Bob Pitt
Cudworth Professor of Urban Water Systems
Department of Civil, Construction, and Environmental Engineering
University of Alabama
Tuscaloosa, AL USA

B.S. Engineering Science, Humboldt State University, Arcata, CA 1970.
MSCE, San Jose State University, San Jose, CA 1971.
Ph.D., Environmental Engineering, University of Wisconsin, Madison, WI 1987.
35 years working in the area of wet weather flows; effects, sources, and control of stormwater. About 100 publications.

1

2

3

Stormwater Control Categories in the International Stormwater "BMP" Database:

Structural Controls:
- Detention ponds
- Grass filter strips
- Infiltration basins
- Media filters
- Porous pavement
- Retention ponds
- Percolation trenches/wells
- Wetland basins
- Wetland channels/swales
- Hydrodynamic devices

Non-Structural Controls:
- Education practice
- Recycling practice
- Maintenance practice
- Source controls

4

WinSLAMM Treatment Practices

	Infiltration Trenches	Biofiltrat-ion/Rain Gardens	Cisterns/ rain barrels	Wet detention pond	Grass Drainage Swale	Street Cleaning	Catch-basins	Porous Pavement	Drainage Discon-nection
Roof	■	■	■	■					■
Paved parking/storage	■	■	■	■				■	■
Unpaved parking/storage	■	■		■					■
Playgrounds	■	■	■	■				■	■
Drivew ays		■	■					■	■
Sidew alks/w alks		■	■					■	■
Streets/alleys		■				■			
Undeveloped areas	■	■		■					
Small landscaped areas	■	■							
Other pervious areas	■	■		■					
Other impervious areas	■	■	■	■				■	■
Freew ay lanes/shoulders	■	■		■					
Large turf areas	■	■		■					
Large landscaped areas	■	■		■					
Drainage system		■			■		■		
Outfall	■	■		■					

Plus, we now have upflow filters and hydrodynamic devices, and are working on other media filters and combination controls

5

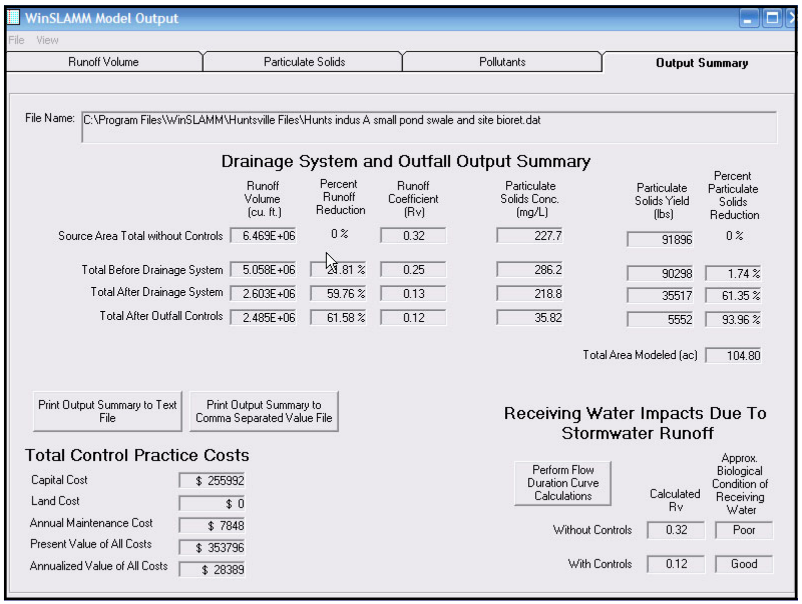
WinSLAMM Summary Data Outputs

- Runoff Volume (ft^3, percent reduction; and Rv, runoff coefficient), particulate solids (lbs and mg/L), for:
  - source area total without controls
  - total before drainage system
  - total after drainage system
  - total after outfall controls

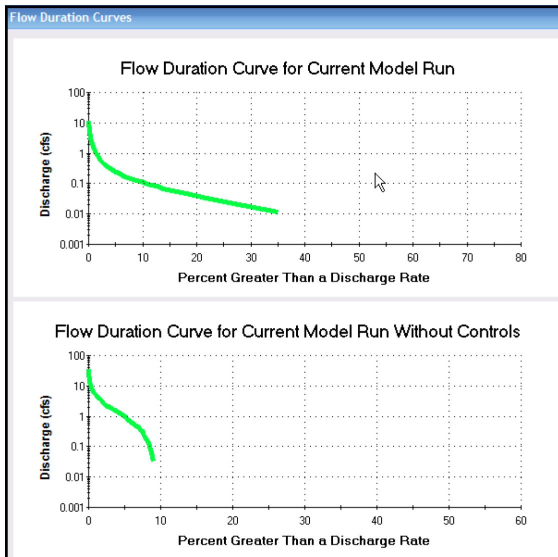
- Total control practice costs:
  - capital costs
  - land cost
  - annual maintenance cost
  - present value of all costs
  - annualized value of all costs

- Receiving water impacts due to stormwater runoff:
  - calculated Rv with and without controls
  - approximate biological condition of receiving water (good, fair, or poor)
  - flow duration curves (probabilities of flow rates for current model run and without controls)

