expected performance

Pond Depth (ft from bottom of pond, the datum)	Surface Area at Depth (acres)	Pond Storage below Elevation (calculated by Detpond) (acre-ft)	Pond slope between this elevation and next highest noted elevation	notes
0	0	0	-	the pond bottom (datum) must be 0 acres for the routing calculations
0.1	0.18	-	15%	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
3	0.35	0.8	25%	this is the top of the sacrificial storage area for the sediment
6	0.49	2.0	4.5%	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)

Final pond profile (continued)

Pond Depth (ft from bottom of pond, the datum)	Surface Area at Depth (acres)	Pond Storage below Elevation (calculated by Detpond) (acre-ft)	Pond slope between this elevation and next highest noted elevation	notes
8	1.16	3.7	4.5%	this is the bottom (invert) of the water quality outlet structure (and live storage volume), a 45° V-notch weir
9	1.5	5.0	4.5%	this is the top of live storage volume, and the bottom of the emergency spillway, a 52 ft long rectangular weir
10	1.8	6.7	-	1 foot of freeboard above maximum expected water depth, the top of the pond

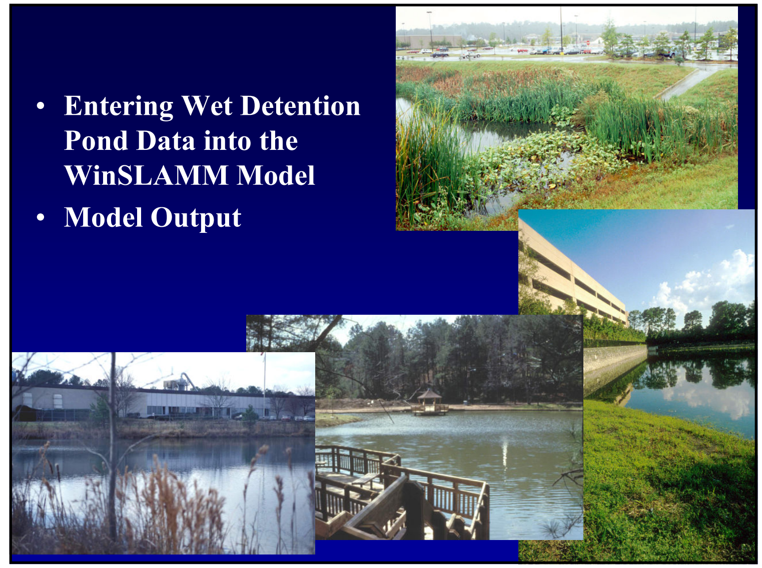


The pond performance for a 30 year period of rain (3,346 events, ranging from 0.01 to 13.6 inches) was calculated using Detpond. During these 30 years, the expected maximum pond stage is slightly more 8 ft. The emergency spillway was used a total of four times in this period. The flow-weighted particulate solids removal rate was about 92%.

	Max. Pond Stage (ft)	Event Inflow Volume (ac-ft)	Event Flushing Ratio	Flow-weighted Particle Size (µm)	Partic. Solids Removed (%)
Maximum	8.1	23	11	6.8	100
Average	6.2	0.10	0.05	n/a	n/a
Flow-weighted Average	n/a	n/a	1.4	2.6	92
Median	6.1	0.012	0.0057	0.39	99.6
Standard Deviation	0.22	0.54	0.26	0.57	1.9
COV	0.035	5.1	5.1	1.1	0.019

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

- **Entering Wet Detention Pond Data into the WinSLAMM Model**
- **Model Output**

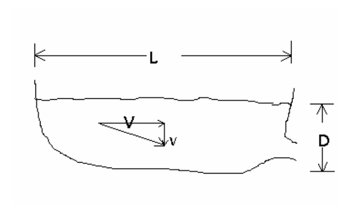


•NURP (1983) found particulates reduced by between 0% (for small ponds and large drainage areas) and 90+% for large ponds. For well designed ponds BOD and COD removals were 70%, and heavy metals between 60 – 95%.

•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.

Particulate Settling

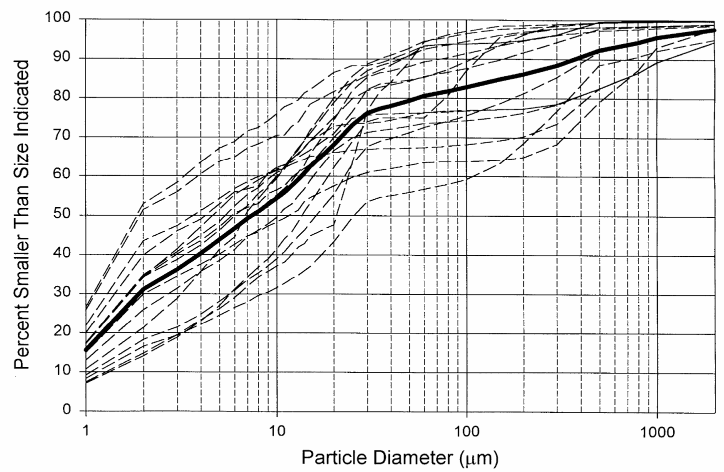


$$\frac{V}{v} = \frac{L}{D} \rightarrow v = \frac{Q_{out}}{A}$$

Pages 23-25 of detention pond design.pdf

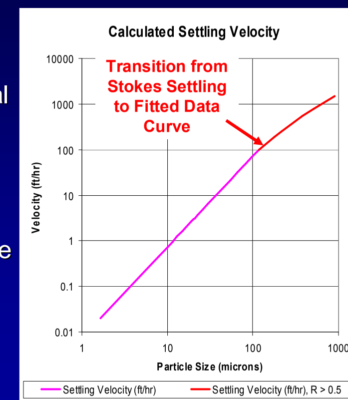
- Ideal Settling – Particle path is vector sum of particle velocity through pond and settling (upflow) velocity
  - L – Pond Length
  - D – Outlet Depth
  - V – Water Velocity through Pond
  - v – Settling Velocity
  - Q_{out} – Outflow from Pond
  - A – Pond Surface Area

