4

Using Decision Analyses to Select an Urban Runoff Control Program

Robert E. Pitt and John Voorhees

Decision analysis techniques may be used as an important guide in selecting an urban runoff control program. Decision analysis is a systematic procedure that enables one to study the trade-offs among multiple and usually conflicting program objectives. An alternative procedure is to separately determine the programs necessary to meet each objective and to use the least costly program that satisfies all the identified critical objectives. This is an acceptable procedure some of the time, but it may not result in the most cost-effective program, especially when multiple objectives need to be considered.

Decision analysis considers the partial fulfillment of all the objectives. It translates these into their relative worth to the decision-maker or other interested parties. This chapter describes the types of output information calculated by WinSLAMM, the Source Loading and Management Model, and how it can be used in decision analysis procedures of varying complexities. Prior descriptions of WinSLAMM have been presented in this conference series and in other publications (Pitt 1986; 1997; 1999; Pitt and Voorhees 2002 for example). The model web site also contains further model descriptions and references (http://www.winslamm.com/).

CHI *Contemporary Modeling of Urban Water Systems*, Monograph 15. James, Irvine, McBean, Pitt and Wright, Eds. ISBN 0-9736716-3-7. © CHI 2007. www.computationalhydraulics.com

4.1 WinSLAMM Data Outputs

Calculated outputs from WinSLAMM are organized in several tiers. For most of the output options, a summary table is presented, unless one of the one-line per event summary options is selected. The data in the summary table includes the following information:

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)

Most of this information is included on the first output page, while the flow duration curves are included on an optional second page (Figures 4.1 and 4.2).

The tabs along the top of the summary table enable additional information to be displayed, such as:

Detailed Data Outputs:

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

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

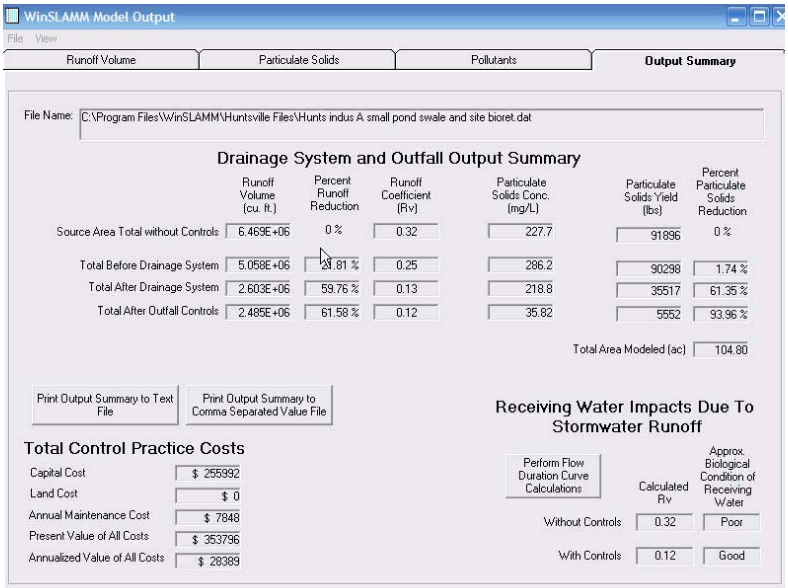


Figure 4.1 Summary WinSLAMM screen.

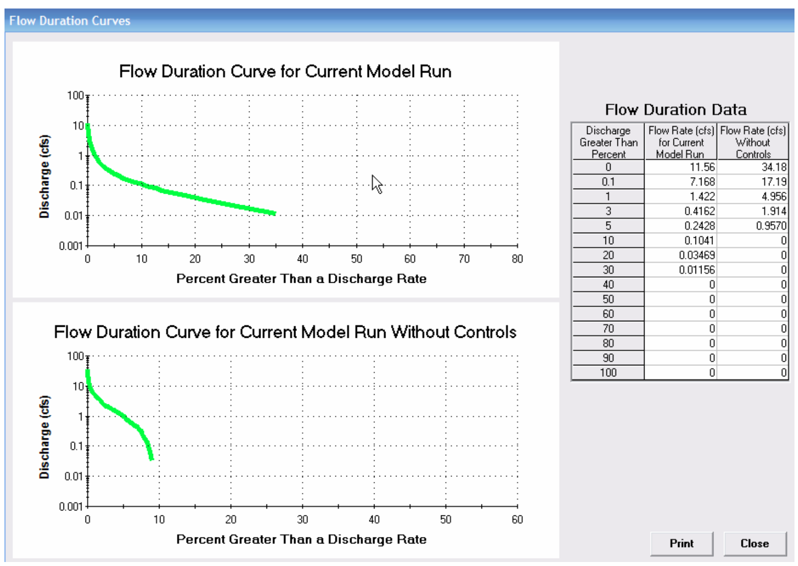
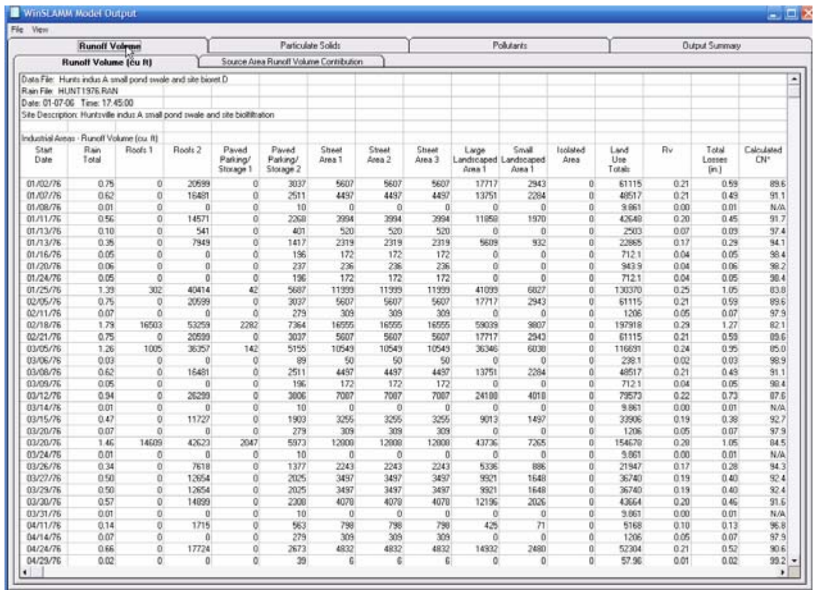


Figure 4.2 Summary flow-duration WinSLAMM output.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007. www.computationalhydraulics.com

- 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)

An example of the detailed data for runoff volume is shown in Figure 4.3.



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	24108	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	154670	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	14099	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

Figure 4.3 Runoff volume detailed WinSLAMM output.

