A GENERIC TOOL FOR EVALUATING THE UTILITY OF SELECTED POLLUTION MITIGATION STRATEGIES WITHIN A WATERSHED

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ABSTRACT
A software application for evaluating the implementation of both agricultural and non-agricultural pollution reduction strategies at the watershed level has recently been developed. This new tool, called PRedICT (Pollution Reduction Impact Comparison Tool), allows the user to create various "scenarios" in which current landscape conditions and pollutant loads (both point and non-point) can be compared against "future" conditions that reflect the use of different pollution reduction strategies (best management practices) such as agricultural and urban BMPs, the conversion of septic systems to centralized wastewater treatment, and upgrading of treatment plants from primary to secondary to tertiary. This tool includes pollutant reduction coefficients for nitrogen, phosphorus and sediment, and also has built-in cost information for an assortment of BMPs and wastewater upgrades.

KEYWORDS: Watershed management, BMP effectiveness, pollution reduction strategies

INTRODUCTION
A software tool has recently been developed for evaluating the implementation of both agricultural and non-agricultural pollution reduction strategies at the watershed level. This new tool, called PRedICT (Pollution Reduction Impact Comparison Tool), allows the user to create various "scenarios" in which current landscape conditions and pollutant loads (both point and non-point) can be compared against "future" conditions that reflect the use of different pollution reduction strategies (best management practices) such as agricultural and urban BMPs, the conversion of septic systems to centralized wastewater treatment, and upgrading of treatment plants from primary to secondary to tertiary. It includes pollutant reduction coefficients for nitrogen, phosphorus and sediment, and also has built-in cost information for an assortment of pollution mitigation techniques. A rather simple cost-accounting approach is used to estimate load reductions and their associated costs. The user specifies desired conditions in terms of such things as acres of agricultural BMPs used, number of septic systems to be converted to centralized wastewater treatment, types of plant upgrades, percentage of urban areas to be treated by wetlands and detention basins, etc.; and built-in reduction coefficients and unit costs are utilized to calculate resultant nutrient and sediment load reductions and scenario costs. However, the user also has the option of using an optimization routine that helps to identify the most efficient reduction strategy in terms of both pollution reduction and cost.

While information for PRedICT can be compiled manually, the most efficient way to accomplish this task is to use the AVGWLF watershed modeling system (Evans, 2002; and Evans et al., 2001). Among others things, this tool automatically creates a "scenario" file that can be used as input to PRedICT. This input file contains information on watershed conditions and pollutant loads that can serve as the "initial" conditions from which future scenarios can be developed. While load information can be developed and brought in via the use of AVGWLF, full editing capabilities are provided within PRedICT to allow for revised data input based on the user's local knowledge of the watershed being considered.

PRedICT was primarily developed using Visual Basic programming software, and is essentially comprised of the following basic components:

- *Input Screens.* These screens (Visual Basic forms) are used to specify data sets and parameter values used in subsequent load and cost calculations.
- *Scenario Files.* These text files with ".scn" extensions are used to import data from the AVGWLF model (if they exist) and to store output from PRedICT model runs.
- *Load and Cost Algorithms.* These compiled Visual Basic routines are imbedded in PRedICT, and are used to make load reduction and cost calculations fundamental to the tool.
- *Optimization Routine.* The optimization routine for PRedICT is actually a customized Microsoft Excel program that runs in tandem with the PRedICT Visual Basic code. The default "solver" within Excel is used to perform optimization on user-compiled input data, and results are written to Excel output files that can be viewed through the VB interface.

BMPS AND POLLUTION MITIGATION OPTIONS
Broadly speaking, Best Management Practices (BMPs) are structural and non-structural approaches used to reduce pollutant loads in watersheds draining both urban and rural areas. Unfortunately, there is no universally accepted definition of BMPs. The Soil and Water Conservation Society (SWCS, 1982) defines a BMP as "a practice or combination of practices that are determined by a state or designated area-wide planning agency to be the most effective

and practicable (including technological, economic, and institutional considerations) means of controlling point and non-point source pollutants at levels compatible with environmental quality goals." Alternatively, Novotny and Olem (1994) state that "BMPs are methods and practices for preventing or reducing non-point source pollution to a level compatible with water quality goals." When referring to rural areas, such BMPs are often called *conservation practices* or *agricultural* and *silvicultural* BMPs.