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



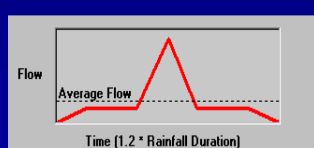
Particulate Settling

- Ideal settling is modeled
  - Using Stokes Law (Ideal Settling) for smaller particles
  - Settling velocity as a function of Reynolds number and particle size for larger particles

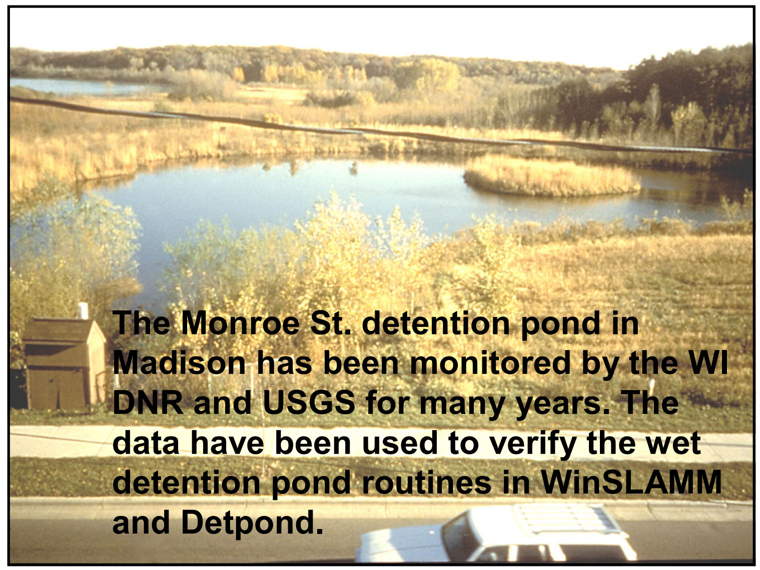


Hydrograph Creation

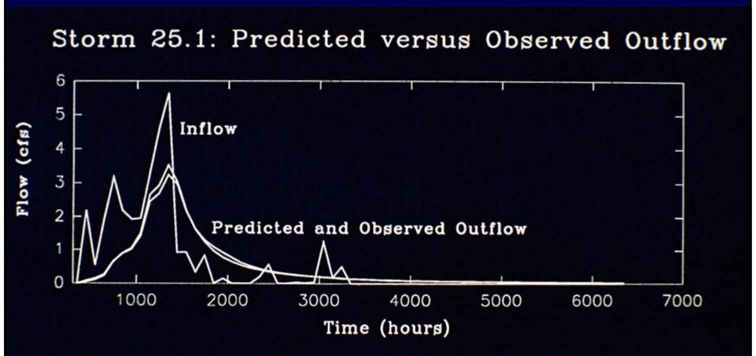
- Flow rate calculated using Complex Triangular Hydrograph
  - Runoff Volume calculated from WinSLAMM
  - Runoff Duration = 1.2 times rainfall duration



Complex Triangular Hydrograph



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.

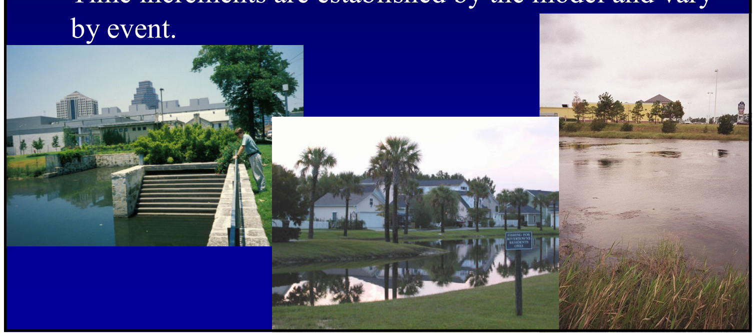


Retrofitted to result in 90% SS control, the long-term monitored results were 87%.

