Chapter 8: Combinations of Technologies

8.1 Introduction

Using the information from the initial technology analysis discussed in the previous chapters of this report, combinations of technologies were used to: 1) represent the future 2020 condition with implementation of Wis. Admin. Code Natural Resources 151 (NR 151) in urban areas, and 2) to develop and evaluate the screening alternatives, the preliminary alternatives and the draft recommended plan. Detailed analyses of these alternatives can be found in Chapter 8, *Common Package* and 9, *Alternative Analysis* of the *Facilities Plan Report* and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) Regional Water Quality Management Plan Update (RWQMPU).

This chapter provides an overview of the process used to assess multiple technology combinations. It illustrates tactics that were employed to assess multiple combinations of point source technologies and nonpoint source technologies.

Note: All costs in this chapter are escalated using the Engineering News Record Construction Cost Index (ENR-CCI), which was projected to be 10,000 in 2007.

8.2 Point Source Technology Analysis

8.2.1 Introduction

A detailed cost benefit analysis on individual technologies is performed in Chapter 3, *Point Source Technologies* of this report. Figure 8-1 shows the cost benefit curves developed for technologies that reduce sanitary sewer overflow (SSO) volume and Figure 8-2 shows the cost benefit curves for technologies that reduce combined sewer overflow (CSO) volume.

Using this information, combinations of the most cost effective technologies were analyzed to achieve cost effective approaches to different levels of overflow reduction. This analysis was used to develop the efficient technology combinations for the screening alternatives 1A, 1B, 1C and 1D (discussed in detail in Appendix 9A, *Screening Alternatives* of the *Facilities Plan Report*) and was ultimately used to determine the components of the preliminary alternatives B1, B1-MMSD Only and B2 (discussed in detail in Section 9.4 of Chapter 9, *Alternative Analysis* of the *Facilities Plan Report*). This work formed the basis for the Recommended Plan.

