NCTXWQ Project:
Evaluating the Economics of Best Management Practices for Tarrant Regional Water District's Cedar Creek Reservoir Watershed

Rister et al. (2009)

Executive Summary

The objective of this component of the North Central Texas Water Quality (NCTXWQ) project is to identify the most economical (i.e., least cost) means of reducing (and/or preventing) phosphorus (P), nitrogen (N), and sediment (Sed) inflows into the Cedar Creek Reservoir and assist in facilitating the development of a sustainable, scientifically-based, and economically-feasible watershed protection plan. Management and consulting engineers estimate current P, N, and Sed inflows of (a) 208, (b) 1,565, and (c) 496,035 English tons (ET), respectively, and substantial reductions of these inflows are required to meet water quality standards outlined for the NCTXWQ project. Specifically, a 35% reduction in P inflows is targeted. During 2002-2009, Texas AgriLife Extension Service and Texas AgriLife Research scientists, in conjunction with Tarrant Regional Water District (TRWD) managers, Natural Resources Conservation Service (NRCS) professionals, and others worked to identify a portfolio of Best Management Practices (BMPs) capable of contributing to such reductions. Economists' responsibilities consist of translating the nutrient/sediment reduction information, related costs, and associated benefits for the respective BMPs (as identified by other team members) into a "Most Economical Best Management Practices" (MEBMP) portfolio.

Background

TRWD owns/operates five major water-supply reservoirs in the Fort Worth-Dallas region - Benbrook, Bridgeport, Eagle Mountain, Richland-Chambers, and Cedar Creek. Approximately 92% of sales are to municipalities, with the bulk of the remainder going to industry, and a very small fraction going to agricultural contracts. TRWD's principal customers are the Fort Worth, Arlington, Mansfield, and Trinity River Authority municipalities. Projections for 2010 indicate that TRWD will have a total of 1.7 million consumers as its customer base through all of the municipalities served. Total annual projected sales for 2010 (all being raw, untreated water) are 119 billion gallons (364,877 acre-feet).

Firm in its commitment to deliver high-quality water to its customers, the TRWD has been proactive in evaluating water quality in its reservoirs. Based on a trend analysis of 1990-1999 data, TRWD's ongoing quality control efforts identified the Cedar Creek Reservoir as its most vulnerable raw water source in terms of impending quality issues in 2000, with consideration of additional data for the previous decade also supporting this conclusion. The Cedar Creek Reservoir is located 60 miles southeast of Dallas, near Kaufman, Texas. The reservoir covers 32,873 surface acres and is estimated to have a storage capacity of 644,785 acre-feet at capacity. The total Cedar Creek Reservoir Watershed extends over 1,007 square miles, encompassing 644,480 acres (260,817 hectares).

The Cedar Creek Partnership was formed in the summer of 2007 by holding a series of stakeholder workshops to introduce the public to the water quality issues of the reservoir and the concept of watershed management. The North Central Texas Water Quality Project is a collaborative effort of the Texas Water Resources Institute, Texas AgriLife Research, Texas AgriLife Extension Service, Natural Resources Conservation Service, Texas Commission on Environmental Quality, Texas State Soil and Water Conservation Board, and Tarrant Regional Water District. Funding for the project comes from the Environmental Protection Agency and the United States Department of Agriculture – Natural Resources Conservation Service.

The objective of the Cedar Creek Watershed Protection Plan is to mitigate the rising trend of the algae-indicator substance chlorophyll-*a* within Cedar Creek Reservoir. This trend is the result of elevated nutrient levels, particularly P, in the water. TRWD water quality studies conducted over the past two decades have shown the Cedar Creek Reservoir to be impacted by inflows from the watershed. The analyses identified an increasing trend in chlorophyll-*a*, which is the primary photosynthetic pigment in algae cells and is used extensively to estimate algae biomass. The abundance of algae identified in the reservoir is associated with high concentrations of total and dissolved organic carbon. The proportion of blue-green algae is highest during the summer-growing season, as a result of low oxygen concentrations developing at bottom depths during this time. The low oxygen concentrations in deep waters cause the release of P from the sediment, an internal reservoir loading which sets a positive feedback that is likely to maintain eutrophic conditions in Cedar Creek Reservoir. Algal abundance roughly doubled during the 19-year study period. Activities within the watershed that contribute to the release of the nutrients which contribute to algae growth are the focus of the NCTXWQ study associated with the Cedar Creek Reservoir Watershed.

In October 2007, NCTXWQ project leaders and stakeholders agreed in principle to the basic goal of reducing watershed-based phosphorus loadings in the Cedar Creek Reservoir by 35 percent, which is equivalent to 72.8 English tons. This decision was predicated on such a reduction in P inflows being substantial enough to mitigate future sub-par quality concerns. It is forecasted that the proposed BMPs introduced to lower P will also assist in the reduction of nitrogen and sediment loadings.

Modeling

The modeling framework for this project, which integrates and facilitates use of the various features of the described economics methodology, is designated BMPEconomics©. Utilization of the Soil and Water Assessment Tool (SWAT) and Water Quality Analysis Simulation Program (WASP) modeling techniques has enabled the NCTXWQ project team to integrate land use features of the Cedar Creek Reservoir Watershed and reservoir dynamics (nutrient fate and transport, flux, and evapotranspiration) with the economic and financial considerations of BMPEconomics© to provide the basis for a feasible, comprehensive watershed protection plan. The SWAT is a watershed and landscape simulation model designed to help scientists and decisionmakers devise strategies to manage soil and water resources in mixed-use watersheds. The SWAT system is a multi-functional modeling tool that can be used to answer questions about the function and management of both large and small watersheds. The SWAT model operates on a continuous, daily-time step, which makes it capable of simulating scenarios over long-term periods. Simulation of the watershed encompasses all aspects of the hydrologic cycle including land, water, and atmospheric interactions. SWAT mimics the flow of water within the watershed, allowing the assessment of water quality and quantity changes due to alterations in global climate, land use, policy, and technology.

Daily mass loadings and inflows from the SWAT model were supplied to the WASP model to simulate the reservoir water quality. WASP is a finite-difference model used to interpret or predict possible changes in the water quality of ponds, lakes, reservoirs, rivers, and coastal waters brought about by inflows of sediment, nutrients, pesticides, and bacteria. Use of WASP-modeling techniques allowed determination of the expected impact of sediment and nutrients within a horizontally- and vertically-segmented model of Cedar Creek Reservoir. The WASP model provides water quality planners a dynamic tool to assess management strategies such as nutrient reduction. The WASP model was applied in the Cedar Creek planning efforts to systematically estimate the necessary phosphorus load reductions that would result in a statistically-significant reduction in Chlorophyll-*a*.

Two research modeling components of research are required to develop useful economic information for TRWD's management and to identify and enable implementation of the most cost-efficient strategies for reducing the objectionable inflows into the Cedar Creek Reservoir: (a) economic and financial cost analyses for each of the viable BMPs (termed Challenger BMPs hereafter), and (b) identifying optimal MEBMP portfolios of the Challenger BMPs. Economists' (and others') in-depth understanding of the problem and collaborative merging with the technical capabilities of NCTXWQ team members are essential for the success of these economic components.

Data Assimilation

A first step toward realizing the objective of a desired 35% reduction in phosphorus inflows is to review all of the BMPs identified for consideration by other aspects of the Cedar Creek Reservoir Watershed project and to eliminate practices for which there is a consensus (among the NCTXWQ team members and TRWD management) that (a) duplications (or inferiorities) exist with regards to other BMPs being evaluated, or (b) their technical and/or economic feasibility is very improbable. Following such a general, but organized, objective "sifting," an array of economic and financial information is identified and organized for each Challenger BMP remaining as a candidate for TRWD's consideration, including:

- reduction impacts on P, N, and Sed inflows expressed in the same units, i.e., as a total percent of the overall target per individual item or total of items comprising the BMP;

- expected life (i.e., years of productive reduction in P, N, and/or Sed) for the total BMP;
- construction period, i.e., when will reduction impacts in P, N, and Sed inflows begin – what length of time is required to construct and implement the BMP;
- initial investment costs required (i.e., construction or program implementation costs);
- recurring annual operating and maintenance costs;
- timing (i.e., expected useful life) and associated costs of intermittent capital replacement required to insure each BMP attains its expected useful life;
- current level of implementation and likelihood of additional adoption;
- appropriate inflation rate by which to increase future years' costs; and
- any inducement payments required for affected entities and/or individuals to encourage/secure their participation.

In the process of identifying appropriate initial construction, maintenance, and intermittent capital replacement costs (during a series of meetings with North Central Texas Water Quality project team members), several of the original BMPs were eliminated from further consideration. The respective BMPs were eliminated due to perceived technical infeasibilities, apparent redundancies (or explicit incorporation, e.g., educational programs, soil testing) with other BMPs considered, excessively high costs, and/or lack of substantive information to support economic analyses.

