Modeling LID Treatment Train Impacts on Runoff, Sediment, and Water Quality in U.S. Urban Areas Using IDEAL: Part 2 – Model Application to Example US Cities

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Abstract

Part 2 of this two part series is an application of IDEAL, an object based post construction hydrology model, to water quality prediction that is suitable for use in cities throughout the US. Example prediction is made of the impact of selected LID concepts and treatment train Best Management Practices (BMPs) for Greenville, SC for which the model was developed. Additional applications are shown based on conditions for Albany, NY; Austin, TX; Baltimore, MD; Honolulu, HI; Salem, OR; Tallahassee, FL and Tulsa, OK. Local rainfall and soils information is used in the model predictions. Comparisons of sediment and nutrient loadings are made for multiple suites of treatment trains as well as for conditions having no BMPs. The results of this modeling effort are intended to show how varying climates and soils impact the effectiveness of varying treatment trains. Low Impact Development (LID) concepts and BMPs modeled by IDEAL include disconnecting storm drains, use of water barrels, bioretention cells, bioswales, sand filters, and VFS. Comparison can be made between the use of LID concepts and BMPs with the more traditional wet and dry ponds.

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Introduction

To adequately address water quality concerns as they relate to storm water discharges, it is important to understand the types of pollutants that are present or expected to exist, as well as their potential impacts on receiving water bodies. It is equally important that the origins of the various pollutants and how they may change as they travel through a drainage system be identified such that source controls and appropriate downstream measures can be applied.

IDEAL (Integrated Design, Evaluation and Assessment of Loadings) is a model developed in response to needs of both regulatory personnel, as well as the regulated community, to have a method that could enable them to evaluate loadings from rural and urban areas as they change in order to understand their potential for downstream impacts. The control of runoff can usually be classified into two categories: runoff quantity control and runoff quality control. Quantity control techniques are relatively well established and are based on the physical laws of conservation and momentum. Such measures seek to attenuate peak runoff flow rates and/or to reduce hydrograph volumes to mitigate flooding and the potential for erosion downstream. A much more difficult task is the water quality control of urban runoff. This problem is confounded by the intermittent nature of rainfall, the variability of rainfall characteristics such as volume and intensity, changing land cover, and the variability of constituent concentrations.

IDEAL considers a variety of post construction best management practices (BMPs) including both wet or dry detention ponds, vegetative filter strips, bioswales, infiltration basins, bioretention cells, sand filters and engineered devices.

An extensive set of outputs and reports are available including both text and graphs to show hydrographs, sedigraphs, chemigraphs, and pollutographs which are available for each object (single storm only) as well as at the discharge (outlet) from the watershed.

Example Scenarios

IDEAL is flexible so that a wide range of scenarios can be addressed ranging from a single subwatershed without any best management practices (BMPs) to many subwatersheds having the same or a different treatment train on each. For example, Figure 1 shows the setup for a relatively simple scenario consisting of a pervious subwatershed draining through an open channel to a vegetative filter strip (VFS) draining through another open channel to a wet detention pond. In addition, an impervious subwatershed drains through a diffuse channel to a bioretention cell which then drains through an open channel to the wet detention pond. The detention pond then drains through a circular conduit to the outlet.

A more complex situation that is used as the basis for this paper is the one contained in Figure 2. In this situation, there are eight identical subwatersheds each consisting of 2.5 acres of pervious area for a total of 20 acres. Each subwatershed is shown to drain through a diffuse channel to a VFS, and then each of the VFSs drain through an open channel to a common dry detention pond that drains through a circular conduit to the outlet where loadings are estimated. The following four scenarios are considered in this paper:

1. Loadings at the outlet only with no BMPs in place,
2. Loadings from the outlet with only the VFSs in place,
3. Loadings from the outlet with only the detention pond in place, and
4. Loadings from the outlet with all VFSs and the detention pond.

