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OPTIMIZING THE RIPARIAN BUFFER:

HAROLD BROOK IN THE SKANEATELES LAKE WATERSHED, NEW YORK*

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ABSTRACT

The use of riparian land buffers to protect water quality for human consumption and wildlife habitat has become an important conservation tool of both government and non-government agencies. The funds available to acquire private lands for riparian buffers are limited, however, and not all land contributes to water quality goals in the same way. Conservation agencies must therefore identify effective ways to allocate their scarce budgets in heterogeneous landscapes. We demonstrate how the acquisition of land for a riparian buffer can be viewed as a binary optimization problem and we apply the resulting model to a case study in New York (JEL Q15, Q25).

I. INTRODUCTION AND OVERVIEW

For many cities in the eastern United States the provision of drinking water involves a source, such as a lake or reservoir, a treatment plant, and a delivery system. Cities like New York City, Boston, and Syracuse made decisions in the 19th century to build reservoirs or seek source water in relatively pristine rural areas, where water was of high quality and would require only chlorination before distribution to city residents. Since 1989, however, the U.S. Environmental Protection Agency's (EPA) Surface Water Treatment Rule (SWTR) requires every water supplier to filter its surface water sources prior to disinfection, unless the source water meets specific water quality criteria and the supplier has developed a watershed management program.

The City of Syracuse (population 163,860) in central New York State draws its water from Skaneateles Lake, the fourth-largest lake in a group of eleven lakes collectively known as the "Finger Lakes." Skaneateles Lake is 16 miles long, with an average width of 0.75 miles, an average depth of 145 feet, and an estimated volume of 412 billion gallons. The quality of its water is high, in part because of a relatively small watershed to lake ratio (59.3 square miles of watershed to 13.6 square miles of lake).

The high quality of the lake's water has permitted the City of Syracuse to meet drinking water standards without coagulation or filtration, using only screening and disinfection by chlorination. In recent years, however, the City has come under increasing pressure to build a filtration plant in order to satisfy the provisions of the EPA's SWTR. In order to avoid building the filtration plant, which is estimated to cost between $64 and $76 million, the City signed a Memorandum of Agreement (MOA) with the New York State Department of Health that allows the City to avoid filtering water from the lake. The MOA requires that the City commit to a long-term watershed management program to reduce pathogen, chemical, nutrient, and sediment loading into the lake. Part of the program involves the establishment of a "riparian buffer" at critical areas within the watershed. A riparian buffer is a strip of land bordering a stream, lake or reservoir that intercepts and sequesters pollutant runoff [Belt *et al.* (1992)]. A municipal government can establish a riparian buffer by the fee-simple purchase of riparian parcels or by the purchase of easements that restrict land use along the riparian edge of a larger parcel.

One of the critical areas within the Skaneateles watershed is the Harold Brook Sub-Watershed (HBSW), at the northwestern end of the lake. Harold Brook is near the Village of Skaneateles and the intake pipes that the City of Syracuse uses to draw approximately 42 million gallons of water per day. The HBSW is the focus of our case study. It contains sixty-four parcels with land-use activities that include field crops, dairy farms, year-round residences, seasonal residences, and a warehouse-distribution facility (see Figure 1).

This paper develops two optimization models that a water authority can use to determine the "best" parcels for inclusion in a riparian buffer. The first model is based on a linear equation developed by the City of Syracuse to score (or rank) parcels. The second model selects parcels based on a parcel index and a weighting of reduced pollutant loads. Both models are binary optimization models and are used to select the best buffer subject to a budget constraint. The optimal buffers for comparable versions of each model are compared and a set of priority parcels is identified.

In the next section we present the binary optimization problems based on the Syracuse Scoring Equation (SSE) and our Parcel-Pollutant-Weighting (PPW) Model. In Section III, data on the parcels in the HBSW are presented along with the weights and reduced pollutant loads used in the SSE and PPW models. Section IV discusses the optimal buffers. Section V summarizes the results of the present study, discusses the sensitivity of the solutions t the SSE and PPW models and concludes with some suggestions for improving the integration of hydrologic and economic models.

II. THE MODELS

The City of Syracuse has earmarked approximately $7 million to acquire easements on privately-owned parcels in the Skaneateles Lake Watershed. An easement places restrictions on land use on portions of a parcel that are deemed important to maintaining high water quality. Of primary concern is the maintenance or introduction of vegetative cover that can prevent sediments, chemicals, nutrients, and pathogens from reducing water quality in the vicinity of the City's intake pipes.

The Syracuse-Scoring-Equation (SSE) Model

To measure the potential contribution of each parcel to Syracuse's water quality objectives, the Department of Water convened a scientific panel to help it develop a parcel scoring system. With the panel's assistance, analysts in the Department proposed a scoring equation that is a weighted sum of parcel attributes. Let $\alpha_{i,k}$ be a numerical measure of the kth attribute for the ith parcel, i=1,2,...,I, k=1,2,...,K. For most attributes, larger values of $\alpha_{i,k}$ imply that the ith parcel is more desirable in the kth dimension. Let ω_k be a subjective weight representing the relative importance of the kth attribute in the set of all attributes. The desirability of the ith parcel is given by the index number D_i where

$$D_i = \sum_{k=1}^{K} \omega_k \alpha_{i,k} \qquad [1]$$

We refer to Equation [1] as the Syracuse Scoring Equation (SSE). Parcel scoring functions, based on land attributes, have been used in other watershed protection initiatives [e.g., Lemunyon and Gilbert, (1993)] and in the multi-billion dollar conservation effort of the U.S. Conservation Reserve Program [Feather *et al.* (1998)], land trusts [e.g., The Nature Conservancy; Master (1991)], international habitat protection groups [e.g., World Wildlife Fund; Olson et al. (2000)], national wildlife protection initiatives [e.g., Partners in Flight; Carter et al. (1999)], and farmland protection initiatives (e.g., American Farmland Trust).

Let C_i denote the cost of buying an easement on the ith parcel, which would secure the attributes $\alpha_{i,k}$[1)]. Let B_i be a binary variable where B_i=0 indicates that the easement to the ith parcel has <u>not</u> been purchased and B_i=1 indicates that the easement to the ith parcel <u>has</u> been purchased. Finally, let M denote the money (budget) available for easement acquisition. The binary optimization problem based on the SSE may be stated as

$$\begin{aligned} &\underset{B_i=0,1}{\text{Maximize}} \quad \sum_{i=1}^{I} D_i B_i \\ &\text{Subject to} \sum_{i=1}^{I} C_i B_i \le M \end{aligned} \qquad [P1]$$

A variation on [P1] is to restrict easement acquisition to riparian parcels. Let R_i=0 indicate that the ith parcel contains <u>no</u> stream footage or lake frontage and R_i=1 indicates that a parcel has positive stream footage or lake frontage. Then the riparian version of [P1] may be stated as

$$\underset{B_i = 0,1}{\text{Maximize}} \sum_{i=1}^{I} R_i D_i B_i$$
$$\text{Subject to } \sum_{i=1}^{I} C_i B_i \leq M \qquad \text{[P2]}$$

The Parcel-Pollutant-Weighting (PPW) Model

As an alternative to the SSE models in [P1] and [P2], consider the same watershed with i=1,2,…,I parcels of land draining into the lake or reservoir. Suppose there are j=1,2,...,J pollutants whose runoff poses a potential water quality problem. Let $X_{i,j}$ denote the loading of the jth pollutant from the ith parcel under its current land use or the potential loading if an easement is <u>not</u> acquired. Let $X_{i,j}^B$ denote the loading of the jth pollutant from the ith parcel if the appropriate easement is acquired and the ith parcel is included in the riparian buffer. Then $(X_{i,j} - X_{i,j}^B) \geq 0$ is the reduced loading of pollutant j from parcel i if the ith easement is purchased.

The effect of different pollutants on water quality may vary. In some watersheds, pathogens may be more of a concern than, say, phosphorus or sediments. As such, we allow watershed managers to associate a weight, W_j, with the jth pollutant. The larger W_j, relative to the weight on other pollutants, the more important are parcels whose acquisition will reduce the loading of the jth pollutant.

As in the SSE model there may be attributes of the ith parcel that influence its contribution to water quality. In the HBSW, a parcel's size, its stream footage, and its distance from the City of Syracuse intake pipes might affect the total loading of pollutants and the likelihood that they will reach Skaneateles Lake. We use these three attributes (parcel size, stream footage, and distance from the City of Syracuse intake pipes) to construct two alternative parcel weights. The ratio (s_i/d_i) can represent either the parcel's size divided by the parcel's distance to the intake pipes or the parcel's stream footage divided by its distance to the intake pipes. The further a parcel is from the intake pipes, the greater will be d_i and the smaller will be the parcel's weight. When s_i is parcel size, larger parcels will have a larger weight for the same distance, and when s_i, is stream footage, only parcels that have stream footage or lake frontage will have a positive weight. When (s_i/d_i) is parcel size divided by distance, the PPW Model is compared to the SSE Model in [P1], where every parcel in the HBSW is considered for inclusion in the riparian buffer. When (s_i/d_i) is stream footage divided by distance, the PPW Model is compared to the riparian version of the SSE Model in [P2]. Figure 2 shows those parcels in the HBSW with stream footage or lake frontage.