The BMPs remaining following after the "sifting" process were labeled as "Challengers." SWAT analyses were conducted for each individual Challenger BMP in those sub-watershed areas in which the respective BMPs were considered feasible. Potential sub-watershed areas (hectares/acres) of implementation within the total watershed were identified in these analyses, accompanied by an estimate of the potential overall reduction in P, N, and Sed inflows into Cedar Creek Reservoir associated with each BMP. For selected BMPs (those affiliated with the Reservoir-in-Lake category), WASP modeling was used to identify their respective effectiveness levels. For the composite "urban suite" BMP in the Urban category, TRWD management and project economists extrapolated effectiveness levels from journal-published research. For the wetland BMPs in the Watershed category, SWAT analyses were modified by TRWD management and project economists to reflect expected operation procedures such as harvest of nutrient-rich plants and upkeep of the wetlands. The Challenger BMPs are identified in **Exhibit ES1** (Exhibit xyz in the full report).

Subsequently, the sub-watershed areas potentially affected by each of the Challenger BMPs were reviewed and revised according to estimations of (a) current existing occurrences of the BMPs within the watershed, (b) maximum possible adoption rates, and (c) perceived "most-likely" marginal adoption rates by the appropriate decisionmakers within the Cedar Creek Reservoir Watershed. The assumption in this step was adequate funding would be available to construct and maintain the respective BMPs through a 50-year planning horizon. NCTXWQ project team members, joined by several agricultural stakeholders and their advisors, participated in the Delphi technique interview process to review these estimations. The Delphi process involved interviewing several of the noted experts repeatedly until a consensus was reached, representing what is perceived as the most accurate information possible under the NCTXWQ project's existing funding and time constraints. Identified during these discussions were levels of monetary incentive payments that would be required to induce landowners to participate in implementing the various agricultural BMPs. Following the elicitation of the above-noted probable Challenger BMP adoption rates and the associated revisions of the areas potentially affected, the original SWAT and WASP estimates were adjusted to reflect each BMP's ability to reduce P, N, and Sed inflows into the Cedar Creek Reservoir.

Identifying "Most Economical Best Management Practices" Portfolios

The decisions confronting Cedar Creek Reservoir Watershed decisionmakers are representative of a classic economic problem:

- attempting to achieve one or more objectives simultaneously, subject to
- several alternative choices of action(s), and
- numerous physical and fiscal constraints.

Each BMP is an alternative available to the decisionmakers. In determining the optimal MEBMP solution, application of the BMPEconomics© model allows consideration of the technical nutrient/sediment reduction performance of each BMP and the internally-calculated annual costs per unit of P, N, and Sed inflow reductions toward meeting Cedar Creek Reservoir Watershed decisionmakers' objectives. The BMPs which enter into the optimal MEBMP solution are possibly also limited by certain constraints specified in the model, including various fiscal and physical limitations, e.g., initial investment capital, annual operating funds, and marginal most-likely adoption rates in qualified sub-watersheds.

Other considerations of importance to the optimization aspect of the economic and financial analyses of the Challenger BMPs are related to their (a) finiteness and (b) exclusivity. In regards to "finiteness," the issue of concern is whether or not a specific BMP must be implemented across/for all of the potential sub-watershed areas affected by the designated most-likely marginal adoption rate for that BMP (i.e., the BMP is of an integer nature, either in the optimal MEBMP solution at 100% or not in the optimal MEBMP solution at any location/in any degree (i.e., 0%)). The project team reviewed each Challenger BMP and identified this characteristic for each, reflecting their consensus perspective of the "real-world" possibilities. Considering "exclusivity," attention is directed toward the independence of the respective Challenger BMPs from one another (e.g., identifying whether or not the inclusion of one or more in the optimal MEBMP solution prohibits one or more of the others being in the optimal MEBMP solution). Again, the project team reviewed each Challenger BMP in consideration of the others and identified this characteristic for each and combinations thereof.

AGEC BMP Number	NCTXWQ BMP Number	NRCS Practice Number	BMP Category	Description
1	#001	#512	Cropland	Conversion of Cropland to Grass
2	#001A	#330	Cropland	Contour Farming
3	#003	#590	Cropland	Fertilizer/ Nutrient Mgmt
4	#004	#393	Cropland	Filter Strip
5	#006	#412	Cropland	Grassed Waterway in Critical Cropland Areas
6	#007	#600	Cropland	Terracing
7	#101	#528	Pasture & Rangeland	Prescribed Grazing
8	#105	#512; #528	Pasture & Rangeland	Pasture Planting
9	#107	#412	Pasture & Rangeland	Critical Pastureland Area Planting
10	#402	#410	Pasture & Rangeland	Grade Stabilization
11	#s 201 - 209		Urban	Phase II Urban BMPs
12	#210		Urban	Voluntary Urban Nutrient Management
13	#211		Urban	Required Urban Nutrient Management in 2,000 ft Buffer Strip around the Reservoir
14	#301A	#390, #391	Channel	Riparian Buffer Strips — All Except Critical Areas
15	#302	#584	Channel	Riparian Buffer Strips — Only in Critical Areas
16	#401A1	#658	Watershed	Wetland Creation -- Lower Kings Creek
17	#401B1	#658	Watershed	Wetland Creation -- End Cedar Creek
18	#501		Reservoir-in-Lake	Hypolimnetic Aeration
19	#502B		Reservoir-in-Lake	P Inactivation with Alum
20	#505		Reservoir-in-Lake	Hypolimnetic Water Release from Reservoir
21	#701	PS-1A	WasteWater Treatment Plant	WWTP - from Level I to Level II quality
22	#702	PS-1B	WasteWater Treatment Plant	WWTP - from level I to Level III quality

Exhibit ES 1. Challenger BMPs Identified for the NCTXWQ Project, Cedar Creek Reservoir Watershed, 2008. [Note: this is Exhibit xyz in Rister et al. (2009)].

Economic and Financial Costs. Comprising the first component of BMPEconomics©, a Microsoft® Excel® spreadsheet was constructed to calculate the annuity equivalent costs for each of the Challenger BMPs, assuming 100% implementation of the marginal most-likely adoption rates within the SWAT- (and WASP-) designated sub-watershed areas of the Cedar Creek Reservoir Watershed. Explicit recognition of the adjusted SWAT effectiveness levels in terms of P, N, and Sed inflow reductions for each Challenger BMP were incorporated into the spreadsheet, along with the details of the sub-watershed areas (within the total watershed) that could potentially be affected by full implementation of the expected marginal most-likely adoption rate. Additional specifications were declared, allowing the calculation of units (e.g., acres, structures, etc.) for each specific Challenger BMP that could be imposed on the potentially-affected areas. The requisite initial capital investments (and expected useful lives) associated with each Challenger BMP were also identified. Corresponding annual operating and maintenance costs and, if appropriate, intermittent capital replacement costs, and timing thereof, were also identified. Estimates of initial and/or annual incentive inducement payments to decisionmakers were also incorporated into the spreadsheet as deemed appropriate for the respective Challenger BMPs. Costs were identified in 2008 values and a 2.043% annual inflation rate was assumed for increasing costs throughout the assumed 50-year planning horizon. A social discount rate of 4.900% was assumed to facilitate calculations of net present values of costs and annuity equivalents.

Several critical-calculated values were developed and organized in the Microsoft® Excel® spreadsheet for transfer to the second component of BMPEconomics©, a LINDO®-based linear programming model designed and used for determining the optimal MEBMP portfolio of Challenger BMPs for a set of specified constraints that represent the decision paradigm of Cedar Creek Reservoir Watershed decisionmakers. These critical-calculated values are employed both to (a) facilitate the optimization mathematical process, and (b) allow for developing a narrative and numeric descriptive summary of the respective optimal MEBMP solutions associated with the baseline situation and several sensitivity scenarios investigated.

Optimal MEBMP Portfolios of Challenger BMPs. The optimization facet of the economic analyses involves investigating a baseline situation considered to be the most representative of the current circumstances in the Cedar Creek Reservoir Watershed, while considering all Challenger BMPs as eligible for adoption and implementation. In that baseline situation, the predominant attribute worthy of mention is a required reduction of 35% (i.e., 72.8 English tons) of P inflows into the Cedar Creek Reservoir. Subsequently, several sensitivity scenarios are evaluated to (a) check the stability of the baseline situation results; (b) identify those assumptions which, when altered, lead to perceptibly different results; and (c) distinguish those assumptions which apparently have limited to no impact on the results. The principal categories of the several sensitivity scenarios analyzed are:

- required P inflow reduction levels;
- consideration of alternative annual flow levels;
- combined simultaneous inflow reduction level requirements for P, N, and Sed; and
- requiring the inclusion or exclusion of individual BMP categories in the solution.

A series of meetings among the project team members and with Cedar Creek Reservoir Watershed stakeholders were held during the project, 2007-2009. Such meetings involved the project team (a) discussing planned activities, (b) reporting on activities and preliminary results, and (c) indicating final results of the optimal MEBMP portfolio of least-cost BMPs and the several other related aspects of the watershed protection plan. Stakeholders were asked to assist in the (a) selection of preferred management practices, (b) examination of selected practices, (c) identification of funding sources, and (d) development of the educational and outreach portion of the watershed protection plan. Three groups were formed to advise on the following targeted constituencies: (a) agricultural, (b) urban and wastewater, and (c) education and outreach. Stakeholders were able to choose in which group to participate based on their areas of interest and experience. Each group was led by a member of the project leadership team in structured discussions designed to solicit input.