6



7



Flow Duration Data

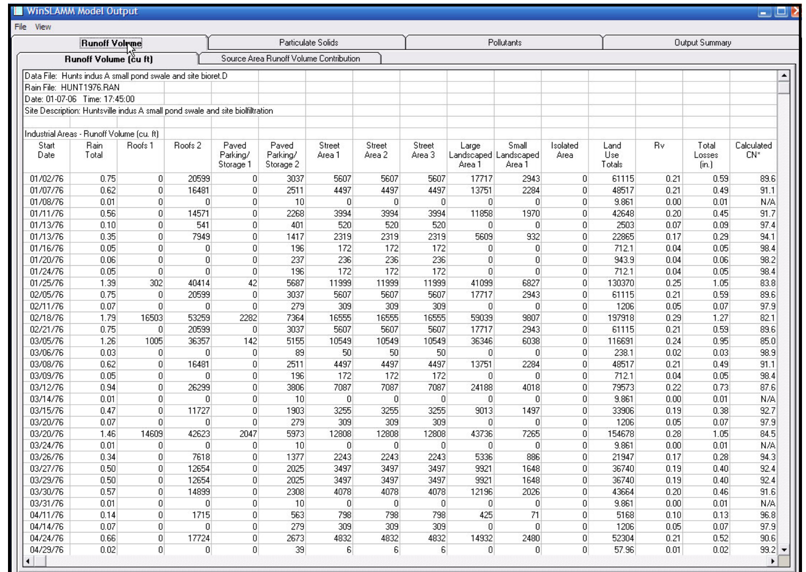
Discharge Greater Than Percent	Flow Rate (cfs) for Current Model Run	Flow Rate (cfs) Without Controls
0	11.56	34.18
0.1	7.168	17.19
1	1.422	4.956
3	0.4162	1.914
5	0.2428	0.9570
10	0.1041	0
20	0.03469	0
30	0.01156	0
40	0	0
50	0	0
60	0	0
70	0	0
80	0	0
90	0	0
100	0	0

8

Detailed Data Outputs for Each Event

Runoff Volume (ft^3), source area contributions, particulate solids (lbs and mg/L), pollutants (lbs and mg/L)
- by source area for each rain event
- land use total
- summary for all rains
- total for land use and for each event
- outfall summary, before and after drainage system and before and after outfall controls
- Rv (runoff volume only)
- total losses (runoff volume only)
- calculated CN (runoff volume only)

9



Start Date	Rain Total	Roofs 1	Roofs 2	Paved Parking/ Storage 1	Paved Parking/ Storage 2	Street Area 1	Street Area 2	Street Area 3	Large Landscaped Area 1	Small Landscaped Area 1	Isolated Area	Land Use Totals	Rv	Total Losses (in.)	Calculated CN*
01/02/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
01/07/76	0.62	0	16481	0	2511	4497	4497	4497	13751	2284	0	48517	0.21	0.49	91.1
01/08/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
01/11/76	0.56	0	14571	0	2268	3994	3994	3994	11858	1970	0	42648	0.20	0.45	91.7
01/13/76	0.10	0	541	0	401	520	520	520	0	0	0	2503	0.07	0.09	97.4
01/13/76	0.35	0	7949	0	1417	2319	2319	2319	5609	932	0	22865	0.17	0.29	94.1
01/16/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
01/20/76	0.06	0	0	0	237	236	236	236	0	0	0	943.9	0.04	0.06	98.2
01/24/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
01/25/76	1.39	302	40414	42	5687	11999	11999	11999	41099	6827	0	130370	0.25	1.05	83.8
02/05/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
02/11/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
02/18/76	1.79	16503	53259	2282	7364	16555	16555	16555	59039	9807	0	197918	0.29	1.27	82.1
02/21/76	0.75	0	20599	0	3037	5607	5607	5607	17717	2943	0	61115	0.21	0.59	89.6
03/05/76	1.26	1005	36357	142	5155	10549	10549	10549	36346	6038	0	116691	0.24	0.95	85.0
03/06/76	0.03	0	0	0	89	50	50	50	0	0	0	238.1	0.02	0.03	98.9
03/08/76	0.62	0	16481	0	2511	4497	4497	4497	13751	2284	0	48517	0.21	0.49	91.1
03/09/76	0.05	0	0	0	196	172	172	172	0	0	0	712.1	0.04	0.05	98.4
03/12/76	0.94	0	26299	0	3806	7087	7087	7087	24188	4018	0	79573	0.22	0.73	87.6
03/14/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
03/15/76	0.47	0	11727	0	1903	3255	3255	3255	9013	1497	0	33906	0.19	0.38	92.7
03/20/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
03/20/76	1.46	14609	42623	2047	5973	12808	12808	12808	43736	7265	0	154678	0.28	1.05	84.5
03/24/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
03/26/76	0.34	0	7618	0	1377	2243	2243	2243	5336	886	0	21947	0.17	0.28	94.3
03/27/76	0.50	0	12654	0	2025	3497	3497	3497	9921	1648	0	36740	0.19	0.40	92.4
03/29/76	0.50	0	12654	0	2025	3497	3497	3497	9921	1648	0	36740	0.19	0.40	92.4
03/30/76	0.57	0	14899	0	2308	4078	4078	4078	12196	2026	0	43664	0.20	0.46	91.6
03/31/76	0.01	0	0	0	10	0	0	0	0	0	0	9.861	0.00	0.01	N/A
04/11/76	0.14	0	1715	0	563	798	798	798	425	71	0	5168	0.10	0.13	96.8
04/14/76	0.07	0	0	0	279	309	309	309	0	0	0	1206	0.05	0.07	97.9
04/24/76	0.66	0	17724	0	2673	4832	4832	4832	14932	2480	0	52304	0.21	0.52	90.6
04/29/76	0.02	0	0	0	39	6	6	6	0	0	0	57.96	0.01	0.02	99.2