Another group of output options are "one-line per event" data sets saved in a csv file format that can be opened in a spreadsheet for further data manipulation. These files can also be examined by selecting the "ulilities/view file/use notepad or use Windows view", pull down menu option from the main WinSLAMM page. The data presented in these files includes "One-Line per Event Runoff Details," with data for each event and statistical summaries for all events (number of events, total, equivalent annual total, minimum, maximum, average of all events, median, standard deviation, and coefficient of variation):

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

- 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)

Figure 4.4 is a composite of two partial screen shots showing the two portions of the bottom section (split) of an example *.csv file for the "one-line per event runoff and flow summary" output option (selected from the "file/output options/output format options" drop down menu from the main WinSLAMM screen).

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

Figure 4.4 Screen shots of portions of detailed "One Line per Event Summary" *.csv WinSLAMM output.

As in most models, there is a great deal of information calculated by WinSLAMM during an analysis for a site and stormwater management alternative. In most cases, just a few of the values presented on the main

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

summary screen are sufficient for quick comparisons. These include the overall percent runoff and particulate solids reductions, the final Rv and runoff volume, and the resulting particulate solids yields and concentrations. Recent enhancements to WinSLAMM also now enable the costs and the expected habitat conditions of the receiving waters to be compared, in addition to flow-duration information. Cost data were summarized from several studies, including those by APWA 1992, Brown and Schueler 1997, Frank 1989, Heaney, *et al*. 2002, Muthukrishnan, *et al*. 2006, Sample, *et al.* 2003, SEWRPC 1991, Wiegand, *et al*. 1986, and Wossink and Hunt 2003.

The batch processor option of WinSLAMM is frequently used to automatically examine all the land use and stormwater control options for a relatively large area, such as for city-wide analysis, especially when used in conjunction with GIS data.

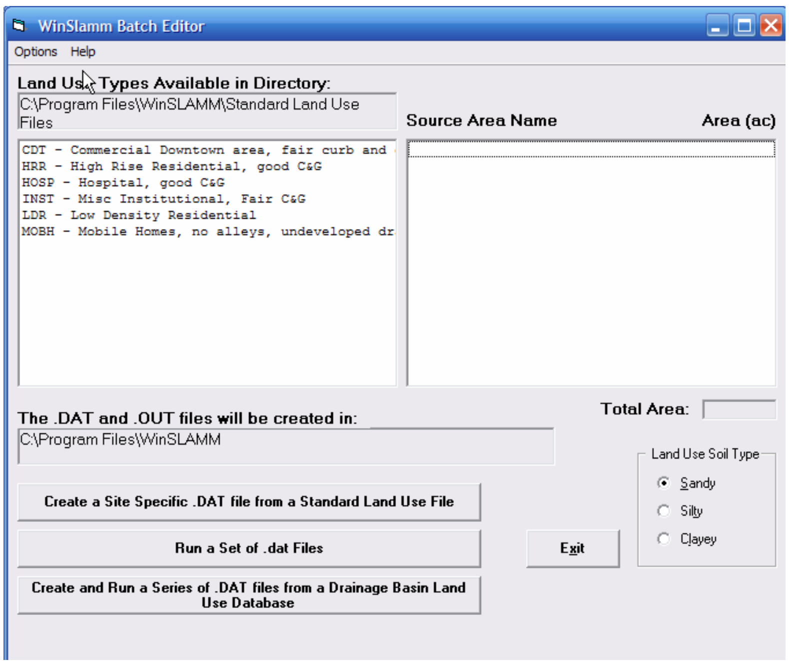


Figure 4.5 WinSLAMM batch editor setup screen.

Figure 4.5 is a screen shot of the main batch processor screen that is used to select the standard land use files for a specific area being examined, along with the areas, and soils. This screen is also used to select a set of *.dat files that can be run in batch mode to compare multiple stormwater controls for

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

the same site, as described later. In that configuration, the first *.dat file listed is the "base" condition that is compared to the other files.

Figure 4.6 is a map showing a GIS representation of a WinSLAMM batch processor run for the City of Racine in Wisconsin, highlighting critical loading rates, prepared by Earth Tech. This is a very powerful tool that can be used to visualize critical areas needing control. Alternative analyses are also usually conducted to examine different stormwater control practices. Detailed discussions of how WinSLAMM and GIS are used together are in the model documentation.

Recent enhancements to WinSLAMM allow the batch processor to be used to enable comparisons of different stormwater control programs for a single site. As noted above, there are many stormwater factors calculated for each analysis, and a stormwater manager may have difficulty comparing the different alternatives. Table 4.1 (appended at the end of this chapter) is a csv output file (only showing a few of the calculated factors, as an example), comparing five alternative stormwater management programs to a base condition for a single 65 ac (26 ha) mixed land use catchment area, that was calculated with the WinSLAMM batch processor. The different stormwater management programs considered in this example include: grass swales (G), wet detention ponds (W), and two levels of porous pavement (P), plus a combination of grass swales and a smaller wet detention pond. WinSLAMM can evaluate many other alternative controls, and combinations, but this is only shown as a short example of the output table.

This table doesn't show the example base costs associated with a conventional storm drainage system, so the costs shown above would need to be further adjusted. If at least 80% particulate solids reductions were needed (a typical goal for some programs, including those in Massachusetts and Wisconsin for new developments), then only the last two options meet this goal. The last option, the use of grass swales plus a smaller wet detention pond, is the least costly of these two options. This option also has the benefit of significant runoff volume reductions, compared to the base condition.

The above example illustrates a relatively straight-forward approach in selecting the "best" stormwater control program for this site. However, it may be desirable to also consider other attributes associated with the different options. The following discussion is based on material originally presented by Pitt (1979) and is a hypothetical example application of a decision analysis procedure that considers conflicting and multiple objectives applied to selecting a street cleaning program as part of a stormwater management plan.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