Agricultural BMPs

There are scores of possible BMPs that can be used to address problems in agricultural areas. Some of the most widely-used ones, however, fall into nine generic categories: 1) Crop Residue Management, 2) Vegetated Buffers, 3) Crop Rotation, 4) Cover Crops, 5) Contour Farming/ Stripcropping, 6) Terraces and Diversions, 7) Grazing Land Management, 8) Streambank Protection, and 9) Nutrient Management. Within PRedICT, BMP systems rather than individual BMPs are used as the basis for agricultural load reductions. This is because, as recognized by the Chesapeake Bay Program of the U.S. Environmental Protection Agency, BMPs are typically used in combination rather than individually to mitigate on-farm loss of soil and nutrients. While not necessarily identical, the BMP systems used in PRedICT are based on these more generic and widely-used BMPs, and are summarized in Table 1.

Urban BMPs

As with agricultural BMPs, urban BMPs can be structural or non-structural in nature. Typically, non-structural BMPs involve the preservation or enhancement of vegetative cover in selected areas (e.g., along streams) or the use of natural landscape features to act as filtration devices (e.g., as in the use of residential lawns to filter storm water runoff from roof tops). The difficulty with implementing the use of urban BMPs within an evaluation tool like PRedICT is that many of these practices are very site-specific (e.g., critical area planting) and others require more information about existing conditions (i.e., existing stormwater sewers) than can be adequately estimated using the GIS data sets currently employed by AVGWLF. Moreover, pollutant reduction efficiencies and cost data for many urban BMPs are not widely available. Given these limitations, it was decided to implement only three commonly-used urban BMPs in the current version of PRedICT. They include detention basins, constructed wetlands, and vegetation buffers along streams.

Table 1. Agricultural BMP systems used in PRedICT

BMP System	System	Individual BMPs/Practices
Permanent vegetative cover	BMP 1	Conservation tillage, cover crops
Strip-cropping and contour farming	BMP 2	Strip-cropping/contour farming
Terraces and diversions		
Grazing land management	BMP 5	Terraces and/or diversions
Cropland protection	BMP 7	Grazing land management
Conservation tillage	BMP 3	Crop rotation, cover crops
	BMP 4	Crop rotations, crop residue management,
Stream protection		contour farming/strip-cropping
Nutrient management	*	Stream bank fencing or stabilization
	BMP 6	Nutrient management

* This BMP is treated as an individual BMP rather than as a "system" in PRedICT

Wastewater Discharge Reduction Options

Wastewater discharges considered within PRedICT include on-lot septic systems and municipal wastewater treatment plants located within the watershed being evaluated. Estimates of the number of people on septic systems within a watershed are calculated as part of the AVGWLF modeling process, and are included in the resultant "scenario" (i.e., *.scn) file associated with any particular AVGWLF model run. If AVGWLF is not used to prepare an initial scenario file, this septic system estimate must be supplied by the user. In all cases, an estimate of the number of people on centralized sewage treatment systems must be supplied by the user as well. The specific wastewater reduction options allowed by PRedICT include: 1) conversion of septic systems to secondary wastewater treatment plants, 2) conversion of septic systems to tertiary wastewater treatment plants, 3) upgrades of primary treatment plants to secondary treatment, 4) upgrades of primary treatment plants to tertiary treatment, and 5) upgrades of secondary treatment plants to tertiary treatment.

LOAD REDUCTION AND COST CALCULATIONS

Calculations of pollutant load reductions and associated costs within PRedICT are accomplished via a series of data handling algorithms and mathematical expressions written in Visual Basic. The general approach in most cases is to calculate load reductions for each pollutant based on the number of additional "units" (e.g., acres, stream miles, per capita septic system conversions, etc.) for which the particular BMP is being implemented and the appropriate pollutant reduction coefficients and unit costs specific to that BMP. These additional "units" are based on the difference between "existing" and "future" values (e.g., acres, stream miles) specified by the user for each BMP or pollutant reduction strategy.