10

Additional Details Available for Each Event (with summaries)

rain duration (hours), rain interevent period (days), runoff duration (hours), rain depth (inches), runoff volume (ft^3), Rv, average flow (cfs), peak flow (cfs), suspended solids (lbs and mg/L)

99	12/11/76	09:00	9,111.38	26.00	2.50	31.20	0.75	23,753	0.08
100	12/14/76	23:00	9,114.96	4.00	4.83	4.80	0.16	4,967	0.08
101	12/19/76	23:00	9,119.96	10.00	4.83	12.00	0.72	23,780	0.09
102	12/25/76	05:00	9,125.21	16.00	4.71	19.20	1.14	42,587	0.10
103	12/30/76	14:00	9,130.58	11.00	0.00	13.20	0.39	6,117	0.04

Summary Statistics	Rain Duration (hrs)	Rain Interevent Period(days)	Runoff Duration (hrs)	Rain Depth (in)	Runoff Volume (cf)	R sub v
Number of Events	102	102	102	102	102	102
Total	733.0	332.7	865.2	53.36	2.485E+06	n/a
Equivalent Annual Total	737.4	334.7	870.4	53.68	2.500E+06	n/a
Minimum	1.000	0	1.200	1.000E+07	1.016E-05	1.045E-09
Maximum	33.00	12.67	39.60	3.700	360283	3.193
Average of All Events	7.117	3.231	8.482	0.5181	24363	0.1842
Median	5.000	2.250	6.000	0.3200	7098	0.07178
Stnd. Deviation	6.701	3.202	8.060	0.6754	53229	0.4423
COV	0.9417	0.9912	0.9502	1.304	2.185	2.402

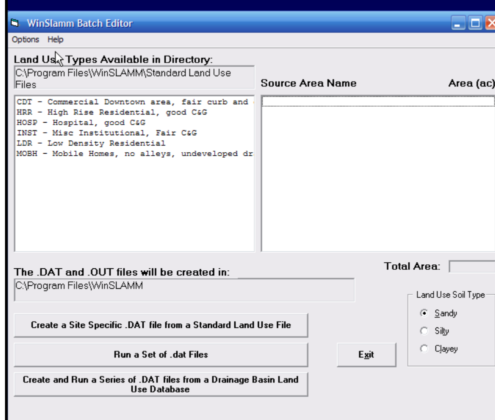
First Rain Date: 01/02/76
Last Rain Date: 12/30/76
Total Time Period (yrs): 0.9940639

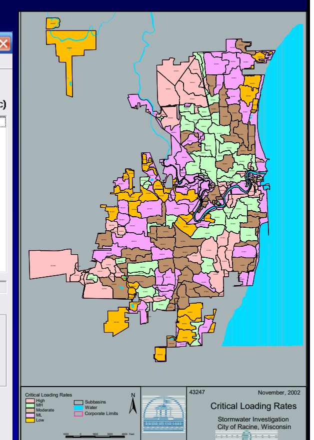
0.08	0.28	6	8	
0.01	0.04	0	0	
0.05	0.37	6	9	
0.09	0.72	15	39	
0.06	0.11	2	1	

Average Flow (cfs)	Peak Flow (cfs)	Suspended Solids Conc(mg/L)	Suspended Solids Mass(lbs)	Pre-Develop. Runoff Volume (cf)
102	102	102	102	Number of Events
n/a	n/a	n/a	5552	Total
n/a	n/a	n/a	5585	Equivalent Annual Total
0.002144	4.657E-10	4.629E-07	3.442E-16	Minimum
2.430	11.66	71.02	1596	Maximum
0.1347	0.6835	7.041	54.43	Average of All Events
0.04042	0.1456	1.644	0.4042	Median
0.3417	1.897	13.89	207.4	Stnd. Deviation
2.537	2.775	1.973	3.809	COV

11

The WinSLAMM batch editor can be used to automatically run a large number of files, usually for integration into a GIS-based map.