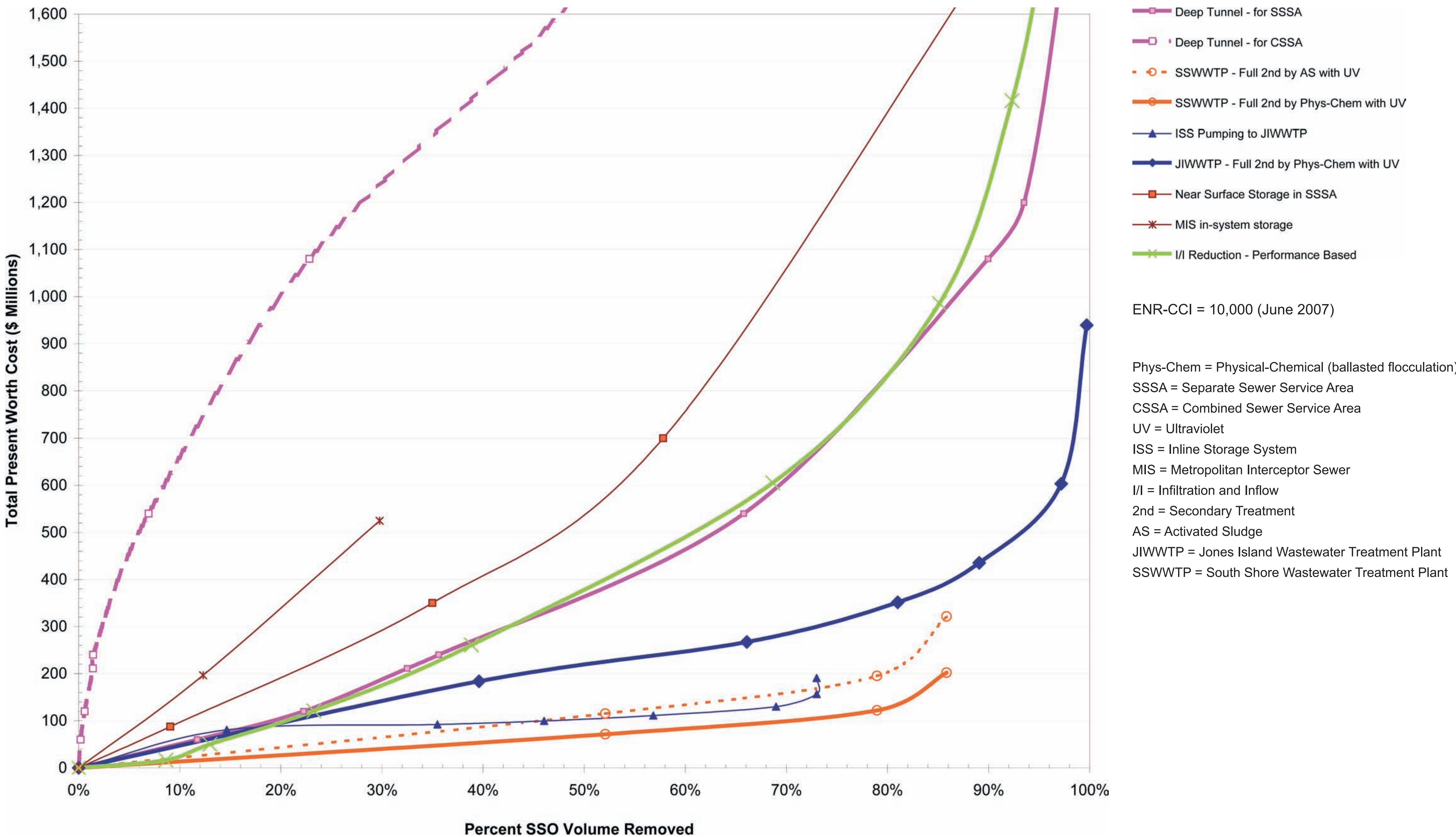

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FIGURE 8-1
SSO VOLUME COST BENEFIT CURVES
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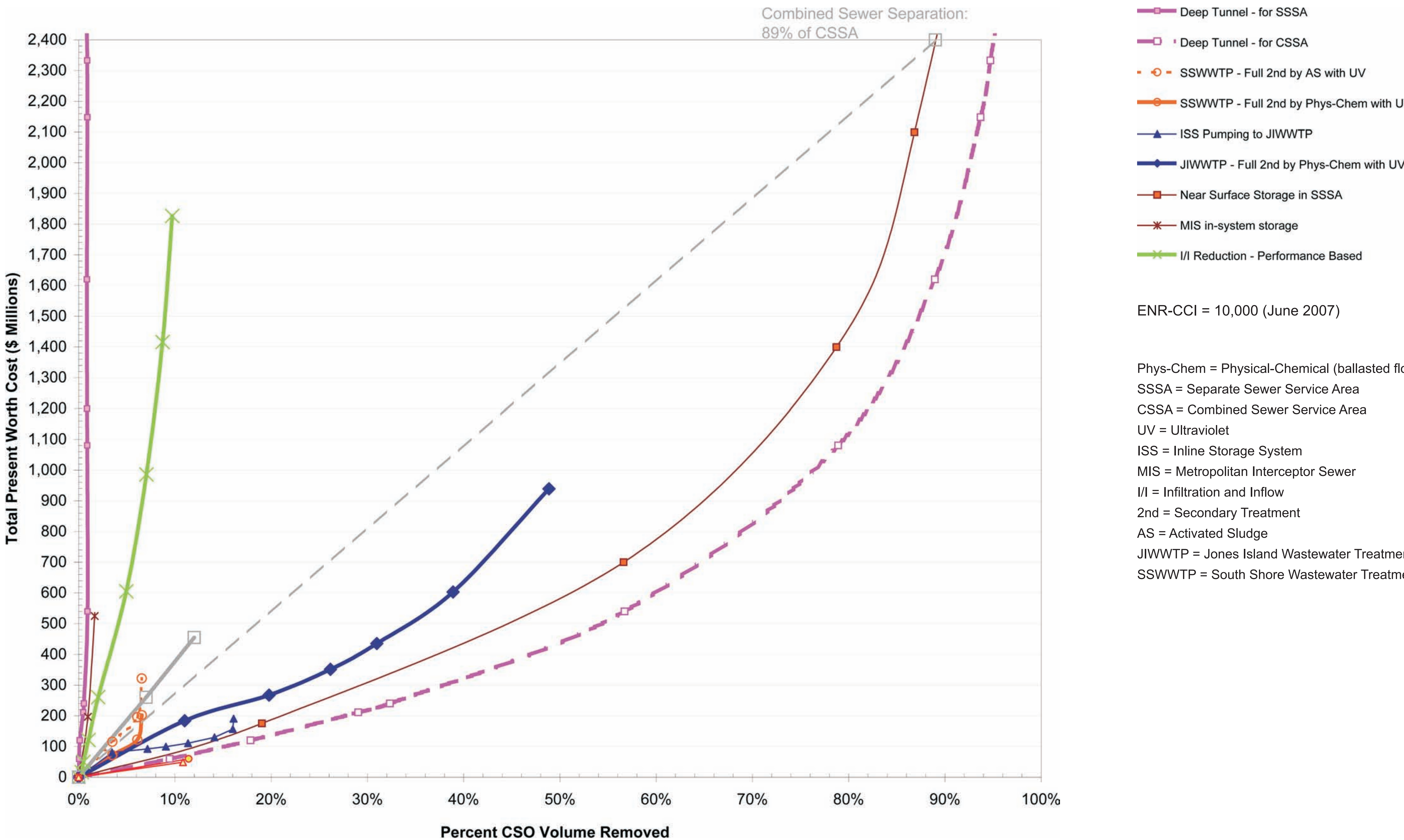