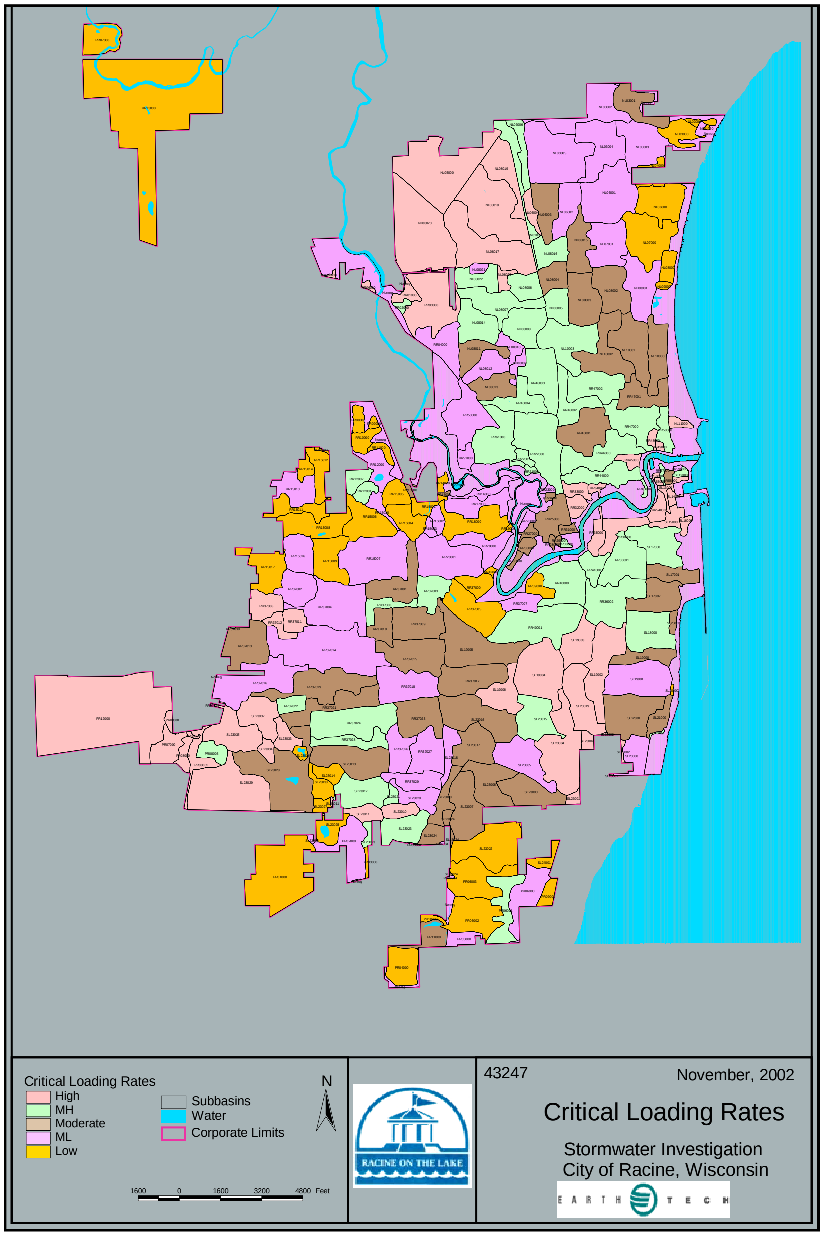


Figure 4.6 Example GIS output using WinSLAMM data for Racine, WI.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

4.2 Decision Analysis with Multiple Conflicting Objectives

The following is a hypothetical example with fictional values that illustrates the basic elements of decision analysis to select a preferred street cleaning program from a list of alternatives. The objectives of such a program might include maximizing air, water, and aesthetic quality and minimizing the noise and cost of street cleaning operations. Unfortunately, some objectives (such as cost and environmental quality) tend to conflict with each other. The decision makers must choose the alternative that makes the best tradeoffs among the competing objectives.

The techniques of decision analysis, as described by Kenney and Raiffa (1976), are used to aid in the selection process. This is an excellent reference and contains detailed discussions on decision analysis theory and should be consulted for further information. This method uses utility curves and trade-offs between the different attributes. The utility curves should be based on data and not reflect personal attitudes or objectives, while the trade-offs between the attributes reflect different viewpoints. This decision analysis method is therefore a powerful tool that can be used to compare the rankings of alternative stormwater management programs for different groups. In many cases, final rankings may be similar amongst the interested parties, although their specific reasons vary. This tool also completely documents the decision making process, enabling full disclosure. This feature is probably more important for site selection projects for power plants than for small public works projects, but this level of documentation is still critical when public policy and taxes are concerned.

The detail and depth of understanding needed to fully use this decision analysis methodology forces the user to acquire a deeper understanding of the problem being solved. This can be both an advantage and a disadvantage. Multiple experts are usually needed to develop the utility curves, but they can hopefully be used for similar projects in the same region sharing similar problems and objectives. The trade-offs are dependent on the mix of decision makers and stakeholders involved in the process, and are expected to change with time. The depth of knowledge obtained and full documentation always is a positive aspect of these methods, but the required resources to fully implement the system can be an insurmountable obstacle to smaller communities. However, sensitivity analyses can be used to focus resources only on those aspects of greatest importance.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

The first step in applying decision analysis techniques consists of defining the alternatives and quantitative measures (attributes) for the objectives. How well each alternative achieves the objective is also determined. In this hypothetical example, five example attributes were chosen to reflect widely different considerations in deciding which street cleaning program to select. These attributes, their units of measurement, and the associated ranges are shown in Table 4.2.

Table 4.2 Decision analysis attributes, measures, and ranges of values.

Attribute Description		Units of Measurements	Range of Values Best	Worst
1.	Aesthetics (residual loading)	lb/curb-mile	68	525
2.	Annual cost	$/curb-mile/year	350	3600
3.	Air quality (particulates)	$\mu g/m^3$	100	200
4.	Water quality (total dissolved solids)	mg/L	200	1500
5.	Noise Level	dB_A	65	82

The second step consists in describing each alternative in terms of the attributes defined in step one. The value of each attribute for each of the alternatives must be determined. The attribute levels may be described either in terms of probabilistic forecasts, where uncertainties are quantified, or by point estimates representing the level expected for each attribute. In this example, five alternative street cleaning programs are considered, and point estimates are made for each attribute. The street cleaning programs consist of combinations of equipment types and their frequencies of use. These alternatives are defined in Table 4.3. Point estimates, for illustrative purposes, are used for this example and summarized in Table 4.4. This table shows that all attributes, except cost, are better than, or equal for alternative two.

Table 4.3 Definition of alternatives.

Alternative	Description
1	Conventional mechanical street cleaner, one pass every week
2	Conventional mechanical street cleaner, one pass every weekday
3	Vacuumized street cleaner, one pass every week
4	Street flusher, one pass every week
5	Conventional mechanical street cleaner followed by a flusher, one pass every week

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

The third step consists of quantifying the preference and tradeoffs for the various attribute levels. The concepts of utility theory provide a consistent scale to quantify how much one gives up when choosing one attribute over another.

Table 4.4 Estimated attribute levels for each alternative (fictional).