Economic Results

In **Table ES1** (Table 9 in the full report), the marginal units most likely to be adopted (assuming adequate available funding support) are identified for each Challenger BMP within the Cedar Creek Reservoir Watershed, along with the annuity equivalents of all respective costs. Nutrient and sediment inflow reduction expectations and cost information are combined to relate the cost per unit of N, P, and Sed inflow reductions. In calculating these costs per unit of inflows reduction, each item is evaluated independently, assuming all costs are associated with reducing that item and ignoring any allocation of costs toward reducing the other items. Also displayed in **Table ES1** is the ranked order of each Challenger BMP in terms of least cost per English ton (ET) reduction for P, N, and Sed, respectively (1 signifying least cost, 2 next least cost, etc.), with the BMPs sorted in the table according to ascending-order of costs per English ton reduction in P inflows into the Cedar Creek Reservoir.

Baseline Situation Analysis – Optimal MEBMP Results. For the baseline situation economic analysis, the focus of the study is only on reducing P inflow levels without any requirements for N and Sed inflow reduction levels. The NCTXWQ project's stated objective of minimizing the costs of reducing P inflows into the Cedar Creek Reservoir by 35% of current levels (i.e., 35% * 208.0 = 72.8 English tons) focuses attention on identifying those Challenger BMPs which have the lowest cost per unit of P inflows reduction. To identify the least-cost approach and achieve this stated objective, the linear programming method employed (in the optimization component of the economic analyses) seeks to identify those Challenger BMPs which have the least cost per unit of P inflows reduction, subject to any other applicable constraints (e.g., the 0,1 integer constraints on some BMPs; the exclusivity bounds on some pairs of BMPs; and the amount of sub-watershed areas/sizes respective BMPs may enter the solution).

BMPEconomics© aggregate linear programming model results for the baseline situation are presented in **Table ES2** (Table 12 in the full report). The Annuity Equivalent Value (AEV) of the optimal MEBMP solution is $2,232,511, and represents the annual expenditure required during the designated 50-year planning horizon. This annual expenditure would cover both (a) the initial construction/establishment costs of the several BMPs included in the optimal MEBMP portfolio (AEV=$839,360) and (b) operating and maintenance plus intermittent capital replacement costs associated with these same select BMPs (AEV=$1,393,161). In present value terms (2008 dollars), the initial construction/establishment cost required to implement the select set of BMPs is $12,972,620. In total for both initial and ensuing annual costs, the nominal costs for the 50-year planning horizon are $115,491,408; the related net present value (2008 dollars) of this amount is $38,387,160. That is, after initially constructing and establishing the eight BMPs included in the optimal MEBMP solution for the baseline situation, a 'sinking' fund could be created in the amount of $25,414,540 (in 2008 dollars) and used to finance the annual $1,393,161 AEV operating and maintenance and intermittent capital replacement expenses required during the subsequent 50 years.

The BMPEconomics© linear programming model results for the baseline situation's optimal MEBMP solution achieve the targeted 35% (72.8 English tons) reduction of P inflows into the Cedar Creek Reservoir, based on the previously noted data from SWAT, WASP, and other modeling research of the NCTXWQ project team. At the margin, if another ton of P inflow reduction was desired, it would cost $70,289; this value is associated with the last BMP which entered into the optimal MEBMP solution (BMP101). Reductions in N and Sed inflows total 25.1% (392.4 ET) and 25.5% (126,503.1 ET), respectively, of current inflow levels. Because no minimal inflow reduction requirements were specified for N and Sed, no marginal cost values for reducing the inflows of these items were determined by the BMPEconomics© linear programming model. The reduction in Sed inflows is equivalent to preserving 59.21 ac-ft of reservoir storage capacity on an annual basis.

Table ES3 includes a detailed specification of the inclusion or exclusion of each of the Challenger BMPs in the optimal MEBMP scenario for the Cedar Creek Reservoir Watershed. The included BMPs are listed here, in ascending order (i.e., lowest to highest) of cost per unit of P inflow reductions, with all except BMP101 in the solution at their maximum possible level:

- BMP004 - Filter Strip;
- BMP402 - Grade Stabilization;
- BMP107 - Critical Pastureland Area Planting;
- BMP007 - Terracing;
- BMP701 - WWTP - - from Level I to attain Level II quality at anticipated flows thru 2050;
- BMP001 - Conversion of Cropland to Grass;
- BMP101 - Prescribed Grazing; and
- BMP211 - Required Urban Nutrient Management in 2,000 ft Buffer Strip around the Reservoir.

The last column of **Table ES3** identifies the "reduced costs" of including a BMP not in the optimal MEBMP solution. These values are, in effect, the penalty or increase in costs that would occur if one unit of a non-optimal BMP were used in place of one or more of the optimal BMPs. These calculated values are somewhat complex in that they account for the differing P inflow reduction performance levels and associated AEV of the respective BMPs. Because of the integer programming nature of the BMPEconomics© linear programming model, these values must be carefully interpreted.

Table ES1. Composite Summary of Financial Annuity Equivalent Costs per Unit of P, N, and Sed Inflows Reduction and Associated Ranked Least-Cost Ordering According to P Cost Reductions for Challenger Best Management Practices, Cedar Creek Reservoir Watershed, 2009 [Note: this is Table xyz in Rister et al. (2009)].

						Annuity Equivalent Cost per English ton of			Ranked Order --1 is Lowest Cost, 2 is next Lowest Cost, …		
AGEC BMP Number	NCTXWQ BMP Number	Description	Marginal Units Affected	Units	Annuity Equivalent of All Costs	P Inflows Reduction	N Inflows Reduction	Sed Inflows Reduction	P Inflows Reduction	N Inflows Reduction	Sed Inflows Reduction
4	#004	Filter Strip	947.5	acs	$ 179,729	$ 5,761	$ 1,351	3	1	1	1
10	#402	Grade Stabilization	33	structures	46,783	9,780	1,869	4	2	3	2
9	#107	Critical Pastureland Area Planting	511.4	acs	98,429	25,264	1,503	7	3	2	3
6	#007	Terracing	77.4	acs	167,195	38,283	23,747	16	4	12	5
2	#001A	Contour Farming	1,625.8	acs	111,955	41,869	33,393	18	5	15	6
21	#701	All Nine (9) WWTP - - from Level I to attain Level II quality at anticipated flows thru 2050	All Nine (9) WWTP	project	486,869	50,892	19,449	∞	6	10	16
1	#001	Conversion of Cropland to Grass	7,959.0	acs	940,976	64,637	16,255	34	7	8	9
7	#101	Prescribed Grazing	102.5	acs	227,392	70,289	3,354	21	8	4	7
13	#211	Required Urban Nutrient Management in 2,000 ft Buffer Strip around the Reservoir	1	program	163,522	70,694	4,748	∞	9	5	16
12	#210	Voluntary Urban Nutrient Management	1	program	314,292	96,770	20,533	224	10	11	15
14	#301A	Riparian Buffer Strips - - All Except Critical Areas	86.4	miles	189,046	113,625	17,261	10	11	9	4
22	#702	All Nine (9) WWTP - - from level I to attain Level III quality at anticipated flows thru 2050	All Nine (9) WWTP	project	1,431,804	129,899	33,894	∞	12	16	16
18	#501	Hypolimnetic Aeration	1	project	436,652	131,224	∞	∞	13	19	16
19	#502B	P Inactivation with Alum	1	project	949,828	144,988	∞	∞	14	19	16
8	#105	Pasture Planting	163,995.0	acs	772,232	157,478	7,514	46	15	6	10
5	#006	Grassed Waterway in Critical Cropland Areas	428.5	acs	78,691	212,836	16,166	28	16	7	8

Table ES1, continued.