12

WinSLAMM can also calculate life-cycle costs and compare different control programs to obtain unit removal costs with the batch processor:

File Name	Runoff Volume (cf)	Partic. Solids Yield (lbs)	Sub Basin Capital Cost	Sub Basin Land Cost	Sub Basin Maint. Cost	Sub Basin Total Annual Cost	Sub Basin Total Present Value Cost	% Part. Solids Reduc.	Cost per lb Sediment Reduced
Cost Example - Base Case No Controls	5246545	37413	0	0	0	0	0	**0%**	**n/a**
Cost Example - G	3136146	22341	119109	0	9100	18658	232515	40%	$ 1.24
Cost Example - P 20 percent	4425257	30761	681686	0	3422	58122	724332	18%	$ 8.74
Cost Example - P 50 percent	3193328	20784	1704215	0	8555	145306	1810829	44%	$ 8.74

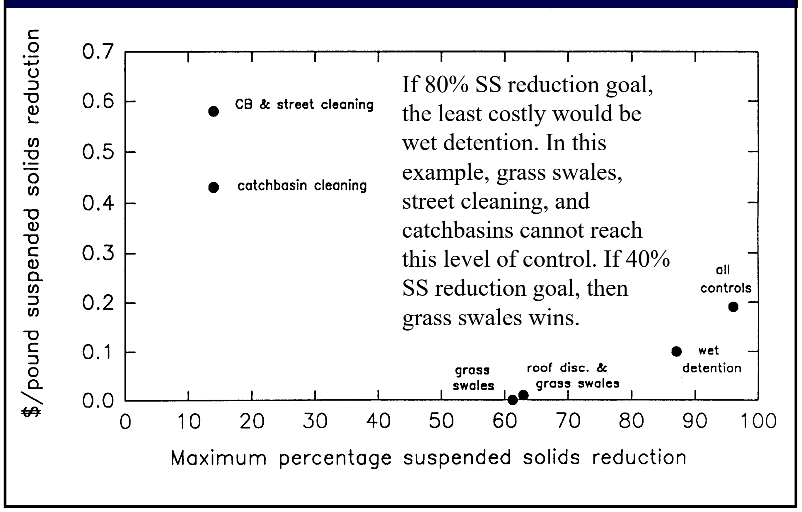
13

Decision Analysis

- With so much data available, and so many options that can be analyzed, how does one select the "best" stormwater control program?
- The least costly that meets the objective?

14

Possible, if only have one numeric standard:



15

If multiple goals, then possibly not as clear and need a more flexible approach. Consider the following example (a conservation design industrial park in Huntsville, AL):

16

This site was divided into four subareas, one area has 13 industrial lots (about 2.6 acres each), plus a large undeveloped area (60.2 acres) and isolated sinkholes (4.6 acres). The developed area is divided into the following:

- Roofs plus paved parking: 20.7 acres
- Streets (1.27 curb-miles): 3.1 acres
- Small landscaped areas (B, or sandy-loam soils, but assumed silty soils due to compaction): 10.0 acres

Conventional drainage system costs (5% over 20 yrs) were estimated to be:

Capital cost of project = $296,400 (2005)
Annual maintenance cost = $2,960/year (2005)
Annual cost of conventional drainage = $26,850 per year

17

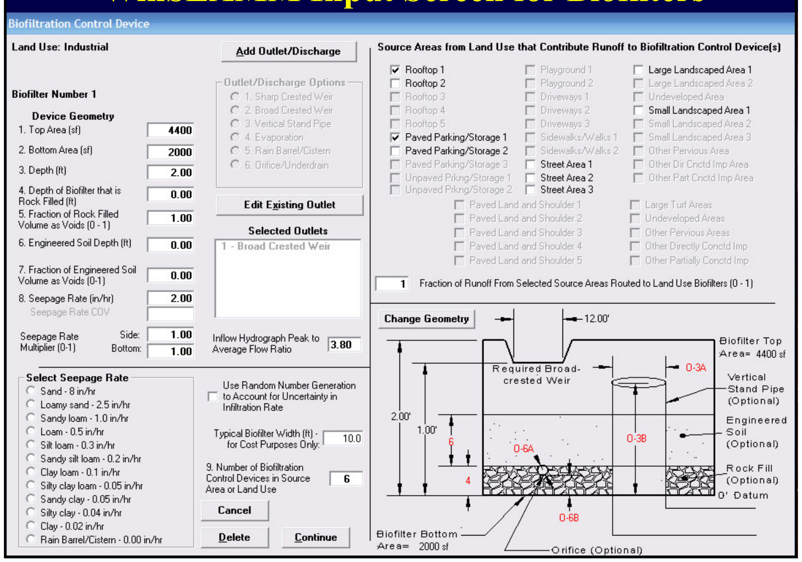
Biofilters to drain site runoff (paved parking and roofs) to regional swales:

- Top area: 4400 ft^2
- Bottom area: 2000 ft^2
- Depth: 2 ft
- Seepage rate: 2 in/hr
- Peak to average flow ratio: 3.8
- Typical width: 10 ft
- Number of biofilters: 13 (one per site)

