Chapter 4

A Preliminary Urban Non-Point Source Management Plan : A Modeling Approach

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The need for a preliminary non-point source pollution management plan has become evident in the Onondaga Lake Watershed, which includes the City of Syracuse, NY, surrounding suburban areas and rural

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farmland. The rural contribution of Non-Point Source (NPS) pollution is being addressed by others. A spatial analysis of just the existing urban areas was conducted using the GRASS (Geographical Resources Analysis Support System) Geographic Information System (GIS). The results of this analysis were then used to construct a conceptual rainfall/runoff model of the urban watershed using the RUNOFF block of the Storm Water Management Model (SWMM). A continuous hydrologic simulation was then used to compute annual pollutant loads based on published unit area loads from other watersheds.

4.1 Introduction

Onondaga Lake, located near Syracuse, N.Y., has a long history of water quality problems. Located in the Oswego River Basin; it has received discharges from both municipal and industrial point discharges, Combined Sewer Overflows (CSOs), and a diverse mixture of NPS runoff pollution. Virtually the entire Onondaga Lake watershed lies within the boundaries of Onondaga County, thus affording an opportunity for effective watershed management. As point sources are being controlled, the impact of diffuse sources is becoming apparent (Nix, Hassett, Wright, 1994). In addition to CSOs and municipal treatment plant effluent, urban NPS pollution is also a significant contributor of nutrients, solids, and toxic pollution to the lake.

Onondaga Lake receives runoff and associated pollutants from a 615 km² (land area) watershed. Of this, 28% (173 km²) is considered either urban or suburban (SOCPA, 1992). The urban portion of the watershed is concentrated in and around the city of Syracuse, NY, located along the southeast shore of Onondaga Lake. The goal of this research was to develop an initial assessment of urban runoff pollution (total phosphorus (TP), total nitrogen (TN) and total suspended solids (TSS)) to Onondaga Lake, and to use this assessment in the development of a preliminary management plan for the watershed (Nix, Hassett, Wright, 1994). The three principal tasks completed to achieve this goal were:

1. review available geospatial data,
2. develop a conceptual model to characterize annual urban runoff pollution loads at various locations, and
3. use the data and the model to target areas for possible management actions.

Figure 4.1 illustrates the interrelationships of primary project tasks and input data. Note that information is routed from the Management Strategy back to the GIS to reflect the ability to model future changes in the watershed.

Figure 4.1
Project Flow Diagram.

4.2 Review of Available Geospatial Data

Pollution derived from runoff may enter the lake via a variety of conduits. In the upper watershed, agricultural runoff enters tributaries directly, carrying with it chemical, solid and nutrient loads. In newly-developed suburban and outer urban areas, storm water usually passes through a storm sewer before being discharged to a tributary, or directly into the lake. The older urbanized sections of Syracuse are served by a combined sewer system, whereby storm water is mixed with sanitary sewage before directly discharging into a tributary of the lake. While this study focused on diffuse sources of pollution from the urban areas in general (CSO areas included), it should be noted that approximately 16% of the urban area (4.5% of the watershed) is serviced by a combined sewer system, which diverts approximately one-third of the annual urban runoff to the Metropolitan Treatment Plant.

The geospatial information necessary for this type of assessment consists of land use, hydrography, and the diffuse pollutant loads associated with various land uses. Past studies have shown that the type and quantity of pollutant expected from a given area is strongly related to the use(s) attributed to that area (CH2MHILL, 1991). A primary task of this research was to determine current land uses, and to quantify this information in digital (e.g. GIS) format. The hydrology of the watershed must then be defined by watershed boundaries, watercourses, slopes, soil, vegetation, etc. The delivered pollutant load from each land use must be measured, assumed or otherwise assigned in a consistent manner for each hydrologic unit to ensure relative accuracy. By combining accurate land use information, hydrology, and pollutant information, runoff-derived pollution can be estimated.