Precipitation Data. IDEAL uses a variety of information which is included in databases contained within the model. A particularly critical component is the precipitation data for the location of interest. By clicking on the cloud icon in the upper left of the IDEAL workspace, the user can select either single storm or multiple storm scenarios. If multiple storms are selected, conditional probabilities of 72 storms are used to estimate loadings on an average annual basis. Table 1 shows the probability, if it occurs, of precipitation for the smallest six storm sizes (bins 1-6), the probability of storm occurrence in the growing or dormant season, and the probability of occurrence in dry, average or wet conditions based on the previous five days of precipitation. Similar information for the 12 storm sizes is shown in Tables 2 and 3 for eight locations across the United States, but because of space limitations, Tables 2 and 3 do not contain the probabilities associated with seasonal or antecedent moisture content. The dormant season was defined for each year of the historical record as the period between the first low temperature less than 33^{o}F in the fall and the last day in the spring having a low temperature less than 33^{o}F. It is worth noting that for some locations such as Honolulu, there will be no dormant season based on the previous definition.

However for purposes of illustration in this paper, the single storm scenario using a 10-yr, 24-hr storm was selected for precipitation. Precipitations corresponding to a 10-yr, 24-hr storm at each location are shown in Table 4 and range from 3.5 in. in Salem, OR to 7.6 in. in Tallahassee, FL. Although Tallahassee, Baltimore and Austin were each located near the dividing line between NRCS Type II and Type III storm distributions, each of them were assumed to be Type II distributions as were all other cities except Salem. Salem was well within the NRCS Type Ia geographic area and was modeled accordingly. Also shown in Table 4 are the interarrival times based on the historical records for each locations. This number was obtained by dividing the number of days in the record by the total number of days having precipitation of at least 0.01 in. and is particularly critical to account for deposition occurring in a wet pond between storms. It is worth noting that there is considerable variation in both the 10-yr, 24-hr storms and the interarrival times for the locations shown across the U.S. Finally, IDEAL considers all precipitation to be rain and currently has no routines to account for snow or icing.

<u>Subwatershed Description</u>. Each of the subwatersheds used in the scenarios is considered to be an identical pervious area consisting of 2.5 ac with a CN of 72, peak rate factor of 325, and a time of concentration of 0.16 hr. The soil consists of 12.5, 21.5 and 66 percent clay, silt and sand, respectively, with a soil erodibility of 0.28. Average annual event mean concentrations for nutrients are assumed to be 2.06 mg/l for total nitrogen and 0.28 mg/l for total phosphorus. The reader should recognize that the conditions were not selected based on the geographic locations for which the scenarios were run; i.e., the soil is not truly representative of Honolulu or Tallahassee but is considered to be a medium textured soil . Instead, the subwatershed, VFS and pond conditions remain constant so that the impact of local climatic conditions is evident. Clearly, there should be differences in soil conditions, event mean concentrations, grasses selected for VFSs, and pond size/configuration from one location to another. The intent herein was not to mask the climatic effects or confuse them with other variables.

<u>Vegetative Filter Strip (VFS) Description</u>. Each of the VFSs was assumed to be 40 ft wide by 100 ft long in the direction of flow with a slope of 0.02 ft/ft. Soil texture, as used to estimated infiltration, was assumed to be sandy clay loam in all cases. The vegetation was taken to be a lawn which could be either mowed or unmowed and having vegetative characteristics similar to those of fescue.

<u>Dry Detention Pond Description</u>. The stormwater detention pond was assumed to be a dry pond with very good performance. The stage at 4 ft provides a pond area of 1 ac. The pond has a low flow orifice near the bottom having a diameter of 4 in. The outlet is a circular 24 in. riser connected to a 16 in. barrel having a length equal to 80 ft. There is also an emergency to prevent overtopping

Scenario Results

Considerable variation was found between results from the various geographic locations as shown in Tables 5 and 6. This result was anticipated, but the purpose was to demonstrate that the model captures this variation and allows the user to evaluate the usefulness of various management practices using local inputs and can do so for a wide range of conditions.