Alternatives	Aesthetics (lb total solids/ curb-mile)	Annual Cost ($/curb-mile/ year)	Air Quality (µg susp partic/m^3)	Water Quality (mg TDS/L)	Noise Level (dB$_A$/pass)
1	340	700	200	1000	65
2	68	3600	120	200	65
3	470	700	150	1400	70
4	525	350	200	1500	80
5	150	1000	150	400	82

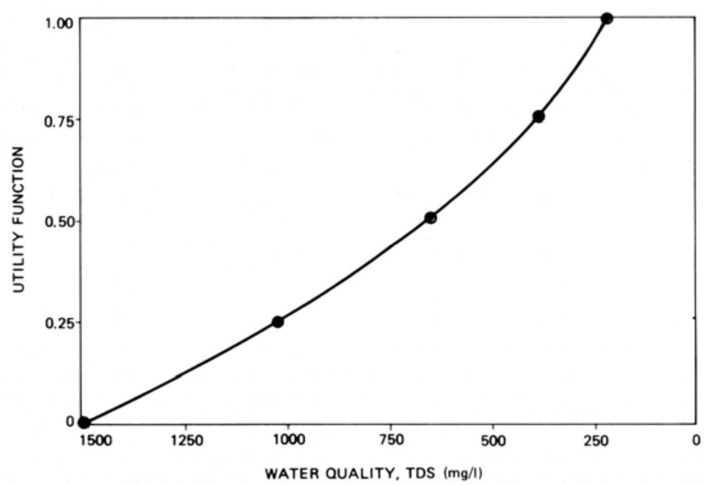


Figure 4.7 Example utility function for a water quality attribute (Pitt 1979).

Utility curves are first assessed for the individual attributes. These curves quantify the preferences that exist for the total range of each attribute. They also quantify attitudes toward risk. This is important when alternatives yield uncertain consequences. The curves are theoretically defined from a series of questions that determine points on each of the utility curves. The most

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

preferred point is defined as having a utility value of 1.00 and the least preferred point a utility value of 0.00. The utility assessments establish where the intermediate points fall on the utility scale. An example of a utility function for a water quality attribute is shown in Figure 4.7. Each of the other attributes can be assessed on a similar curve.

The formal development of a utility curve can be determined through a series or questions. In many cases, the shape of the utility curve can be reasonably determined through direct knowledge of the attribute. In other cases, it is suitable to assume a linear relationship between the maximum and minimum attribute levels. The utility curves are technology-based and reflect how different levels of an attribute relate to other levels of the same attribute. As an example, further degradation of a receiving water is unlikely after the dissolved oxygen levels reach anaerobic conditions, but increasing stress occurs as that level is approached. This information can be used to determine the shape of the utility curve. In the example of cost, spending twice as much is probably twice as “bad,” reflecting a straight-line relationship between cost and utility.

The questions that can be used to define the individual attribute utility curves consist of asking the decision maker to choose one of two possible situations. In this example, one situation is uncertain and describes a 50-50 chance for a successful outcome of one of the two possible levels of the attribute; the second situation occurs with certainty and consists of achieving a specified level of the attribute. The level of the attribute in the second situation is somewhere between the two equally possible levels of the first situation. The utility assessment for each point on the curve is determined by the attribute level in the second situation, where the decision maker is indifferent to the choice of the two situations. Since, at the point of indifference, each choice is equally acceptable, the expected utility values of the two situations must be equal, and a point of the utility curve can be established.

Consider for example a situation with a 50-50 chance of achieving water quality at either 1,500 or 200 mg TDS/L. What level of water quality (if known with certainty) would be equally preferable to the uncertain situation above? After a series of trial choices, it was determined that a water quality level of 650 mg TDS/L would be indifferent to the uncertain situation. Again, this would be based on knowledge of the attribute, such as how the risk varies for different concentrations, such as how the toxicity response varied for different conditions during controlled toxicity tests. Thus, the utility of a water quality level of 650 mg/L must equal the expected utility of the uncertain situation with a 50-50 chance of achieving either 1500 or 200

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

mg/L. Since the utility values of 1,500 and 200 mg/L are known to be 0.00 and 1.00 respectively, the expected utility of the first situation can be calculated to be 0.5 (0) + 0.5 (1.00) = 0.5. Therefore, the utility value of 650 mg/L must equal 0.5. This point is plotted on Figure 4.7. Similar questions can be used to define the other points shown on Figure 4.7.

The trade-offs that exist among the attributes are established next. While the utility curves should be based on scientific knowledge, the trade-offs should reflect the different attitudes of the different interested parties. Different trade-offs will result in possibly different final rankings for the different street cleaning programs for the different groups. The determination of the trade-offs is accomplished by first ranking the attributes in order of importance. The trade-offs result in values given to each attribute, such that the sums of the values equal one. The simplest approach is to request the decision makers to rank the attributes and arbitrarily assign trade-offs such that the trade-off values equal one.

The rank order and trade-off values can be theoretically established by answering the following types of questions: "Given that all attributes are at their worst levels, which attribute would one first move to its best level?" The question is repeated to determine which attribute would next be moved to its best level. This process is continued until the complete rank order of the attributes is established. In this example, the following rank order of the attributes was established:

- Water Quality
- Annual Cost
- Air Quality
- Aesthetics
- Noise Level

The trade-offs among attributes are addressed next. This can be accomplished by considering the choice between two possible situations for a pair of attributes. Both situations are certain but consist of different levels for the pair of attributes. The levels for the pair of attributes are in the form of "worst, best" compared with "?,worst." The unknown attribute level is established after repeated trials until the decision maker is indifferent to the two situations. Considering the water quality/annual cost attribute pair, the two situations would be "1500 mg/L, $350" and "?, $3600." In this situation, we are determining how much people would expect the water quality to improve with an increase in cost. In this hypothetical example, if the water quality were 650 mg/l, the second situation would be indifferent to the first situation. Similar questions were asked for other pairs of attributes, determining how much the attribute level was expected to improve with

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

increasing cost. These hypothetical results are summarized below, using the notation (≅) to indicate indifference.

• (Water quality, annual cost) = (1500 mg/L, \$350) ≅ (650 mg/L, \$3600)
• (Annual cost, noise level) = (\$3600, 65 dbA/pass) ≅ (\$3000, 82 dBA/pass)
• (Annual cost, aesthetics) = (\$3600, 68 lb/mile) ≅ (\$3000, 525 lb/mile)
• (Annul cost, air quality) = (\$3600, 100 µg/m3) ≅ (\$1500, 200 µg/m3)

The above information concerning the preferences for achieving levels for the attributes can be used to establish a multiattribute utility function. A multiattribute utility function is a mathematical expression that summarizes attribute utility functions and the trade-offs between the attributes. The mathematical form of the multiattribute utility function is established by verifying several reasonable assumptions regarding preferences. To illustrate, an additive multiattribute utility function is used. It is represented as:

$$u(x_1, x_2, x_3, x_4, x_5) = \sum_{i=1}^{5} k_i v_i(x_i) \tag{4.1}$$

where:

x_i = the level of the ith (i-1,5) attributes,
$u_i(x_i)$ = the utility of the ith individual attribute,
v = the multiattribute utility,
k_i = trade-off constant for ith attribute, and

$$\sum_{i=1}^{5} k_i = 1$$

The trade-off constants in Equation 4.1, k_i, are calculated based on the individual attribute utility functions and indifference points for pairs of attributes. These individual trade-off constants can be calculated as shown below, based on the equivalent pairings from the preceding questions. Although the utility functions actually assessed would normally be used to illustrate this example, it is assumed that each of the individual attribute utility functions is linear in this example. Keeney and Raiffa (1976) illustrate many other examples for these calculations for other conditions.