PROBABILITY IN % UNDER	10%	50%	90%
Suspended solids	35	87	97
Total Residue	<0	52	86
Volatile Residue	<0	41	76
Filtered Residue	<0	<0	56
Particulate COD	15	80	95
Total COD	29	60	84
FilteredCOD	<0	24	80
Particulate Phosphorus	-20	60	80
Total Phosphorus	<0	47	81
Filtered Phosphorus	<0	43	83
Particulate TKN	-40	40	80
Total TKN	<0	45	75
Filtered TKN	<0	12	68
Particulate Zinc	-117	70	95
Total Zinc	<0	31	69
Filtered Zinc	<0	<0	59

Modeling Notes

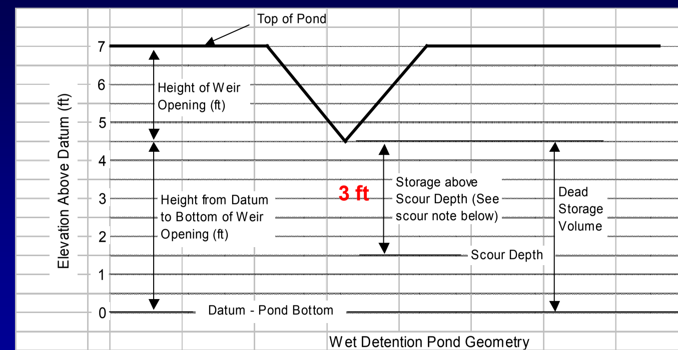
- WinSLAMM assumes a 3.0 ft scour depth.
- Pond routing is performed using the Modified Puls–Indication Storage Method.
- Time increments are established by the model and vary by event.



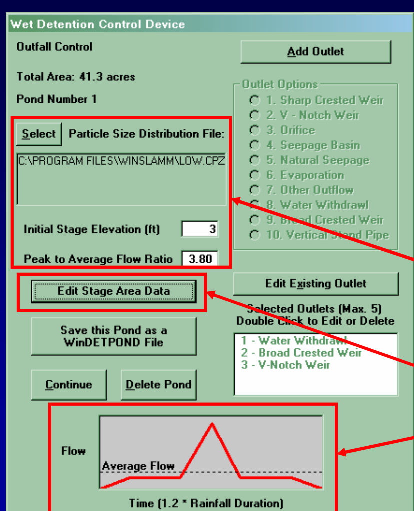
Three Components to Modeling Wet Detention Ponds

1. Pond Geometry
2. Flow, Initial Stage and Particle Size Data
3. Outlet Information

Pond Geometry



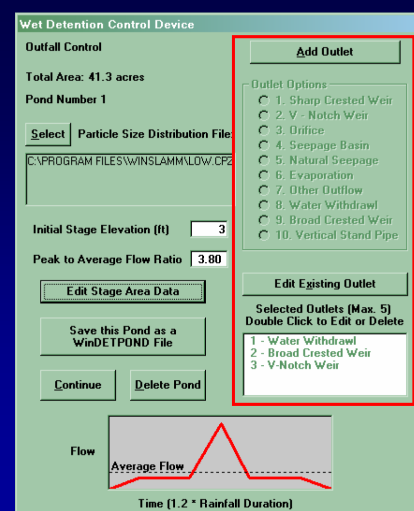
Pond Datum is always zero ft.



Wet Detention Pond Data Entry Form

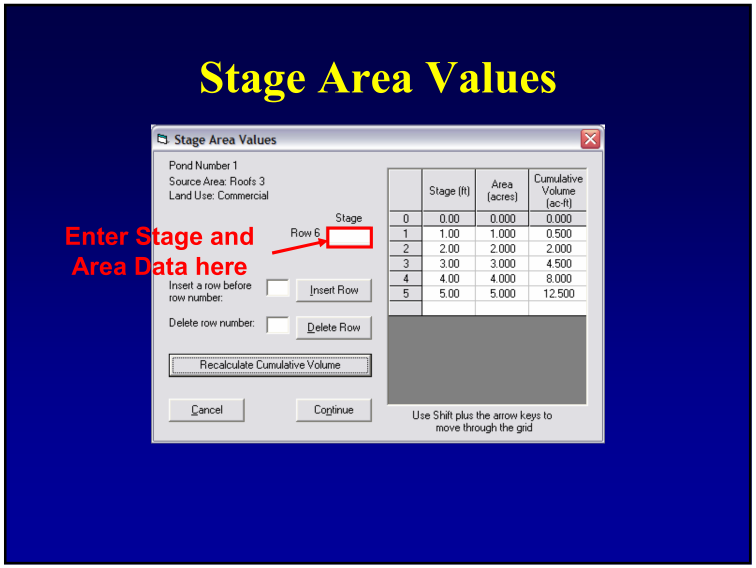
Flow, Initial Stage and Particle Size Information