<u>Scenario 1: No BMPs</u>. Scenario 1 results are for the situation where there are eight, 2.5 ac subwatersheds with no BMPs and are shown in Tables 5 and 6 for the eight cities across the U.S. There is a wide range of loadings between locations with Tallahassee having the largest values and Salem having the lowest. While this might be expected from the standpoint of Tallahassee having the largest 10-yr, 24-hr rainfall, the magnitude of the differences in loadings are much greater than the difference between the design storms.

<u>Scenario 2: VFS Only</u>. Scenario 2 results include the benefit of having a VFS associated with each of the subwatersheds. In most locations, reduction in sediment yield is about 70-75% while runoff volume is only reduced about 5% because of some infiltration within the VFS. Total nitrogen is reduced slightly by about 5-10%, and total phosphorus is reduced approximately 4-15% as a result of phosphorus that settles along with clay particles.

Scenario 3: Pond Only. Scenario 3 includes the benefit of having the eight subwatersheds drain through a single dry detention pond before exiting the watershed. The pond provides substantial reduction in peak flow although the values not shown, but provides significant reductions in volume of 14-40%. Hence, trapping of sediment leads to a reduction in sediment yield of 92-98%. Total phosphorus exhibits slight reductions ranging from about 5-33% while total nitrogen ranges from about 5-38%. Again, nitrogen is expected to be trapped primarily as a result of infiltration whereas phosphorus will be captured as a result of settling.

Scenario 4: Pond and VFSs. Scenario 4 demonstrates the benefits of having both VFSs directly connected to each subwatershed as well as a downstream detention pond. Runoff volume is reduced by from 15-42%. Similarly, sediment and nutrients also are reduced slightly compared to the pond only scenario. In all cases shown, the pond has a much greater impact than do VFSs alone.

Conclusions

IDEAL provides an organized system for evaluating the effectiveness of a single management practice or a treatment train for reducing loadings from a watershed at locations across the U.S. Combinations of low impact development and traditional management practices can be evaluated quickly to determine whether practices are providing the desired benefits. Questions remain about the cost/benefit of small structures scattered around a development as compared to larger structures located near the outlet point. In cases where a specific problem exists such as phosphorus issues, IDEAL can also be used to easily make decisions as to whether a particular BMP or combination of BMPs is actually worthwhile in reducing the critical pollutant.

