THE CONNECTICUT WATERSHED MODEL – A TOOL FOR BMP IMPACT ASSESSMENT

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ABSTRACT

Nutrient loadings from watersheds within the state of Connecticut have a large impact on the water quality and aquatic health of Long Island Sound (LIS). Over the past 15 years, state and federal efforts have focused on improving the water quality and natural resources of LIS, with a specific emphasis on addressing the issue of hypoxia. In this study, funded by EPA and the Connecticut Department of Environmental Protection (CTDEP), a statewide watershed model was developed using the U.S. EPA Hydrological Simulation Program - FORTRAN (HSPF) and the U.S. Geological Survey's graphical user interface GenScn to quantify all sources of key nutrients to LIS.

The Connecticut Watershed Model (CTWM) was developed to evaluate nutrient sources and loadings within each of six nutrient management zones that lie primarily within the state of Connecticut, and assess their delivery efficiency to LIS. The CTWM evolved by first performing calibration and validation on three small test basins across the state (Norwalk, Quinnipiac, and Salmon) representing a range of land uses, including urban, forest, and agricultural. The model was then extended to three major river calibration basins (Farmington, Housatonic, and Quinebaug) and subsequently expanded to a statewide model by using the most spatially applicable set of calibrated watershed parameters in non-calibrated areas. The user-friendly interface and framework of the CTWM was specifically designed to promote continuing use by CT DEP staff to assess multiple BMPs, implementation levels, and relative impacts of point source controls for nutrient reductions to LIS

This paper presents procedures and results of using the CTWM to evaluate the loading impacts of alternative future growth conditions, and mitigative impact of BMPs for reducing nutrient loads to LIS. A companion paper at this conference describes the model development, watershed characterization, database, and calibration/validation efforts for the CTWM (Love and Donigian, 2002).

KEYWORDS

HSPF, GenScn, calibration, validation, watershed model, nutrients, nonpoint, hypoxia, BMPs

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INTRODUCTION

Background

Over the past 15 years, state and federal efforts have focused on improving the water quality and natural resources of Long Island Sound (LIS). In 1985, the Long Island Sound Study (LISS) was begun when Congress appropriated funds for the U.S. Environmental Protection Agency (EPA) to carry out a program to research, monitor, and assess the water quality of LIS in concert with the Connecticut Department of Environmental Protection (CT DEP) and the New York State Department of Environmental Conservation (NYSDEC). As part of the Clean Water Act (CWA) Amendments of 1987, the National Estuary Program was established, and at the request of the states of both Connecticut and New York, LIS was designated an 'Estuary of National Significance' under this program (NYSDEC and CT DEP, 1999). Since that time, the ongoing study, conducted as a joint effort between EPA, CT DEP, NYSDEC, and a broad coalition of academic, consulting, and public interest organizations, has identified periodic hypoxia, especially in the western portions of the Sound, as a critical issue in need of management.

The issue of hypoxia, usually defined as levels of DO less than 3.0 mg/l, has been the focus of the development of a comprehensive multi-phase management plan under the LISS to reduce nitrogen loads entering the Sound. The hypoxia condition results from high concentrations of nitrogen in LIS promoting excessive growth of algae, combined with the naturally occurring density stratification of the water column. When these algae die, they decompose, consuming oxygen in the process and leading to the hypoxic, or low DO conditions, and occasionally even anoxic (zero DO) conditions. The hypoxia in LIS typically occurs during the late summer months, adversely affecting the habitat for shellfish, juvenile fish, and invertebrates. The LISS has estimated that the load of nitrogen delivered to LIS has more than doubled since pre-colonial times, and that discharges from sewage treatment plants, atmospheric deposition, and nonpoint runoff are the primary sources of nitrogen enrichment to LIS (NYSDEC and CT DEP, 1999).

The most recent phase of the comprehensive management effort adopted nitrogen reduction targets of 58.5% for 11 management zones that comprise the CT and NY portion of the LIS watershed. The plan, adopted by EPA, CT, and NY, includes a commitment to administer and enforce the nitrogen reduction targets through development of a Total Maximum Daily Load (TMDL) analysis, needed to achieve DO water quality standards, consistent with the requirements under Section 303(d) of the CWA (NYSDEC and CT DEP, 1999). In addition, the TMDL process also requires the states of CT and NY to identify appropriate point and nonpoint source management options, in conjunction with the affected parties (e.g. municipalities and industry), that can meet the 58.5% nitrogen reduction target, and allow for periodic review and revision every five years (NYSDEC and CT DEP, 1999).