The definitions of C_i, B_i, and M are the same as in the SSE Models. The binary optimization problem, based on the Parcel-Pollutant-Weighting Model, is

$$\begin{aligned} &\underset{B_i=0,1}{\text{Maximize}} \quad \sum_{i=1}^{I}\sum_{j=1}^{J}(s_i/d_i)W_j(X_{i,j}-X_{i,j}^{B})B_i \\ &\text{Subject to} \quad \sum_{i=1}^{I} C_i B_i \le M \end{aligned} \qquad \text{[P3] or [P4]}$$

The problem is denoted [P3] when s_i is acreage and [P4] when s_i is stream footage.

III. THE HAROLD BROOK SUB-WATERSHED (HBSW)

The SSE Model

The SSE for each of the I=64 parcels in the HBSW is based on five attributes ($\alpha_{i,k}$): k=1=acreage, k=2=priority zone, k=3=distance to the intake pipes, k=4=hydrologic sensitivity and k=5=stream length. For each parcel, these attributes were measured and normalized. Normalization ensures that the units of measurement (for example, acres versus hectares or feet versus meters) do not influence a parcel's score, D_i. Parcel attributes were normalized based on the following ratio-scale formula

$$N\alpha_{i,k} = \frac{(\alpha_{i,k} - \alpha_k^{min})}{(\alpha_k^{max} - \alpha_k^{min})} \qquad [2]$$

According to Equation [2], a parcel with the lowest attribute score has a normalized score of zero and a parcel with the highest attribute score has a normalized score of one. When normalizing k=3=distance to intake pipes, parcels closer to the intake pipes (with smaller distances) are more desirable for inclusion in a buffer, since the runoff from such parcels is more likely to reach the intake pipes. Thus for k=3, the complement, $(1 - N\alpha_{i,3})$, is used in the SSE Model. Parcel #64, for example, is the closest parcel to the intake pipes and has a normalized distance of zero, but a complement of $(1 - N\alpha_{64,3})=1$. In calculating D_i, the third term in Equation (1) took the form $\omega_3(1 - N\alpha_{i,3})$, while all other terms were $\omega_k N\alpha_{i,k}$, k=1,2,4,5.

In the SSE Models, the normalized attributes were assigned weights of $\omega_1=0.2$, $\omega_2=0.2$, $\omega_3=0.25$, $\omega_4=0.25$, and $\omega_5=0.1$[2)]. The nominal attribute values, normalized attribute values, and the desirability index, D_i, for all sixty-four parcels are given in the Appendix in Spreadsheet #1. This spreadsheet also contains the estimated cost of acquiring an easement for each parcel, C_i, and initially assumed that no easements had been acquired; i.e., $B_i=0$, i=1,2,...,64. The estimates of easement costs were based on the assessed value of the land parcel (see Footnote 1). The sum, over i, of D_iB_i and C_iB_i are given in cells E5 and E7, respectively, while the budget, M=1,000,000 dollars, is given in E3. One can then use Excel's Solver to maximize the Set Cell, E5, by changing the value in the cells M11:M74, subject to M11:M74 being binary and E7≤E3. The optimal buffer for problem [P1] is indicated in cells M11:M74.

Spreadsheet #2 in the Appendix inserts the column R_i, indicating whether a parcel is riparian (R_i=1) or not (R_i=0) and then calculates $R_iD_iB_i$ in spreadsheet column P. The sum over i of $R_iD_iB_i$ is now calculated in cell E5 and the cost of a candidate buffer is again calculated in E7. Using Solver on Spreadsheet #2, one can solve for the optimal riparian buffer for the SSE Model in [P2]. This is now indicated in cells N11:N74.

The PPW Model

A critical component of the PPW Models in [P3] or [P4] is the reduction in pollutant j if an easement to the ith parcel is purchased. The values used for the current pollutant load, $X_{i,j}$, and the reduced load, $X^B_{i,j}$, were based on a parcel's current land use. In 1999, the New York State Department of Health released a report entitled the *Source Water Assessment Program Plan*. In that report a panel of experts were asked to qualitatively assess the likely loading of 14 pollutants from 15 land-cover types (see New York State Department of Health, 1999, Table 5, p.73.) The land-cover types included low-intensity residential, high-intensity residential, high-intensity commercial, pasture, row crops, mixed forest and wetlands, which corresponds closely to the City of Syracuse's land-use classifications for the sixty-four parcels in the HBSW. The City of Syracuse land-use classification system is listed in Table 1 and the specific classification of parcels in the HBSW was shown in Figure 1.

We applied the qualitative assessment from the New York State Department of Health to the corresponding City of Syracuse land-use classification in the HBSW. The qualitative assessment was converted into an index number where H=10, M(H)=8.33, M=6.67, L=3.33 and N=0. The resulting indices for phosphorus and pathogens are shown Table 2.

The index numbers in Table 2 correspond to the current land-use loadings, $X_{i,j}$. It was then necessary to make some assumption about the potential reduction in the index numbers if a parcel were acquired for the HBSW riparian buffer. We based the percentage reductions on the discussion in Hermans (1999, p.136). We assumed that a 65% reduction was possible for parcels with a high level of phosphorus runoff. For a parcel with a high pathogen loading, a reduction of 25% would be possible under buffer status. These percentages decline to a 50% reduction for phosphorus if a parcel's current loading was low (L), and a 17% reduction for pathogens if a parcel currently had a low loading of that pollutant. The pollutant rating, index number and the percentage reduction in phosphorus and pathogens are given in Table 3.

With the percentage reductions given in Table 3, we calculated an index for pollutant loading under buffer status, corresponding to $X_{i,j}^{B}$. The $X_{i,j}$ and $X_{i,j}^{B}$ index numbers by parcel class and land cover are given in Table 4.

To summarize, the sixty-four parcels in the HBSW were assigned to a land-use classification. Based on this classification and the results of a published water quality study, we qualitatively assessed each parcel's potential loading of phosphorus and pathogens. This qualitative assessment was then assigned an index number ranging from 10, for a qualitative assessment of "high," to 3.33, for a qualitative assessment of "low." If a parcel was acquired for the HBSW Riparian Buffer, a percentage reduction in loading was assumed, based on the current qualitative assessment. This analysis is consistent with the approach taken by the New York State Department of Health (1999) and Hermans (1999). Admittedly, this approach is less than ideal. It would be better to generate $X_{i,j}$ and $X^B_{i,j}$ using non-point source simulation models. We will return to this issue in Section V.

Spreadsheet #3 in the Appendix repeats the normalized data on acreage, stream footage, distance to the City of Syracuse intake pipes, and easement costs, C_i, but also contains the pollutant loadings for phosphorus (j=1) and pathogens (j=2), both without easement, $X_{i,j}$, and with easement, $X^B_{i,j}$. On this spreadsheet the pollutant weights were both set equal to one ($W_1 = W_2 = 1$) and (s_i/d_i) was normalized acreage divided by normalized distance.

The sum over i of the sum of the parcel-weighted, pollutant-weighted, reduced loadings in column L is calculated in cell E4 with the cost of a candidate buffer given in cell E5 and the budget in cell E3. Solver and Spreadsheet #3 was used to determine the optimal buffer for problem [P3], shown in cells K8:K71.

Finally, Spreadsheet #4, appearing identical to Spreadsheet #3, has (s_i/d_i) calculated as normalized stream footage or lake frontage divided by normalized distance. Since parcels with zero stream footage or lake frontage have a zero parcel weight, the optimal buffer from this initial spreadsheet, corresponding to [P4], will be compared to the optimal buffer from the SSE Model in problem [P2].

In the PPW Models, where we divided by distance, we used the normalized distance $N\alpha_{i,3}$. Parcel #64, with a normalized distance of zero, would make (s_{64}/d_{64}) undefined. Therefore, in the PPW Models, [P3] and [P4], a small, but positive normalized distance, $N\alpha_{64,3}$=0.04, was assigned to Parcel #64.

IV. RESULTS

The optimal buffers for problems [P1] - [P4] within the HBWS are given in Table 5. For ease of comparison, [P3] is listed immediately to the right of [P1] and [P4] to the right of [P2]. A "1" in the column indicates that the parcel was selected for inclusion in the riparian buffer. Identical optimal buffers were obtained starting from an initial spreadsheet with B_i=0 or B_i=1, i=1,2,...,64. All problems were solved for a budget of M=$1,000,000.

In comparing [P1] with [P3], we are comparing the optimal buffer using the SSE Equation, for all parcels, with the PPW Model where (s_i/d_i) is acres divided by distance. We note

$$\{(P1) \cap (P3)\} = [4,5,7,10,11,12,13,14,17,18,22,23,24,39,62,63,64\}$$
$$\{(P1) - [(P1) \cap (P3)]\} = \{2,3,8,9,15,16,31,33,35,44,49,51,52,54,60,61\}$$
$$\{(P3) - [(P1) \cap (P3)]\} = \{26,28,40,41\}$$

In words, the optimal buffers to problems [P1] and [P3] share seventeen parcels in common, the optimal buffer to problem [P1] has sixteen parcels not in common with the optimal buffer for [P3], and the optimal buffer to problem [P3] has four parcels not in common with the optimal buffer for [P1].