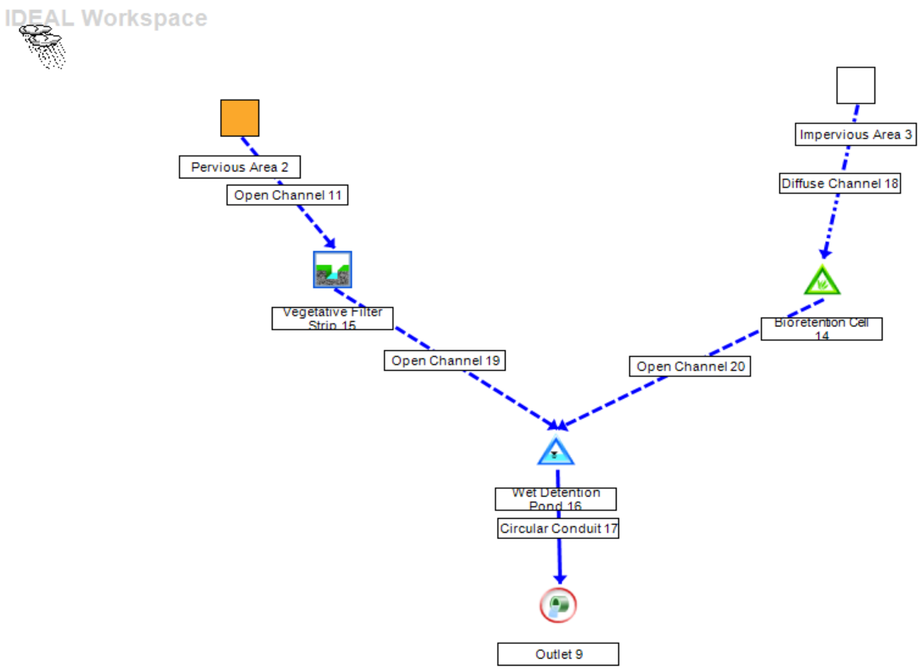

Figure 1. Simple workspace for IDEAL showing icons for precipitation, pervious and impervious subwatersheds connected to BMPs with conveyances.

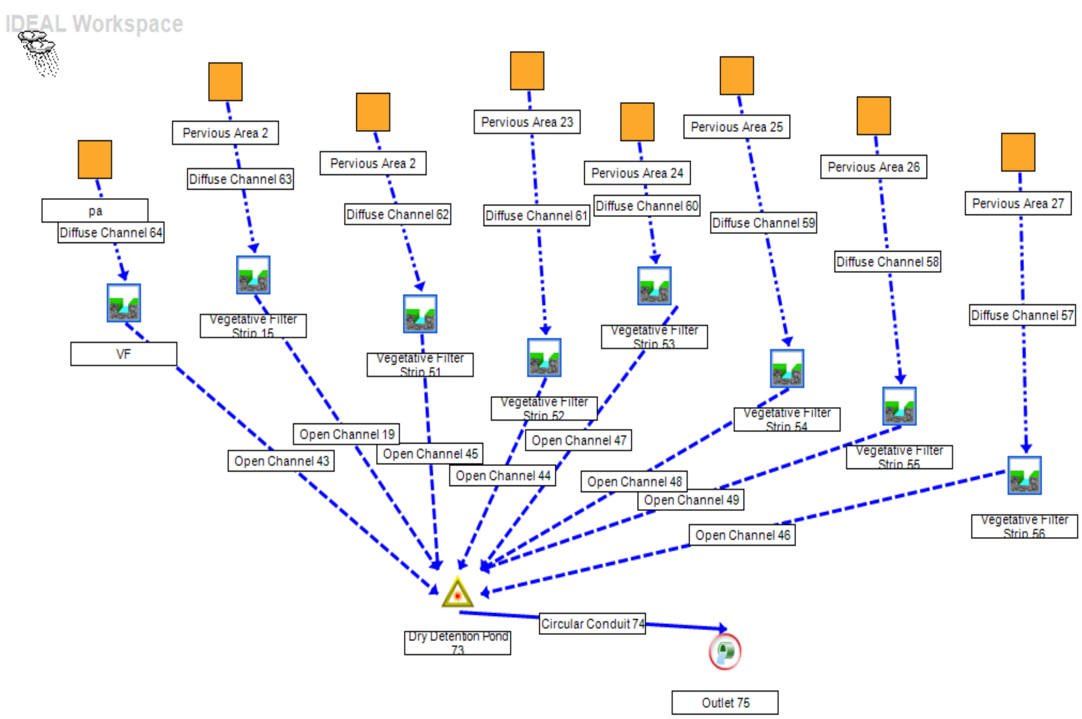

Figure 2. Scenario showing multiple subwatersheds, vegetative filters and wet pond connected to the outlet.

Table 1. Precipitation and conditional probabilities for storm indices 1 through 6 of 12 used for Greenville, SC.