Parking lot biofilter example, Portland, OR

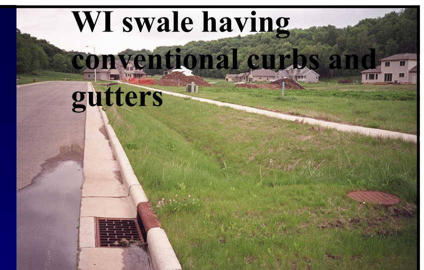
18

WinSLAMM Input Screen for Biofilters



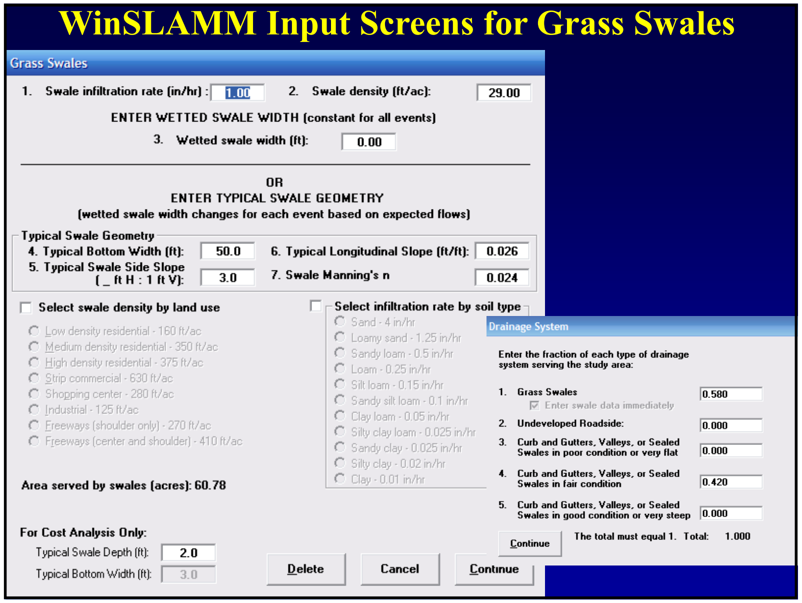
19

Regional swales to collect site runoff and direct to wet detention ponds:

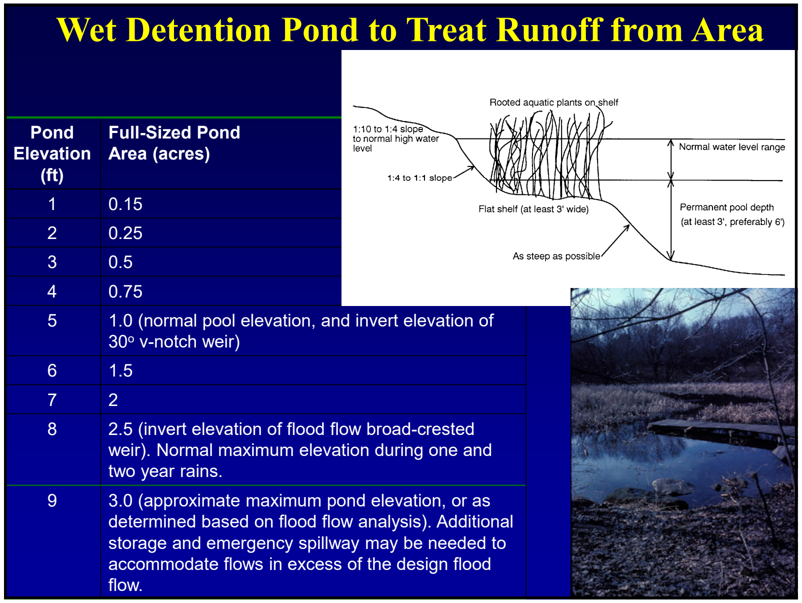


- Length: 1653 ft
- infiltration rate in the swale: 1 in/hr
- swale bottom width: 50 ft
- 3H:1V side slopes
- longitudinal slope: 0.026 ft/ft
- Manning's n roughness coefficient: 0.024
- typical swale depth: 1 ft