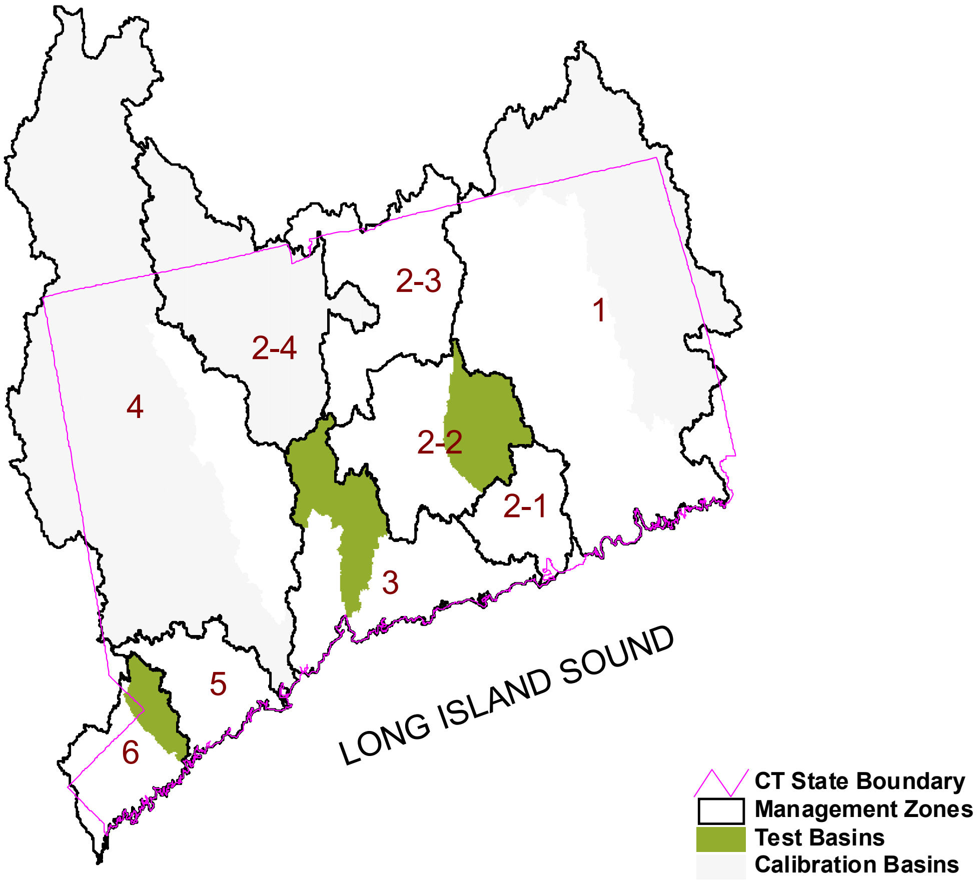

Figure 1. Nutrient management zones within the Connecticut Watershed Model

Of the 11 nitrogen management zones contributing to LIS, Figure 1 shows the six zones primarily located within CT. These management zones follow existing natural basin boundaries and thus, are amenable to watershed or basin-wide planning efforts needed to address the nitrogen reduction goals. Nutrient loadings from watersheds within the state of Connecticut are thought to be a significant portion of the total loads to LIS, and thus they are likely to have a significant impact on the water quality and aquatic health of LIS.

Objectives

The primary objectives of the study are to provide a watershed modeling framework for both (1) estimating the nutrient loads from the six CT management zones, and their delivery to LIS, and (2) evaluating the potential of alternative management options to provide the reductions needed to achieve the DO water quality standard in LIS. Although the primary focus is on nitrogen, deemed to be the limiting nutrient for LIS, phosphorous and carbon loadings are also important nutrients due to their importance in aquatic nutrient cycles, their impacts on algal growth, and the resulting processes and mechanisms controlling delivery to LIS.

In meeting these objectives, the Connecticut Watershed Model (CTWM) (AQUA TERRA Consultants and HydroQual, Inc., 2001), developed in this effort, can serve as a tool for the ongoing TMDL process by providing the framework for evaluating the impacts of alternative management options, analyzing potential tradeoffs between point and nonpoint loads, and performing the periodic reviews and revisions required by the regulation.

This paper discusses the final phase of the study, using the CTWM to evaluate alternative future growth conditions and scenarios of BMPs to reduce nutrient loadings. The model development, database and setup, calibration, and validation have been discussed in detail by Love and Donigian (2002)(these proceedings) and in the original report (AQUA TERRA Consultants and HydroQual, Inc., 2001).

STUDY METHODOLOGY

Model Selection and Approach

The development of a watershed model of nutrient loadings to Long Island Sound from Connecticut watersheds was patterned after the U.S. EPA Chesapeake Bay Program (CBP) Study. The U.S. EPA Hydrologic Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997, 2000; Donigian et al., 1995) is the framework for the CBP Watershed Model used to generate nutrient loadings, and investigate the impacts of alternative management strategies, to the Chesapeake Bay and as inputs to the hydrodynamic/water quality model being used to assess Bay water quality impacts (Linker et al., 1993; 1996).

The use of HSPF as the Watershed Model for the CBP Study has confirmed its ability to estimate nutrient loads and delivery from watershed areas; calculate contributions from point, nonpoint, and atmospheric sources; and provide a means of evaluating impacts of alternative management strategies to reduce nutrient loads and improve water quality conditions. In addition, HSPF is currently being used for watershed studies with similar objectives in Minnesota, Washington State, Oregon, Australia, Kentucky, South Carolina, Nevada, and Florida. Consequently, HSPF was selected as the watershed model framework for this study.

In order to address the study objectives, the CT statewide watershed model was developed using the U.S. EPA HSPF, and the U.S. Geological Survey's graphical user interface (**GenScn**). HSPF is a watershed-scale hydrologic and water quality model that allows simulation of both water quantity and quality in simple to complex watersheds. It provides the capability to handle a diversity of water quality constituents, represent complex multi-land use watersheds, include hydraulic structures and complex operational scenarios, and to represent impacts of point and nonpoint sources, diversions, and various land management (urban, agricultural, forest) practices. In short, it provides all the capabilities needed to represent the nutrient loads to LIS from the six CT management zones. **GenScn,** an acronym for ***'Gen***eration and analysis of model simulation ***Scen***arios' (Kittle et al., 1998) was developed to create simulation scenarios using HSPF, analyze the results of the scenarios, and compare scenarios. In addition, GenScn was used extensively during the model calibration phase, as it provides a user-friendly framework for HSPF applications and associated evaluation of the impacts of alternative watershed conditions and management options.

The Connecticut Watershed Model (CTWM) was developed to evaluate nutrient sources and loadings within each of six nutrient management zones that lie primarily within the state of Connecticut, and assess their delivery efficiency to LIS. The CTWM evolved by first performing calibration and validation on three small test watersheds across the state (Norwalk, Quinnipiac, and Salmon) representing a range of land uses, including urban, forest, and agriculture. The model was then extended to three major river calibration basins (Farmington, Housatonic, and Quinebaug) and subsequently expanded to a statewide model by using the most spatially applicable set of calibrated watershed parameters in the non-calibrated areas. Figure 2 shows the locations of both the test watersheds and the major calibration basins; the calibration sites were chosen to provide good spatial coverage for the entire state.

A limitation of the HSPF model is that it cannot model estuaries nor tidally-impacted stream segments. Thus, in order to assess the delivery efficiency of the watershed model loads for the lower portions of the major rivers, the System-Wide Eutrophication Model (SWEM), coupled hydrodynamic/water quality model, developed for the New York City Department of Environmental Protection, is used (HydroQual, 1999). SWEM was applied to the mainstem of Connecticut River, since it is tidal for essentially it's entire length within the state limits, and the Quinnipiac and Housatonic river estuaries. The focus of the SWEM application was to develop 'attenuation factors' for the nutrient loads to represent the efficiency of each estuary to deliver the watershed loads to LIS. These attenuation factors are then used in a simplified assessment tool (spreadsheet) to apply the same factors for each alternative watershed scenario of management practices. For additional discussion on the SWEM model and assessment tool refer to the complete report, *Modeling Nutrient Loads to Long Island Sound from Connecticut Watersheds, and Impacts of Future Buildout and Management Scenarios* (AQUA TERRA Consultants and HydroQual, Inc., 2001).