						Annuity Equivalent Cost per English ton of			Ranked Order --1 is Lowest Cost, 2 is next Lowest Cost, …		
AGEC BMP Number	NCTXWQ BMP Number	Description	Marginal Units Affected	Units	Annuity Equivalent of All Costs	P Inflows Reduction	N Inflows Reduction	Sed Inflows Reduction	P Inflows Reduction	N Inflows Reduction	Sed Inflows Reduction
11	#s 201 - 209	Phase II Urban BMPs	1	program	$ 3,410,093	$ 212,948	$ 25,642	$ 196	17	13	14
16	#401A1	Wetland Creation - - Lower Kings Creek	1	wetland	959,253	286,487	32,269	65	18	14	11
17	#401B1	Wetland Creation - - End Cedar Creek	1	wetland	759,348	579,559	46,667	97	19	17	13
3	#003	Fertilizer/ Nutrient Mgmt	29,846.2	acs	2,197,088	704,293	∞	∞	20	19	16
15	#302	Riparian Buffer Strips - - Only in Critical Areas	3.5	miles	207,647	768,033	165,896	82	21	18	12
20	#505	Hypolimnetic Water Release from Reservoir	1	project	2,020,451	1,494,625	∞	∞	22	19	16

Table ES2. Aggregate BMPEconomics© Optimization Results for Baseline Situation Analysis of Challenger Best Management Practices, Cedar Creek Reservoir Watershed, 2009 [Note: this is Table xyz in Rister et al. (2009)]. [a]

Baseline Cost-Item Results	Units	Nominal Value	Real Value [b]
Initial Construction/Establishment Cost	2008 dollars	$12,972,620	$12,972,620
- annuity equivalent	$/year		$839,360
O&M and Intermittent Capital Repl. Cost	2008 dollars	$102,518,788	$25,414,540
- annuity equivalent	$/year		$1,393,161
NPV of Total Cost Stream	2008 dollars	$115,491,408	$38,387,160
- annuity equivalent [c]	$/year		$2,232,511
Reductions	**$/English Ton**	**English Tons**	**%**
Reductions in Phosphorous (P) Inflows		72.80	35.0%
- marginal cost of reducing by 1 more unit	$70,289.08		
Reductions in Nitrogen (N) Inflows		392.36	25.1%
- marginal cost of reducing by 1 more unit	nc [d]		
Reductions in Sediment (Sed) Inflows		126,503.10	25.5%
- marginal cost of reducing by 1 more unit	nc [d]		
Capacity	**ac-ft**	**$**	
Reservoir Capacity Preserved	59.21		
Value of Saved Reservoir Capacity		nc [d]	

[a] Current levels of inflows into the reservoir are estimated to be 188,670 kg (208 English tons) of P, 1,419,380 kg (1,565 English tons) of N, and 450,000 MT (496,035 English tons) of Sed (i.e., sediment).

[b] Determined using a 2.043% compound rate and a 4.9% social discount rate.

[c] Calculated as the net sum of the annuity equivalents for the respective BMPs included in the calculated optimal portfolio which minimizes the costs, given the specified constraints and available alternatives.

[d] This value not calculated for this analysis scenario.

Table ES3. Specific BMPEconomics© Optimization Results for Base Scenario Analysis of Challenger Best Management Practices, Cedar Creek Reservoir Watershed, 2009 [Note: this is Table xyz in Rister et al. (2009)]. [a]

AGEC BMP Number	NCTXWQ BMP Number	Description	Solution Level (%)	Reduced Cost ($) [b]
1	#001	Conversion of Cropland to Grass	100	$0
2	#001A	Contour Farming	0 [c]	$0
3	#003	Fertilizer/ Nutrient Mgmt	0	$1,977,816
4	#004	Filter Strip	100	$0
5	#006	Grassed Waterway in Critical Cropland Areas	0	$52,703
6	#007	Terracing	100	$0
7	#101	Prescribed Grazing	65.53 [d]	$0
8	#105	Pasture Planting	0	$427,553
9	#107	Critical Pastureland Area Planting	100	$0
10	#402	Grade Stabilization	0	$667,254
11	#s 201-209	Phase II Urban BMPs	100	$0
12	#210	Voluntary Urban Nutrient Management	0	$2,284,500
13	#211	Required Urban Nutrient Management in 2,000 ft Buffer Strip around the Reservoir	0	$86,007
14	#301A	Riparian Buffer Strips -- All Except Critical Areas	100 [d]	$937
15	#302	Riparian Buffer Strips -- Only in Critical Areas	0	$72,102
16	#401A1	Wetland Creation -- Lower Kings Creek	0	$188,644
17	#401B1	Wetland Creation -- End Cedar Creek	0	$723,902
18	#501	Hypolimnetic Aeration	0	($4,536,767)[e]
19	#502B	P Inactivation with Alum	0	($8,841,590)[e]
20	#505	Hypolimnetic Water Release from Reservoir	0	$0
21	#701	All Nine (9) WWTP - from Level I to Level II quality	100	($185,563)[e]
22	#702	All Nine (9) WWTP - from level I to Level III quality	0	$657,045

[a] Current levels of inflows into the reservoir are estimated to be 188,670 kg (208 English tons) of P, 1,419,380 kg (1,565 English tons) of N, and 450,000 MT (496,035 English tons) of Sed (i.e., sediment).

[b] The amount by which the annuity equivalent cost of the respective BMP must be decreased in order for the BMP to enter the optimal MEBMP solution, holding all other things constant (HAOTC). Alternatively, it is the amount by which the annual cost of this solution will increase if one unit of the respective BMP is forced into the solution, HAOTC.

[c] Because of the exclusivity constraint and the relative costs per unit of P reduction, BMP007 is in the optimal MEBMP solution and BMP001A is not.

[d] Because of the 0,1 integer nature of BMP211 and the requisite 72.8 ET reduction in P inflows, BMP211 is at 100% and BMP101, although with a less expensive per unit of P reduction, is at less than 100%.

[e] A negative reduced cost signifies the additional cost reduction that could be achieved if the upper limit was not constraining the level of this and other integer BMPs. Cautious interpretation is advised in regards to reduced costs and dual prices resulting from an integer model.

Figure ES1 (Figure 12 in Rister et al. 2009) is an illustration of the aggregate (i.e., total for all included BMPs) financial costs occurring for the optimal MEBMP solution over the complete 50-year planning horizon. AEV are represented on the left vertical axis and are associated with the annual amounts to be budgeted for (a) the initial construction/establishment costs of the BMPs included in the optimal MEBMP portfolio (AEV=$839,360); (b) operating and maintenance plus intermittent capital replacement costs associated with these same select BMPs (AEV=$1,393,161); and (c) the total of all costs (AEV=$2,232,513). The nominal initial construction/establishment costs ($12,972,663) and the nominal projections of annual cash flows are represented on the right vertical axis.

Figure ES2 (Figure 13 in the full report) is an illustration of the optimal MEBMP baseline situation's optimal MEBMP solution superimposed on a bar chart of the Challenger BMPs in ascending order according to the calculated annuity equivalent cost per ET of P inflow reductions. The vertical line appearing between BMP211 and BMP210 indicates the breaking point between those BMPs in the optimal MEBMP solution and those that are excluded. The exclusivity constraint imposed on BMP007 and BMP001A is highlighted, with the model selecting BMP007 (indicated as "YES") rather than BMP001 (indicated as "no") because of the former's lower cost per unit of P inflow reductions.

Figure ES3 (Figure 14 in the full report) is an illustration of the optimal MEBMP baseline solution's respective eight BMPs contribution toward achieving the targeted 35% reduction in P inflows into the Cedar Creek Reservoir. Each "slice of the pie" in **Figure ES3** is labeled according to (a) which BMP it represents, (b) the percent reduction of current P inflows into the reservoir for the total watershed (summing to 35%), and (c) the respective BMP's proportionate share of the targeted 35% reduction (summing to 100%). For example, BMP004 is the greatest contributor toward achieving the 35% objective, providing an expected reduction of 15% P inflows into the reservoir, or 43% of the total 35% reduction. Similarly, BMP001 is the second-largest contributor, providing an expected reduction of 7% P inflows into the reservoir, representing 20% of the total 35% reduction. **Figure ES4** (Figure 15 in the full report) is a related illustration displaying similar information from the perspective of which categories of Challenger BMPs offer the most substantial potential for achieving the reductions in P inflows into the reservoir. "Cropland" BMPs are the greatest contributors, providing an expected reduction of 24.1% P inflows into the reservoir, or 69% of the total 35% reduction. "Pasture and Range" BMPs are second in importance, contributing 15%, followed by WWTP at 13%, and "Urban" at 3%, to total 100% of the targeted 35% reduction.