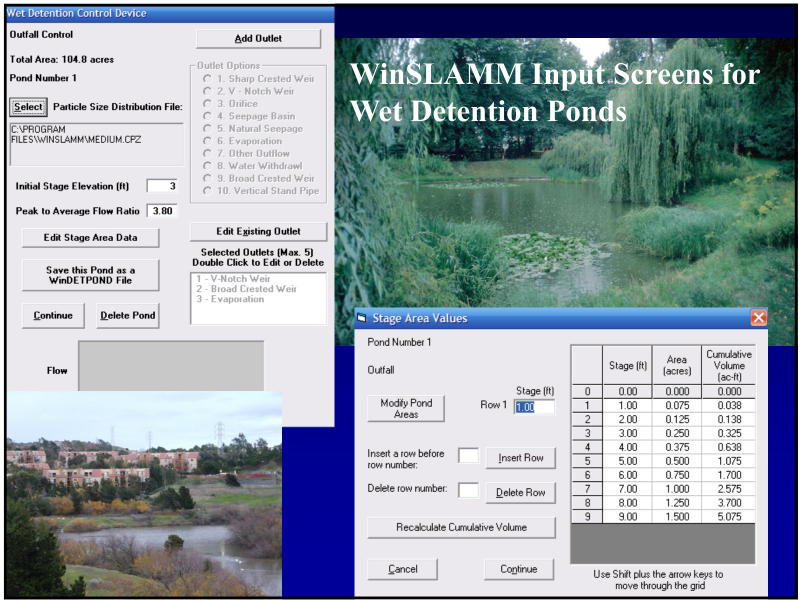
20



21

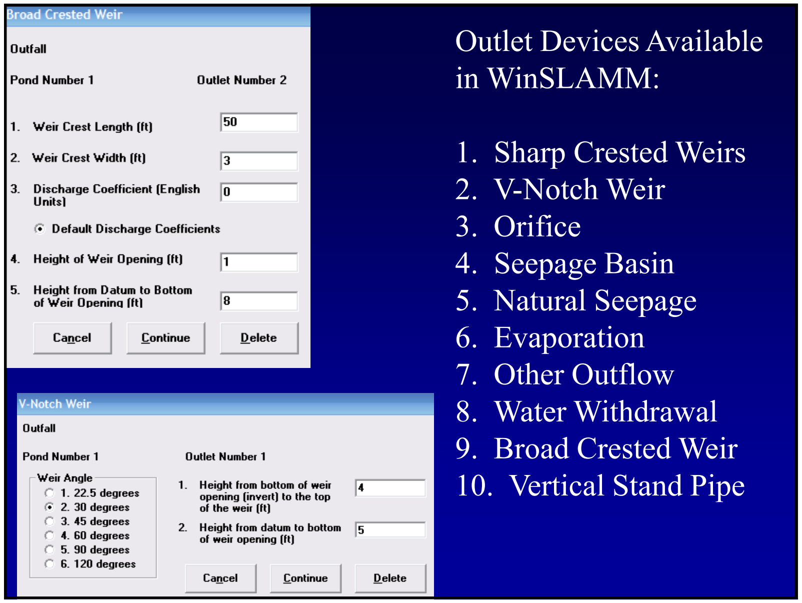


22



	Stage (ft)	Area (acres)	Cumulative Volume (ac-ft)
0	0.00	0.000	0.000
1	1.00	0.075	0.038
2	2.00	0.125	0.138
3	3.00	0.250	0.325
4	4.00	0.375	0.638
5	5.00	0.500	1.075
6	6.00	0.750	1.700
7	7.00	1.000	2.575
8	8.00	1.250	3.700
9	9.00	1.500	5.075

23



24

Batch Processor Data for Combinations of Above Controls

Stormwater Treatment Option	Annual Total SW Treat. Cost ($/yr)	Annual Addit. Drain. System Cost ($/yr)	Total Annual Cost ($/yr)	Land Needs for SW mgt (acres)	Runoff Volume (cf/yr)	Part. Solids Yield (lbs/yr)	Reduc in SS Yield (%)
Base, No Controls	0	64,230	64,230	0	5,600,000	71,375	n/a
Option 1 Pond	19,134	64,230	83,364	4.5	5,507,000	10,192	86
Option 2 Reg. Swale	3,158	26,850	30,008	0	2,926,000	32,231	55
Option 3 Site Biofilter	32,330	37,380	69,710	0	2,705,000	68,890	1
Option 4 Small pond	10,209	64,230	74,439	2.3	5,557,000	19,552	73
Option 5 Pond and reg. swale	22,292	26,850	49,142	4.5	2,844,000	4,133	94
Option 6 Pond, swale, biofilter	54,622	0	54,622	4.5	1,203,000	2,183	97
Option 7 Small pond and swale	13,367	26,850	40,217	2.3	2,887,000	6,937	90
Option 8 Small pond, swale and biofilter	45,698	0	45,698	2.3	1,253,000	4,125	94

25

Additional Batch Processor Data (cont.)

Stormwater Treatment Option	Part. Phos Yield (lbs/yr)	Volum. Runoff Coeff. (Rv) (est. bio. cond.)	% of time flow >1 cfs	% of time flow >10 cfs	SS conc. (mg/L)	Part. P conc. (mg/L)	Zn conc. (µg/L)
Base, No Controls	174	0.29 (poor)	4.5	0.3	204	0.50	359
Option 1 Pond	25	0.29 (poor)	4	0.05	30	0.073	128
Option 2 Reg. Swale	79	0.15 (fair)	2	0.1	178	0.43	390
Option 3 Site Biofilter	172	0.14 (fair)	2	0.2	408	1.0	696
Option 4 Small pond	41	0.29 (poor)	4	0.2	48	0.12	151
Option 5 Pond and reg. swale	10	0.15 (fair)	2	0	23	0.057	203
Option 6 Pond, swale, biofilter	5.5	0.06 (good)	0.5	0	29	0.073	386
Option 7 Small pond and swale	17	0.15 (fair)	2	0.05	39	0.095	220
Option 8 Small pond, swale and biofilter	10	0.07 (good)	0.8	0	53	0.13	390

26

Decision Analysis Approaches

1) Specific criteria or limits that must be met.

It is possible to simply filter out (remove) the options that do not meet all of the absolutely required criteria. If the options remaining are too few, or otherwise not very satisfying, continue to explore additional options. The above examples only considered combinations of 3 types of stormwater control devices, for example. There are many others that can also be explored. If the options that meet the absolute criteria look interesting and encouraging, then continue.