The multiattribute utility values for assessed points of indifference between pairs of attributes must be equal because they are equally preferable. Holding all attributes not considered in the pair trade-offs at their worst level so that their utility value is zero, the k_i values (where the

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.

subscript *i* is for each attribute shown in Table 4.4) in Equation 4.1 can be calculated. The ratio between the trade-off constants for any two attributes (such as k_2/k_4, the ratio of the cost and water quality trade-off constants) is therefore equal to the utility value of the attributes that is the denominator for this worst-case comparison.

As an example, the water quality attribute value of 650 mg/L relates to the worst case cost attribute value of $3600. The corresponding utility value for this water quality attribute value is 0.65, the ratio between the cost and water quality trade-off constant (k_2/k_4). The following relationships show the ratios of the other trade-off values:

$$\frac{k_2}{k_4} = u_4(650\, mg/L) = 0.65 \tag{4.2}$$

$$\frac{k_5}{k_2} = u_2(\$3000) = 0.23 \tag{4.3}$$

$$\frac{k_1}{k_2} = u_2(\$3000) = 0.23 \tag{4.4}$$

$$\frac{k_3}{k_2} = u_2(\$1500) = 0.46 \tag{4.5}$$

Using Equation 4.2:

$$\sum_{i=1}^{5} k_i = (0.23 + 1.00 + 0.46 + 1.54 + 0.23)k_2 = 1 \tag{4.6}$$

$k_2 = 0.29$ for the annual cost attribute (4.7)

Therefore:

$k_1 = 0.07$ the aesthetics attribute (4.8)
$k_3 = 0.13$ for the air quality attribute (4.9)
$k_4 = 0.42$ for the water quality attribute (4.10)
$k_5 = 0.07$ for the noise level attribute (4.11)

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

The above trade-off constant values, the individual attribute utility functions, and the original equation completely define the multiattribute utility function.

The fourth step consists in synthesizing the information. The multiattribute preferences, when combined with the attribute levels associated with each alternative, allow a ranking of the five alternative street cleaning systems. The estimated attribute levels for each alternative shown in Table 4.4 and the individual attribute utility functions are used to determine ui (xi) for each alternative. The individual attribute utility values associated with each alternative are summarized in Table 4.5.

Table 4.5 Individual attribute utility values for each alternative.

Alternatives	Aesthetics	Annual Cost	Air Quality	Water Quality	Noise Level
1	0.40	0.90	0	0.38	1.00
2	1.00	0	0.80	1.00	1.00
3	0.12	0.90	0.50	0.08	0.71
4	0	1.00	0	0	0.12
5	0.82	0.80	0.50	0.85	0

The information given in Table 4.5 is then substituted into Equation 4.1 to define the multiattribute utility associated with each alternative. These utility values provide the basis for determining the rank order of the alternatives and the degree to which one alternative is preferred over another. The utility values associated with each alternative are shown in Table 4.6.

Table 4.6 Utility of each alternative.

Alternative	Utility
1	0.52
2	0.66
3	0.42
4	0.30
5	0.72

The most preferred alternative is that with the highest utility value. For this example, examination of Table 4.6 reveals that alternative five (conventional mechanical street cleaner followed by a flusher, every five days) is the most preferred alternative. This is followed closely by alternative two (conventional mechanical street cleaner, one pass everyday).

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

The least desirable was alternative four (flusher, one pass every five days). Again, this is a hypothetical example used to illustrate a procedure that can be used for this type of decision analysis approach; the values used are fictional as are the result of this hypothetical analysis.

Obviously, changes in preferences for the attributes or estimated attribute levels associated with each alternative may alter the order of preference for the alternatives. The decision analysis methodology summarized here would allow such changes to be rapidly investigated by a sensitivity analysis of the rank order of alternatives. For example, if the trade-off between annual cost and water quality were changed so that the annual cost is somewhat more important than in the previous tradeoff, alternatives one and two can become equally preferred, but alternative five is still the most preferred. Also, new attributes may be added to the analysis and the alternatives ranked again.

4.3 Example Application with Extended Data Output

The above example was prepared some time ago when stormwater modeling techniques were still in their infancy, and environmental regulations, especially for stormwater, were not well developed (and when we were very optimistic concerning the benefits of street cleaning). It is now possible, such as with the recent enhancements made to WinSLAMM, to more completely evaluate different stormwater management options that consider a wide variety of conflicting objectives. The following example is based on a recent project and illustrates the procedure, based on the above discussions.

4.3.1 Attribute Levels Associated with Different Stormwater Management Programs

WinSLAMM generates a great deal of information when stormwater management options are evaluated, as previously described. New revisions to the batch processor option in the model make it possible to summarize many of the important attributes in a simple spreadsheet format. The site and corresponding stormwater management options for this example are described below. All costs are in US dollars.

Descriptions of Site and Alternative Stormwater Controls

This example site is a new industrial park in northern Alabama. The portion of the site considered below is about 98 acres (40 ha) in area, comprising

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

about 33.8 acres (13.7 ha) of industrial land, 60.2 acres (24.5 ha) of open space land, and 4.6 acres (1.9 ha) surrounding sinkholes. There are 13 industrial lots in this subarea, each about 2.6 acres (1.1 ha) in area. The following list shows the estimated total surface covers for these 98 acres:

- Roofs: 18.4 acres (7.5 ha)
- Paved parking: 2.3 acres (0.9 ha)
- Streets (1.27 curb-miles): 3.1 acres (1.3 ha)
- Small landscaped areas (B, or sandy-loam soils, but assumed silty soils due to compaction): 10.0 acres (4.1 ha)
- Large undeveloped area (B or sandy-loam soils, but assumed silty soils due to compaction): 60.2 acres
- Isolated areas (sinkholes): 4.6 acres

The stormwater control options examined in this subarea included the following:

<u>Conventional storm drainage system elements:</u>

The base conditions (associated with the "Base Conditions, No Controls" option) have conventional curb and gutters with concrete storm drainage pipes, and the roofs and paved parking areas are directly connected to the storm drainage system. The main components of the conventional drainage system for base conditions are assumed to comprise: 5,200 ft (1,585 m) of 18 inch (457 mm) and 3,360 ft (1,024 m) of 36 inch (914 mm) storm drainage pipe, plus 39 on-site and 45 public street inlets. The estimated costs for these conventional storm drainage elements are from RS Means (1996 and 2005) and are $19 per ft (304 mm) for 18 inch and $72 per ft for 36-inch reinforced concrete pipe. Excavation and backfilling costs add $\$6/yd^3$. The inlets are $3,000 each.