4.2.1 Land Use Data

A large portion of the spatial analysis had been completed by the local planning agency (SOCPA) for other purposes. Detailed land use maps had been created from aerial photography in 1992. These maps constitute the most recent and most accurate land use information available. However, since they were done for other purposes, they did not meet the exact needs of the runoff/modeling study. The maps were completed by hand on 1:24,000 paper maps, thereby making quantification of areas difficult. In addition, the land use categories were not defined in a manner

consistent with previous runoff studies. It was decided that the most efficient method of overcoming these deficiencies was to transfer the paper map information to a form easily analyzed by a computer. A GIS is a computer program designed to analyze, map, and store spatial information. There is a wide variety of these programs available, namely, ARCINFO, SPANS, IDRISI, GRASS etc. GRASS was used for this project, largely as a result of the previous involvement of the USDA Soil Conservation Service (SCS). GRASS is a GIS developed by the United States federal government, and is used by the SCS.

The conversion of the information from maps to GIS format consisted of digitizing the land use polygons, thus creating a database of spatial information. Given the cartographic details (scale, latitude, longitude), a digital map was created within the GIS. The GIS added the value of rapid area measurements, along with overlay and cross-product capabilities, to the existing land use data. These capabilities are important when developing a conceptual model of a watershed. Additionally, GIS allows the comparison of alternative control options with ease.

4.2.2 Hydrography and Geography

Other data crucial to the runoff study were added to the digital map. Watershed boundaries, soil series, political boundaries and watercourses were included for analysis and presentation purposes. The watershed boundaries were subdivided into 41 subwatersheds, which had an average size of 15 km², and were the basis for the runoff model discussed below. Tributaries and intermittent watercourses were not modeled in this study, since annual loads to the major water body were of interest.

The soil series within the watershed were mapped via the GIS. The average slope of each soils series was classified in the GIS and the average slope of each urban area was calculated accordingly.

4.2.3 Diffuse Pollutant Loads

The areas of various land uses within each hydrologic unit (defined by watershed boundaries) were calculated. Since the land uses defined by the local planning agency were different from those needed for a pollutant/runoff study, some land uses were combined with other land uses with similar runoff characteristics. For instance, industrial lands

were added to transportation lands, since pollutant studies have rarely discerned differences between the two. The land use areas computed via the GIS were tabulated for each subwatershed within the basin, thus providing the discretization needed to develop a conceptual runoff model.

A review of relevant literature revealed a wide range of possible area loads to associate with the land use areas. The pollutant loads used in the model were taken from Marsalek (1978), as shown in Table 4.1. These values were chosen primarily because they represent an average of several urban areas within the Great Lakes region, and appeared to be a reasonable starting point for this preliminary study.

Table 4.1
Typical Annual Surface Loads of Pollutants from PLUARG studies by Marsalek (1978).

Land Use	TSS (kg/ha)	TP (kg/ha)	TN (kg/ha)
Low Density Residential	390	1.6	9
High Density Residential & Commercial	360	3.4	11.2
Industrial	672	2.2	7.8
Parks, Open Space	11.2	0.04	0.22

4.3 Development of the Conceptual Model

The USEPA's Storm Water Management Model (SWMM) was used to estimate the annual loads of TSS, TP and TN from each hydrologic unit identified within the watershed.

4.3.1 Runoff Model

The SWMM model was developed by first configuring a rainfall/runoff model of all urban lands within the watershed. In each of the 41 hydrologic units, all similar urban land uses were lumped into one

catchment area. While this constituted a degree of spatial lumping within each hydrologic unit, the hydrologic units were small enough relative to the entire watershed to justify this spatial averaging. Figure 4.2 illustrates the method used for converting the land use map information into a conceptual runoff area for use in SWMM. The percent imperviousness for each urban land use was estimated using 1991 aerial photography. Representative land use parcels were used for this estimation, and the resulting values were then assigned to each land use over the entire watershed.

All land uses within a hydrologic unit were then routed together, to produce one hydrograph from each unit. This simple model was used to simulate runoff from 30 years of hourly rainfall. The annual runoff volumes from the combined sewer area were verified with previously calibrated and verified long-term simulations of the combined sewer area. This comparison showed that in an average year, approximately 30 cm of urban runoff occurs from an annual precipitation of 112 cm.