The optimal buffers for problems [P2] and [P4] only contain riparian parcels. A careful analysis of the optimal buffers for these two cases reveals

$$\{(P2) \cap (P4)\} = \{8,9,12,14,24,26,27,31,32,39,52,62,63,64\}$$

$$\{(P2) - [(P2) \cap (P4)]\} = \{3,15,34,40,51,61\}$$

$$\{(P4) - [(P2) \cap (P4)]\} = \{28,41\}$$

In words, the optimal buffers to problems [P2] and [P4] share fourteen parcels in common, the optimal buffer to problem [P2] has six parcels not in common with the optimal buffer to [P4], and the optimal buffer for the problem [P4] has two parcels not in common with [P2].

The optimal buffers for [P1], [P2], [P3] and [P4] cost $998,000, $994,300, $998,800, and $996,900, respectively. Finally,

$\{(P1) \cap (P2) \cap (P3) \cap (P4)\} = \{12,14,24,39,62,63,64\}$

Easements to the seven riparian parcels common to all four optimal buffers would cost $373,400. These seven parcels might be regarded as "high priority" for an easement acquisition program since they were included in all four optimal buffers.

V. CONCLUSIONS AND CAVEATS

Protecting the quality of lakes and reservoirs is important to many cities that use them as a source for drinking water. Watershed management can involve a variety of strategies to reduce the runoff of phosphorus, nitrogen, pathogens and sediment. The establishment of a riparian buffer, by the acquisition of fee-simple titles or conservation easements, offers municipalities greater precision in reducing runoff by controlling land use and vegetative cover.

Finding the best collection of parcels to include in a riparian buffer might be viewed as a binary optimization problem. Parcels have different uses and attributes that will influence the loading of various pollutants. Pollutants may vary in terms of their public health consequences or the ability of officials to remove them from drinking water before distribution. Budget constraints may limit the amount of money a municipality can spend on a riparian buffer.

Two models were constructed to optimize a riparian buffer. They were applied to the Harold Brook Sub-Watershed (HBSW), an area within the larger Skaneateles Lake watershed in central New York State. Skaneateles Lake serves as the source of drinking water for the City of Syracuse. The lake's water is of such high quality that it requires only screening and chlorination before distribution to city residents. To protect the high water quality of the lake, and thus to avoid costly filtration, the City of Syracuse has embarked on several watershed management strategies, including the purchase of conservation easements to establish a riparian buffer.

We determined the optimal buffer in the HBSW under four different optimization problems [[P1] - [P4]]. Problems [P1] and [P2] were based on the Syracuse Scoring Equation (SSE) and problems [P3] and [P4] were based on a parcel-pollutant-weighting (PPW) model. All problems had the same acquisition budget of $1 million and [P2] and [P4] were formulated so that the optimal buffer would only include parcels with positive stream footage or lake frontage. Such riparian parcels are often critical to reducing runoff. The optimal buffers to [P1], [P2], [P3] and [P4] contained thirty-three, twenty, twenty-one, and sixteen parcels respectively. Seven parcels, {12,14,24,39,62,63,64}, with an easement acquisition cost of $373,400, were common to all optimal buffers.

Limited sensitivity analysis was conducted on models (P.1) - (P.4). We solved (P.1) and (P.2) for two alternative sets of attribute weights; $\omega_k=0.2$ for k=1,2,3,4,5, and $\omega_1=\omega_5=0.35$, $\omega_2=\omega_3=\omega_4=0.1$. In the second set, acreage (k=1) and stream length (k=5) receive a weight of 0.35. Models (P.3) and (P.4) were solved with pollutant weights $W_1=1$, $W_2=2$ and with $W_1=2$, $W_2=1$. We denote by (P.1)' and (P.2)' the solutions to (P.1) and (P.2) when $\omega_k=0.2$ for k=1,2,3,4,5, and by (P.1)" and (P.2)" the solutions to (P.1) and (P.2) when $\omega_1=\omega_5=0.35$,

$\omega_2=\omega_3=\omega_4=0.1$. We then compare (P.1)' and (P.1)" to (P.1) and (P.2)' and (P.2)" to (P.2). In a similar fashion we denote the solutions to (P.3) and (P.4) when $W_1=1$ and $W_2=2$ by (P.3)' and (P.4)', and the solutions when $W_1=2$ and $W_2=1$ as (P.3)" and (P.4)". We then compare (P.3)' and (P.3)" to (P.3) and (P.4)' and (P.4)" to (P.4).

The original solutions, (P.1) - (P.4) are relatively robust. Specifically, when $\omega_k=0.2$ for k=1,2,3,4,5, (P.1)'=(P.1) and (P.2)'=(P.2). When $\omega_1=\omega_5=0.35$, $\omega_2=\omega_3=\omega_4=0.1$, there are some changes in the optimal buffers. Specifically,

$$\{(P.1)'' - [(P.1)'' \cap (P.1)]\} = \{27,30\}$$
$$\{(P.1) - [(P.1)'' \cap (P.1)]\} = \{33,44,49,51,52,54\}$$
$$\{(P.2)'' - [(P.2)'' \cap (P.2)]\} = \{28,54\}$$
$$\{(P.2) - [(P.2)'' \cap (P.2)]\} = \{40,52\}$$

Thus (P.1)" had two parcels, {27,30}, not in (P.1) and (P.1) had five parcels, {33,44,49,51,52,54}, not in (P.1)". Similarly, (P.2)" had two parcels, {28,54}, not in (P.2) and (P.2) had two parcels, {40,52}, not in (P.2)".

For the two alternative sets of pollutant weight ($W_1=1$, $W_2=2$ and $W_1=2$, $W_2=1$) in (P.3) and (P.4) there were no changes in the optimal buffers; that is, (P.3)'=(P.3)"=(P.3) and (P.4)'=(P.4)"=(P.4).

The SSE model was based on a parcel desirability index that was developed by the City of Syracuse, Department of Water. The index represents the subjective opinion of knowledgeable people about the importance of parcel attributes in contributing to water quality. In the PPW model, we incorporated the subjective opinion of knowledgeable people about the loading of pollutants from certain types of parcels without ($X_{i,j}$) and with ($X^B_{i,j}$) buffer status.

This gave us a subjective estimate of the reduced loading of pollutant j if an easement to parcel i was acquired ($X_{i,j}$ - $X^{B}_{i,j}$) ≥ 0. A preferred approach would be to use non-point source simulation models, calibrated to the watershed or sub-watershed of interest. Models such as the Watershed Information Management System - Non-Point Source Pollution (WIMS-NPS) described by Harou *et al*. (2001) and the Riparian Ecosystem Management Model (REMM) described in Lowrance *et al.* (2000) have the potential to generate estimates of $X_{i,j}$ and $X^{B}_{i,j}$[3]. The output of such models would in turn serve as inputs to a buffer optimization problem similar to the PPW model presented here.