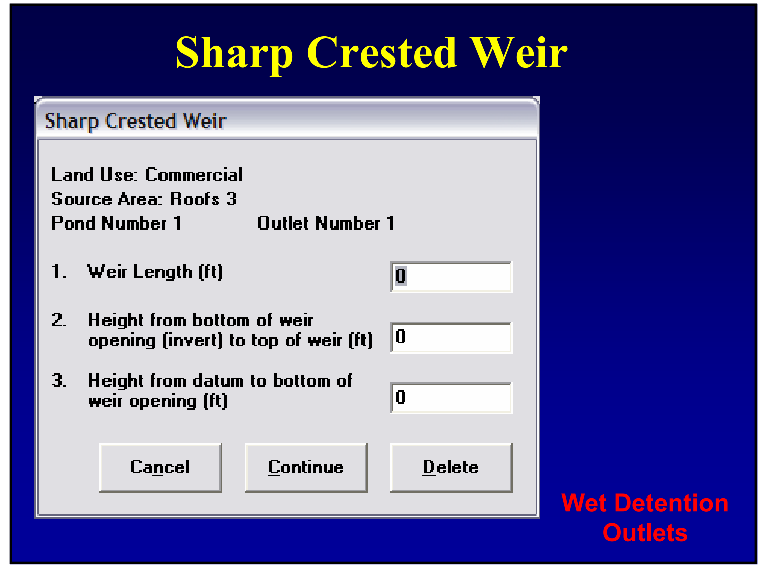
Pond Geometry Information

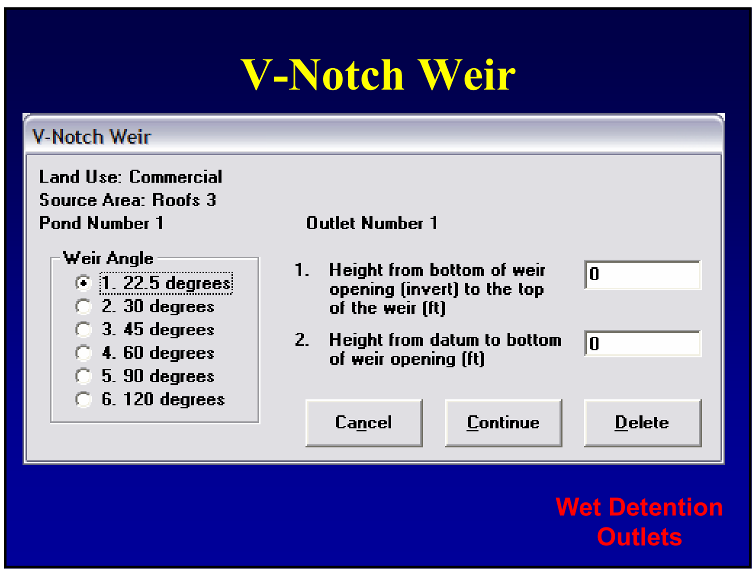


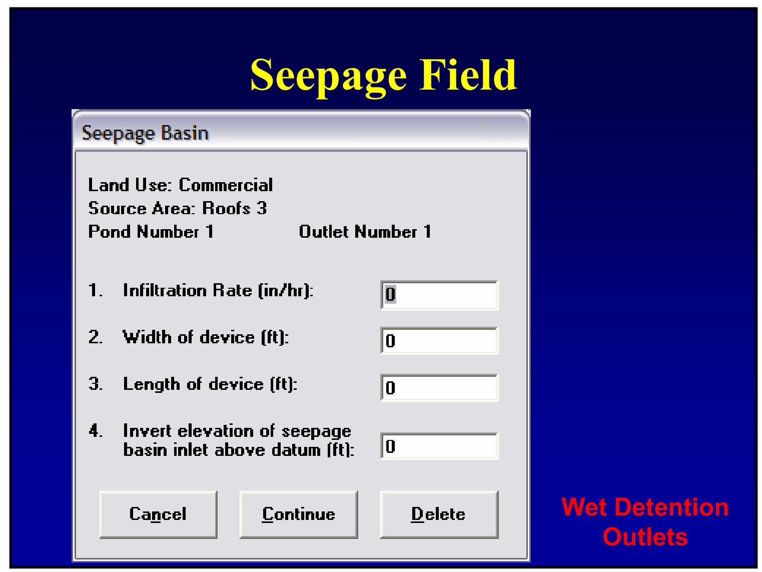
Wet Detention Pond Data Entry Form

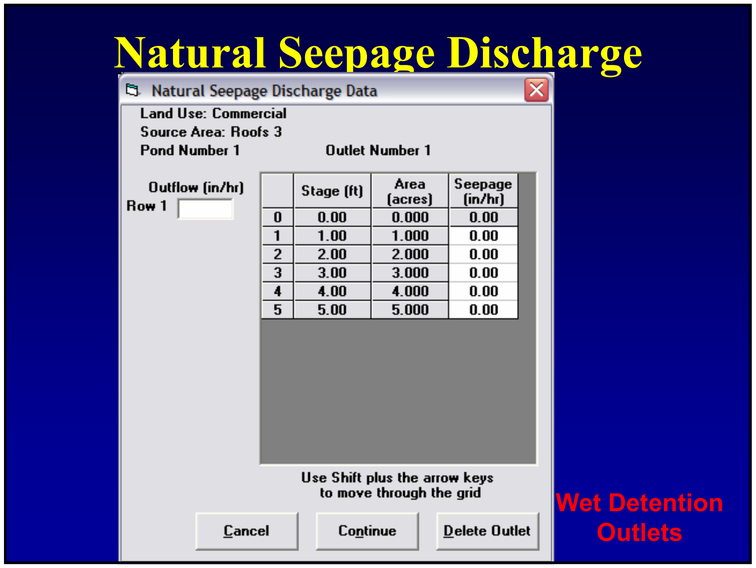
Pond Outlet Information

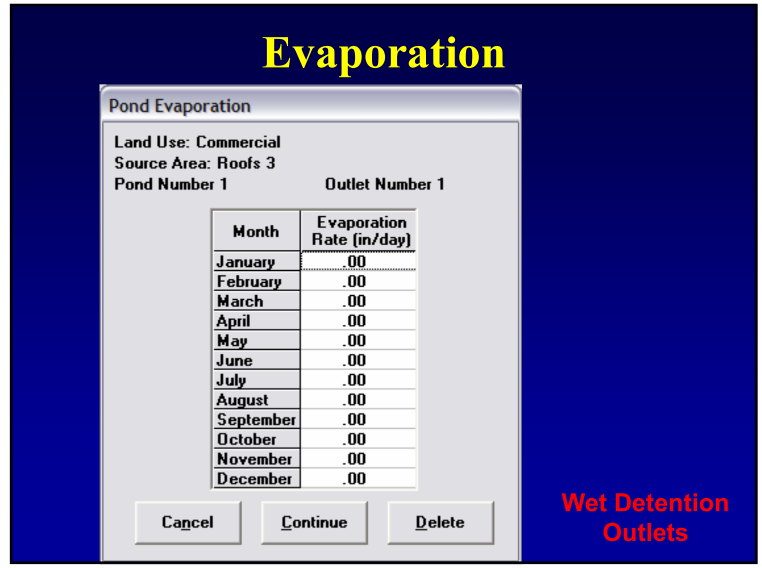

Stage Area Values
Stage Area Values
Pond Number 1
Source Area: Roofs 3
Land Use: Commercial
Enter Stage and Area Data here
Row 6
Stage
Insert a row before row number:
Insert Row
Delete row number:
Delete Row
Recalculate Cumulative Volume
Cancel
Continue
Stage (ft)
Area (acres)
Cumulative Volume (ac-ft)
0 0.00 0.000 0.000
1 1.00 1.000 0.500
2 2.00 2.000 2.000
3 3.00 3.000 4.500
4 4.00 4.000 8.000
5 5.00 5.000 12.500
Use Shift plus the arrow keys to move through the grid