27

Control Options Meeting 80% SS Reduction Requirement, Ranked by Cost

Stormwater Treatment Option	Total Annual Cost ($/yr)	Reduction in SS Yield (%)	Meet 80% particulate solids reduction goal?	Rank based on annual cost
Option 1 Pond	83,364	***86***	Yes	5
Option 2 Regional Swale	30,008	55	No	n/a
Option 3 Site Biofilter	69,710	1	No	n/a
Option 4 Half-sized pond	74,439	73	No	n/a
Option 5 Pond and reg. swale	49,142	***94***	Yes	3
Option 6 Pond, reg. swale and biofilter	54,622	***97***	Yes	4
Option 7 Small pond and reg. swale	40,217	***90***	Yes	1
Option 8 Small pond, reg. swale and biofilter	45,698	***94***	Yes	2

28

2) Goals that are not absolute (based on methods developed by Keeney, R.L. and H. Raiffa. 1976. *Decision Analysis with Multiple Conflicting Objectives*. John Wiley & Sons. New York.)

Utility curves and tradeoffs can be developed for the remaining attributes, after all the absolutely required goals are met. The above example includes attributes of several different types:

- costs
- land requirements
- runoff volume (volumes, habitat responses, and rates)
- particulate solids (reductions, yields and concentrations)
- particulate phosphorus (reductions, yields and concentrations)
- total zinc (reductions, yields and concentrations)

29

Attribute Value Ranges, plus Example Ranks and Trade-offs (ranks and trade-offs could vary for different interested parties)

Attribute	Range of attribute value for acceptable options	Attribute ranks for selection (after absolute goals are met)	Trade-offs between remaining attributes
Total annual cost ($/year)	$40,217 to 83,364	2	0.20
Land needs (acres)	2.3 to 4.5 acres	5	0.08
Rv	0.06 to 0.29	1	0.30
% of time flow >1 cfs	0.5 to 4 %	7	0.05
% of time flow >10 cfs	0 to 0.05 %	3	0.18
Particulate solids yield (lbs/yr)	2,183 to 10,192 lbs/yr	6	0.07
Part. Phosphorus yield (lbs/yr)	5.5 to 25 lbs/yr	4	0.12
			Sum = 1.0

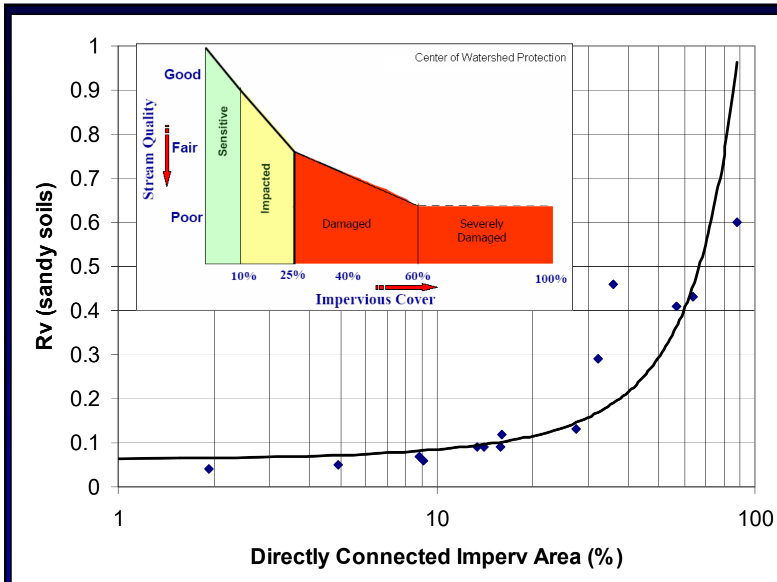
30

Utility Curves for Different Attributes (technically based, would not vary for different interested parties)

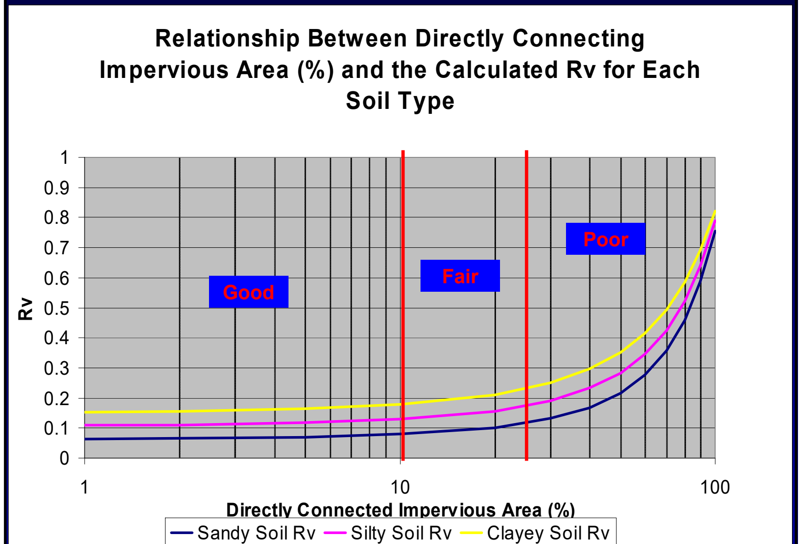
- Volumetric runoff coefficient (Rv) as an indicator of habitat quality and aquatic biology stress:

Attribute Value	Expected Habitat Condition	Utility Value
<0.1	Good	1.0
0.1 to 0.25	Fair	0.75
0.26 to 0.50	Poor	0.25
0.51 to 1.0	Really lousy	0

31



32



33

Example Utility Values for Other Attributes:

- Total annual cost: straight line, with $83,364 = 0 and $40,217 = 1.0.