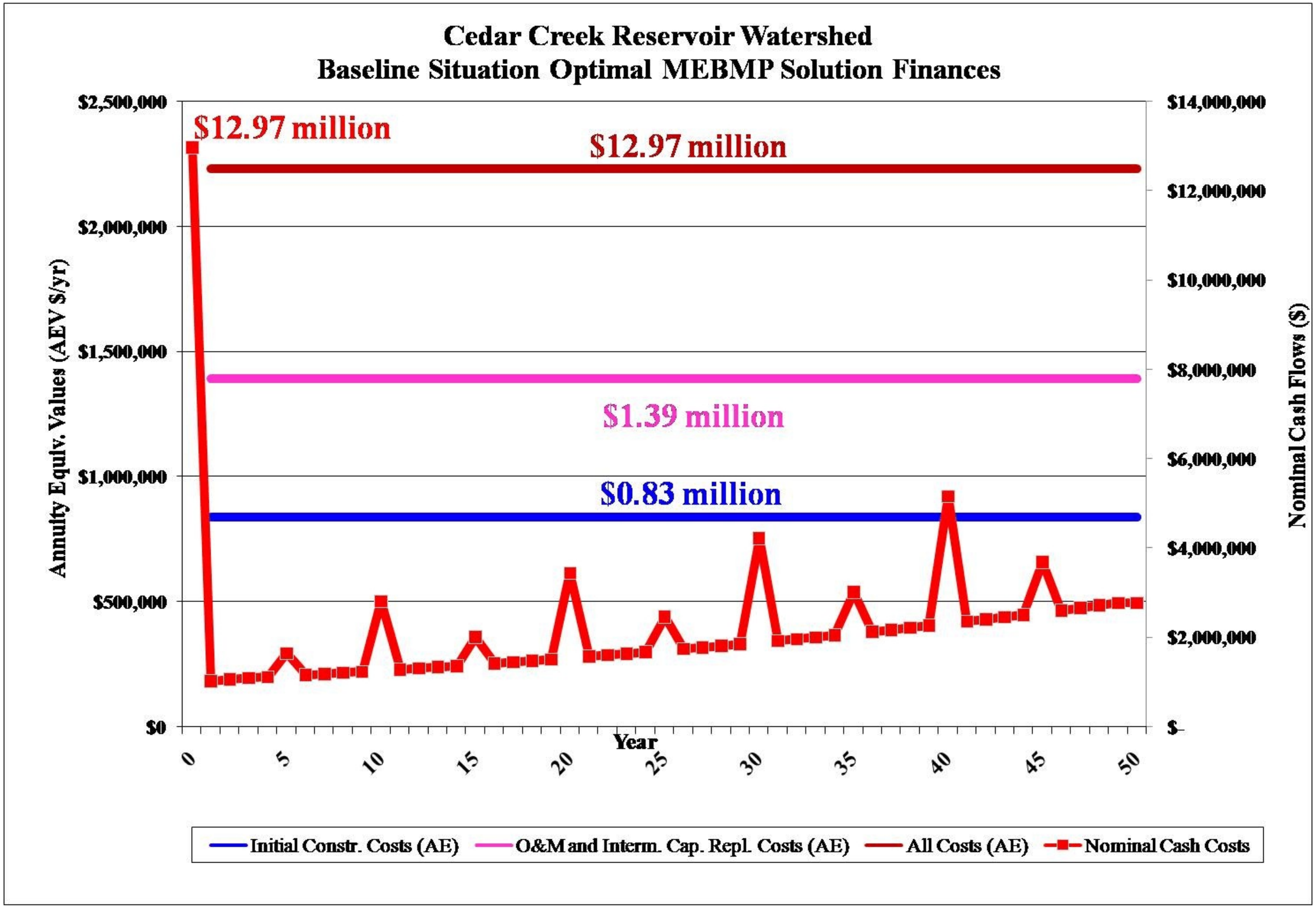

Figure ES1. Illustration of BMPEconomics© Optimization Results, Aggregate Finances for Optimal, Most Economical, Least-Cost Portfolio of Challenger Best Management Practices for Baseline Situation, Cedar Creek Reservoir Watershed, 2009 [Note: this is Figure 12 in Rister et al. (2009)].

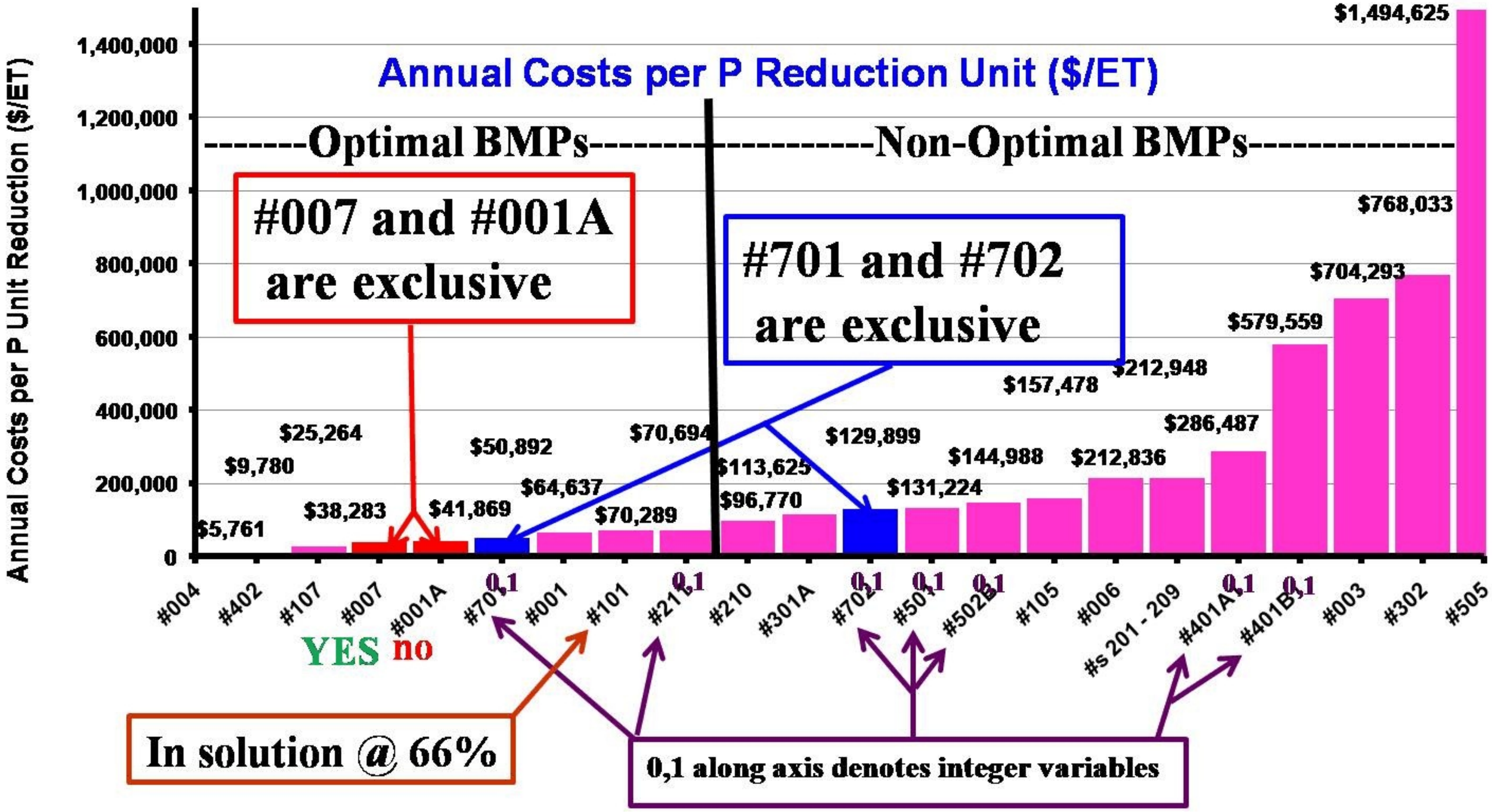

Figure ES2. Illustration of Most Economical BMPs Included in Optimal MEBMP Plan for Baseline Situation, Cedar Creek Reservoir Watershed, 2009 [Note: this is Figure 13 in Rister et al. (2009)].

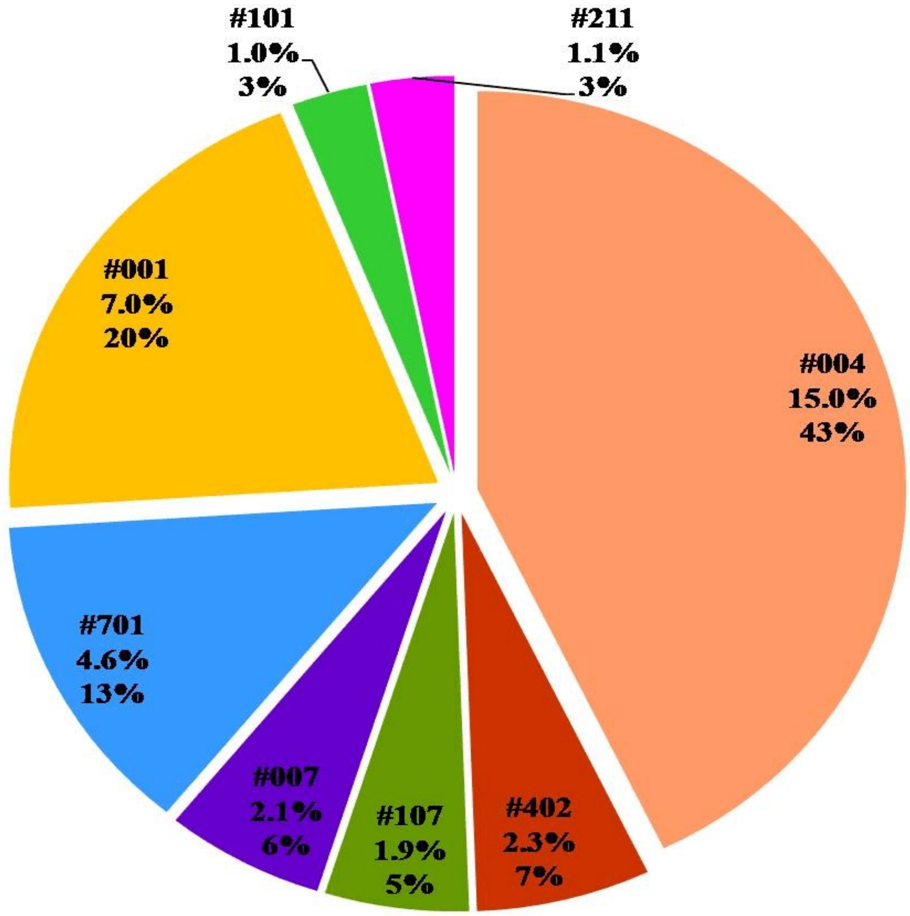

Figure ES3. Illustration of BMPEconomics© Optimization Results, Contributions to P Inflow Reductions for Individual BMPs Comprising the Optimal, Most Economical, Least-Cost Portfolio of Challenger Best Management Practices for Baseline Situation, Cedar Creek Reservoir Watershed, 2009 [Note: this is Figure 14 in Rister et al. (2009)].