Figure 3 shows the final watershed segmentation demonstrating the spatial detail of the land and channel areas represented in the model, along with the boundary conditions on the Connecticut and Housatonic rivers. The final statewide CTWM segmentation resulted in 34 watershed segments ranging in size from 11.2 sq. miles (7,158 acres) to 386 sq. miles (247,850 acres). Each segment is divided into six land use categories - forest, agriculture/other, wetlands, urban pervious, urban impervious, roads. The watershed segments are aggregations of the subregional basins and thus follow basin divides. Aggregation of the subregional basins was performed at a level that would allow model parameters and input/execution data (e.g., precipitation and meteorologic data) to adequately represent the spatial variability of soils, slopes, topography, physiography, and climate within the state. A more spatially detailed segmentation was performed for the Test Watersheds to support the initial calibration effort and parameter development for the subsequent statewide expansion.

Within the watershed segments, 84 non-tidal reaches are explicitly modeled ranging in length from 1.0 to 21 miles, with an average length of 8.7 miles. The contributing drainage areas for these reaches ranges from 2.2 sq. miles (1,423 acres) to 165 sq. miles (105,653 acres).

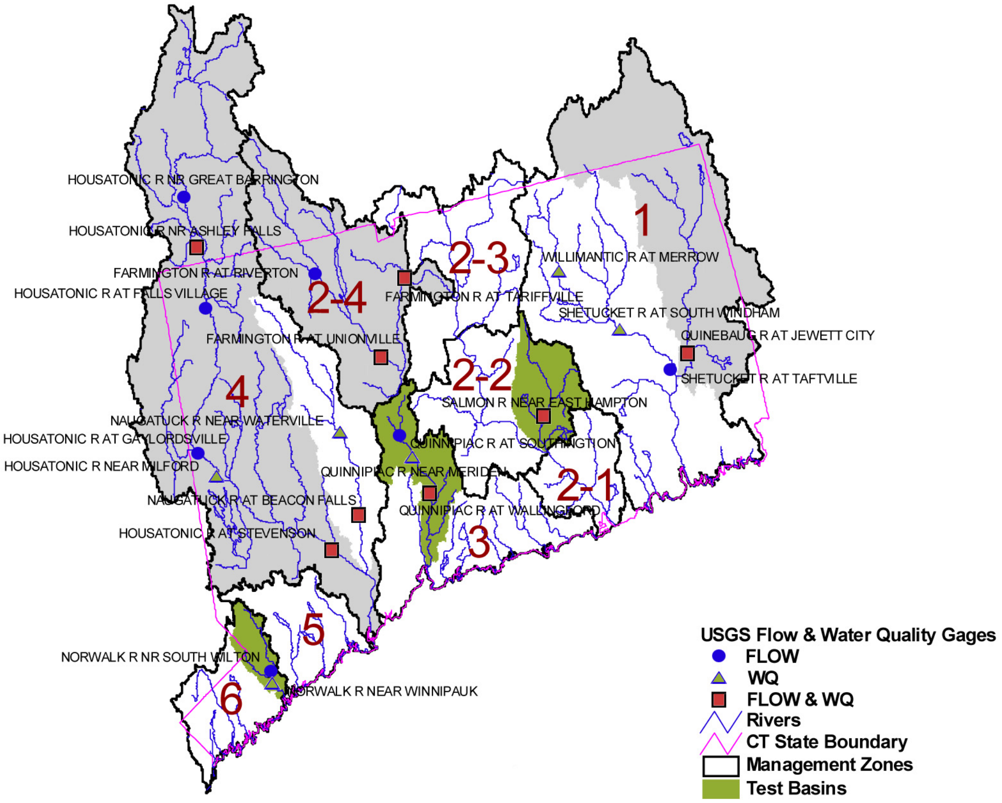

Figure 2. CTWN Test and Calibration Basins and Locations

Model segments and management zones within the CTWM share hydrologic boundaries. Therefore, the model segments can be aggregated to collectively comprise a management zone and allow for the evaluation of the water quantity and quality response, and nutrient loadings to LIS, at a management zone level. The CTWM simulations were performed for the entire study area shown in Figure 3, except for the upper boundary condition on the Housatonic River. As noted earlier, details on the model development, calibration, and validation are described in a companion paper by Love and Donigian (2002) (these proceedings).

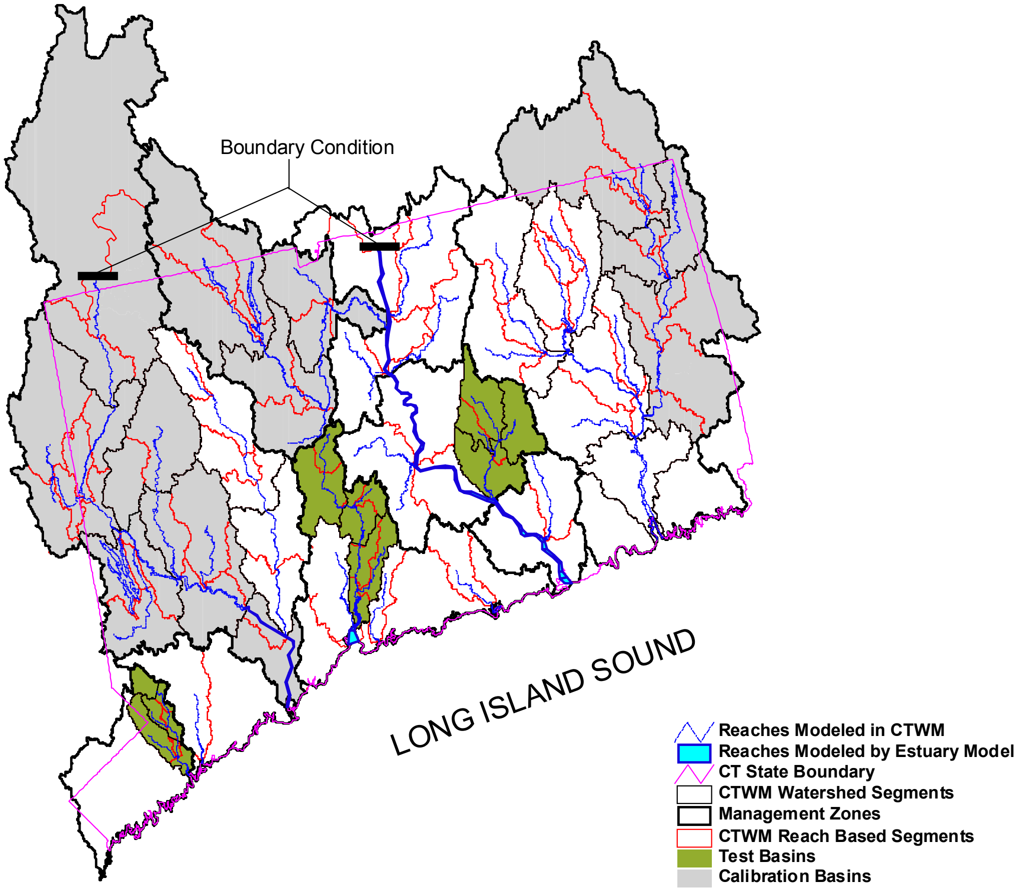

Figure 3. **Final CTWM Segmentation and Boundary Conditions**

ALTERNATIVE WATERSHED SCENARIO DEVELOPMENT AND ASSESSMENT

The process of evaluating the impacts of alternative watershed conditions on nutrient loadings to LIS involves (1) establishing a base condition for comparison, (2) defining the alternative conditions to be simulated, (3) changing the model to represent those alternatives, and (4) comparing model results for each alternative to those from the base condition. This section discusses those steps in the process of using the CTWM to assess LIS nutrient loadings under alternative future growth and BMP implementation scenarios.