- % of time flow >10 cfs — Utility value

% of time flow >10 cfs	Utility value
<0.05	1.0
0.05 - 1	0.75
1.1 – 2.5	0.25
>2.5	0

34

Example Utility Values for Other Attributes (cont):

- Part. Phosphorus yield (lbs/yr): straight line, with 25 lbs/yr = 0 and 5.5 lbs/yr = 1.0

- Land needs (acres): straight line, with 4.5 acres = 0 and 2.3 acres = 1.0

- Particulate solids yield (lbs/yr): straight line, with 10,192 lbs/yr = 0 and 2,183 lbs/yr = 1.0

- % of time flow >1 cfs — Utility value

% of time flow >1 cfs	Utility value
<1	1.0
1 – 3	0.75
3.1 – 10	0.25
>10	0

35

Attribute Values and Associated Utilities for Example

Stormwater Control Option	Total Annual Cost ($/yr)	Cost utility	Land Needs for SW mgt (acres)	Land utility	Part. Solids Yield (lbs/yr)	Part. Solids utility	Part. Phos. Yield (lbs/yr)	Phos utility
Tradeoff Value		**0.20**		**0.08**		**0.07**		**0.12**
Option 1 Pond	83,364	0	4.5	0	10,192	0	25	0
Option 5 Pond and reg. swale	49,142	0.79	4.5	0	4,133	0.76	10	0.77
Option 6 Pond, reg. swale and biofilter	54,622	0.67	4.5	0	2,183	1.0	5.5	1.0
Option 7 Small pond and reg. swale	40,217	1	2.3	1	6,937	0.41	17	0.41
Option 8 Small pond, reg. swale and biofilter	45,698	0.87	2.3	1	4,125	0.76	10	0.77

36

Attribute Values and Associated Utilities for Example (cont.)

Stormwater Control Option	Volumetric Runoff Coefficient (Rv)	Rv utility	% of time flow >1 cfs	Mod flow utility	% of time flow >10 cfs	High flow utility
Tradeoff Value		**0.30**		**0.05**		**0.18**
Option 1 Pond	0.29	0.25	4	0.25	0.05	0.75
Option 5 Pond and reg. swale	0.15	0.75	2	0.75	0	1.0
Option 6 Pond, reg. swale and biofilter	0.06	1.0	0.5	1.0	0	1.0
Option 7 Small pond and reg. swale	0.15	0.75	2	0.75	0.05	0.75
Option 8 Small pond, reg. swale and biofilter	0.07	1.0	0.8	1.0	0	1.0

Calculation of Factors for Each Option

(Attribute Utility times Attribute Trade-off)

Stormwater Control Option	Cost utility	Cost factor	Land utility	Land factor	Part. utility	Part. factor	Phos. utility	Phos factor
Tradeoff Value	**0.20**		**0.08**		**0.07**		**0.12**	
Option 1 Pond	0	0	0	0	0	0	0	0
Option 5 Pond and reg. swale	0.79	0.158	0	0	0.76	0.053	0.77	0.092
Option 6 Pond, reg. swale and biofilter	0.67	0.134	0	0	1.0	0.07	1.0	0.12
Option 7 Small pond and reg. swale	1	0.20	1	0.08	0.41	0.029	0.41	0.049
Option 8 Small pond, reg. swale and biofilter	0.87	0.174	1	0.08	0.76	0.053	0.77	0.092

Calculation of Factors for Each Option (cont.), Sum of Factors, and Overall Rank

Stormwater Control Option	Rv utility	Rv factor	Mod flow utility	Mod flow factor	High flow utility	High flow factor	Sum of factors	Over-all Rank
Tradeoff Value	**0.30**		**0.05**		**0.18**			
Option 1 Pond	0.25	0.075	0.25	0.0125	0.75	0.135	0.2225	5
Option 5 Pond and reg. swale	0.75	0.225	0.75	0.0375	1.0	0.18	0.7455	4
Option 6 Pond, reg. swale and biofilter	1.0	0.30	1.0	0.05	1.0	0.18	0.8540	2
Option 7 Small pond and reg. swale	0.75	0.225	0.75	0.0375	0.75	0.135	0.7555	3
Option 8 Small pond, reg. swale and biofilter	1.0	0.30	1.0	0.05	1.0	0.18	0.9290	1

Conclusions

- Calibrated and verified stormwater models can be used to develop a great deal of information concerning many different stormwater management options.
- Regulations and criteria also need to have different formats to acknowledge site specific problems and objectives.
- The use of clear and flexible decision analysis techniques, as outlined in this presentation, is therefore important when selecting the most appropriate stormwater control program for a site.

Acknowledgements

The authors would like to acknowledge the support of the Tennessee Valley Authority (TVA), Economic Development Technical Services, and the Center for Economic Development and Resource Stewardship (CEDARS) of Nashville, TN, which has allowed us to develop extensions to WinSLAMM to enable the use of a decision analysis framework in evaluating alternative stormwater management options. The Stormwater Management Authority of Jefferson County, AL, is also acknowledged for their recent support that enabled the cost analyses to be added to WinSLAMM