Agricultural Loads

Information on how load reductions and cost calculations are to be made in agricultural areas is derived predominantly from the "*Agricultural Land BMP Scenario Editor*", "*Agricultural BMP Load Reduction Efficiency Editor*", and "*BMP Cost Editor*" input screens (see Figures 1-3). Based on the number of additional acres or stream miles on which specified BMPs are to applied, along with their corresponding pollutant reduction efficiency values and unit costs, the "new" (i.e., re-calculated) pollutant loads and associated BMP costs are then determined.

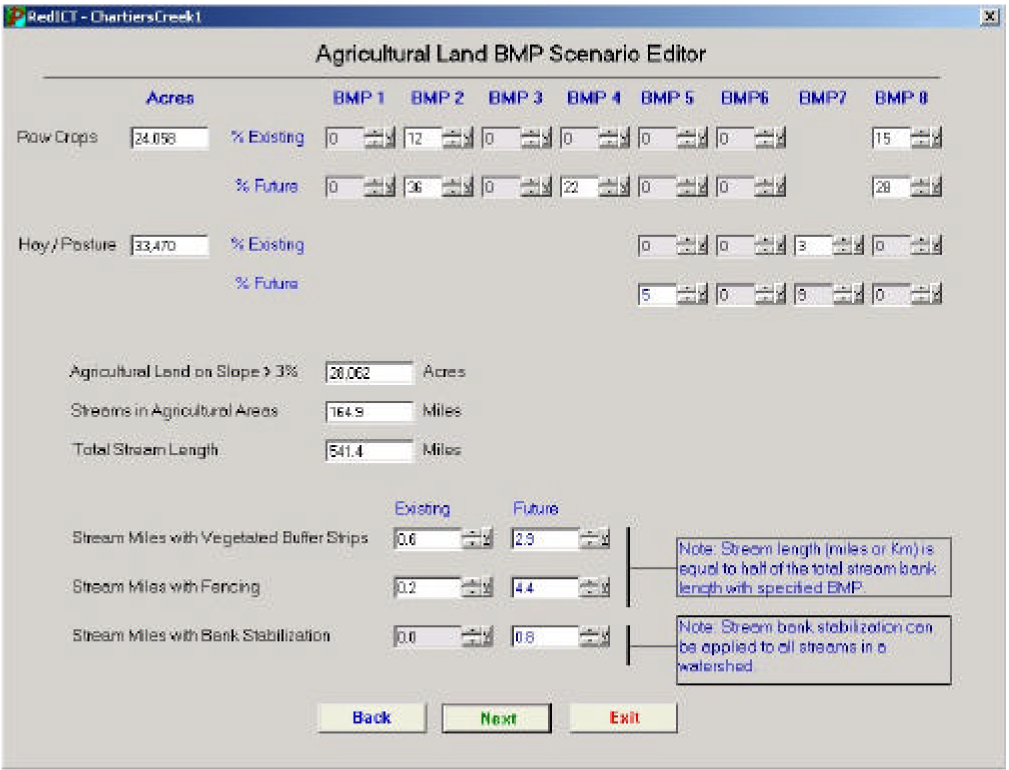

Figure 1. Agricultural Land BMP Scenario Screen with sample user-supplied data.

Within PRedICT, composite pollutant reduction values for the nine generic BMP systems described above are used. These values essentially reflect the median of the values for the individual BMPs that comprise each BMP system. Values for the *streambank fencing* and *vegetated buffer strip* BMPs represent reductions on a "per mile" basis. That is, for each stream mile in which that particular BMP is implemented, the "streambank" or "surface runoff" load, respectively, is reduced by the percentage amount shown. The values for all other BMPs signify reductions on a "per acre" basis.