The on-site drainage elements are needed whenever the site biofilter-swale option is not being used:

5,200 ft of 18 inch concrete pipe (buried in a 5 ft (1.5 m) deep trench) at $25/ft = $130,000

39 inlets = $117,000

Total on-site drainage costs: $247,000 (1996 costs) x 1.2 = $296,400 (2005 costs, based on ENR index).

In addition, it is assumed that annual maintenance costs for these drainage elements will be 1% of the total capital costs for each year = $2,960/y (2005 costs)

The roadside drainage elements are needed whenever the regional swale option is not being used:

3,360 ft of 36 inch concrete pipe (buried in an 8 ft (2.4 m) deep trench) at $80/ft = $268,800

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

25 inlets = $75,000

Total roadside drainage costs: $343,800 (1996 costs) x 1.2 = $412,560 (2005 costs, based on ENR index). In addition, it is assumed that annual maintenance costs for these drainage elements will be 1% of the total capital costs for each year = $4,130/y (2005 costs)

These initial costs need to be converted to annualized costs. The following is based on the procedures outlined by Narayanan and Pitt (2005) and is the same procedure used in WinSLAMM for calculating the costs of the stormwater controls.

Annual on-site drainage costs:
Interest rate on debt capital = 5%
Project financing period = 20 years
Capital cost of project = $296,400 (2005)
Annual maintenance cost = $2,960/year (2005)

Annual value of present amount = $\frac{i(1+i)^N}{(1+i)^N - 1}$

Annual value of present amount (or) annual value multiplier = $\frac{0.05(1+0.05)^{20}}{(1+0.05)^{20} - 1}$ = 0.0806

Annualized value of all costs = Annualized value of (total capital cost of project) + annual maintenance and operation cost.

= 0.0806 * ($296,400) + $2,960 = $26,850 per year

Annual roadside drainage costs:
Interest rate on debt capital = 5%
Project financing period = 20 years
Capital cost of project = $412,560 (2005)
Annual maintenance cost = $4,130/year (2005)

Annualized value of all costs = Annualized value of (total capital cost of project) + annual maintenance and operation cost.

= 0.0806 * ($412,560) + $4,130 = $37,380 per year

<u>On-site biofilter swales</u>:

These small drainage swales, included in options 3, 6, and 8, collect the on-site water from the roofs and paved areas and direct it to the large natural swales. These have the following general characteristics: 200 ft (61 m) long, with 10 ft (3.1 m) bottom widths, 3 to 1 (H to V) side slopes (or less), and 2 inches (51 mm) per hour infiltration rates. One of these will be used at each of the 13 sites on the site. These swales will end at the back property

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

lines with level spreaders (broad crested weirs) to create sheetflow towards the large drainage swale.

When modeling the site biofilters, the following dimensions were used:

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 for cost purposes: 10 ft
Number of biofilters: 13 (one per site)
All roofs and all paved parking/storage areas drained to the Biofilters

The level spreader located at the end of the biofilter was modeled assuming a broad-crested weir having a crest length of 12 ft , a crest width of 10 ft, and the height from the datum to bottom of opening was 1 ft. Table 4.7 shows the evaporation rates used for this example analyses.

Table 4.7 Example monthly average evaporate rates (in/day).

January	0.01
February	0.03
March	0.06
April	0.08
May	0.12
June	0.25
July	0.25
August	0.15
September	0.08
October	0.06
November	0.03
December	0.01

<u>Large regional drainage swale</u>:
Options 2, 5, 6, 7, and 8 include a natural drainage swale in this subarea that will collect the sheetflows from the bioretention swales from each site and direct the excess water to the ponds. This swale is about 1700 feet long, on about a 2.6% slope, and is 50 ft wide. It has 3 to 1 (H to V) side slopes, or less, and 1 inch per hour infiltration rates. The bottom of the swale will be deep vibratory cultivated during proper moisture conditions to increase the infiltration rate, if compacted. This swale also has limestone check dams every 100 ft to add alkalinity to the water and to encourage infiltration. The vegetation in the drainage will be native grasses having deep roots and be

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

mowed to a height of about 6 inches, or higher. Any cut grass will be left in place to act as a mulch that will help preserve infiltration rates. The swale will also have a natural buffer on each side at least 50 ft wide.

When modeling this large regional swale, the model used a swale density of 29 ft/ac with 57 acres served by the swales, resulting in a total swale length of 1653 ft. The drainage system is comprised of 58% grass swales and 42% undeveloped roadside. The infiltration rate in the swale was 1 in/hr. The swale bottom width was 50 ft, with 3H:1V side slopes. The longitudinal slope was 0.026 ft/ft, and the Manning's n roughness coefficient was 0.024. For the cost analysis, the typical swale depth was assumed to be 1 ft.

Wet detention pond:

Options 1, 4, 5, 6, 7 and 8 include a wet detention pond located across the main road next to the southern property boundary. The regional swale will direct excess water into the pond far from the discharge point. The pond is a wet pond having the approximate dimensions and depths shown in Table 4.8.

Table 4.8 Wet detention pond size and elevation characteristics.

Pond Elevation (ft)	Pond Area (acres)
1	0.15
2	0.25
3	0.5
4	0.75
5	1.0 (normal pool elevation, and invert elevation of 30^o v-notch weir)
6	1.5
7	2
8	2.5 (invert elevation of flood flow broad-crested weir). Normal maximum elevation during one and two year rains.
9	3.0 (approximate maximum pond elevation, or as determined based on flood flow analysis). Additional storage and emergency spillway may be needed to accommodate flows in excess of the design flood flow.

The pond storage between 5 and 9 feet is about 8 acre-ft. If additional storage is needed for flood control, either the pond can be enlarged, or an additional dry pond can be located immediately north of the road crossing of the drainageway upstream of the wet pond.

The normal pool elevation of the pond is at 5 ft, about 4 ft below the ground elevation, with an overall pond excavation of 9 ft. The pond is

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

created by a combination of excavation and a downstream embankment. Accessible forebays are located near each of the flow entrance locations to encourage pre-settling of larger sediment in restricted areas. A safety ledge 6-12 inches underwater also extends out 3-10 ft around the pond perimeter. and is planted with a thick stand of emerging vegetation to restrict access to deep water. The edge of the pond along the water is also planted with appropriate vegetation as a barrier. Perimeter plantings also discourage nuisance geese populations. A boardwalk extends through this perimeter vegetation at selected locations for access for demonstration purposes. This boardwalk is also connected with the path system through the industrial park that connects other points of interest for recreational use by site workers.

When modeling the pond, the particle size distribution was assumed to have a median particle size of about 20 µm, with 90% of the particles (by mass) less than 250 µm in diameter. A 4 ft high 30^o v-notch weir 5 ft off the pond bottom was used for water quality control. The emergency spillway was a 50 ft long broad crested weir, having a 3 ft width, with one foot of freeboard. The same evaporation rates used for the biofilters were also used for the ponds.