Storm Index	Precipi-tation Bin	Precipitation Probability	Storm Type	Season	Seasonal Probability	AMC	AMC Probability
1	0.25	0.6910	2	1	0.5871	1	0.7977
1	0.25	0.6910	2	1	0.5871	2	0.0941
1	0.25	0.6910	2	1	0.5871	3	0.1082
1	0.25	0.6910	2	2	0.4129	1	0.5236
1	0.25	0.6910	2	2	0.4129	2	0.2344
1	0.25	0.6910	2	2	0.4129	3	0.2420
2	0.75	0.1989	2	1	0.5871	1	0.7977
2	0.75	0.1989	2	1	0.5871	2	0.0941
2	0.75	0.1989	2	1	0.5871	3	0.1082
2	0.75	0.1989	2	2	0.4129	1	0.5236
2	0.75	0.1989	2	2	0.4129	2	0.2344
2	0.75	0.1989	2	2	0.4129	3	0.2420
3	1.5	0.0840	2	1	0.5871	1	0.7977
3	1.5	0.0840	2	1	0.5871	2	0.0941
3	1.5	0.0840	2	1	0.5871	3	0.1082
3	1.5	0.0840	2	2	0.4129	1	0.5236
3	1.5	0.0840	2	2	0.4129	2	0.2344
3	1.5	0.0840	2	2	0.4129	3	0.2420
4	2.5	0.0191	2	1	0.5871	1	0.7977
4	2.5	0.0191	2	1	0.5871	2	0.0941
4	2.5	0.0191	2	1	0.5871	3	0.1082
4	2.5	0.0191	2	2	0.4129	1	0.5236
4	2.5	0.0191	2	2	0.4129	2	0.2344
4	2.5	0.0191	2	2	0.4129	3	0.2420
5	3.5	0.0052	2	1	0.5871	1	0.7977
5	3.5	0.0052	2	1	0.5871	2	0.0941
5	3.5	0.0052	2	1	0.5871	3	0.1082
5	3.5	0.0052	2	2	0.4129	1	0.5236
5	3.5	0.0052	2	2	0.4129	2	0.2344
5	3.5	0.0052	2	2	0.4129	3	0.2420
6	4.5	0.0011	2	1	0.5871	1	0.7977
6	4.5	0.0011	2	1	0.5871	2	0.0941
6	4.5	0.0011	2	1	0.5871	3	0.1082
6	4.5	0.0011	2	2	0.4129	1	0.5236
6	4.5	0.0011	2	2	0.4129	2	0.2344
6	4.5	0.0011	2	2	0.4129	3	0.2420

Table 2. Precipitation summary by depth and probability for locations in U.S.

	Albany, NY		Austin, TX		Baltimore, MD		Greenville, SC	
Bin Precipitaion (in.)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)
12.5	0.190	0.009	0.000	0.000	0.000	0.000	0.000	0.000
11.5	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000
10.5	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.000
9.5	0.000	0.009	0.000	0.000	0.000	0.000	0.227	0.014
8.5	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.014
7.5	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.014
6.5	0.000	0.009	0.246	0.033	0.000	0.000	0.000	0.014
5.5	0.086	0.018	0.302	0.082	0.283	0.035	0.000	0.014
4.5	0.063	0.027	1.030	0.294	0.389	0.093	0.742	0.115
3.5	0.414	0.102	1.734	0.767	1.051	0.292	2.308	0.517
2.5	1.170	0.398	3.300	2.040	3.134	1.167	5.510	1.910
1.5	7.488	3.770	8.983	7.985	11.167	6.587	14.991	8.403
0.75	11.776	14.128	5.861	16.895	11.603	17.778	12.853	19.889
0.25	15.01	81.49	8.68	71.90	12.89	74.05	13.47	69.10
Total	36.20	100.00	30.14	100.00	40.52	100.00	50.11	100.00

Table 3. Precipitation summary by depth and probability for locations in U.S.