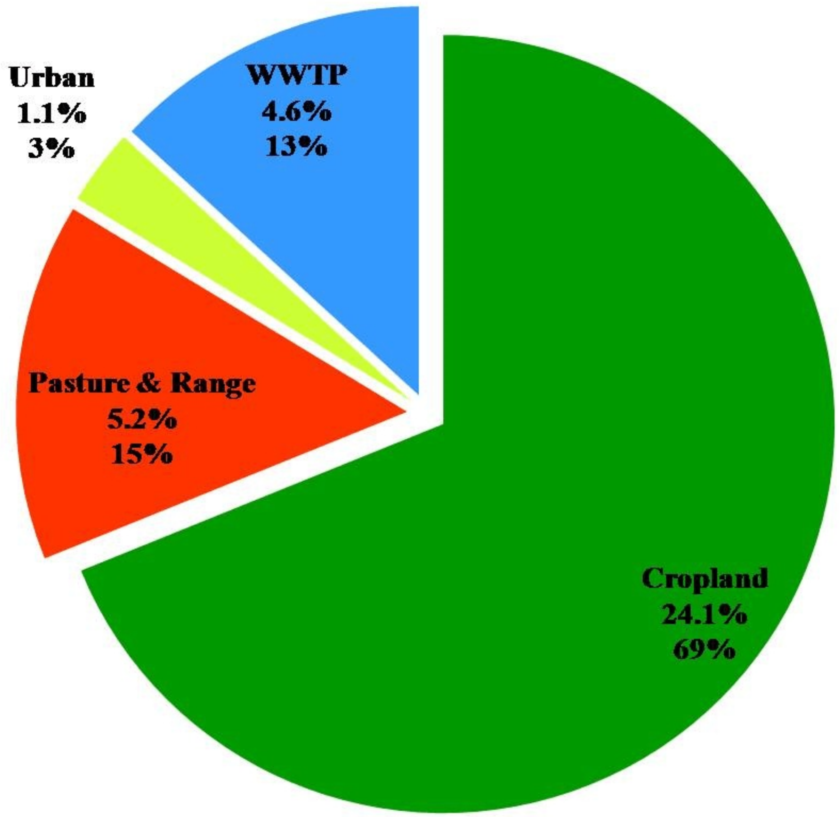

Figure ES4. Illustration of BMPEconomics© Optimization Results, Contributions to P Inflow Reductions for BMPs Categories Comprising the Optimal, Most Economical, Least-Cost Portfolio of Challenger Best Management Practices for Baseline Situation, Cedar Creek Reservoir Watershed, 2009 [Note: this is Figure 15 in Rister et al. (2009)].

In what may first appear as a paradox, error, or oddity, **Table ES1** includes an indication that additional P inflow reductions can be achieved for $70,289 per unit, yet **Figure ES2** represents the highest per unit cost of P inflow reduction in the optimal MEBMP solution as $70,694 for BMP211. Close examination of the results and consideration of the assumptions embedded in the BMPEconomics© linear programming model reveal, however, that the results in **Table ES1** are accurate. To achieve the 35% targeted P inflow reductions, the model seeks to include BMP211 in the solution; however, because of its integer nature, it must be included at a 100% level. If all of the lower cost BMPs were also included at 100% levels, P inflow reductions in excess of 35% would occur. Inasmuch as the objective function of the BMPEconomics© linear programming model is to minimize the cost of achieving a 35% reduction in P inflows, the model recognizes that this objective can be achieved by identifying the most expensive non-integer BMP(s) included in the optimal MEBMP solution, BMP101 in this case, and reducing its (their) level of inclusion such that exactly a 35% reduction is determined. Thus, BMP101 appears in the optimal MEBMP solution at 65.53% of its maximum possible level.

Summary Comments Regarding Baseline Situation's Optimal MEBMP Solution. Considering and accepting all of the assumptions developed in the course of the SWAT, WASP, and BMPEconomics© modeling, a 35% reduction (72.8 ET) of P inflows into the Cedar Creek Reservoir is achievable. Using a select subset portfolio of the 22 Challenger BMPs facilitates this reduction. On an annual basis, the financial costs for achieving this 35% reduction are approximately $2.25 million ($2,232,513). Initial construction/establishment costs are approximately $13.0 million ($12,972,663). The optimal MEBMP portfolio of least-cost BMPs includes several agricultural-related BMPs. When the costs of the respective BMPs are translated into a cost per unit of P inflow reductions (after considering the impacts of most-likely adoption rates and the resulting adjusted-SWAT effectiveness rates) for each BMP, several of the Challenger BMPs are found to be relatively cost inefficient in comparison to those eight BMPs included in the optimal MEBMP solution (for the baseline situation).

Sensitivity Analyses. The baseline situation's optimal MEBMP economic solution is based on numerous factors. Consideration of the complexity and interlinkages among the various factors of importance prompts several questions:

- Are there other solutions with similar costs? i.e., how dominant is the baseline situation's optimal MEBMP solution?
- How do various assumptions imposed on the analysis affect the results?
- What are the tradeoffs in targeting different P inflow reduction levels?
- What are the implications of simultaneously targeting reductions in P, N, and Sed inflows?
- Does valuing sediment reduction, recognizing delayed requirements for constructing reservoirs, affect the optimal MEBMP solution?
- If BMPs in each category are required to reduce the load associated with that category, what are the implications? and
- If different categories of BMPs are excluded (or mandatorily included), what are the consequences?

The principal purposes of sensitivity analyses in economic and financial research are to examine the dominance of the baseline situation's optimal MEBMP solution and to investigate issues such as the above-stated questions. The stability of the optimal MEBMP results may range from (a) the minimal cost portfolio being relatively dominant, with annuity equivalent costs increasing at a rapid rate as alternative portfolios are considered, to (b) where there are several alternative BMP portfolios with relatively similar costs, suggesting that the optimal MEBMP solution's dominance is not strong. In the latter case, the implicit suggestion is that one or more of the alternatives might perhaps receive serious consideration as the preferred strategy based on characteristics of the watershed. Several (i.e., eight sets of) sensitivity scenarios are evaluated to (a) assess the stability of the baseline situation results; (b) identify those assumptions which, when altered, lead to perceptible different results; and (c) identify those assumptions which apparently have limited to no impact on the results.

(1) Targeting Different P Inflow Reduction Levels. The baseline situation was defined to require a 35% (72.8 ET) reduction of P inflows into the Cedar Creek Reservoir. In the first set of sensitivity analyses, several alternative levels of P inflow reductions (ranging from 25% to 50%) are examined, using the BMPEconomics© linear programming model to identify optimal MEBMP portfolios of BMPs for each specified alternative level of reduction.

As expected, the lower (higher) the target P inflow reduction level, the lower (higher) the costs of the optimal MEBMP solutions are, both with respect to initial construction/ establishment costs and annual budgeted costs. The BMPs enter into the solution according to AEV $ per P unit, with the least-expensive BMPs entering first. As noted for the baseline situation's optimal MEBMP solution, the imposition of integer constraints on some BMPs may result in a lower cost non-integer BMP occurring in optimal MEBMP solutions at less than 100%. Agriculture-related BMPs and the WWTP BMP701 are important as represented by their inclusion in the optimal MEBMP solutions across all of the P inflow reduction scenarios considered. The relatively-more expensive options of Channel and Reservoir-in-Lake BMPs (according to AEV $ per P unit) are apparent by their inclusion in the optimal MEBMP solution only at high-target P inflow reduction levels.