APPENDIX

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Spreadsheet #1: Optimal Buffer for the SSE Model as Stated in Problem [P1]**														
2															
3	Attribute Weights			Budget M=	1000000		Number of Parcels in Optimal Buffer =			33					
4	ω1=	0.2													
5	ω2=	0.2		Sum DiBi=	9.9488465										
6	ω3=	0.25													
7	ω4=	0.25		Sum CiBi=	998900										
8	ω5=	0.1													
9															
10	Parcel	Acres	NAcres	Zone	Nzone	Distance	(1-Ndist.)	HydroSens	NHydroSens	Stream ft.	Nstream ft.	**Di**	Bi	**Ci**	DiBi
11	1	1.11	0.00454	D	0.1	3.39	0.07937	0	0	0	0	0.040751	0	10000	0
12	2	3.43	0.02561	D	0.1	2.46	0.57143	0	0	0	0	0.167980	1	4000	0.1679795
13	3	7.91	0.06630	B	0.6	3.23	0.16402	0	0	536.63	0.08664	0.182929	1	17500	0.182929
14	4	8.44	0.07111	B	0.6	2.49	0.55556	0	0	0	0	0.273112	1	7200	0.273112
15	5	10.26	0.08764	D	0.1	2.39	0.60847	0	0	0	0	0.189646	1	8400	0.1896455
16	6	12.97	0.11225	D	0.1	3.49	0.02646	0	0	0	0	0.049065	0	26000	0
17	7	14.82	0.12905	D	0.1	2.96	0.30688	0	0	0	0	0.122530	1	9000	0.12253
18	8	15.98	0.13959	B	0.6	2.45	0.57672	0	0	1173.53	0.18948	0.311046	1	21000	0.311046
19	9	16.48	0.14413	B	0.6	2.68	0.45503	0	0	2912.33	0.47023	0.309607	1	21500	0.3096065
20	10	21.7	0.19154	D	0.1	2.76	0.4127	0	0	0	0	0.161483	1	14700	0.161483
21	11	22.6	0.19971	D	0.1	2.77	0.40741	0	0	0	0	0.161795	1	9000	0.1617945
22	12	23.36	0.20661	B	0.6	2.17	0.72487	0	0	1849.57	0.29863	0.372403	1	18300	0.3724025
23	13	25.76	0.22841	B	0.6	2.3	0.65608	0	0	0	0	0.329702	1	18600	0.329702
24	14	26.76	0.23749	B	0.6	2.52	0.53968	5.39	0.17812	3024.62	0.48836	0.395784	1	20200	0.395784
25	15	32.01	0.28517	B	0.6	2.66	0.46561	0	0	222.92	0.03599	0.297036	1	32000	0.2970355
26	16	32.02	0.28526	B	0.6	2.94	0.31746	0.15	0.00496	0	0	0.257657	1	26400	0.257657
27	17	34.75	0.31005	B	0.6	2.85	0.36508	0	0	0	0	0.273280	1	27500	0.27328
28	18	40.74	0.36445	B	0.6	2.9	0.33862	0	0	0	0	0.277545	1	31500	0.277545
29	19	41.26	0.36918	B	0.6	3.24	0.15873	0	0	0	0	0.233519	0	49500	0
30	20	42.34	0.37898	B	0.6	3.27	0.14286	0	0	0	0	0.231511	0	48400	0
31	21	42.45	0.37998	C	0.3	3.54	0	0.8	0.02644	0	0	0.142606	0	51000	0
32	22	42.7	0.38225	B	0.6	2.89	0.34392	0	0	0	0	0.282430	1	28700	0.28243
33	23	52.9	0.47489	B	0.6	2.18	0.71958	0	0	0	0	0.394873	1	42300	0.394873
34	24	67.72	0.60948	B	0.6	2.28	0.66667	0	0	6193.45	1	0.508564	1	81300	0.5085635
35	25	69	0.62111	B	0.6	2.99	0.29101	0.08	0.00264	120.61	0.01947	0.319582	0	111000	0
36	26	72.98	0.65725	B	0.6	2.13	0.74603	0	0	2877.6	0.46462	0.484420	0	100400	0
37	27	82.15	0.74053	B	0.6	2.76	0.4127	5.21	0.17217	4758.31	0.76828	0.491152	0	98400	0
38	28	91.07	0.82154	B	0.6	2.46	0.57143	0	0	2487.16	0.40158	0.467324	0	109400	0
39	29	93.78	0.84615	B	0.6	3.13	0.21693	5.37	0.17746	0	0	0.387828	0	75800	0
40	30	98.83	0.89202	B	0.6	3.4	0.07407	0	0	0	0	0.316922	0	64900	0
41	31	65.36	0.58805	B	0.6	2.97	0.30159	2.08	0.06874	4397.95	0.7101	0.401203	1	69700	0.4012025
42	32	15.69	0.13695	C	0.3	2.25	0.68254	0	0	1231.12	0.19878	0.277903	0	47600	0
43	33	18.85	0.16565	B	0.6	2.56	0.51852	0	0	0	0	0.282760	1	38100	0.28276
44	34	30.62	0.27255	B	0.6	3.18	0.19048	0	0	1301.07	0.21007	0.243137	0	39800	0
45	35	33.74	0.30088	B	0.6	2.69	0.44974	0	0	0	0	0.292611	1	35000	0.292611
46	36	50.69	0.45482	D	0.1	2.61	0.49206	0	0	0	0	0.233979	0	68900	0
47	37	55.82	0.50141	B	0.6	3.14	0.21164	0	0	2062.02	0.33294	0.306486	0	84800	0
48	38	69.56	0.62619	B	0.6	3.25	0.15344	0	0	275.41	0.04447	0.288045	0	78000	0
49	39	83.56	0.75334	B	0.6	2.44	0.58201	0	0	6129.45	0.98967	0.515138	1	84700	0.5151375
50	40	85.01	0.76651	B	0.6	1.82	0.91005	5.89	0.19465	294.14	0.04749	0.554226	0	97200	0
51	41	110.72	1	B	0.6	1.97	0.83069	0	0	1550.79	0.25039	0.552712	0	121500	0
52	42	0.61	0	C	0.3	2.46	0.57143	0	0	0	0	0.202858	0	85000	0
53	43	0.92	0.00282	D	0.1	3.1	0.2328	0	0	0	0	0.078764	0	19600	0
54	44	1	0.00354	D	0.1	2.63	0.48148	0	0	0	0	0.141078	1	20200	0.141078
55	45	1.32	0.00645	C	0.3	2.43	0.5873	0.76	0.02512	996.54	0.1609	0.230485	0	215900	0
56	46	2.05	0.01308	D	0.1	3.27	0.14286	0	0	0	0	0.058331	0	20500	0
57	47	2.15	0.01399	D	0.1	3.44	0.05291	0	0	0	0	0.036026	0	20600	0
58	48	2.8	0.01989	D	0.1	3.49	0.02646	0	0	0	0	0.030593	0	25000	0
59	49	3.41	0.02543	D	0.1	2.45	0.57672	0	0	0	0	0.169266	1	24000	0.169266
60	50	4.24	0.03297	D	0.1	3.54	0	0	0	0	0	0.026594	0	21600	0
61	51	4.59	0.03615	C	0.3	2.4	0.60317	0.08	0.00264	21.77	0.00352	0.219035	1	21800	0.2190345
62	52	5.22	0.04187	C	0.3	2.54	0.5291	1.42	0.04693	767.92	0.12399	0.224781	1	34000	0.2247805
63	53	8.3	0.06984	D	0.1	3.54	0	0	0	0	0	0.033968	0	24000	0
64	54	7.91	0.06630	B	0.6	3.24	0.15873	0	0	512.13	0.08269	0.181212	1	25400	0.1812115
65	55	0.7	0.00082	C	0.3	2.47	0.56614	0	0	0	0	0.201699	0	165000	0
66	56	0.76	0.00136	C	0.3	2.41	0.59788	0	0	0	0	0.209742	0	175000	0
67	57	1.73	0.01017	C	0.3	2.45	0.57672	0.52	0.01718	179.2	0.02893	0.213402	0	120000	0
68	58	7.72	0.06457	C	0.3	2.37	0.61905	0	0	1689.82	0.27284	0.254961	0	210000	0
69	59	8.56	0.07220	C	0.3	2.53	0.53439	0	0	0	0	0.208038	0	102000	0
70	60	4.96	0.03951	B	0.6	2.56	0.51852	0	0	0	0	0.257532	1	18000	0.257532
71	61	2.28	0.01517	C	0.3	2.45	0.57672	0.94	0.03106	711.08	0.11481	0.226460	1	20000	0.22646
72	62	1.51	0.00817	C	0.3	2.45	0.57672	1.14	0.03767	872.59	0.14089	0.229321	1	2000	0.2293205
73	63	73.72	0.66397	B	0.6	1.75	0.94709	11.99	0.39623	3697.73	0.59704	0.648328	1	52500	0.648328
74	64	97.4	0.87903	B	0.6	1.65	1	30.26	1	5878.85	0.9492	0.890726	1	114400	0.890726
75															
76															
77															