4. 3. 2 Calculated Performance of Stormwater Control Options

Table 4.9 (at the end of the chapter) summarizes the calculated stormwater discharges for different site options. WinSLAMM, version 9.1, was used along with a typical Huntsville rain year (1976). This year had 102 recorded rains ranging from 0.01 to 3.70 inches in depth. The total rain recorded was 53.4 inches and the average rain depth was 0.52 inches.

4 3.2.1 Utility Functions for and Tradeoffs between the Different Attributes

The utility functions and tradeoffs between the different attributes are highly dependent on the local goals and regulations that need to be addressed in a stormwater management program. The following discussion describes several alternative goals for a hypothetical situation, and how the attributes for each option can be evaluated.

(1) Single Absolute Goal/Limit at Least Cost

In some cases, a watershed analysis may have been completed that recognizes the critical pollutants, and set removal goals. This may be especially relevant for areas attempting to address retrofitting stormwater controls in areas already developed. For new developments, some areas may

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.

require an 80% reduction in suspended solids, compared to traditional development. If this was the case, the utility functions for particulate solids would be easily defined as being zero for outcomes that do not meet the reduction goal, and one for outcomes that do meet the reduction goal. The ranking of the options would simply be based on examining only those options that meet this simple goal, possibly by cost of implementation. In this example, outcomes for eight stormwater control programs made up of combinations of the different stormwater controls are shown on Table 4.10.

Table 4.10 Suspended solids reduction goals and costs (values in italics meet the numeric criterion of 80% TSS goals).

Stormwater Treatment Option	Total Annual Cost ($/y)	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

Therefore, the use of a small pond in conjunction with a regional swale would be the cheapest option to meet the reduction goal of 80% particulate solids removal. The most costly option to meet the particulate solids removal goal is the use of a pond with a conventional storm drainage system, at about twice the expected annual cost. In this example, no other attributes of the different stormwater management options are considered. This solution simply meets the single goal at the least cost. In fact, it exceeds the goal. It would therefore be worthwhile to examine slightly smaller ponds that will more closely meet the single target, with some additional cost savings for the

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

pond construction. The simple ranking method shown in this example would also apply for any other situation where there is a single goal that must be met at the least total cost.

(2) Several Absolute Goals/Limits

When more than one absolute goal is required to be met, the analysis becomes only slightly more complex. It is still relatively simple with absolute goals; the first step is to filter out the options that do not meet all of the required goals. This situation may occur when water quality numeric standards must be met. As an example, assume that the effluent concentration limits shown on Table 4.11 must be met. The attribute table only shows the flow-weighted concentrations. If standards need to be met for all rains with a specific recurrence probability, then those concentrations can be summarized from the probability distributions of outfall concentrations that WinSLAMM can calculate.

Table 4.11 Options and specific criteria (values in italics meet numeric criteria).

	Total Annual Cost ($/y)	SS conc. (mg/L)	Part. P conc. (mg/L)	Zn conc. (µg/L)	Meets all Numeric Standards?	Rank Based on Annual Cost
Applicable Numeric Limit:		<50 mg/L	<0.2 mg/L	<400 µg/L		
Option 1-Pond	83,364	*30*	*0.073*	*128*	Yes	6
Option 2 Regional Swale	30,008	178	0.43	*390*	No	n/a
Option 3 Site Biofilter	69,710	408	1.0	696	No	n/a
Option 4 Half-sized pond	74,439	*48*	*0.12*	*151*	Yes	5
Option 5 Pond and reg. swale	49,142	*23*	*0.057*	*203*	Yes	3
Option 6 Pond, reg. swale and biofilter	54,622	*29*	*0.073*	*386*	Yes	4
Option 7 Small pond and reg. swale	40,217	*39*	*0.095*	*220*	Yes	1
Option 8 Small pond, reg. swale and biofilter	45,698	53	*0.13*	*390*	Yes	2

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

Again, simple filtering enables the suitable options to be identified, and these can be ranked based on their annual cost to identify the least costly option that meets the applicable numeric standards (option 7 again is the least costly option that meets all of these three goals).

(3) Combinations of Goals/Limits

Things get more complicated as the goals become more involved. In these situations, a more formal decision analysis approach may be worthwhile, possibly as described previously following Keeney and Raiffa (1976) methods. The goals may be separated into different classes:

(i) Specific criteria or limits that must be met. As in the above examples, 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, it may be desirable to 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, it is possible to continue onto the next steps. Options 1, 5, 6, 7, and 8 are the five remaining options, after the specific criteria listed above are met.

(ii) Goals that are not absolute. In this case, utility curves and tradeoffs can be developed for the remaining attributes. 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 (concentrations)
- total zinc (concentrations)

In this example, the particulate solids reductions, suspended solids concentrations, particulate phosphorus concentrations, and total zinc concentrations are assumed to have absolute criteria, and only those options that meet them will be further considered. This leaves the attributes, shown in Table 4.12, that need tradeoffs and utility curves. The rankings and trade-offs shown on Table 4.12 were selected for the attributes based on their assumed importance for this project site. These trade-offs could be expected to vary for different decision makers and other interested parties. Separate analyses can therefore be conducted for each different set of trade-offs, resulting in slightly different, but hopefully similar, rankings of the options. As noted above, these trade-offs can be mathematically determined,

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

basically by determining the expected improvements in each attribute for a specific increase in expenditures, and then by solving the set of simultaneous equations. They can also be rather arbitrarily selected, as in this example, by assigning the rankings and values to each attribute so the resultant trade-off values are summed to equal 1.0.

Table 4.12 Ranges of attributes for pre-screened options.

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/y)	2,183 to 10,192 lbs/y	6	0.07
Part. Phosphorus yield (lbs/y)	5.5 to 25 lbs/y	4	0.12
			Sum = 1.0

The utility curve values for these attributes are shown below. For the flow rates and volumetric runoff coefficients, site conditions and local receiving waters enabled groupings of the attribute values into categories having specific utility values. The best categories were intended to protect the receiving water aquatic habitat by minimizing sediment scour and stream enlargement, while the poorest categories would be associated with conventional development practices that frequently are associated with severe receiving water problems. The flow rate groupings are very specific to the site, based on local hydrology and hydrologic calculations, while the Rv groupings may be more generally applicable. The other utility curves (for cost, phosphorus yield, land needs, and particulate solids yields) are simple straight line relationships, with the best attribute values obtained for the different options assigned a value of 1.0, and the worst attribute values obtained assigned a value of 0.0. Intermediate values are simply interpolated between these extreme values.

• 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		0

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

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

• % of time flow >10 cfs:

% 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

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

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

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

• % of time flow >1 cfs:

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

4.3.2.2 Calculation of Utilities and Ranking of Alternative Stormwater Management Programs

At this site, most of the particulate solids originate from the non-developed areas, so the site biofilters have minimal benefits on reducing the overall particulate solids discharges. Also, the site biofilters infiltrate water having much lower particulate concentrations compared to the undeveloped areas (in order to minimize clogging), so the resulting outfall concentrations actually increase. The regional swale and detention ponds treat all of the site water, so they have a much larger benefit on the particulate solids.