Urban Area Loads

Information on how reductions are to be made in urban areas is derived primarily from the "*Urban Land BMP Scenario Editor*", "*Urban BMP Load Reduction Efficiency Editor*" (Figure 2), and "*BMP Cost Editor*" (Figure 3) input screens (while the first screen is not shown, it is similar to the one in Figure 1). In the first screen, the user is asked to specify the amount (i.e., percentage) of high and/or low density urban land that will be "treated" via the use of detention basins and/or constructed wetlands under a future scenario. Based on the specified values, along with their corresponding pollutant reduction efficiency values and unit costs, the "new" (i.e., re-calculated) pollutant loads are subsequently calculated. Within PRedICT, default values for urban BMPs are used for sediment and nutrient reduction efficiencies. Costs for the detention basin and constructed wetland BMPs used in PRedICT are based on average costs for construction as determined in telephone calls to several firms involved in stormwater management in Pennsylvania. These costs, provided on a per acre basis, only consider the cost of constructing the BMPs, and do not include any operational and maintenance costs beyond the initial construction costs.

Wastewater Load Reductions

As described previously, wastewater reduction options include septic system conversions to central wastewater treatment systems as well as upgrades from primary to secondary to tertiary treatment plants. Information on how various wastewater reductions are to be made is derived primarily from the "*Septic System and Point Source Discharge Scenario Editor*", "*Wastewater Discharge Reduction Efficiency Editor*", and "*BMP Cost Editor*" input screens (the first two screens, not shown due to space limitations, are similar to the ones shown in Figures 1 and 2). In the first screen, the user is asked to provide information on the number of people on septic systems under existing and future scenarios, as well as the percentage of current and future wastewater treatment plant loads undergoing primary, secondary and/or tertiary treatment. Based on the specified values, the loads and corresponding pollutant reduction efficiency values are used to re-compute future loads using the following steps:

- Step 1: Calculate septic system load reductions based on transfers to wastewater treatment plants
- Step 2: Calculate initial point source nitrogen and phosphorus loads based on wastewater treatment plant type
- Step 3: Calculate nitrogen and phosphorus load reductions based on wastewater treatment plant upgrades
- Step 4: Calculate final future nitrogen and phosphorus loads based on wastewater treatment plant upgrades and septic system conversions

Re-computed "future" costs are based on the number of septic systems converted to centralized systems and the number of "per capita" upgrades between different treatment plant types.

PRedICT OUTPUT

After providing appropriate input data and executing PRedICT, load reductions based on specified "future" conditions are determined and written to the *"Estimated Load Reductions"* form shown in Figure 4. This form shows the initial nitrogen, phosphorus, and sediment load information provided either by AVGWLF or via manual entry in the *"Mean Annual Load Data Editor"* form (not shown here), and the estimates of projected loads after implementation of the specified BMPs and wastewater upgrades. Also provided are cost estimates for the different types of pollution reduction strategies.

OPTIMIZATION PROCEDURES

To aid in the investigation of different pollution reduction strategies, an optimization procedure has also been built into PRedICT. The optimization module allows the user to either solve for specific pollution reduction targets with minimal costs, or to maximize pollution reductions given a specified budget (see Figure 5). For each of the optimization tasks, the user can specify which pollutant (or combination of pollutants) to target, and whether existing structural BMPs should be maintained or eliminated. This particular function is accessed via the "Perform Optimization" button located on the output form shown in Figure 4.