Base Conditions And Scenario Development

The 1991-95 water quality calibration period was selected to form the Base Conditions for comparing the nutrient loadings from the alternative watershed conditions and scenarios. Ideally, a longer time period would be advisable for calculating average annual loads to consider the effects of a larger range of climatic conditions. Unfortunately, point source loading information was not available for all plants for the earlier time period, 1986-90, for which the climate data was prepared. Table 1 shows the average annual nutrient loads, for Total Nitrogen, Total Phosphorus, and Total Organic Carbon, delivered to LIS from each Management Zone for the 1991-95 period. **These numbers include the effects of the delivery attenuation factors for the three tributary estuaries affecting the loads for Management Zones 2, 3, and 4.**

Note that the table shows the calculated nutrient loads delivered to LIS from each management zone, along with the total loads shown at the bottom of the table. The table includes both the nonpoint source only (NPS) contribution and the Total Loads for Total Nitrogen, Total Phosphorus, and Total Organic Carbon. The NPS column was developed by the difference of two model runs of the CTWM; one Base Condition run with ALL sources included along with the direct point source discharges to LIS and attenuation in the three estuaries noted above, and one without the watershed point sources, thus isolating just the NPS contribution delivered to LIS.

The results show that about 24,000 tons per year of nitrogen, 2,200 tons per year of phosphorus, and 93,000 tons per year of carbon are delivered each year to LIS based on the 1991-95 simulation period of the CTWM. The division between nonpoint sources and point sources varies by management zone, with the totals showing that about 25% to 70% of nitrogen, 15% to 40% of phosphorus, and 40% to 60% of carbon are derived from nonpoint sources; management zones 2 and 4 are not included in these calculations as they also have upper boundary condition loads. Note that the loads **(10^3 lbs/yr)** in Table 1 **include** the 'out-of-state' boundary condition loads for the Connecticut River at Thompsonville and the Housatonic River at Ashley Falls, as shown below:

	Zone 2 - Thompsonville		Zone 4 - Ashley Falls	
	Boundary Load	Delivered to LIS	Boundary Load	Delivered to LIS
TN	22,637	21,505	1,950	746
TP	1,489	1,415	159	19
TOC	105,036	76,676	9,600	203

Note that the Zone 2, Thompsonville, values are for the 10/94 through 9/95 period used in the Estuary Model to calculate the attenuation factors, while Zone 4 values are average annual loads for 1991-95 simulation period of the CTWM.

Table 1. Average Annual Nutrient Loads (10^3 lbs/yr) Delivered to LIS for Each of the Management Zones

Management Zone	Total Nitrogen		Total Phosphorus		Total Organic Carbon	
	NPS	Total	NPS	Total	NPS	Total
1	4,078	5,757	209	552	32,334	51,669
2	3,043	29,343	168	2,505	17,173	101,395
3	978	4,052	54	398	2,511	5,184
4	3,929	6,061	316	521	13,824	15,386
5	475	1,855	25	194	2,262	5,724
6	629	1,616	34	169	3,141	5,852
Total (10^3 lbs / yr)	13,132	48,684	807	4,338	71,244	185,211
Total (tons / yr)	6,566	24,342	403	2,169	35,622	92,605

Note: The totals for Management Zone 2 includes the Fall-Line boundary condition loads for the Connecticut River at Thompsonville, while for Management Zone 4 they include the boundary conditions for the Housatonic River at Ashley Falls, MA.

In order to evaluate potential impacts of alternative watershed conditions, including projected future conditions, these conditions, or scenarios, need to be defined in sufficient detail to establish specific quantified changes in the model input, parameters, or watershed configuration (i.e., setup or segmentation characteristics). The CTWM is based on HSPF Version 12 which includes the recent addition of a Best Management Practice (BMP) module specifically designed to allow flexible representation of a wide range of BMPs (Patwardhan et al., 2000). The selected BMPs can be applied to each land use category separately, or in combination with other different land uses, at desired points within a watershed based on the level of detail of the model segmentation. In its current form, the BMP module relies on specification of 'removal efficiencies' to characterize BMP impacts on input loads; future plans include more detailed representation of individual BMPs, including design capabilities.

Discussions with CT DEP staff identified 'future growth' and 'BMP implementation levels' as the primary watershed alternative scenarios to be evaluated under this effort. **Seven alternative**

watershed scenarios were simulated, including the **Base Conditions** and **six combinations** of future growth and BMP implementation levels, as follows:

- Base Conditions
- 10% BMP Implementation
- 30% BMP Implementation
- 50% BMP Implementation
- 2020 Buildout
- Double (2X) 2020 Buildout
- Double (2X) 2020 Buildout plus 50% BMP Implementation

The levels of BMP implementation correspond to the percent of urban and agricultural areas to be treated or controlled by BMPs within each model segment, and the Buildout conditions represent increases in the urban land categories corresponding to projected 2020 conditions. Although these scenarios represent only a subset of potential 'alternative futures' that may be of interest in controlling nitrogen loads, they focus on the key issues of immediate concern. In addition, the CTWM and all associated files will be provided to CT DEP staff, and other interested parties, to provide the capability for analyzing additional watershed management scenarios.