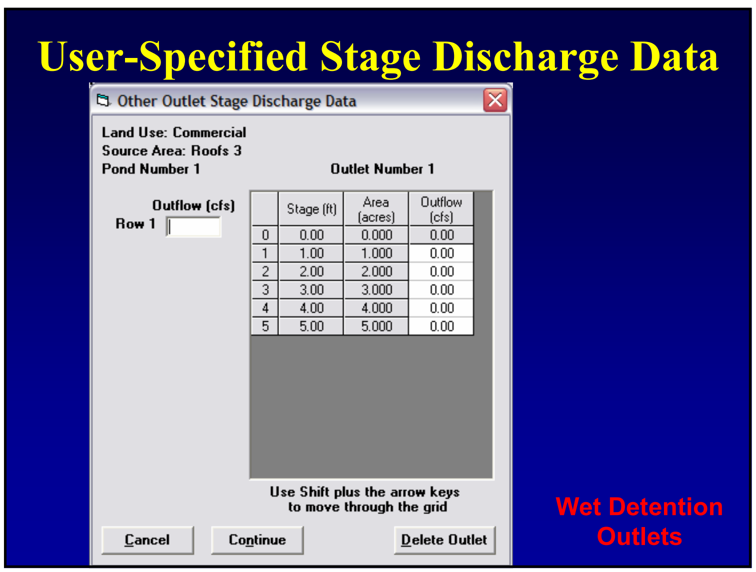

Sharp Crested Weir
Sharp Crested Weir
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
1. Weir Length (ft)
0
2. Height from bottom of weir opening (invert) to top of weir (ft)
0
3. Height from datum to bottom of weir opening (ft)
0
Cancel
Continue
Delete
Wet Detention Outlets

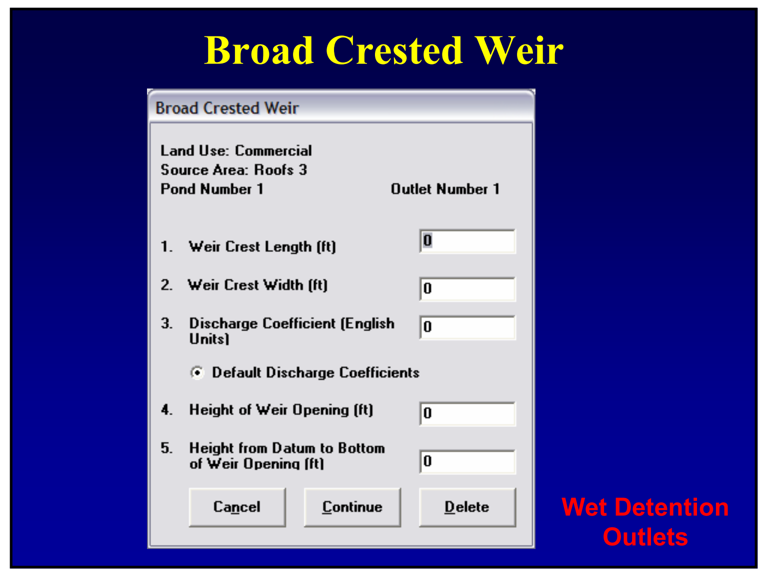

V-Notch Weir
V-Notch Weir
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
Weir Angle
1. 22.5 degrees
2. 30 degrees
3. 45 degrees
4. 60 degrees
5. 90 degrees
6. 120 degrees
1. Height from bottom of weir opening (invert) to the top of the weir (ft)
0
2. Height from datum to bottom of weir opening (ft)
0
Cancel
Continue
Delete
Wet Detention Outlets