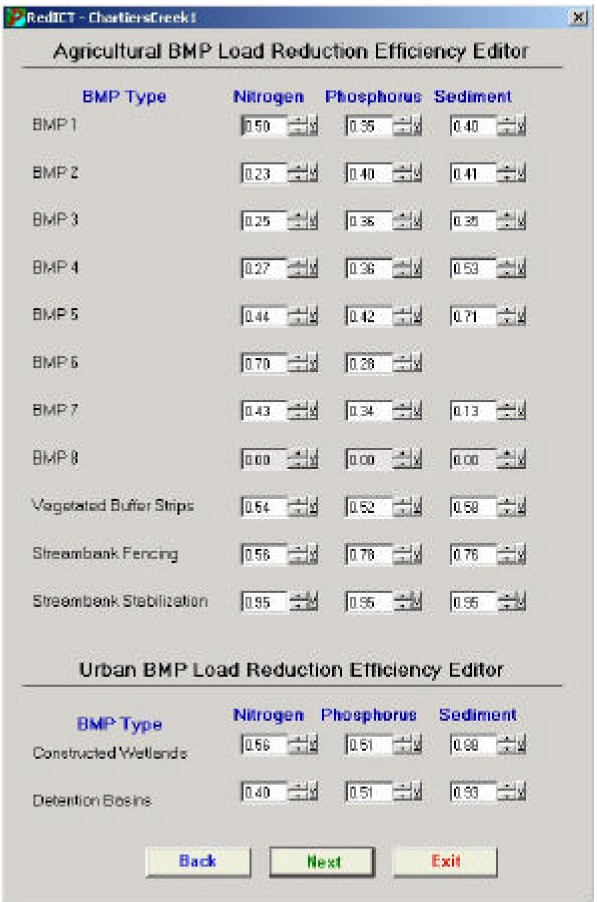

Figure 2. Agricultural and Urban BMP Load Reduction Efficiency Editor with default values for identified BMPs.

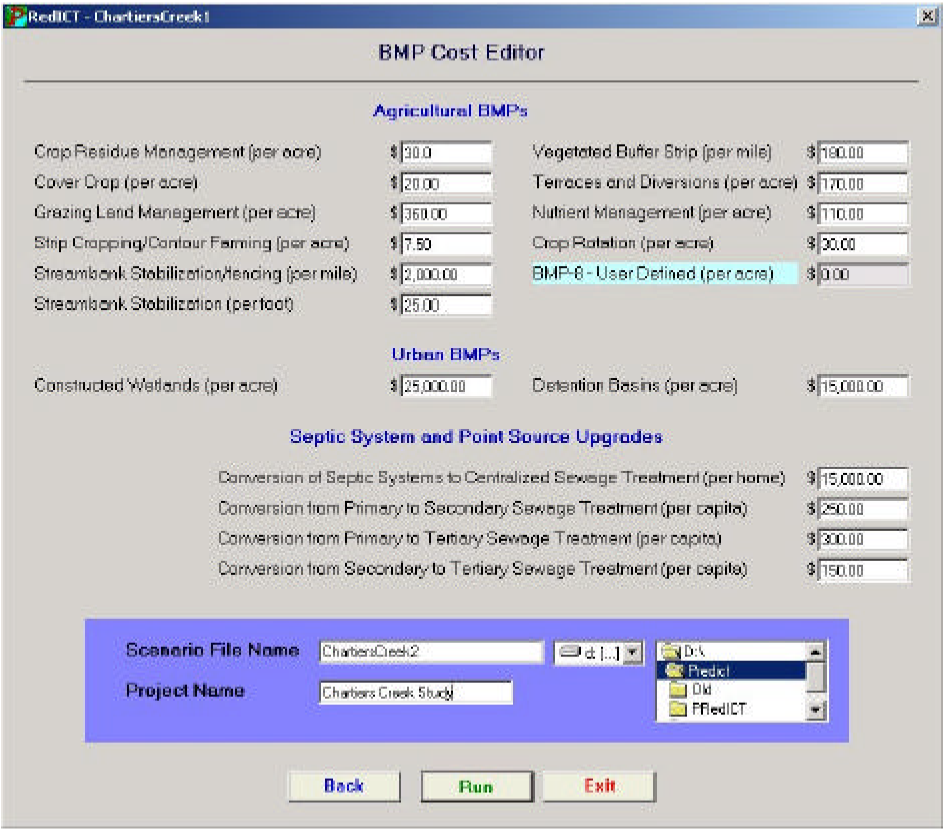

Figure 3. BMP Cost Editor with default BMP and wastewater upgrade costs.