Model Representation of Scenarios

In order to represent the above scenarios with separate model runs of the CTWM, we need to define the following:

a. Land use distributions for each model segment for the 2020 Buildout and 2X 2020 Buildout scenarios

b. BMP removal efficiencies for urban and agricultural BMPs for all modeled constituents

c. Model land use affected by the BMP implementation levels - 10%, 30%, 50%

Land use Changes for 2020 Buildout Scenarios

The land use changes for the Buildout scenarios were derived from town-by-town population growth projections for 2020. Individual towns were assigned to their encompassing subregional basin and associated model segments, and a weighted growth rate was calculated based on the relative land areas of each town so that small or large towns would not have undue impacts. The projected population growth rate was assumed to correspond to a growth in urban land area for each model segment. The resulting increase in urban land segments, including urban pervious, urban impervious, and roads, was taken from the forest and agriculture land segments in relative proportion to their areas within the segment; thus, if urban land increases by 100 acres and the model segment has a 4:1 ratio of forest to agriculture, then 80 acres of forest and 20 acres of agriculture were converted to produce the 100 acres increase in urban land.

The actual growth rates for the subregional basins, corresponding to individual model segments ranged from 0.0 % to 24.3 %, with a mean of 7.7 % and a standard deviation of 5.3 %; these numbers represent the total increase from 1991-95 conditions to 2020 conditions. The 2X 2020 Buildout scenario was produced by simply doubling these growth rates. Table 2 shows the resulting land use distribution for the Base, 2020 Buildout, and 2X 2020 Buildout scenarios for each Management Zone. Areas outside CT were assumed to grow at the same rate as the subregional basin or model segment.

BMP Removal Efficiencies

To develop appropriate BMP removal efficiencies, the Center for Watershed Protection provided recommendations for selected nutrient and organic constituents for a variety of specific stormwater treatment practices, including infiltration basins, grass filter strips and swales, wetlands, and wet and dry detention ponds (D. Caracao, personal communication, 2000). These values were derived from their *National Pollutant Removal Performance Database (Winer, 2000)*. To supplement this information, we also reviewed BMP efficiency values from the *National Stormwater Best Management Practices Database (ASCE and Wright Water Engineers, Inc., 1999)* and other modeling studies (Donigian et al., 1997; Donigian et al., 1993) to include both urban and agricultural conditions.

Due to the subregional scale of the modeling (i.e. CTWM model segments), the focus on generalized planning estimates of loads to LIS, and resource limitations, the approach for representing BMPs was to define a ‘standard’ set of percent removal efficiency factors to represent average removal performance values for typical BMPs applied to both urban and agricultural lands. The databases noted above clearly show a wide range of removal efficiency values derived from field studies, depending on a variety of local factors, such as climate, site conditions, soils, design parameters, etc. The removal efficiency values used in the CTWM are shown below:

Constituent	Removal Efficiency (%)
BODu	40 %
NO_x	35 %
NH_3	45 %
PO_4	50 %
Organic N	55 %
Organic P	55 %
Organic C	55 %

Table 2. CTWM Land use Distribution by Management Zone for Base and Buildout Scenarios

Management Zone 1					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	726777	719176	-1.05%	711576	-2.09%
Ag.	105012	103887	-1.07%	102762	-2.14%
Urban Per.	62588	68294	9.12%	74001	18.24%
Wetland	86308	86308	0.00%	86308	0.00%
Urban Imp.	11546	12618	9.29%	13690	18.57%
Road	20936	22882	9.30%	24829	18.59%
Total	1013166	1013166	0.00%	1013166	0.00%

Management Zone 2					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	624377	615719	-1.39%	607062	-2.77%
Ag.	139492	136566	-2.10%	133641	-4.19%
Urban Per.	115425	123530	7.02%	131635	14.04%
Wetland	80279	80279	0.00%	80279	0.00%
Urban Imp.	31670	33630	6.19%	35589	12.37%
Road	18685	20203	8.13%	21721	16.25%
Total	1009928	1009928	0.00%	1009928	0.00%

Management Zone 3					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	172191	167638	-2.64%	163085	-5.29%
Ag.	39151	37666	-3.79%	36181	-7.59%
Urban Per.	66812	71161	6.51%	75511	13.02%
Wetland	18150	18150	0.00%	18150	0.00%
Urban Imp.	21050	22345	6.15%	23640	12.30%
Road	5467	5861	7.21%	6255	14.41%
Total	322821	322821	0.00%	322821	0.00%

Management Zone 4					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	657673	647631	-1.53%	637588	-3.05%
Ag.	168038	165804	-1.33%	163571	-2.66%
Urban Per.	96427	105195	9.09%	113964	18.19%
Wetland	58357	58357	0.00%	58357	0.00%
Urban Imp.	22539	24620	9.23%	26701	18.46%
Road	16175	17603	8.82%	19030	17.65%
Total	1019209	1019209	0.00%	1019209	0.00%

Management Zone 5					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	68644	67571	-1.56%	66498	-3.13%
Ag.	10680	10273	-3.81%	9866	-7.62%
Urban Per.	32473	33513	3.20%	34553	6.41%
Wetland	3730	3730	0.00%	3730	0.00%
Urban Imp.	11058	11409	3.17%	11759	6.34%
Road	2689	2778	3.31%	2867	6.62%
Total	129274	129274	0.00%	129274	0.00%

Management Zone 6					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	74193	72304	-2.55%	70414	-5.09%
Ag.	14380	13822	-3.88%	13264	-7.76%
Urban Per.	42745	44464	4.02%	46182	8.04%
Wetland	3286	3286	0.00%	3286	0.00%
Urban Imp.	14027	14591	4.02%	15155	8.04%
Road	4115	4281	4.01%	4446	8.03%
Total	152747	152747	0.00%	152747	0.00%

Total of ALL Management Zones					
	Base	Buildout		2 x Buildout	
Land use	**acres**	**acres**	**% Change**	**acres**	**% Change**
Forest	2323855	2290039	-1.46%	2256223	-2.91%
Ag.	476753	468019	-1.83%	459284	-3.66%
Urban Per.	416470	446157	7.13%	475845	14.26%
Wetland	250111	250111	0.00%	250111	0.00%
Urban Imp.	111891	119213	6.54%	126535	13.09%
Road	68068	73608	8.14%	79148	16.28%
Total	3647146	3647146	0.00%	3647146	0.00%

This same set of removal factors were applied to both urban and agricultural lands because the available literature values demonstrated such a wide range of efficiencies for practices applied to both land use categories, and the mean values could equally well represent both conditions. Some of these values may be optimistic, especially for the N components, since they apply to the entire load and many BMPs are designed to control only surface runoff contributions. In addition, many of the field studies presented in the above data sources were for *research* conditions which may over-estimate removal factors compared to real-world BMP implementation applications.