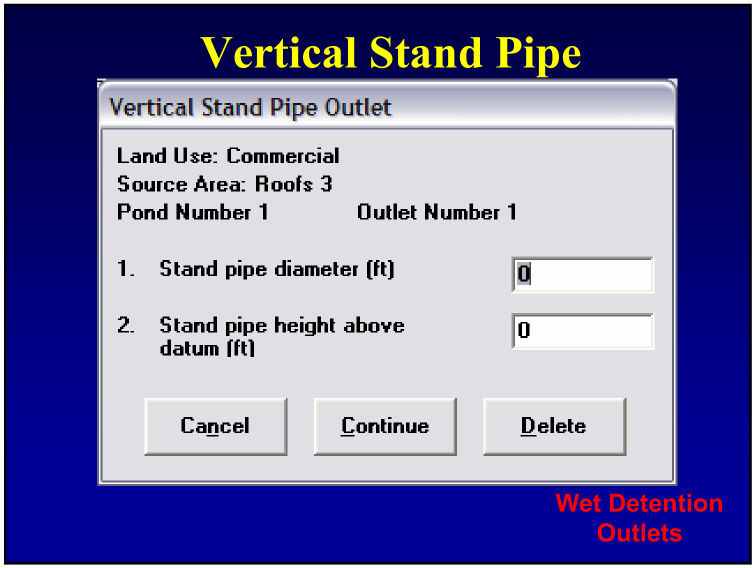

Seepage Field
Seepage Basin
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
1. Infiltration Rate (in/hr):
0
2. Width of device (ft):
0
3. Length of device (ft):
0
4. Invert elevation of seepage basin inlet above datum (ft):
0
Cancel
Continue
Delete
Wet Detention Outlets

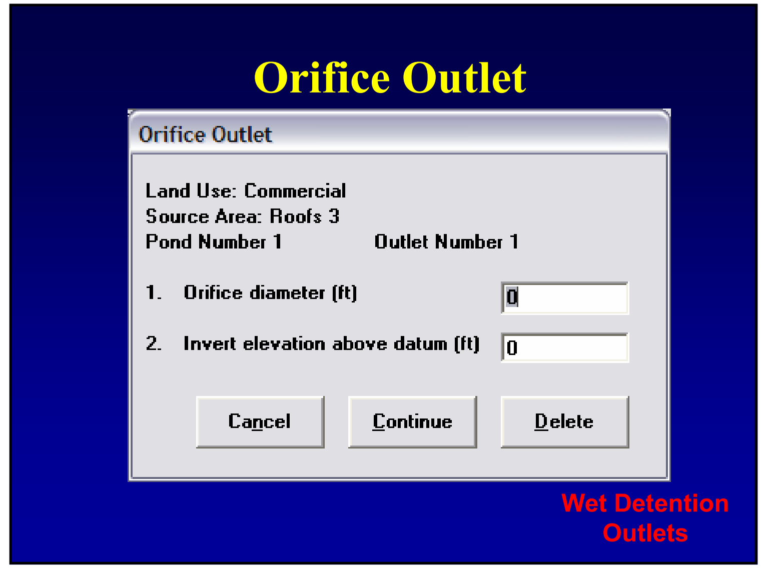

Natural Seepage Discharge
Natural Seepage Discharge Data
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
Outflow (in/hr)
Row 1
Stage (ft) | Area (acres) | Seepage (in/hr)
0 0.00 0.000 0.00
1 1.00 1.000 0.00
2 2.00 2.000 0.00
3 3.00 3.000 0.00
4 4.00 4.000 0.00
5 5.00 5.000 0.00
Use Shift plus the arrow keys to move through the grid
Cancel
Continue
Delete Outlet
Wet Detention Outlets

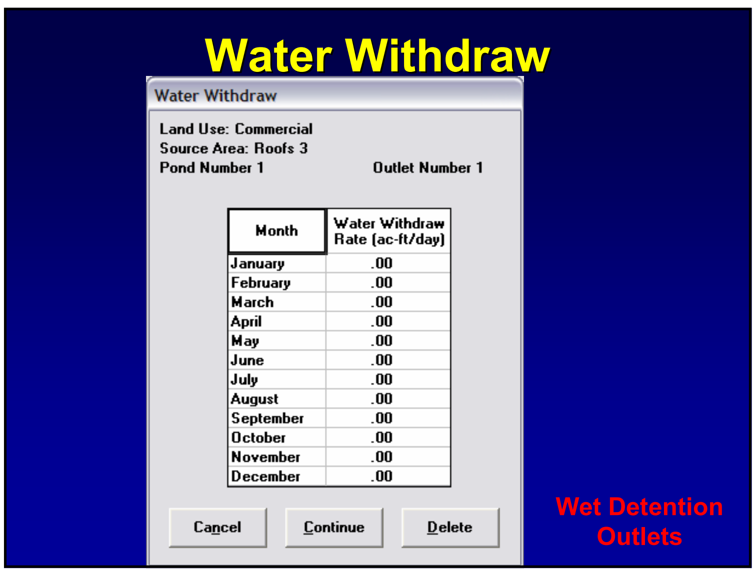

Evaporation
Pond Evaporation
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
Month | Evaporation Rate (in/day)
January .00
February .00
March .00
April .00
May .00
June .00
July .00
August .00
September .00
October .00
November .00
December .00
Cancel
Continue
Delete
Wet Detention Outlets