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Spreadsheet #2: Optimal Buffer for the SSE Model as Stated in Problem [P2]**														
2															
3	Attribute Weights			Budget M=	1000000		Number of Parcels in the Optimal Buff			20					
4	ω1=	0.2													
5	ω2=	0.2		Sum RiDiBi=	7.7831935										
6	ω3=	0.25													
7	ω4=	0.25		Sum CiBi=	994300										
8	ω5=	0.1													
9															
10	Parcel	Acres	NAcres	Zone	Nzone	Distance	(1-Ndist.)	HydroSens	NHydroSens	Stream ft.	Nstream ft.	Di	Ri	Bi	Ci
11	1	1.11	0.00454	D	0.1	3.39	0.07937	0	0	0	0	0.040751	0	0	10000
12	2	3.43	0.02561	D	0.1	2.46	0.57143	0	0	0	0	0.167980	0	0	4000
13	3	7.91	0.06630	B	0.6	3.23	0.16402	0	0	536.63	0.08664	0.182929	1	1	17500
14	4	8.44	0.07111	B	0.6	2.49	0.55556	0	0	0	0	0.273112	0	0	7200
15	5	10.26	0.08764	D	0.1	2.39	0.60847	0	0	0	0	0.189646	0	0	8400
16	6	12.97	0.11225	D	0.1	3.49	0.02646	0	0	0	0	0.049065	0	0	26000
17	7	14.82	0.12905	D	0.1	2.96	0.30688	0	0	0	0	0.122530	0	0	9000
18	8	15.98	0.13959	B	0.6	2.45	0.57672	0	0	1173.53	0.18948	0.311046	1	1	21000
19	9	16.48	0.14413	B	0.6	2.68	0.45503	0	0	2912.33	0.47023	0.309607	1	1	21500
20	10	21.7	0.19154	D	0.1	2.76	0.4127	0	0	0	0	0.161483	0	0	14700
21	11	22.6	0.19971	D	0.1	2.77	0.40741	0	0	0	0	0.161795	0	0	9000
22	12	23.36	0.20661	B	0.6	2.17	0.72487	0	0	1849.57	0.29863	0.372403	1	1	18300
23	13	25.76	0.22841	B	0.6	2.3	0.65608	0	0	0	0	0.329702	0	0	18600
24	14	26.76	0.23749	B	0.6	2.52	0.53968	5.39	0.17812	3024.62	0.48836	0.395784	1	1	20200
25	15	32.01	0.28517	B	0.6	2.66	0.46561	0	0	222.92	0.03599	0.297036	1	1	32000
26	16	32.02	0.28526	B	0.6	2.94	0.31746	0.15	0.00496	0	0	0.257657	0	0	26400
27	17	34.75	0.31005	B	0.6	2.85	0.36508	0	0	0	0	0.273280	0	0	27500
28	18	40.74	0.36445	B	0.6	2.9	0.33862	0	0	0	0	0.277545	0	0	31500
29	19	41.26	0.36918	B	0.6	3.24	0.15873	0	0	0	0	0.233519	0	0	49500
30	20	42.34	0.37898	B	0.6	3.27	0.14286	0	0	0	0	0.231511	0	0	48400
31	21	42.45	0.37998	C	0.3	3.54	0	0.8	0.02644	0	0	0.142606	0	0	51000
32	22	42.7	0.38225	B	0.6	2.89	0.34392	0	0	0	0	0.282430	0	0	28700
33	23	52.9	0.47489	B	0.6	2.18	0.71958	0	0	0	0	0.394873	0	0	42300
34	24	67.72	0.60948	B	0.6	2.28	0.66667	0	0	6193.45	1	0.508564	1	1	81300
35	25	69	0.62111	B	0.6	2.99	0.29101	0.08	0.00264	120.61	0.01947	0.319582	1	0	111000
36	26	72.98	0.65725	B	0.6	2.13	0.74603	0	0	2877.6	0.46462	0.484420	1	1	100400
37	27	82.15	0.74053	B	0.6	2.76	0.4127	5.21	0.17217	4758.31	0.76828	0.491152	1	1	98400
38	28	91.07	0.82154	B	0.6	2.46	0.57143	0	0	2487.16	0.40158	0.467324	1	0	109400
39	29	93.78	0.84615	B	0.6	3.13	0.21693	5.37	0.17746	0	0	0.387828	0	0	75800
40	30	98.83	0.89202	B	0.6	3.4	0.07407	0	0	0	0	0.316922	0	0	64900
41	31	65.36	0.58805	B	0.6	2.97	0.30159	2.08	0.06874	4397.95	0.7101	0.401203	1	1	69700
42	32	15.69	0.13695	C	0.3	2.25	0.68254	0	0	1231.12	0.19878	0.277903	1	1	47600
43	33	18.85	0.16565	B	0.6	2.56	0.51852	0	0	0	0	0.282760	0	0	38100
44	34	30.62	0.27255	B	0.6	3.18	0.19048	0	0	1301.07	0.21007	0.243137	1	1	39800
45	35	33.74	0.30088	B	0.6	2.69	0.44974	0	0	0	0	0.292611	0	0	35000
46	36	50.69	0.45482	D	0.1	2.61	0.49206	0	0	0	0	0.233979	0	0	68900
47	37	55.82	0.50141	B	0.6	3.14	0.21164	0	0	2062.02	0.33294	0.306486	1	0	84800
48	38	69.56	0.62619	B	0.6	3.25	0.15344	0	0	275.41	0.04447	0.288045	1	0	78000
49	39	83.56	0.75334	B	0.6	2.44	0.58201	0	0	6129.45	0.98967	0.515138	1	1	84700
50	40	85.01	0.76651	B	0.6	1.82	0.91005	5.89	0.19465	294.14	0.04749	0.554226	1	1	97200
51	41	110.72	1	B	0.6	1.97	0.83069	0	0	1550.79	0.25039	0.552712	1	0	121500
52	42	0.61	0	C	0.3	2.46	0.57143	0	0	0	0	0.202858	0	0	85000
53	43	0.92	0.00282	D	0.1	3.1	0.2328	0	0	0	0	0.078764	0	0	19600
54	44	1	0.00354	D	0.1	2.63	0.48148	0	0	0	0	0.141078	0	0	20200
55	45	1.32	0.00645	C	0.3	2.43	0.5873	0.76	0.02512	996.54	0.1609	0.230485	1	0	215900
56	46	2.05	0.01308	D	0.1	3.27	0.14286	0	0	0	0	0.058331	0	0	20500
57	47	2.15	0.01399	D	0.1	3.44	0.05291	0	0	0	0	0.036026	0	0	20600
58	48	2.8	0.01989	D	0.1	3.49	0.02646	0	0	0	0	0.030593	0	0	25000
59	49	3.41	0.02543	D	0.1	2.45	0.57672	0	0	0	0	0.169266	0	0	24000
60	50	4.24	0.03297	D	0.1	3.54	0	0	0	0	0	0.026594	0	0	21600
61	51	4.59	0.03615	C	0.3	2.4	0.60317	0.08	0.00264	21.77	0.00352	0.219035	1	1	21800
62	52	5.22	0.04187	C	0.3	2.54	0.5291	1.42	0.04693	767.92	0.12399	0.224781	1	1	34000
63	53	8.3	0.06984	D	0.1	3.54	0	0	0	0	0	0.033968	0	0	24000
64	54	7.91	0.06630	B	0.6	3.24	0.15873	0	0	512.13	0.08269	0.181212	1	0	25400
65	55	0.7	0.00082	C	0.3	2.47	0.56614	0	0	0	0	0.201699	0	0	165000
66	56	0.76	0.00136	C	0.3	2.41	0.59788	0	0	0	0	0.209742	0	0	175000
67	57	1.73	0.01017	C	0.3	2.45	0.57672	0.52	0.01718	179.2	0.02893	0.213402	1	0	120000
68	58	7.72	0.06457	C	0.3	2.37	0.61905	0	0	1689.82	0.27284	0.254961	1	0	210000
69	59	8.56	0.07220	C	0.3	2.53	0.53439	0	0	0	0	0.208038	0	0	102000
70	60	4.96	0.03951	B	0.6	2.56	0.51852	0	0	0	0	0.257532	0	0	18000
71	61	2.28	0.01517	C	0.3	2.45	0.57672	0.94	0.03106	711.08	0.11481	0.226460	1	1	20000
72	62	1.51	0.00817	C	0.3	2.45	0.57672	1.14	0.03767	872.59	0.14089	0.229321	1	1	2000
73	63	73.72	0.66397	B	0.6	1.75	0.94709	11.99	0.39623	3697.73	0.59704	0.648328	1	1	52500
74	64	97.4	0.87903	B	0.6	1.65	1	30.26	1	5878.85	0.9492	0.890726	1	1	114400
75															
76															
77															