BMP Implementation Levels

The three levels of BMP implementation - 10 %, 30 %, 50 % - were selected to correspond to low, mean, and high levels of nutrient reduction. This is implemented in the CTWM by applying the standard set of removal efficiencies to the **total loads** generated by the corresponding fractions of both urban and agricultural lands within each model segment. That is, a 10% BMP implementation means that 10% of the urban and agricultural land within a model segment will have its nonpoint source loads reduced by the removal efficiencies listed above. In partial support of these levels, the 50 % implementation level is consistent with the LISS Phase III management goal being incorporated into the LIS TMDL analysis (NYSDEC and CT DEP, 1999).

The same implementation levels are used for both urban and agriculture lands so that a general relationship (i.e., simplified model or spreadsheet) might be developed between BMP implementation and load reduction percentages.

Although the Buildout, BMP removal efficiency, and BMP implementation assumptions discussed above may not receive universal agreement, they provide a reasonable basis for evaluating nutrient loads to LIS under the stated conditions. In addition, since the CTWM will be available for use by CT DEP staff, and others, they will be able to redo these same scenarios under alternative values, and evaluate other scenarios, as needed.

LIS NUTRIENT LOADS UNDER ALTERNATIVE WATERSHED SCENARIOS

The CTWM was run for each of the six scenarios for the five-year 1991-95 time period. Table 3 shows the average annual ***Nonpoint Source Loads*** for Total N, Total P, and TOC for each Management Zone and for the entire State, along with the percent change from the Base Condition; Table 4 shows the corresponding results for ***Total Loads***. These results include the impacts of the attenuation factors for the Connecticut River, Housatonic River, and Quinnipiac River in reducing the loads delivered to LIS. A spreadsheet, the CTWM Loadings Tool (provided on CD), was developed to tabulate the CTWM scenario results, impose the attenuation factors for the appropriate Management Zones, calculate the percent changes from the Base Conditions, and generate the summarized results shown in Tables 3 and 4. The Loadings Tool also allows incorporation of the LIS direct point source loads so that the Total Loads can be calculated, along with generalized planning cost estimates for BMP implementation for each of the BMP scenarios. These tables show the impacts of the BMPs on both the Total Loads and just the NPS contributions since the BMPs are designed for NPS reductions only. These NPS

Table 3. Summary of Total N, Total P, and TOC Nonpoint Source Loads for Each Watershed Scenario, and Percent Change from Base and Buildout Conditions

Total Nitrogen Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	4,078	4,009	-1.71%	3,870	-5.11%	3,731	-8.52%	4,124	1.12%	4,170	2.24%	3,793	-7.0%	-9.0%
2	3,043	2,974	-2.28%	2,835	-6.84%	2,696	-11.40%	3,088	1.46%	3,133	2.93%	2,761	-9.3%	-11.8%
3	978	951	-2.70%	899	-8.10%	846	-13.50%	999	2.22%	1,020	4.31%	878	-10.2%	-13.9%
4	3,929	3,888	-1.04%	3,760	-4.29%	3,633	-7.54%	3,984	1.40%	4,016	2.22%	3,680	-6.3%	-8.4%
5	475	466	-1.93%	447	-5.80%	429	-9.67%	480	1.08%	485	2.15%	437	-7.9%	-9.8%
6	629	610	-3.00%	572	-8.99%	534	-14.99%	638	1.47%	644	2.46%	548	-12.9%	-15.0%
Total	13,132	12,898	-1.78%	12,383	-5.70%	11,869	-9.62%	13,313	1.38%	13,467	2.56%	12,097	-7.9%	-10.2%

Total Phosphorus Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	209	204	-2.49%	193	-7.47%	183	-12.44%	212	1.51%	215	3.02%	187	-10.3%	-12.9%
2	168	163	-3.37%	151	-10.09%	140	-16.81%	171	1.59%	174	3.17%	144	-14.5%	-17.2%
3	54	52	-3.84%	48	-11.50%	44	-19.16%	55	2.59%	57	4.85%	46	-15.4%	-19.3%
4	316	314	-0.61%	308	-2.61%	301	-4.60%	319	0.92%	320	1.46%	304	-3.8%	-5.2%
5	25	24	-2.96%	23	-8.88%	21	-14.80%	26	1.37%	26	2.73%	22	-12.6%	-14.9%
6	34	33	-4.02%	30	-12.05%	28	-20.09%	35	1.82%	35	2.43%	28	-17.5%	-19.4%
Total	807	790	-2.11%	753	-6.62%	717	-11.13%	818	1.38%	827	2.53%	731	-9.4%	-11.6%

Total Organic Carbon Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	32,334	31,486	-2.62%	29,791	-7.86%	28,095	-13.11%	32,755	1.30%	33,176	2.60%	28,617	-11.5%	-13.7%
2	17,173	16,550	-3.63%	15,304	-10.88%	14,057	-18.14%	17,417	1.42%	17,661	2.84%	14,374	-16.3%	-18.6%
3	2,511	2,418	-3.70%	2,232	-11.09%	2,047	-18.48%	2,576	2.61%	2,634	4.93%	2,135	-15.0%	-19.0%
4	13,824	13,615	-1.51%	12,741	-7.83%	11,867	-14.16%	14,240	3.01%	14,429	4.37%	12,113	-12.4%	-16.1%
5	2,262	2,186	-3.36%	2,034	-10.07%	1,882	-16.79%	2,290	1.24%	2,318	2.47%	1,925	-14.9%	-17.0%
6	3,141	3,006	-4.30%	2,736	-12.89%	2,466	-21.49%	3,193	1.65%	3,227	2.75%	2,535	-19.3%	-21.5%
Total	71,245	69,262	-2.78%	64,838	-8.99%	60,414	-15.20%	72,470	1.72%	73,445	3.09%	61,699	-13.4%	-16.0%

Table 4. Summary of Total N, Total P, and TOC Total Loads (NPS + PS) for Each Watershed Scenario, and Percent Change from Base and Buildout Conditions

Total Nitrogen Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	5,757	5,687	-1.21%	5,548	-3.62%	5,409	-6.03%	5,802	0.79%	5,848	1.59%	5,472	-4.9%	-6.4%
2	29,343	29,274	-0.24%	29,135	-0.71%	28,996	-1.18%	29,388	0.15%	29,432	0.30%	29,061	-1.0%	-1.3%
3	4,052	4,026	-0.65%	3,973	-1.95%	3,920	-3.26%	4,074	0.54%	4,095	1.04%	3,952	-2.5%	-3.5%
4	6,061	6,020	-0.67%	5,892	-2.78%	5,764	-4.89%	6,116	0.91%	6,148	1.44%	5,811	-4.1%	-5.5%
5	1,855	1,845	-0.49%	1,827	-1.48%	1,809	-2.47%	1,860	0.28%	1,865	0.55%	1,817	-2.0%	-2.6%
6	1,616	1,598	-1.17%	1,560	-3.50%	1,522	-5.83%	1,626	0.57%	1,632	0.96%	1,535	-5.0%	-5.9%
Total	48,684	48,450	-0.48%	47,935	-1.54%	47,421	-2.59%	48,865	0.37%	49,019	0.69%	47,650	-2.1%	-2.8%