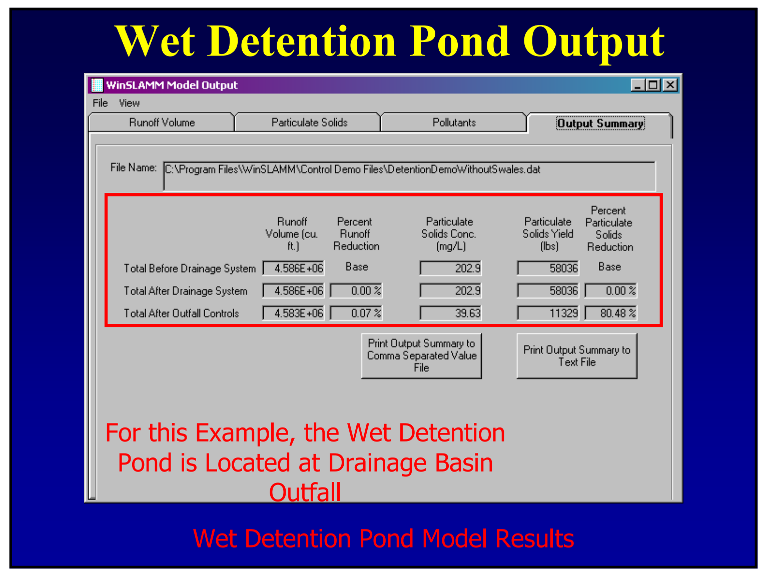

User-Specified Stage Discharge Data
Other Outlet Stage Discharge Data
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
Outflow (cfs)
Row 1
Stage (ft) | Area (acres) | Outflow (cfs)
0 0.00 0.000 0.00
1 1.00 1.000 0.00
2 2.00 2.000 0.00
3 3.00 3.000 0.00
4 4.00 4.000 0.00
5 5.00 5.000 0.00
Use Shift plus the arrow keys to move through the grid
Cancel
Continue
Delete Outlet
Wet Detention Outlets

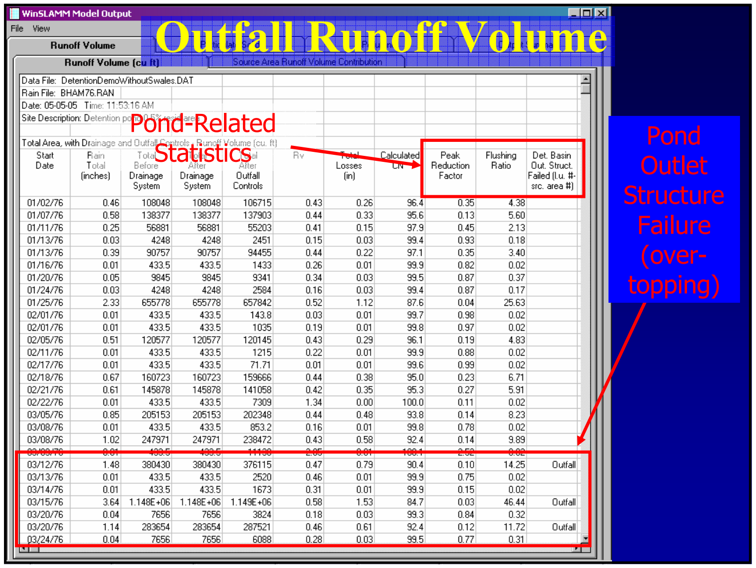

Broad Crested Weir
Broad Crested Weir
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
1. Weir Crest Length (ft) 0
2. Weir Crest Width (ft) 0
3. Discharge Coefficient (English Units) 0
Default Discharge Coefficients
4. Height of Weir Opening (ft) 0
5. Height from Datum to Bottom of Weir Opening (ft) 0
Cancel
Continue
Delete
Wet Detention Outlets

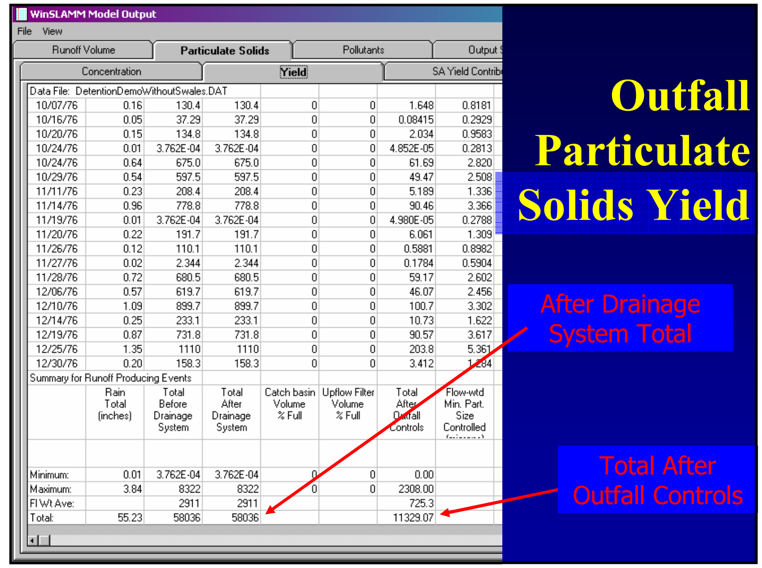

Vertical Stand Pipe
Vertical Stand Pipe Outlet
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
1. Stand pipe diameter (ft) 0
2. Stand pipe height above datum (ft) 0
Cancel
Continue
Delete
Wet Detention Outlets