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Spreadsheet #3: Optimal Buffer for the PPW Model as Stated in Problem [P3], si=acres**														
2															
3	Wj			M=	1000000		Number of Parcels =		21						
4	W1=	1		Sum PPW=	410.05996										
5	W2=	1		Sum C i*B i=	998800										
6															
7	Parcel	NAcres	Nstream ft.	(1-Ndist.)	Ndistance	(si /di)	Xi,1	Xi,1B	Xi,2	Xi,2B	Bi	Sum PPW	Ci	CiBi	
8	1	0.00454	0	0.07937	0.92063	0.0049314	8.33	3	8.33	6.29	0	0	10000	0	
9	2	0.02561	0	0.57143	0.42857	0.0597569	8.33	3	8.33	6.29	0	0	4000	0	
10	3	0.06630	0.08664	0.16402	0.83598	0.0793081	8.33	3	8.33	6.29	0	0	17500	0	
11	4	0.07111	0	0.55556	0.44444	0.1599991	8.33	3	8.33	6.29	1	1.1791934	7200	7200	
12	5	0.08764	0	0.60847	0.39153	0.2238398	8.33	3	8.33	6.29	1	1.6496994	8400	8400	
13	6	0.11225	0	0.02646	0.97354	0.1153009	8.33	3	8.33	6.29	0	0	26000	0	
14	7	0.12905	0	0.30688	0.69312	0.1861871	8.33	3	8.33	6.29	1	1.3721989	9000	9000	
15	8	0.13959	0.18948	0.57672	0.42328	0.3297817	8.33	3	8.33	6.29	0	0	21000	0	
16	9	0.14413	0.47023	0.45503	0.54497	0.2644733	8.33	3	8.33	6.29	0	0	21500	0	
17	10	0.19154	0	0.4127	0.5873	0.3261366	8.33	3	8.33	6.29	1	2.4036264	14700	14700	
18	11	0.19971	0	0.40741	0.59259	0.3370121	8.33	3	8.33	6.29	1	2.4837792	9000	9000	
19	12	0.20661	0.29863	0.72487	0.27513	0.7509541	8.33	3	8.33	6.29	1	5.5345317	18300	18300	
20	13	0.22841	0	0.65608	0.34392	0.664137	8.33	3	8.33	6.29	1	4.8946898	18600	18600	
21	14	0.23749	0.48836	0.53968	0.46032	0.5159237	8.33	3	8.33	6.29	1	3.8023577	20200	20200	
22	15	0.28517	0.03599	0.46561	0.53439	0.5336365	8.33	3	8.33	6.29	0	0	32000	0	
23	16	0.28526	0	0.31746	0.68254	0.4179389	8.33	3	8.33	6.29	0	0	26400	0	
24	17	0.31005	0	0.36508	0.63492	0.4883292	8.33	3	8.33	6.29	1	3.5989865	27500	27500	
25	18	0.36445	0	0.33862	0.66138	0.5510448	8.33	3	8.33	6.29	1	4.0612001	31500	31500	
26	19	0.36918	0	0.15873	0.84127	0.4388365	8.33	3	8.33	6.29	0	0	49500	0	
27	20	0.37898	0	0.14286	0.85714	0.4421448	8.33	3	8.33	6.29	0	0	48400	0	
28	21	0.37998	0	0	1	0.37998	8.33	3	8.33	6.29	0	0	51000	0	
29	22	0.38225	0	0.34392	0.65608	0.5826271	8.33	3	8.33	6.29	1	4.2939619	28700	28700	
30	23	0.47489	0	0.71958	0.28042	1.6934955	8.33	3	8.33	6.29	1	12.481062	42300	42300	
31	24	0.60948	1	0.66667	0.33333	1.8284583	8.33	3	8.33	6.29	1	13.475738	81300	81300	
32	25	0.62111	0.01947	0.29101	0.70899	0.876049	8.33	3	8.33	6.29	0	0	111000	0	
33	26	0.65725	0.46462	0.74603	0.25397	2.5879041	8.33	3	8.33	6.29	1	19.072853	100400	100400	
34	27	0.74053	0.76828	0.4127	0.5873	1.2609058	8.33	3	8.33	6.29	0	0	98400	0	
35	28	0.82154	0.40158	0.57143	0.42857	1.9169331	8.33	3	8.33	6.29	1	14.127797	109400	109400	
36	29	0.84615	0	0.21693	0.78307	1.0805547	8.33	3	8.33	6.29	0	0	75800	0	
37	30	0.89202	0	0.07407	0.92593	0.9633774	8.33	3	8.33	6.29	0	0	64900	0	
38	31	0.58805	0.7101	0.30159	0.69841	0.8419839	10	3.5	10	7.5	0	0	69700	0	
39	32	0.13695	0.19878	0.68254	0.31746	0.4313929	8.33	3	8.33	6.29	0	0	47600	0	
40	33	0.16565	0	0.51852	0.48148	0.3440434	8.33	3	8.33	6.29	0	0	38100	0	
41	34	0.27255	0.21007	0.19048	0.80952	0.336681	8.33	3	8.33	6.29	0	0	39800	0	
42	35	0.30088	0	0.44974	0.55026	0.5467961	8.33	3	8.33	6.29	0	0	35000	0	
43	36	0.45482	0	0.49206	0.50794	0.8954207	8.33	3	8.33	6.29	0	0	68900	0	
44	37	0.50141	0.33294	0.21164	0.78836	0.6360165	8.33	3	8.33	6.29	0	0	84800	0	
45	38	0.62619	0.04447	0.15344	0.84656	0.7396877	8.33	3	8.33	6.29	0	0	78000	0	
46	39	0.75334	0.98967	0.58201	0.41799	1.8022919	8.33	3	8.33	6.29	1	13.282891	84700	84700	
47	40	0.76651	0.04749	0.91005	0.08995	8.521512	8.33	3	8.33	6.29	1	62.803543	97200	97200	
48	41	1	0.25039	0.83069	0.16931	5.9063257	8.33	3	8.33	6.29	1	43.52962	121500	121500	
49	42	0	0	0.57143	0.42857	0	6.67	2.53	6.67	5.13	0	0	85000	0	
50	43	0.00282	0	0.2328	0.7672	0.0036757	6.67	2.53	6.67	5.13	0	0	19600	0	
51	44	0.00354	0	0.48148	0.51852	0.0068271	6.67	2.53	6.67	5.13	0	0	20200	0	
52	45	0.00645	0.1609	0.5873	0.4127	0.0156288	6.67	2.53	6.67	5.13	0	0	215900	0	
53	46	0.01308	0	0.14286	0.85714	0.0152601	6.67	2.53	6.67	5.13	0	0	20500	0	
54	47	0.01399	0	0.05291	0.94709	0.0147716	6.67	2.53	6.67	5.13	0	0	20600	0	
55	48	0.01989	0	0.02646	0.97354	0.0204306	6.67	2.53	6.67	5.13	0	0	25000	0	
56	49	0.02543	0	0.57672	0.42328	0.0600784	6.67	2.53	6.67	5.13	0	0	24000	0	
57	50	0.03297	0	0	1	0.03297	6.67	2.53	6.67	5.13	0	0	21600	0	
58	51	0.03615	0.00352	0.60317	0.39683	0.0910969	6.67	2.53	6.67	5.13	0	0	21800	0	
59	52	0.04187	0.12399	0.5291	0.4709	0.0889148	6.67	2.53	6.67	5.13	0	0	34000	0	
60	53	0.06984	0	0	1	0.06984	6.67	2.53	6.67	5.13	0	0	24000	0	
61	54	0.06630	0.08269	0.15873	0.84127	0.0788094	6.67	2.53	6.67	5.13	0	0	25400	0	
62	55	0.00082	0	0.56614	0.43386	0.00189	6.67	2.53	6.67	5.13	0	0	165000	0	
63	56	0.00136	0	0.59788	0.40212	0.0033821	6.67	2.53	6.67	5.13	0	0	175000	0	
64	57	0.01017	0.02893	0.57672	0.42328	0.0240266	6.67	2.53	6.67	5.13	0	0	120000	0	
65	58	0.06457	0.27284	0.61905	0.38095	0.1694973	6.67	2.53	6.67	5.13	0	0	210000	0	
66	59	0.07220	0	0.53439	0.46561	0.1550654	6.67	2.53	6.67	5.13	0	0	102000	0	
67	60	0.03951	0	0.51852	0.48148	0.0820595	3.33	1.67	3.33	2.76	0	0	18000	0	
68	61	0.01517	0.11481	0.57672	0.42328	0.0358392	3.33	1.67	3.33	2.76	0	0	20000	0	
69	62	0.00817	0.14089	0.57672	0.42328	0.0193016	3.33	1.67	3.33	2.76	1	0.0430427	2000	2000	
70	63	0.66397	0.59704	0.94709	0.05291	12.549046	3.33	1.67	5	3.95	1	34.007913	52500	52500	
71	64	0.87903	0.9492	0.96	0.04	21.97575	8.33	3	8.33	6.29	1	161.96128	114400	114400	
72															
73															
74															
75															
76															
77															