With the “minimal cost” option, the program adjusts “future” BMP levels in such a way that the reduction target for the specified pollutant(s) is achieved with minimal costs subject to the criteria

$$PollutLoad^{f} \le (1 - PollutGoal) \cdot PollutLoad^{c}$$

where: $PollutLoad^{f,c}$ = future (optimal) and current pollution levels respectively

PollutGoal = the pollution reduction target specified by the user (as percent from current load)

Alternatively, the user can choose to maximize pollution reduction for one or more pollutants considering a finite budget. For the case when more than one pollutant is targeted, the program maximizes a linear combination of pollution reductions. For example, if the user decides to target all three pollutants the following problem is solved as follows:

$$\max_{z_i} (w_1 \cdot \%N + w_2 \cdot \%P + w_3 \cdot \%S)$$

subject to

$$Cost \le Budget$$

where: w_i = weights specified by the user, and

$\%N$, $\%P$ and $\%S$ = nitrogen, phosphorus, and sediment loads as percentage of the initial load

CONCLUSION

Work on PRedICT was not quite completed at the time of this writing, although it is expected to be available for operational use in Pennsylvania by mid-2003. It will primarily be used by watershed conservation groups and government agencies for the purpose of evaluating financially viable strategies for resolving surface water quality problems as mandated by state and national water pollution legislation. The software is flexible in that required data can be input manually; although it’s use is optimized when utilized in combination the AVGWLF watershed modeling software. The possibility also exists for including BMPs and reduction strategies not currently implemented.

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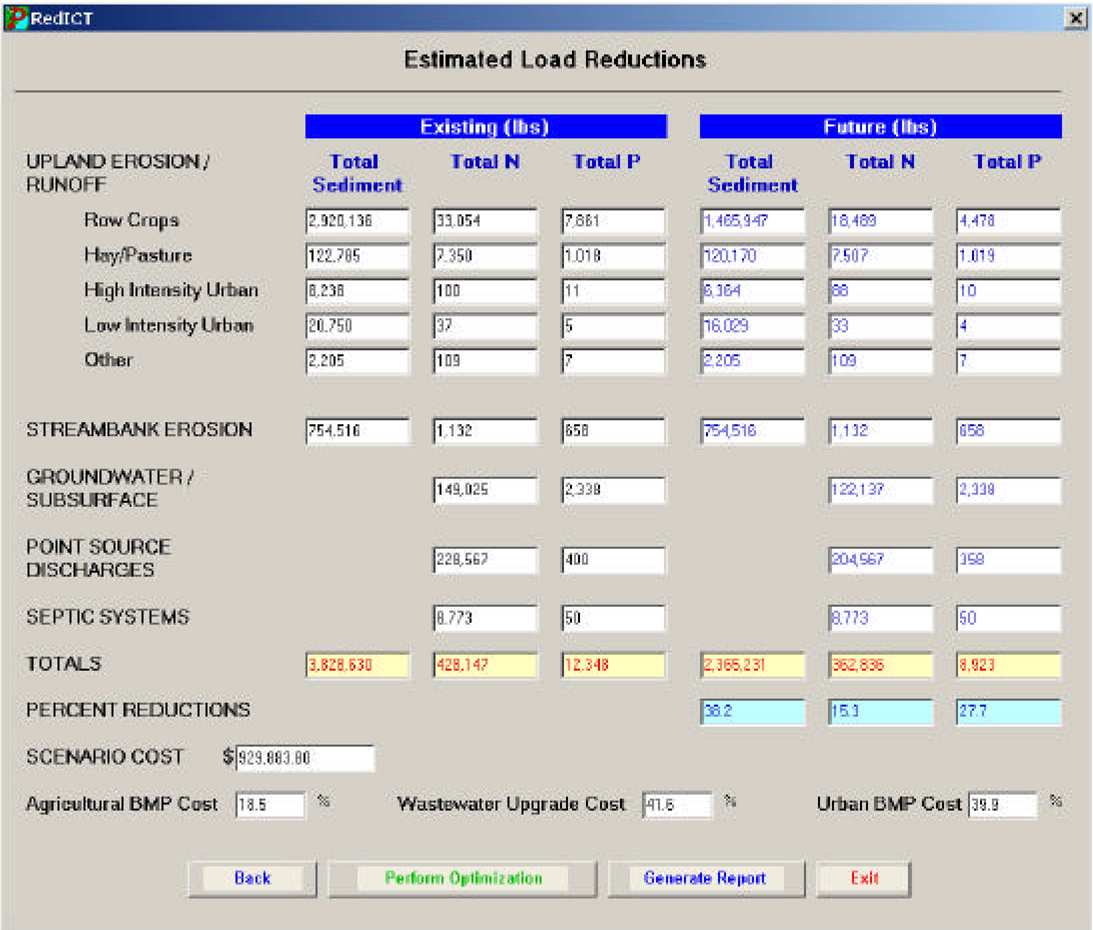