Total Phosphorus Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	552	547	-0.94%	537	-2.83%	526	-4.71%	555	0.57%	558	1.14%	531	-3.9%	-5.0%
2	2,505	2,499	-0.23%	2,488	-0.68%	2,476	-1.13%	2,507	0.11%	2,510	0.21%	2,480	-1.0%	-1.2%
3	398	396	-0.52%	392	-1.56%	387	-2.60%	399	0.35%	400	0.66%	389	-2.1%	-2.7%
4	521	519	-0.37%	513	-1.58%	506	-2.79%	524	0.56%	525	0.88%	509	-2.3%	-3.2%
5	194	193	-0.38%	191	-1.15%	190	-1.92%	194	0.18%	194	0.36%	191	-1.6%	-2.0%
6	169	167	-0.82%	165	-2.46%	162	-4.10%	169	0.37%	170	0.50%	163	-3.6%	-4.0%
Total	4,338	4,321	-0.39%	4,284	-1.23%	4,248	-2.07%	4,349	0.26%	4,358	0.47%	4,262	-1.7%	-2.2%

Total Organic Carbon Loading

	Scenario													
	Base	Base + 10% BMP		Base + 30% BMP		Base + 50% BMP		Buildout		2 x Buildout		2 x Buildout + 50% BMP		
Management Zone	(10^3 lbs. / year)	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	(10^3 lbs. / year)	% Δ from Base	% Δ from 2 x Buildout
1	51,669	50,822	-1.64%	49,126	-4.92%	47,430	-8.20%	52,090	0.81%	52,511	1.63%	47,952	-7.2%	-8.7%
2	101,395	100,772	-0.61%	99,526	-1.84%	98,280	-3.07%	101,639	0.24%	101,883	0.48%	98,597	-2.8%	-3.2%
3	5,184	5,091	-1.79%	4,906	-5.37%	4,720	-8.95%	5,250	1.26%	5,308	2.39%	4,808	-7.2%	-9.4%
4	15,386	15,178	-1.36%	14,303	-7.04%	13,429	-12.72%	15,802	2.70%	15,991	3.93%	13,675	-11.1%	-14.5%
5	5,724	5,648	-1.33%	5,496	-3.98%	5,344	-6.64%	5,752	0.49%	5,780	0.98%	5,387	-5.9%	-6.8%
6	5,852	5,717	-2.31%	5,447	-6.92%	5,177	-11.53%	5,904	0.88%	5,938	1.47%	5,246	-10.4%	-11.7%
Total	185,211	183,228	-1.07%	178,805	-3.46%	174,380	-5.85%	186,436	0.66%	187,411	1.19%	175,665	-5.2%	-6.3%

reductions were derived from the CTWM model scenario runs, and the reductions are calculated in the Loadings Tool when the delivery and total loads are considered.

Based on the CTWM scenario results shown in Tables 3 and 4, the following observations and conclusions are provided:

a. The statewide changes for the three BMP implementation scenarios appear to be relatively small, but become significant at the 50% implementation level, with NPS values ranging from 5% to 10 %, but the values for the individual Management Zones are higher, up to 20%; the Total reductions are less, ranging from 3% to 7%, due to point source contributions. However, it is important to realize that the BMPs in these scenarios were implemented ONLY on urban and agricultural lands; these two categories only represent a combined 30% of the entire land area. So a 50% implementation, on 30% of the area, with BMPs that are 35 % to 55 % effective (for selected constituents) produces state-wide reductions that are mostly less than 10%.

b. There are significant differences in NPS impacts between management zones, with Management Zones 3 and 6 showing higher reductions, especially for Phosphorus. Management Zone 3 includes the Quinnipiac, which is primarily point source dominated, and when the point sources are removed from the analysis the remaining nonpoint sources are derived primarily from the urban and agriculture. For example, for the Quinnipiac, more than 90 % of nonpoint sources of Phosphorus originates from these two categories, leading to the large changes seen in Table 3.

c. Note that the loadings for Management Zone 2 include the Fall-Line boundary condition loads for the Connecticut River at Thompsonville, representing delivered loads for Total N, Total P, and TOC of about 21,500; 1,400; and 76,700 tons/yr, respectively, to LIS. Without this component, the percent changes for Management Zone 2 would be significantly larger.

d. Phosphorus and Total Organic Carbon reductions are the highest, followed by Total Nitrogen, for the BMP implementation scenarios. This ordering for the NPS loads is likely the end result of the combined effects of the removal efficiencies, the loading rates, delivery processes, and sources.

e. The Buildout scenarios show that nonpoint loading effects of future urban growth are almost linear, i.e., the percent changes for the 2X Buildout are just about twice those of the Buildout scenario. The absolute values of these changes are small because the growth only affects the urban model segments (both pervious and impervious), which represent about 16 % of the total area.

f. Figure 4 shows the relationship between the percent reduction in both NPS and Total loads delivered to LIS and the percent BMP implementation, derived from the values in Tables 3 and 4. Based on the 10 %, 30%, and 50 % BMP implementation scenarios, the relationship is almost linear; as expected the NPS lines are considerably higher than the Total lines. It is interesting to note that the ordering of the lines changes between NPS and Total; the TP line is between the TOC and TN lines, but it is the lowest of the lines for the Total Loads; this reflects the larger relative contribution from point sources. This simple graph can be used to estimate impacts of alternative implementation levels for BMPs for urban lands and agriculture. Analogous relationships can be developed for individual Management Zones, and BMPs applied to other land use categories, as general planning level tools.

g. If higher levels of nonpoint source nutrient reductions are needed to meet TMDL or nitrogen control targets, the potential alternatives include:

1. increasing the percent of area treated (i.e. the BMP implementation level),
2. increasing the percent removal efficiencies, but this has physical and technological limits, or
3. expanding BMPs to other land uses, with forest lands being the obvious target.

Generalized Costs For BMP Implementation

Generalized costs estimates were developed for BMP implementation for each of the BMP scenarios, as required by the project contract. BMP costs vary considerably as a function of specific practices (structural and non-structural), site conditions, pollutant removal objectives, climate, and available information (e.g. mapping). Moreover, our approach for representing the BMP impacts with the CTWM relied on removal efficiencies that reflected 'typical' BMPs without specifying the specific BMP to be implemented. Thus, **the cost estimates provided herein should be considered appropriate only for generalized planning purposes at the state or management zone level.** The real costs are likely to vary by an order of magnitude or more from detailed costs to be obtained from site designs following detailed watershed assessments.