4.3.2 Pollutant Model Build-up/Wash-off Model

After the runoff model was completed, the SWMM RUNOFF block was used to simulate the build-up and eventual wash-off of TSS, TP, and TN. A simple linear build-up function was used to simulate the accumulation of solids on the catchment areas over time. Likewise, an exponential wash-off function was used to simulate the amount of accumulated solids washed off with runoff. This is an important consideration when performing long-term simulations, as pollutant accumulation over time is accounted for during dry periods (Nix, 1990). The concentrations of TSS, TP, and TN within the accumulated dry solids were calculated from unit area loads published by Marsalek (1978) for each urban land use.

The resultant pollutant load from each hydrologic unit was then tabulated for TSS, TN, TP and total flow. These were ranked and mapped with the GIS on the basis of total pollutant delivered and by the total pollutant intensity (mass/area). It should be noted that since this study focused only on urban contributions, hydrologic units with a small percent of urban area may have ranked high in the intensity list due to a small parcel of industrial land. Likewise, a completely suburban (low density residential) hydrologic unit may have ranked low on the intensity list, but very high in the total load list. This is critical in determining areas for possible abatement on the basis of hydrologic units.

Figure 4.2
Illustration of conceptualized land use/runoff model.

A comparison of the model output values presented in Table 4.2 with those in Table 4.1 shows that the modeled output is lower than the values presented by Marsalek (1978) in Table 4.1. However, it should be noted that the values are consistently lower, thus adding credence to the relative accuracy of the modeled results.

Table 4.2
Estimated annual delivered pollutant loads and average concentrations.

Land Use	TSS (kg/ha)	TSS (mg/l)	TN (kg/ha)	TN (mg/l)	TP (kg/ha)	TP (mg/l)
Low Density Residential	330	110	8	2.6	1.3	0.5
High Density Residential & Commercial	310	70	10	2.2	2.9	0.7
Industrial	580	100	7	1.2	1.9	0.4
Open Space	6	8	0.1	0.2	0.02	0.03

4.4 Development of a Preliminary Pollution Prevention Plan

The results of this study are being used to develop a preliminary management plan for the watershed. This plan will include the following recommendations:

1. Specific abatement and/or management alternatives will be targeted for specific areas of both high intensity loading and areas of high total loads. These activities may include structural changes within the watershed, optimization of existing detention facilities to better capture solids, public education and source control, and administrative restructuring to focus governmental attention on Nonpoint Source Pollution. These activities will be concentrated within the hydrologic units that produce both the highest intensity loads (mass/area delivered) and the highest total loads, based on a prioritization of simulated runoff responses. The prioritization

of urban areas within the watershed is the primary product of this research effort.

2. Develop a comprehensive watershed management model. This should be done to properly prioritize all sources of pollution. Agricultural land uses within the watershed contribute an unknown amount of pollutants to the lake. In order to assess the potential improvement of lake quality and increase its ecological and economic value to the region, all point and NPS sources (including the urban sources under this study and rural sources being evaluated by others) should be evaluated together, in an integrated model. For instance, the potential impacts of abatement for various sources could be evaluated, along with an analysis of sensitivity to various watershed and abatement parameters. This sensitivity may shed light on the possible receiving water impacts that could be expected for various scenarios. For instance, it is now believed that the potential impact of nutrients derived from all nonpoint sources are so great that even if all other sources of nutrients to the lake ceased, lake eutrophication may persist (Heidtke and Auer, 1991).
3. Conduct a site specific sampling survey to characterize actual pollutant loads. This is important, due to the well documented geographical heterogeneity of diffuse pollution sources (Water Environment Federation, American Society of Civil Engineers, 1992). This would also provide a data base for calibration and verification of any future modeling efforts.

4.5 Conclusions

This study has shown that a relativistic model of urban runoff pollutant loads can be efficiently developed to provide important information for analyzing the reduction of runoff pollution from an urban watershed. A runoff model was developed, along with a GIS to analyze geospatial data, for a preliminary nonpoint source pollution management plan. Inasmuch as unit load values were arrived at through deterministic modeling using SWMM, and compared consistently with published values, the model developed for this study is considered acceptable for preliminary purposes. While many of the same conclusions may be drawn

from a simpler analysis of the land uses within the watershed (without the use of a runoff model), the development of the runoff model provides a tool to analyze alternative control measures, compute the impact of future changes within the watershed, measure abatement benefits, and prioritize hydrologic units on the basis of hydrology and land use.

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