(2) Considering Alternative Annual P Inflow Levels. The original BMP effectiveness levels and subsequent adjusted (considering probable, most-likely adoption rates) effectiveness levels utilized in the economic and financial analyses are associated with the annual average of 1966-2002 inflows data. That is, SWAT and WASP analyses of the individual years' data were conducted and, subsequently, the effectiveness levels used in this study were determined for the annual average of the 37-year data period. However, there is considerable variation in the amount of annual water inflows into the Cedar Creek Reservoir in association with the varying climatic conditions during the 1966-2002 period. Recognizing these phenomena of flow variation and the broad range thereof, an attempt was made to evaluate the impact on the optimal MEBMP portfolio of BMPs and associated costs if different P inflow rates were targeted rather than the baseline situation annual average rate of 208.8 ET over the noted 37-year period. That is, the same target level of 35% reduction in P inflows is assumed, but the total inflows level against which this 35% rate is assessed is varied according to different annual flow levels. The results obtained are presented in the report because they are revealing, in a limited sense, as to the direction of impact to be expected if different tributary flow rates are incorporated into the analysis. Several caveats are identified in regards to weaknesses of the data used in this particular sensitivity scenario, however, pointing to the necessity of additional research to more adequately address this issue.

Five alternative levels of annual P inflows (ranging from the 10th percentile flow level to the 90th percentile flow level occurring during 1966-2002) are evaluated relative to the baseline situation average annual P inflows of 208.0 ET and targeted 35% inflow reductions of 72.8 ET. Employing all of the data previously utilized for the baseline analysis, the BMPEconomics© linear programming model was used to identify optimal MEBMP portfolios of BMPs for each of these five scenarios. The results are markedly similar to those for the first set of sensitivity scenarios. That is, the lower (higher) the target P inflows reduction level, the lower (higher) the costs of the optimal MEBMP solutions are, both with respect to initial, up front construction/ establishment costs and annual budgeted costs.

Results for both of the initial two sets of sensitivity scenarios highlight the issue of identifying the appropriate target P inflows reduction level. Whereas the initial set of sensitivity scenarios related to <u>what proportion of the inflows are to be reduced</u> (i.e., a 25% vs. 30% vs. 35% vs. 40% vs. 50% reduction of current P inflows), however, this set of scenarios relates to <u>what measure of total annual inflows should be considered</u> in applying that target reduction level. In the baseline situation, total inflows of 208.8 ET are assumed to develop the targeted 35% reduction of 72.8 ET of P inflows into the reservoir. This 208.8 ET level of total inflows or less occurs approximately 40% of the time; that is, 60% of the time, during 1966-2002, total P inflows exceeded 208.8 ET. Thus, 60% of the time, there are excess P inflows that would not be controlled by the optimal MEBMP portfolios identified for the baseline situation.

<u>(3) Targeting Reductions in P, N, and Sed Inflow Levels Simultaneously</u>. For the Cedar Creek Reservoir Watershed, the focus is on reducing P inflows, with any reductions in N and Sed inflows considered being beneficial, but not required to the extent that minimal levels must be specified for them. In this set of sensitivity scenarios, consideration is accorded by reducing P, N, and Sed inflows simultaneously by the same percentage amounts, ranging from 25%-50%.

With regards to the economic and financial consequences of reducing P, N, and Sed inflows by the same percentages simultaneously, the 35% targeted level scenario is more expensive than the baseline situation, in terms of both AEV and initial construction/ establishment costs. Reflection on the baseline situation's optimal MEBMP solution indicates that the cumulative N and Sed inflow reduction levels accompanying the 35% reduction in P inflows were both less than 35%; thus, increasing the reductions in both N and Sed inflows necessarily increases the costs above that of the baseline situation's optimal MEBMP solution. Similar to the results for the previous set of sensitivity scenarios, recognition of this phenomenon begs the question, "What are the appropriate target N and Sed inflow reduction levels?"

<u>(4) Different Values for Avoiding Sed Deposits into the Reservoir</u>. The inflows of Sed into a reservoir reduces its storage capacity, necessitating either the eventual dredging of sediment from the reservoir and/or construction of a new reservoir. In effect, there is value to be associated with avoiding sediment inflows into a reservoir because, by doing so, dredging costs and/or new construction costs are avoided. In the baseline situation, no value is credited to avoiding the annual sediment inflows. In this set of sensitivity scenarios, however, three alternative values of such avoidance are considered: \$4,200 per ac-ft; \$5,000 per ac-ft; and \$6,000 per ac-ft. To facilitate this set of evaluations in the BMPEconomics© model, a constraint was added that represented 2,136 tons of Sed inflows as equivalent to one acre-foot of reservoir space.

In each of these three sensitivity scenarios, the optimal MEBMP solution is the same as that for the baseline situation. For consistency purposes, the BMPEconomics© linear programming model's objective function values are reported without consideration to the value of the avoided Sed inflows into the reservoir. However, the magnitudes of such values incorporated into the analyses are as follows, recognizing credit of the non-cash value attributed to reducing Sed inflow levels by the equivalent of 59.2 ac-ft:

- with Sed inflows valued at \$4,200 per ac-ft, \$248,672;
- with Sed inflows valued at \$5,000 per ac-ft, \$296,038; and
- with Sed inflows valued at \$6,000 per ac-ft, \$355,246.

The results suggest that a value <u>greater than</u> \$6,000/ac-ft of reclaimed reservoir space (i.e., 59.2 ac-ft) must be assigned to the newly-created water-storage space in order to bring other BMPs, that are relatively-more productive in reducing Sed inflows, into the optimal MEBMP solution.

<u>(5) Requiring BMPs in Each Category to Mitigate the P Loads from that Category</u>. In the baseline situation and in the sensitivity scenarios presented thus far, it has been assumed that the optimal MEBMP solutions desired are with respect to the total Cedar Creek Reservoir Watershed, without any consideration of the source of the P load or of the optimal MEBMP BMPs affiliation (in the optimal MEBMP suite) with a specific category. In this set of sensitivity scenarios, these other issues are addressed. Based on the annual average of 1966-2002 data, Cropland is the dominant contributor, accounting for 41.5% (86.32 ET) of the total 208.8 ET annual inflows. Agricultural pasturelands are a distant, but significant contributor, accounting for 23.4% (48.67 ET) of the total annual inflows. Substantially lower levels of contribution are associated with the Channel, Urban, Wastewater Treatment Plants (WWTP), and naturally-occurring reservoir processes.

Several observations are apparent in these results, consistent with data analyses prior to using the optimization model. Challenger BMPs associated with the Pasture category have difficulty in satisfying that category's proportional responsibilities for the targeted 35% reduction. Similarly, but more extensively, BMPs for the Channel category are unable to satisfy that category's responsibility for both 35% and 30% targeted P inflow reduction levels. No BMP category has difficulty in fulfilling its responsibilities for targeted P inflow reductions of 25%. Even with the individual categories required to meet their respective responsibilities and with two categories not being able to do so for the targeted 35% P inflows reduction level, overall, there are no difficulties in meeting the 35% reduction because the integer nature of the WWTP and Reservoir-in-Lake BMPs provide for excess reductions beyond the needs of those categories.

These sensitivity scenarios illustrate the excess capacity (beyond the respective categories' defined self responsibilities) of the Cropland, Urban, WWTP, and Reservoir-in-Lake categories.

Further, there are fewer Cropland BMPs in the optimal MEBMP solution when the source of inflows per BMP category are considered for a targeted reduction of 35% in P inflows. It is apparent that requiring each category to be accountable for its generated share of the total load is more expensive than using the most economic BMPs without concern as to the category affiliations of the BMPs in the optimal MEBMP suite (as was assumed in the baseline situation).

(6) Excluding Specific Categories of BMPs. In this set of sensitivity scenarios, the impacts associated with the exclusion of the Agricultural and Urban BMPs are investigated. Excluding Cropland BMPs is expensive – the optimal MEBMP solution's annual AEV increases from \$2.23 million for the baseline situation to \$11.93 million and initial construction/establishment costs increase from \$12.97 million for the baseline to \$58.8 million. More important, perhaps, is that without the Cropland BMPs, the targeted 35% reduction in P inflows cannot be achieved, i.e., reductions of only 67.2 ET (32.3%) are identified with the best optimal MEBMP scenario for this sensitivity scenario. The assumed unavailability of the Cropland BMPs requires the WWTP to increase water quality status to Level III (i.e., BMP702 instead of BMP701) and all Channel and Reservoir-in-Lake BMPs to enter the solution – these are all more expensive BMPs on a per P inflows reduction unit basis and are also less productive (on the basis of total (i.e., ET) P inflows reduction).

Relative to Cropland BMPs, Pasture BMPs are not contributing as substantially, albeit they are more economical than the next best alternatives. The optimal MEBMP solution's annual AEV increases from \$2.23 million for the baseline situation to \$3.32 million, and initial construction/establishment costs increase from \$12.97 million to \$18.9 million. It is possible to obtain the targeted 35% reduction in P inflows under the assumptions of the "No Pasture BMPs" sensitivity scenario. Excluding both the Cropland and Pasture BMPs further documents, however, the importance of including agriculture's participation in the Cedar Creek Reservoir Watershed Protection Plan. While it appears that this sensitivity scenario is less expensive than the "No Agricultural Cropland BMPs" scenario, only 50.4 ET (24.2%) of P inflows reduction is being achieved, with all possible remaining Challenger BMPs included in the optimal MEBMP solution.