Tables 4.13 and 4.14 (at the end of this chapter) show the calculated utility factors for each option, along with the sums of the factors and the overall ranking of the options. Option 8, the small pond with the regional swale and the on-site biofilter swale was ranked significantly ahead of the other options. Options 5 (large pond and regional swale) and 7 (small pond and regional swale) ranked next and were basically tied. Option 1, the large pond alone, ranked far below the other options.

The factors are calculated by multiplying the utilities by the trade-off values. As an example, for Option 5, the cost trade-off was 0.20 and the cost utility was 0.79, and the calculated cost factor is therefore 0.20 X 0.79 = 0.158. The sum of factors is the sum of the individual factors for all attributes for each option. The ranks are based on the sum of factors, with the largest sum of factors ranked 1.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

Table 4.14 shows that Option 8, having the small pond, the regional swale, and the on-site biofilters, is the clear choice using these trade-offs and utility curves (and was actually used for this site). Option 6, the same set of controls, except that a large pond is used, is the second best choice, while Options 5 and 7 are very close and Option 1 (just a large pond alone) is a clear poor performer, compared to the other options.

4.4 Conclusions

The decision analysis approach outlined in this chapter has the flexibility of allowing for variable levels of analytical depth, depending on the problem requirements. The preliminary level of defining the problem explicitly in terms of attributes often serves to make the most preferred alternatives clear. The next level of analysis might consist of a first-cut assessment and ranking as described in this example. Several different utility function curve types were assumed and an additive model was employed. Spreadsheet calculations with such a model are easily performed, making it possible to conduct several decision analysis evaluations using different trade-offs, representing different viewpoints. It is possible there will be a small set of options that everyone agrees are the best choices. Also, this procedure documents the process for later discussion and review. Sensitivity analyses can also be conducted to identify the most significant factors that affect the decisions. The deepest level of analysis can utilize all the analytical information one collects, such as probabilistic forecasts for each of the alternatives and the preferences of experts over the range of individual attributes. Monte Carlo options available in WinSLAMM can also be used that consider the uncertainties in the calculated attributes for each option.

In summary, decision analysis has several important advantages. It is very explicit in specifying trade-offs, objectives, alternatives, and sensitivity of changes to the results. It is theoretically sound in its treatment of trade-offs and uncertainty. Other methods ignore uncertainty and often rank attributes in importance without regard to their ranges in the problem. This decision analysis procedure can be implemented flexibly with varying degrees of analytical depth, depending on the requirements of the problem and the available resources.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com

Acknowledgments

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 additional extensions to WinSLAMM to enable the use of a decision analysis framework in evaluating alternative stormwater management options, as outlined in this chapter. The Stormwater Authority of Jefferson County, Alabama, is also acknowledged for their recent support that enabled the cost analyses to be added to WinSLAMM.

References

American Public Works Association (APWA). 1992. A Study of Nationwide Costs to Implement Municipal Storm Water Best Management Practices. Southern California Chapter. Water Resource Committee.

Brown, W. and T. Schueler. 1997. The Economics of Storm Water BMPs in the Mid-Atlantic Region. Center for Watershed Protection. Ellicott City, MD.

Frank, J. 1989. The Costs of Alternative Development Patterns: A Review of the Literature. Urban Land Institute. Washington, DC.

Heaney, James P.; David Sample and Leonard Wright. 2002. Costs of Urban Stormwater Control. EPA Contract No. 68-C7-0011. National Risk Management Research Laboratory Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH.

Keeney, R.L. and H. Raiffa. 1976. Decision Analysis with Multiple Conflicting Objectives. John Wiley & Sons. New York.

Means, R.S. *RS Means Building Construction Cost Data* (64th Annual Edition). Reed Publications. 2006.

McGraw Hill Construction. Engineering News Record. ENR.com.

Muthukrishnan, Swarna; Bethany Madge, Ari Selvakumar, Richard Field and Daniel Sullivan. 2006. The Use of Best Management Practices (BMPs) in Urban Watersheds. National Risk Management Research Laboratory Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio. ISBN No. 1-932078-46-0.

Narayanan, A. and R. Pitt. (2005). Costs of Urban Stormwater Control Practices (Preliminary Report). Stormwater Management Authority of Jefferson County, AL

Pitt, R. Demonstration of Nonpoint Pollution Abatement Through Improved Street Cleaning Practices, EPA-600/2-79-161, U.S. Environmental Protection Agency, Cincinnati, Ohio. 270 pgs. 1979.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7.
www.computationalhydraulics.com

Pitt, R. “The Incorporation of Urban Runoff Controls in the Wisconsin Priority Watershed Program.” In: Advanced Topics in Urban Runoff Research, (Edited by B. Urbonas and L.A. Roesner). Engineering Foundation and ASCE, New York. pp. 290-313. 1986.

Pitt, R. “Unique Features of the Source Loading and Management Model (SLAMM).” In: Advances in Modeling the Management of Stormwater Impacts, Volume 6. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. pp. 13 – 37. 1997.

Pitt, R. “Small storm hydrology and why it is important for the design of stormwater control practices.” In: Advances in Modeling the Management of Stormwater Impacts, Volume 7. (Edited by W. James). Computational Hydraulics International, Guelph, Ontario and Lewis Publishers/CRC Press. 1999.

Pitt, R. and J. Voorhees. “SLAMM, the Source Loading and Management Model.” In: Wet-Weather Flow in the Urban Watershed (Edited by Richard Field and Daniel Sullivan). CRC Press, Boca Raton. pp 103 – 139. 2002.

Sample, D.J., J.P.Heaney, L.T.Wright, C.Y.Fan, F.H.Lai, and R.Field. 2003. Cost of Best Management Practices and Associated Land for Urban Stormwater Control. Journal of Water Resources Planning and Management, Vol. 129, No.1, pp. 59-68

Southeastern Wisconsin Regional Planning Commission (SEWRPC). 1991. Costs of Urban Nonpoint Source Water Pollution Control Measure. Waukesha, WI.

Wiegand, C., T. Schueler, W.Chittenden and D.Jellick. 1986. Cost of Urban Runoff Quality Controls. pp 366-380. In: Urban Runoff Quality. Engineering Foundation Conference. ASCE, Henniker, NH. June 23-27.

Wossink, Ada, and Bill Hunt. 2003. An Evaluation of Cost and Benefits of Structural Stormwater Best Management Practices in North Carolina, North Carolina State University.

Pitt and Voorhees. Using Decision Analyses to Select an Urban Runoff Control Program. In: *Contemporary Modeling of Urban Water Systems*, Monograph 15. ISBN 0-9736716-3-7. © CHI 2007.
www.computationalhydraulics.com