RedICT

Estimated Load Reductions

	Existing (lbs) Total Sediment	Existing (lbs) Total N	Existing (lbs) Total P	Future (lbs) Total Sediment	Future (lbs) Total N	Future (lbs) Total P
UPLAND EROSION / RUNOFF						
Row Crops	2,920,136	33,054	7,861	1,465,947	18,489	4,478
Hay/Pasture	122,705	7,350	1,018	120,170	7,507	1,019
High Intensity Urban	8,238	100	11	6,364	88	10
Low Intensity Urban	20,750	37	5	16,029	33	4
Other	2,205	109	7	2,205	109	7
STREAMBANK EROSION	754,516	1,132	658	754,516	1,132	658
GROUNDWATER / SUBSURFACE		149,025	2,338		122,137	2,338
POINT SOURCE DISCHARGES		228,567	400		204,567	358
SEPTIC SYSTEMS		8,773	50		8,773	50
TOTALS	3,828,630	428,147	12,348	2,365,231	362,836	8,923
PERCENT REDUCTIONS				38.2	15.3	27.7

SCENARIO COST $929,883.80

Agricultural BMP Cost 18.5 % Wastewater Upgrade Cost 41.6 % Urban BMP Cost 39.9 %

Back Perform Optimization Generate Report Exit

Figure 4. Example output from PRedICT.

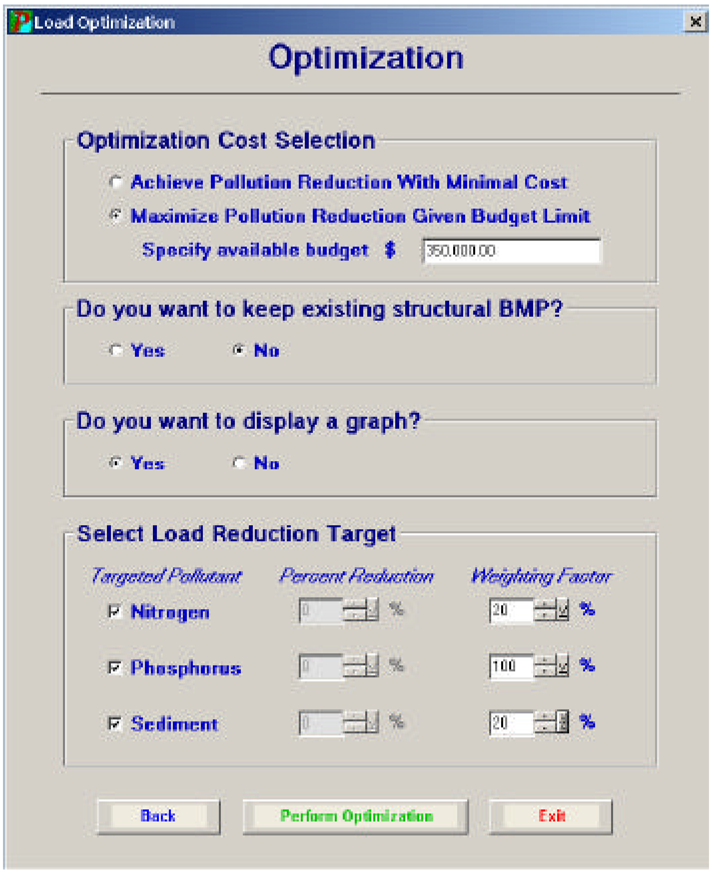

Figure 5. Optimization form with sample settings.

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