Orifice Outlet
Orifice Outlet
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
1. Orifice diameter (ft) 0
2. Invert elevation above datum (ft) 0
Cancel
Continue
Delete
Wet Detention Outlets


Water Withdraw
Water Withdraw
Land Use: Commercial
Source Area: Roofs 3
Pond Number 1
Outlet Number 1
Month
Water Withdraw Rate (ac-ft/day)
January .00
February .00
March .00
April .00
May .00
June .00
July .00
August .00
September .00
October .00
November .00
December .00
Cancel
Continue
Delete
Wet Detention Outlets


Wet Detention Pond Output
WinSLAMM Model Output
File View
Runoff Volume
Particulate Solids
Pollutants
Output Summary
File Name: C:\Program Files\WinSLAMM\Control Demo Files\DetentionDemoWithoutSwales.dat
Runoff Volume (cu. ft.)
Percent Runoff Reduction
Particulate Solids Conc. (mg/L)
Particulate Solids Yield (lbs)
Percent Particulate Solids Reduction
Total Before Drainage System 4.586E+06 Base 202.9 58036 Base
Total After Drainage System 4.586E+06 0.00 % 202.9 58036 0.00 %
Total After Outfall Controls 4.583E+06 0.07 % 39.63 11329 80.48 %
Print Output Summary to Comma Separated Value File
Print Output Summary to Text File
For this Example, the Wet Detention Pond is Located at Drainage Basin Outfall
Wet Detention Pond Model Results





Additional Output

- StageOutflowDP.csv
- <filename>. PWB

Detention Pond Source Area Number	Pond Rain Number	Water Rain Depth (in)	Balance Time (Julian Date)	Performan Maximum Pond Stage (ft)	Summary, Minimum Pond Stage (ft)	by Event Inflow Volume (ac-ft)	Event Event Hydr Outflow (ac-ft)	Event Infil Outflow (ac-ft)	Event Evap Outflow (ac-ft)	Event Wtr_Wdrl Outflow (ac-ft)	Event Total Outflow (ac-ft)	Event Flow Balance (ac-ft)	Total Outflow (ac-ft)	Cum Flow Balance (ac-ft)
162	1	0.46	0	3.67	3	0.63	0.6	0	0	0	0.6	0.03	0.6	0.03
162	2	0.58	5	3.57	3.06	0.843	0.834	0	0	0	0.834	0.009	1.434	0.039
162	3	0.25	9	3.38	3.08	0.277	0.249	0	0	0	0.249	0.029	1.683	0.068
162	4	0.03	11	3.14	3.12	0.009	0.013	0	0	0	0.013	-0.004	1.696	0.064
162	5	0.39	11	3.55	3.08	0.476	0.501	0	0	0	0.501	-0.025	2.198	0.039
162	6	0.01	14	3.08	3.03	0	0.026	0	0	0	0.026	-0.026	2.224	0.013
162	7	0.05	18	3.08	3.03	0.029	0.029	0	0	0	0.029	0	2.253	0.013
162	8	0.03	22	3.04	3.03	0.009	0.006	0	0	0	0.006	0.003	2.259	0.016
162	9	2.33	23	4.35	3.03	5.329	5.326	0	0	0	5.326	0.004	7.585	0.02
162	10	0.01	30	3.04	3.03	0	0.002	0	0	0	0.002	-0.002	7.587	0.017
162	11	0.01	30	3.03	3.01	0	0.012	0	0	0	0.012	-0.012	7.599	0.006
162	12	0.51	34	3.57	3.01	0.71	0.694	0	0	0	0.694	0.015	8.293	0.021
162	13	0.01	40	3.04	3.01	0	0.018	0	0	0	0.018	-0.018	8.312	0.003
162	14	0.01	46	3.01	3.01	0	0	0	0	0	0	0	8.312	0.003
162	15	0.67	47	3.94	3.01	1.026	0.991	0	0	0	0.991	0.035	9.303	0.038
162	16	0.61	50	3.86	3.08	0.896	0.8	0	0	0	0.8	0.096	10.103	0.134
162	17	0.01	51	3.25	3	0	0.133	0	0	0	0.133	-0.133	10.236	0.001
162	18	0.85	63	3.78	3	1.28	1.22	0	0	0	1.22	0.06	11.455	0.062
162	19	0.01	66	3.12	3.1	0	0.013	0	0	0	0.013	-0.013	11.468	0.049
162	20	1.02	66	3.94	3.1	1.56	1.402	0	0	0	1.402	0.158	12.87	0.207
162	21	0.01	67	3.38	3.08	0	0.166	0	0	0	0.166	-0.166	13.036	0.041
162	22	1.48	70	4.23	3.08	2.524	2.442	0	0	0	2.442	0.082	15.479	0.123
162	23	0.01	71	3.24	3.15	0	0.046	0	0	0	0.046	-0.046	15.524	0.078
162	24	0.01	72	3.15	3.1	0	0.028	0	0	0	0.028	-0.028	15.552	0.05
162	25	3.64	73	4.82	3.06	11.492	11.511	0	0	0	11.511	-0.019	27.063	0.031
162	26	0.04	78	3.1	3.06	0.022	0.008	0	0	0	0.008	0.014	27.071	0.045