Excluding the Urban category BMPs has minimal effect on the annual AEV in terms of differences from the baseline, optimal MEBMP solution. In this scenario, AEV increases from \$2.23 million for the baseline situation to \$2.28 million and initial construction/establishment costs increase from \$12.97 million to \$15.5 million.

(7) Requiring Specific BMPs. This set of sensitivity scenarios focuses on understanding the potential ramifications of implementing policies and/or other policy institutions that require (a) the implementation of selected BMPs and (b) allowing other Challenger BMPs to enter the optimal MEBMP solutions in a complementary sense. A cursory review of the results for these sensitivity scenarios is surprisingly unsurprising. For example, implementing all three of the Urban BMPs more than doubles annual costs, with some of the less expensive Cropland BMPs not entering the optimal MEBMP solution. In regards to evaluating the WWTP category BMPs, requiring Level II is inconsequential, as it is already in the baseline situation's optimal MEBMP solution. Requiring WWTPs to increase their water quality status to Level III (i.e., implement BMP702 instead of BMP701) is more expensive, as expected. Changing the WWTP BMPs to a non-integer variable has no effect relative to the baseline optimal MEBMP solution, i.e., the optimal MEBMP solution continued to include BMP701 at a 100% Level. Requiring the Channel category wetlands BMPs (i.e., BMP401A and/or BMP401B) is more expensive, on both an annual AEV basis and in terms of initial construction/establishment costs. These BMPs contribute minimal P inflow reductions, and their inclusion results in BMP211, "Mandatory Reservoir Buffer Strip," falling out of the optimal MEBMP solution.

(8) Speculating on the Probable Level of Adoption of Different BMPs. During the course of several meetings with the NCTXWQ project team and Cedar Creek Reservoir Watershed stakeholders, numerous discussions regarding the prospects for adoption of the various Challenger BMPs focused on the applicability and appropriateness of selected management practices. Stakeholders offered anecdotal insight from their own experiences, and proposed practices as well as provided a "barometer" as to how proposed practiced would be received by targeted landowners. In this set of sensitivity scenarios, two alternatives are evaluated:

- requiring all BMPs, except the wetlands (i.e., BMP401A and BMP401B), be implemented, with the integer and exclusivity constraints effective; and
- excluding several "Most Unlikely" Challenger BMPs.

The results for this final set of sensitivity scenarios support the prior-presented and discussed results and observed interpretations for the baseline situation and other sensitivity scenarios. A subjective interpretation of "what might happen" is suggestive of more expensive solutions than the baseline situation's optimal MEBMP solution – annual AEV costs could more than double and initial construction/establishment costs could be $1-11 million higher.

Post-Economic Optimal MEBMP Solution SWAT and WASP Analyses

There is some question as to whether implementing the optimal MEBMP solution based on a modeled 35% total phosphorus reduction will actually realize the desired impacts in Cedar Creek Reservoir. Subsequent to the BMPEconomics© modeling and analyses, the optimal MEBMP solution for the Cedar Creek Reservoir Watershed baseline situation was examined using the SWAT and WASP models. The objective of these analyses was to validate the potential of the optimal MEBMP economic solution to achieve the targeted 35% reduction in P inflows into the Cedar Creek Reservoir. Following introduction of the first, lowest-cost BMP (i.e., BMP004 "Filter Strip" is the least expensive on a per P inflows reduction basis) into the relevant sub-watersheds, the SWAT model was used to reevaluate the potential for the next lowest-cost BMP (i.e., BMP402 "Grade Stabilization") accomplishing reductions in P inflows, assuming the presence of BMP004. This process was repeated in a stepwise-manner, while taking into account those BMPs already assumed to be implemented, sequentially introducing BMP107 (Critical Pasture Area Planting), BMP007 (Terracing), BMP701 (WWTP upgrade to Level II), BMP001 (Conversion of Cropland to Grass), and BMP211 (2,000 feet Buffer of Nutrient Management Surrounding the Reservoir) into those remaining eligible sub-watersheds with the highest likelihood of generating P inflow reductions. In total, 35.0% of P inflows is reduced, according to this framework of analysis; thus, the SWAT model confirms the validity of the

BMPEconomics© optimal MEBMP solution for the Cedar Creek Reservoir Watershed baseline situation.

The 11-year WASP model was initially used in the Cedar Creek Project to provide direction on the degree of phosphorus reduction that would be necessary to translate into a reduction in chlorophyll-*a* that was meaningful. The daily watershed loading file was systematically reduced by a scaling factor from 15% to 65% to determine when chlorophyll-*a* was significantly ($p<0.05$) less than the calibration results at two sites in the main pool of the reservoir. This exercise determined a 30-35% reduction in total phosphorus is necessary to see a statistically-significant reduction that would be necessary to translate into a meaningful chlorophyll-*a* reduction. Using the revised daily watershed loading file generated by the SWAT model to reflect adoption and implementation of the eight BMPS in the optimal MEBMP solution, the WASP model was used to evaluate (a) total phosphorus (TP) and (b) chlorophyll-*a* at segment six of the Cedar Creek dam for three scenarios:

(1) the original calibrated model;
(2) the optimal MEBMP solution with the eight BMPs for the baseline situation; and
(3) the systematic reduction of 35% scenario.

The WASP modeling results for these scenarios suggest that the eight BMPs in the baseline situation's optimal MEBMP solution will reduce the phosphorus loading to a sufficient level to result in significant reductions in the chlorophyll-*a* targeted by this project.

Sources of Funds

Successful acquisition of funding to support implementation of management measures will be critical for the success of the Cedar Creek Watershed Protection Plan. While some management measures require only minor adjustments to current activities, some of the most important measures require significant funding for both initial and sustained implementation. Discussions with the steering committee and work groups, city officials, agency representatives, and other professionals were used to estimate financial needs. In some cases, funding for key activities is already secured, either in part or full (e.g., Clean Water Act (CWA), Section 106, funding for outreach and education efforts). Other watershed management activities outside of the scope of this study will require funding to conduct preliminary assessments to guide implementation, such as in the case of urban stormwater control. Funding sources such as those stipulated through the Clean Water Act, will be utilized in conjunction with targeted grant programs from the Texas Water Development Board. Additionally, the Cedar Creek Partnership will seek out new sources of funding such as municipalities, counties, and private or corporate support.

Implementation – Targeting BMPs and Areas

Implementation of a model-generated solution on such a large-scale project involving numerous stakeholders with no one central authority is a complex paradigm. Assuming the previously discussed funding issues can be successfully managed, several issues remain to be considered and managed.

Limitations and Implications for Future Research

The magnitude of this project, in terms of the diversity and size of the watershed, the heterogeneity of the stakeholders, the dynamics of the watershed during the 2002-2009 project period, the perspectives of the several disciplines involved, and the inclusion of academic, municipal, and consulting professionals in the research, are sources of both strengths and weaknesses in the final results. The systems paradigm employed in the project provided for an evolution of research, with latter-period efforts building on results derived during the early stages. As a consequence, due in part to both time and funding constraints, some of what was learned/realized during the latter stages could not be incorporated into all of the materials first developed. Purposefully, the issues noted in the report are constrained to those potentially affecting economic and financial methods and associated results. The validity and value of the results presented for the baseline situation and the related sensitivity scenarios are not compromised by these limitations. Readers of this report and users of the results are cautioned to carefully interpret and understand the extent to which the results are and are not applicable. It should also be noted that the economic performance and nutrient reduction figures listed in this report are partially a result of computer modeling specific to the Cedar Creek Watershed and should not be accepted as an indicator of cost or pollutant reduction in other watersheds. Further, the future urbanization and changes in infrastructure across the watershed are not included. Also, any impacts of Global Climate Change and associated runoff and land use implications are not incorporated.

Conclusions

The economic aspect of the NCTXWQ Cedar Creek Reservoir Watershed project extends beyond the SWAT and WASP modeling efforts to evaluate the expected potential costs associated with adopting and implementing alternative portfolios of Challenger BMPs which will collectively meet the targeted 35% reduction of P inflows into the reservoir. Least-cost solutions are determined for a baseline situation and several sets of sensitivity scenarios, with the set of multiple results intended to test the superiority (or lack thereof) of the baseline solution. The data assimilation process to support the economic and financial analyses revealed several challenges potentially affecting successful implementation of the optimal MEBMP watershed protection plan. It appears the optimal MEBMP solution for the baseline situation is relatively dominant in comparison to the optimal MEBMP solutions for the several alternatives investigated in the sensitivity analyses. That is, when the costs of the respective BMPs are translated into a cost per unit of P inflows reduction after considering the impacts of most-likely adoption rates and the resulting adjusted SWAT effectiveness rates for each BMP, several of the Challenger BMPs are relatively cost inefficient in comparison to those eight BMPs included in the optimal MEBMP solution for the baseline situation. It is evident that the optimal MEBMP economic solution is based on a myriad of factors. The several optimal MEBMP analyses solutions reveal the considerable importance (cost wise) of assuring participation by agricultural decisionmakers in adopting and implementing BMPs on their properties.

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