Unit cost estimates were developed, for both urban and agricultural land, as 'dollars per acre' so that the acreage treated by the various BMP implementation levels could be used to derive the desired planning estimates. Urban unit costs (annualized) were derived from information provided by the Center for Watershed Protection (CWP) (D. Caraco, 2001, personal communication). CWP calculated typical costs for urban and suburban retrofit BMPs, and new development BMPs. These costs included pre-design studies, design/contingency, construction, and maintenance costs, which were then annualized assuming a 25-year life and a 3% discount rate. Average annual unit costs for suburban retrofit, urban retrofit, and new development BMPs ranged from $288 to $1,255 per acre, with an average of $570. We used the average **$570 per acre** as the annual unit cost for urban areas treated with BMPs.

For agricultural areas, BMP costs are expected to be considerably less reflecting a range of practices from conservation tillage and nutrient management, which could be implemented with little or no additional costs, to expensive structural practices like grass waterways, terracing, and detention ponds. Novotny and Chesters (1981) provide estimated annual unit costs for selected agricultural BMPs with a cost range of $0 to $70 per acre (1978 basis), with an average of about $10 per acre. Inflating this value to the year 2000 by a factor of 2.5 (based on the Consumer Price Index) produces a unit cost of $25 per acre. We used this value of **$25 per acre** for agricultural areas treated with BMPs. These cost factors can be easily changed in the CTWM Loadings Tool so that users can assess the cost implications of alternative cost factors.

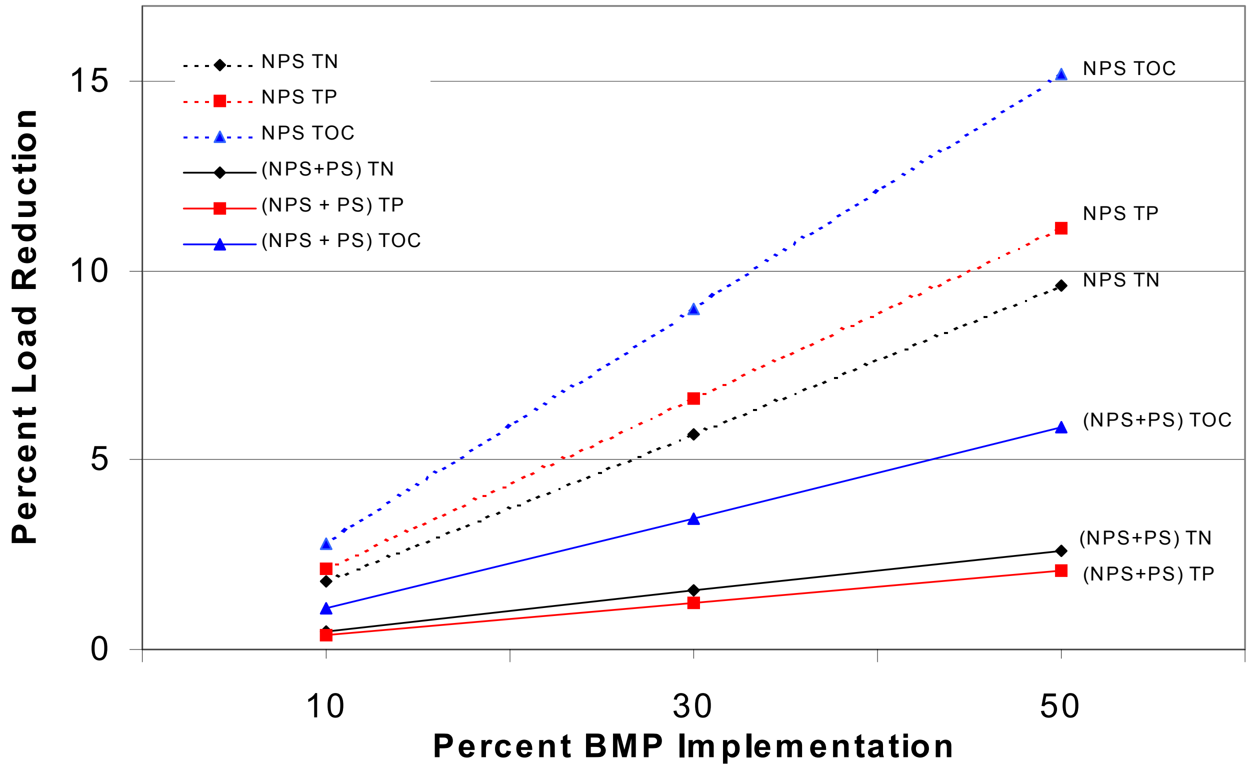

Figure 4. **Relationship Between Percent Reduction in Nonpoint Source (NPS) and Total Loads (NPS+PS) Delivered to LIS and Percent BMP Implementation on Urban and Agricultural Land**

Table 5 shows the annual costs for both agricultural and urban BMPs, along with the total, for each of the four scenarios involving BMP implementation. The urban costs are about 30 times more than the agricultural costs, with the total costs ranging from $31M to $156M for the three implementation levels with the Base Conditions. The '2X Buildout + 50% BMP' scenario shows increased costs to $177M reflecting the increase in urban land and a decrease in agriculture. As noted above, these cost estimates should be used only as generalized planning level values at the state or management zone level.

Table 5. **Generalized Annual Cost Estimates for BMP Implementation**

Landuse	Base + 10% BMP	Base + 30% BMP	Base + 50% BMP	2 x Buildout + 50%BMP
Agriculture	$ 1,192,000	$ 3,576,000	$ 5,959,000	$ 5,741,000
Urban	$ 30,117,000	$ 90,350,000	$ 150,583,000	$ 171,678,000
Total	$ 31,309,000	$ 93,926,000	$ 156,542,000	$ 177,419,000

CLOSURE

The CTWM was developed to allow quantification and evaluation of nutrient loads to LIS from the six management zones within the state of Connecticut, and provide a framework for evaluating potential impacts of future growth scenarios and BMPs. The CTWM was calibrated and validated to available flow and water quality data, and then used to assess alternative scenarios of growth and BMP implementation. Although the spatial detail of the CTWM is insufficient for BMP design, it can be used effectively for BMP screening and TMDL assessments at the subbasin level and for delivered loads to LIS.

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