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	**Spreadsheet #4: Optimal Buffer for the PPW Model as Stated in Problem [P4], si=stream footage**														
2															
3	Wj			M=	1000000		Number of Parcels =		16						
4	W1=	1		Sum PPW=	327.43934										
5	W2=	1		Sum C i*B i=	996900										
6															
7	Parcel	NAcres	Nstream ft.	(1-Ndist)	Ndistance	(si /di)	Xi,1	Xi,1B	Xi,2	Xi,2B	Bi	Sum PPW	Ci	CiBi	
8	1	0.00454	0	0.07937	0.92063	0	8.33	3	8.33	6.29	0	0	10000	0	
9	2	0.02561	0	0.57143	0.42857	0	8.33	3	8.33	6.29	0	0	4000	0	
10	3	0.06630	0.08664	0.16402	0.83598	0.1036388	8.33	3	8.33	6.29	0	0	17500	0	
11	4	0.07111	0	0.55556	0.44444	0	8.33	3	8.33	6.29	0	0	7200	0	
12	5	0.08764	0	0.60847	0.39153	0	8.33	3	8.33	6.29	0	0	8400	0	
13	6	0.11225	0	0.02646	0.97354	0	8.33	3	8.33	6.29	0	0	26000	0	
14	7	0.12905	0	0.30688	0.69312	0	8.33	3	8.33	6.29	0	0	9000	0	
15	8	0.13959	0.18948	0.57672	0.42328	0.4476469	8.33	3	8.33	6.29	1	3.299158	21000	21000	
16	9	0.14413	0.47023	0.45503	0.54497	0.8628548	8.33	3	8.33	6.29	1	6.3592401	21500	21500	
17	10	0.19154	0	0.4127	0.5873	0	8.33	3	8.33	6.29	0	0	14700	0	
18	11	0.19971	0	0.40741	0.59259	0	8.33	3	8.33	6.29	0	0	9000	0	
19	12	0.20661	0.29863	0.72487	0.27513	1.0854142	8.33	3	8.33	6.29	1	7.9995024	18300	18300	
20	13	0.22841	0	0.65608	0.34392	0	8.33	3	8.33	6.29	0	0	18600	0	
21	14	0.23749	0.48836	0.53968	0.46032	1.0609141	8.33	3	8.33	6.29	1	7.8189373	20200	20200	
22	15	0.28517	0.03599	0.46561	0.53439	0.0673478	8.33	3	8.33	6.29	0	0	32000	0	
23	16	0.28526	0	0.31746	0.68254	0	8.33	3	8.33	6.29	0	0	26400	0	
24	17	0.31005	0	0.36508	0.63492	0	8.33	3	8.33	6.29	0	0	27500	0	
25	18	0.36445	0	0.33862	0.66138	0	8.33	3	8.33	6.29	0	0	31500	0	
26	19	0.36918	0	0.15873	0.84127	0	8.33	3	8.33	6.29	0	0	49500	0	
27	20	0.37898	0	0.14286	0.85714	0	8.33	3	8.33	6.29	0	0	48400	0	
28	21	0.37998	0	0	1	0	8.33	3	8.33	6.29	0	0	51000	0	
29	22	0.38225	0	0.34392	0.65608	0	8.33	3	8.33	6.29	0	0	28700	0	
30	23	0.47489	0	0.71958	0.28042	0	8.33	3	8.33	6.29	0	0	42300	0	
31	24	0.60948	1	0.66667	0.33333	3.00003	8.33	3	8.33	6.29	1	22.110221	81300	81300	
32	25	0.62111	0.01947	0.29101	0.70899	0.0274616	8.33	3	8.33	6.29	0	0	111000	0	
33	26	0.65725	0.46462	0.74603	0.25397	1.8294287	8.33	3	8.33	6.29	1	13.482889	100400	100400	
34	27	0.74053	0.76828	0.4127	0.5873	1.308156	8.33	3	8.33	6.29	1	9.6411095	98400	98400	
35	28	0.82154	0.40158	0.57143	0.42857	0.9370231	8.33	3	8.33	6.29	1	6.9058604	109400	109400	
36	29	0.84615	0	0.21693	0.78307	0	8.33	3	8.33	6.29	0	0	75800	0	
37	30	0.89202	0	0.07407	0.92593	0	8.33	3	8.33	6.29	0	0	64900	0	
38	31	0.58805	0.7101	0.30159	0.69841	1.016738	10	3.5	10	7.5	1	9.1506422	69700	69700	
39	32	0.13695	0.19878	0.68254	0.31746	0.6261576	8.33	3	8.33	6.29	1	4.6147817	47600	47600	
40	33	0.16565	0	0.51852	0.48148	0	8.33	3	8.33	6.29	0	0	38100	0	
41	34	0.27255	0.21007	0.19048	0.80952	0.2594995	8.33	3	8.33	6.29	0	0	39800	0	
42	35	0.30088	0	0.44974	0.55026	0	8.33	3	8.33	6.29	0	0	35000	0	
43	36	0.45482	0	0.49206	0.50794	0	8.33	3	8.33	6.29	0	0	68900	0	
44	37	0.50141	0.33294	0.21164	0.78836	0.4223198	8.33	3	8.33	6.29	0	0	84800	0	
45	38	0.62619	0.04447	0.15344	0.84656	0.0525302	8.33	3	8.33	6.29	0	0	78000	0	
46	39	0.75334	0.98967	0.58201	0.41799	2.3676882	8.33	3	8.33	6.29	1	17.449862	84700	84700	
47	40	0.76651	0.04749	0.91005	0.08995	0.52796	8.33	3	8.33	6.29	0	0	97200	0	
48	41	1	0.25039	0.83069	0.16931	1.4788849	8.33	3	8.33	6.29	1	10.899382	121500	121500	
49	42	0	0	0.57143	0.42857	0	6.67	2.53	6.67	5.13	0	0	85000	0	
50	43	0.00282	0	0.2328	0.7672	0	6.67	2.53	6.67	5.13	0	0	19600	0	
51	44	0.00354	0	0.48148	0.51852	0	6.67	2.53	6.67	5.13	0	0	20200	0	
52	45	0.00645	0.1609	0.5873	0.4127	0.3898716	6.67	2.53	6.67	5.13	0	0	215900	0	
53	46	0.01308	0	0.14286	0.85714	0	6.67	2.53	6.67	5.13	0	0	20500	0	
54	47	0.01399	0	0.05291	0.94709	0	6.67	2.53	6.67	5.13	0	0	20600	0	
55	48	0.01989	0	0.02646	0.97354	0	6.67	2.53	6.67	5.13	0	0	25000	0	
56	49	0.02543	0	0.57672	0.42328	0	6.67	2.53	6.67	5.13	0	0	24000	0	
57	50	0.03297	0	0	1	0	6.67	2.53	6.67	5.13	0	0	21600	0	
58	51	0.03615	0.00352	0.60317	0.39683	0.0088703	6.67	2.53	6.67	5.13	0	0	21800	0	
59	52	0.04187	0.12399	0.5291	0.4709	0.2633043	6.67	2.53	6.67	5.13	1	1.4955685	34000	34000	
60	53	0.06984	0	0	1	0	6.67	2.53	6.67	5.13	0	0	24000	0	
61	54	0.06630	0.08269	0.15873	0.84127	0.0982919	6.67	2.53	6.67	5.13	0	0	25400	0	
62	55	0.00082	0	0.56614	0.43386	0	6.67	2.53	6.67	5.13	0	0	165000	0	
63	56	0.00136	0	0.59788	0.40212	0	6.67	2.53	6.67	5.13	0	0	175000	0	
64	57	0.01017	0.02893	0.57672	0.42328	0.0683472	6.67	2.53	6.67	5.13	0	0	120000	0	
65	58	0.06457	0.27284	0.61905	0.38095	0.7162095	6.67	2.53	6.67	5.13	0	0	210000	0	
66	59	0.07220	0	0.53439	0.46561	0	6.67	2.53	6.67	5.13	0	0	102000	0	
67	60	0.03951	0	0.51852	0.48148	0	3.33	1.67	3.33	2.76	0	0	18000	0	
68	61	0.01517	0.11481	0.57672	0.42328	0.2712389	3.33	1.67	3.33	2.76	0	0	20000	0	
69	62	0.00817	0.14089	0.57672	0.42328	0.332853	3.33	1.67	3.33	2.76	1	0.7422621	2000	2000	
70	63	0.66397	0.59704	0.94709	0.05291	11.284067	3.33	1.67	5	3.95	1	30.579822	52500	52500	
71	64	0.87903	0.9492	0.96	0.04	23.73	8.33	3	8.33	6.29	1	174.8901	114400	114400	
72															
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FOOTNOTES

1) In our application of the SSE and PPW models to the HBSW, the C_i were the assessed land value for the entire parcel. The assessed land values are known to underestimate the actual market value for an entire parcel but were regarded as reasonable estimates of the cost of acquiring a partial easement. When the City of Syracuse begins to implement the buffer acquisition program it will retain a third-party, independent assessor to provide it with an estimate of the "fair-market value" of an easement. The City will then make a "take-it-or-leave-it" offer of the assessor's fair-market value to the owners of priority parcels. This approach was adopted for two reasons. First, it should reduce transactions costs by avoiding long, drawn out negotiations. Second, and perhaps most important, it protects the City from charges of favoritism if it were seen paying above market value for easements on some parcels. While these rules do not allow the City to pay above market value because of "hydrologic" characteristics, they would prevent strategic behavior on the part of land owners since they will know that the City will only make one, take-it-or-leave-it, offer.

2) These weights were arrived at through discussions between the hydrologists, engineers, and planners within the Department of Water, City of Syracuse. There was no public participation or formal scientific review. We have conducted limited sensitivity analysis of the ω_k in the SSE models and the W_j in the PPW models and will report the results of that analysis in Section V.

3) Non-point source simulation models are typically finite-element models that are used to approximate the flow of surface and groundwater within a watershed. They may include randomly generated "precipitation events" or other stochastic processes when simulating the

dynamics of pollutants transported by surface and groundwater. The general models, such as WIMS-NPS and REMM need to be calibrated for the soils and topography of a particular watershed and, if possible, validated through measurements at monitoring sites after a precipitation event or during high, run-off, seasons.

TABLES

Table 1. The City of Syracuse Parcel Classification System

Parcel Class	Description
105	Agricultural Vacant land (Productive)
112	Dairy products - milk, butter and cheese
120	Field Crops: Potatoes, wheat, hay, dry beans, corn, oats, and other field crops.
210	One Family Year-Round Residence
240	Rural Residence with Acreages:
260	Seasonal Residence
311	Residential Vacant Land: vacant lots or acreage located in residential areas.
312	Residential Land including a small improvement. Not being used for living accommodations.
314	Rural Lots of 10 Acres or less, located in rural residential areas.
322	Residential Over 10 Acres: Residential property greater than 10 acres located in rural areas.
449	Other Storage, Warehouse and Distribution Facilities

Table 2. Land Cover and Loading of Phosphorus and Pathogens

Parcel Class	Land Cover	Total Phosphorus		Pathogen	
105	Row Crop	M(H)	8.33	M(H)	8.33
112	Dairy Farm	H	10.00	H	10.00
120	Row Crop	M(H)	8.33	M(H)	8.33
210	Resident (L)	M	6.67	M	6.67
240	Resident (L)	M	6.67	M	6.67
260	Resident (L)	M	6.67	M	6.67
311	Resident (L)	L	3.33	L	3.33
312	Resident (L)	L	3.33	L	3.33
314	Other	L	3.33	L	3.33
322	Other	L	3.33	L(M)	5.00
449	Commercial	M(H)	8.33	M(H)	8.33