	Honolulu, HI		Salem, OR		Tallahassee, FL		Tulsa, OK	
Bin Precipitation (in.)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)	Average Depth/yr (in./yr)	Prob if Rain (%)
12.5	0.279	0.017	0.000	0.000	0.000	0.000	0.000	0.000
11.5	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000
10.5	0.000	0.017	0.000	0.000	0.000	0.000	0.000	0.000
8.5	0.000	0.016	0.000	0.000	0.467	0.031	0.000	0.000
7.5	0.000	0.016	0.000	0.000	0.000	0.031	0.000	0.000
6.5	0.512	0.083	0.000	0.000	0.938	0.104	0.259	0.028
5.5	0.584	0.183	0.000	0.000	1.315	0.238	0.296	0.070
4.5	0.716	0.333	0.000	0.000	2.045	0.497	1.039	0.253
3.5	1.709	0.783	0.047	0.009	4.413	1.223	1.380	0.577
2.5	2.209	1.633	1.420	0.363	8.264	3.172	4.095	1.900
1.5	3.835	4.202	7.333	3.617	18.146	10.581	12.076	8.788
0.75	2.472	8.397	12.063	13.848	11.584	21.289	8.805	19.788
0.25	7.11	84.29	17.93	82.16	13.53	62.83	9.71	68.60
Total	19.43	100.00	38.79	100.00	60.70	100.00	37.66	100.00

Table 4. Ten-year, 24-hr return period precipitation depths used in scenarios.

Location	Interarrival Time (hrs)	Precipitation Depth (in.)
Greenville, SC	75	5.6
Tulsa, OK	101	6.0
Baltimore, MD	77	5.3
Tallahassee, FL	78	7.6
Honolulu, HI	96	7.0
Salem, OR	62	3.5
Austin, TX	111	6.6
Albany, NY	65	5.0

Table 5. Results for selected cities, BMPs and constituents.

Greenville, SC				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	4.4	4.3	3.6	3.4
Sediment (lbs)	162,095	42,580	6,845	6,263
Nitrogen (lbs)	24.9	24.2	22.1	21.3
Phosphorus (lbs)	3.4	3.2	3.0	2.8
Tulsa,OK				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	5.0	4.8	4.1	4.0
Sediment (lbs)	184,380	50,773	9,217	8,482
Nitrogen (lbs)	27.9	27.3	25.4	24.6
Phosphorus (lbs)	3.8	3.7	3.4	3.3
Baltimore, MD				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	4.1	3.9	3.2	3.1
Sediment (lbs)	145,876	36,793	5,333	4,901
Nitrogen (lbs)	22.7	22.0	19.7	18.9
Phosphorus (lbs)	3.1	2.9	2.7	2.5
Tallahassee, FL				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	7.2	7.1	6.4	6.2
Sediment (lbs)	279,622	88,382	21,640	20,598
Nitrogen (lbs)	40.6	39.9	38.6	37.9
Phosphorus (lbs)	5.5	5.4	5.2	5.1

Table 6. Results for selected cities, BMPs and constituents.

Honolulu, HI				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	6.4	6.2	5.5	5.3
Sediment (lbs)	242,892	73,452	16,649	15,680
Nitrogen (lbs)	35.8	35.1	33.6	32.9
Phosphorus (lbs)	4.9	4.7	4.6	4.4
Salem, OR				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	1.9	1.7	1.2	1.1
Sediment (lbs)	20,169	526	314	209
Nitrogen (lbs)	10.5	8.8	6.8	5.8
Phosphorus (lbs)	1.4	1.2	0.9	0.8
Austin, TX				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	5.8	5.6	5.0	4.8
Sediment (lbs)	219,047	63,959	13,447	12,526
Nitrogen (lbs)	32.6	31.9	30.3	29.5
Phosphorus (lbs)	4.4	4.3	4.1	4.0
Albany, NY				
	No BMPs	VFS only	Pond only	Pond + VFSs
Runoff (ac-ft)	3.7	3.5	2.8	2.7
Sediment (lbs)	130,164	31,146	4,079	3,748
Nitrogen (lbs)	20.5	19.8	17.3	16.4
Phosphorus (lbs)	2.8	2.6	2.3	2.2