Table 3. Percentage Reductions in Total Phosphorus and Pathogens

Pollutant Rating	Index	% Reduction	
		TP	Pathogen
H	10.00	65	25
M(H)	8.33	64	24.5
M	6.67	62	23
L(M)	5.00	58	21
L	3.33	50	17

Table 4. $X_{i,j}$ and $X^B_{i,j}$ by Parcel Class and Land Cover

Parcel Class	Land Cover	Total Phosphorus		Pathogen	
		$X_{i,1}$	$X^B_{i,1}$	$X_{i,2}$	$X^B_{i,2}$
105	Row Crop	8.33	3.00	8.33	6.29
112	Dairy Farm	10.00	3.50	10.00	7.50
120	Row Crop	8.33	3.00	8.33	6.29
210	Resident (L)	6.67	2.53	6.67	5.13
240	Resident (L)	6.67	2.53	6.67	5.13
260	Resident (L)	6.67	2.53	6.67	5.13
311	Resident (L)	3.33	1.67	3.33	2.76
312	Resident (L)	3.33	1.67	3.33	2.76
314	Other	3.33	1.67	3.33	2.76
322	Other	3.33	1.67	5.00	3.95
449	Commercial	8.33	3.00	8.33	6.29

Table 5. A Comparison of [P1] to [P3] and [P2] to [P4]

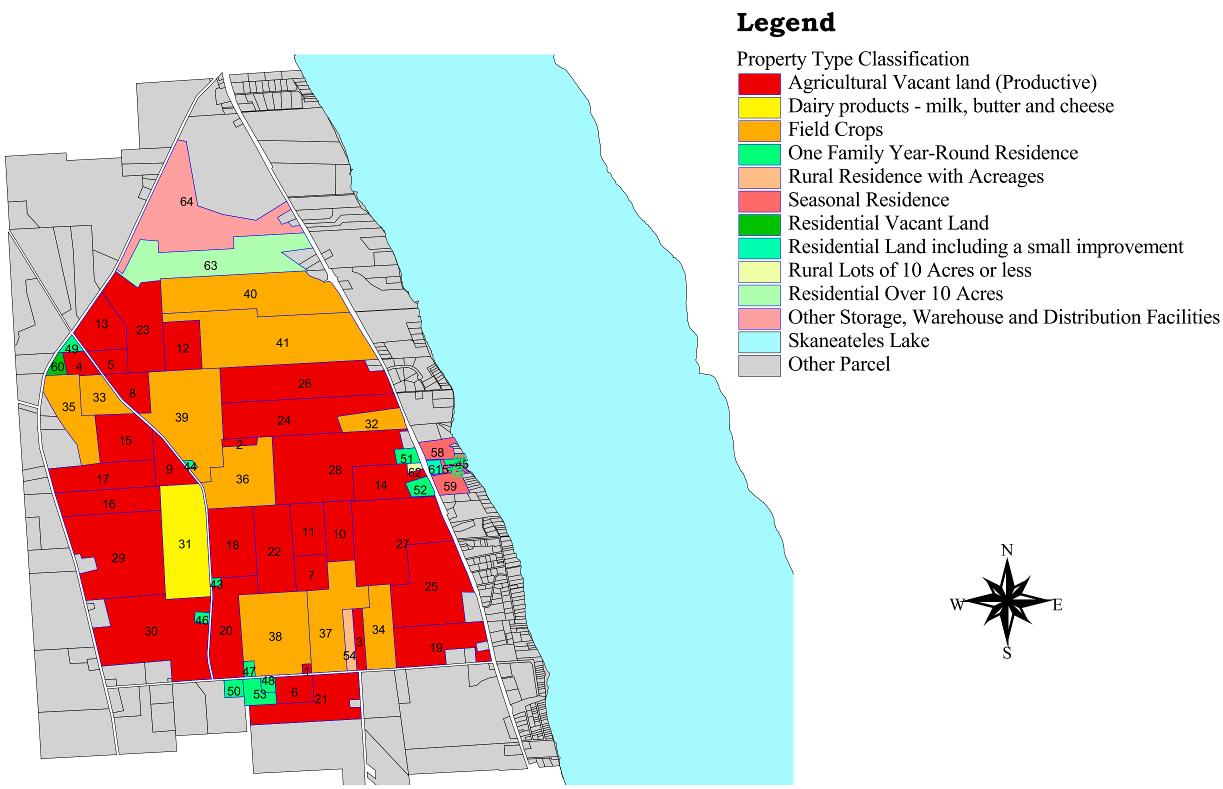
Parcel	[P1]	[P3]	[P2]	[P4]
1	0	0	0	0
2	1	0	0	0
3	1	0	1	0
4	1	1	0	0
5	1	1	0	0
6	0	0	0	0
7	1	1	0	0
8	1	0	1	1
9	1	0	1	1
10	1	1	0	0
11	1	1	0	0
12	1	1	1	1
13	1	1	0	0
14	1	1	1	1
15	1	0	1	0
16	1	0	0	0
17	1	1	0	0
18	1	1	0	0
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	1	1	0	0
23	1	1	0	0
24	1	1	1	1
25	0	0	0	0
26	0	1	1	1
27	0	0	1	1
28	0	1	0	1
29	0	0	0	0
30	0	0	0	0
31	1	0	1	1
32	0	0	1	1
33	1	0	0	0
34	0	0	1	0
35	1	0	0	0
36	0	0	0	0
37	0	0	0	0
38	0	0	0	0
39	1	1	1	1
40	0	1	1	0
41	0	1	0	1
42	0	0	0	0
43	0	0	0	0
44	1	0	0	0
45	0	0	0	0
46	0	0	0	0
47	0	0	0	0
48	0	0	0	0
49	1	0	0	0
50	0	0	0	0
51	1	0	1	0
52	1	0	1	1
53	0	0	0	0
54	1	0	0	0
55	0	0	0	0
56	0	0	0	0
57	0	0	0	0
58	0	0	0	0
59	0	0	0	0
60	1	0	0	0
61	1	0	1	0
62	1	1	1	1
63	1	1	1	1
64	1	1	1	1
	33	21	20	16

FIGURES

Figure 1. Parcel Classification in the Harold Brook Watershed

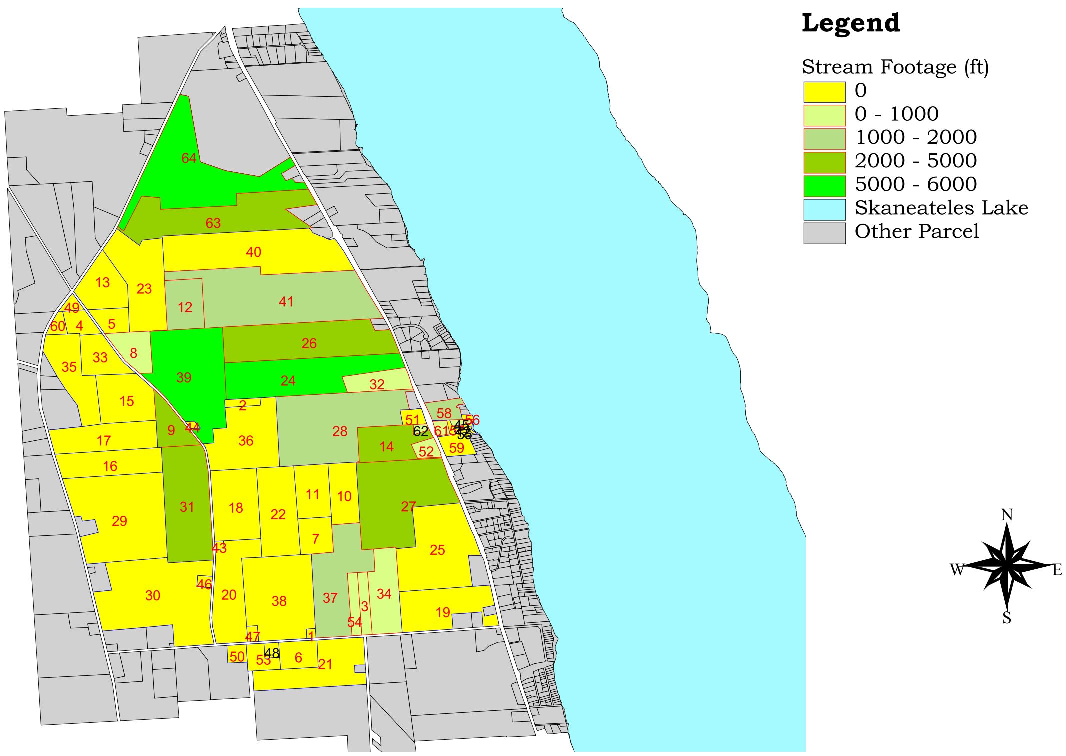
Figure 2. Parcels with Stream Footage in the Harold Brook Watershed

Figure 1. Parcel Classification in the Harold Brook Watershed



Data Sources: Department of Water, City of Syracuse

Figure 2. Parcels with Stream Footage in the Harold Brook Watershed



Data Sources: Department of Water, City of Syracuse