ENR-CCI = 10,000 (June 2007)

Phys-Chem = Physical-Chemical (ballasted flocculation)
SSSA = Separate Sewer Service Area
CSSA = Combined Sewer Service Area
UV = Ultraviolet
ISS = Inline Storage System
MIS = Metropolitan Interceptor Sewer
I/I = Infiltration and Inflow
2nd = Secondary Treatment
AS = Activated Sludge
JIWWTP = Jones Island Wastewater Treatment Plant
SSWWTP = South Shore Wastewater Treatment Plant

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FIGURE 8-2
CSO VOLUME COST BENEFIT CURVES
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8.2.2 Analysis Summary

Various combinations of technologies can be used to achieve the same outcome. Thus, system level combinations of technologies were developed. Additional preliminary and final design engineering will be required to develop the exact combination of technologies necessary to achieve these results. The analysis developed in this chapter presents planning-level costs for successful combinations of technologies that achieve the goals of each alternative.

The primary technological variables in this analysis are the treatment capacities of South Shore Wastewater Treatment Plant (SSWWTP) and Jones Island Wastewater Treatment Plant (JIWWTP), the storage volume of the inline storage system (ISS), and the ISS pumping capacities to each treatment plant. Other technologies described in this report, such as near surface storage, metropolitan interceptor sewer (MIS) in-system storage, roof top storage, and satellite treatment, were not implemented in these alternatives because of the higher cost or limited benefit of those technologies.

The term "elimination of overflows" in this report means the elimination of overflows in the model simulations using the 64.5 years of historical meteorological data. "Elimination of overflows" does not mean the configuration of technologies simulated in the models would be guaranteed to prevent all future overflows, as there is always a chance future conditions that lead to overflows, such as antecedent conditions and rainfall, could be worse than those simulated.

- Screening Alternative 1A assumes elimination of SSOs and CSOs through sewer separation of the combined sewer area to the maximum extent practicable and the implementation of other technologies as needed.
- Screening Alternative 1B eliminates both SSOs and CSOs using combinations of treatment and storage without combined sewer separation.
- Screening Alternative 1C uses treatment and storage to eliminate SSOs but not necessarily CSOs.
- Screening Alternative 1D eliminates SSOs by reducing infiltration and inflow (I/I). The assumptions for each alternative are listed in Table 8-1.

TABLE 8-1

SCREENING ALTERNATIVE COMPARISONS

	Overflows Eliminated		Technology		
Alternative	SSO	CSO	Treatment and Storage	Sewer Separation	Reduced I/I
1A	X	X	X	X	
1B	X	X	X		
1C	X		X		
1D	X				X

CSO = Combined Sewer Overflow
I/I = Infiltration and Inflow
SSO = Sanitary Sewer Overflow

Models

Several combinations of point source pollution control technologies were compared for each alternative goal. The method used to determine the most cost effective technology set was completed using graphical techniques that mimic the production theory linear programming techniques discussed in Appendix 1A, *Production Theory*. Graphical techniques were used to show cost benefit results (as illustrated in Figure 8-1 and 8-2 of this chapter), which identified those technologies that were most efficient in reducing SSOs or CSOs.

The performance of each combination was analyzed with the MACRO and Streamline-MOUSE models in order to determine the best combination(s) of technologies:

- *The MACRO model* is a simple volumetric model of the MMSD system that accounts for treatment at the wastewater treatment plants, storage in the ISS, and overflows (both CSOs and SSOs). The MACRO model results were used to roughly define the relative benefits of treatment, storage, and pumping over the 64.5-year period of record (January 1940 – June 2004).
- *The Streamline-MOUSE model* refines the analysis by simulating the routing in the MIS and the interactions between the processes that are sensitive to the timing of the event. The March 1960 event was used to define the system requirements to eliminate SSOs. The August 1986 event was used to define the maximum CSO conditions.

For example, Figure 8-3 shows several combinations of technologies that successfully end SSOs for the March 1960 event. In most combinations, the additional treatment capacity at SSWWTP is assumed equal to 185 million gallons per day (MGD) and the trade-off is between additional treatment at JIWWTP and additional storage volume. After roughly defining these combinations using the MACRO model, simulations were run in Streamline-MOUSE to refine the facility sizes, which are presented in Figure 8-3.

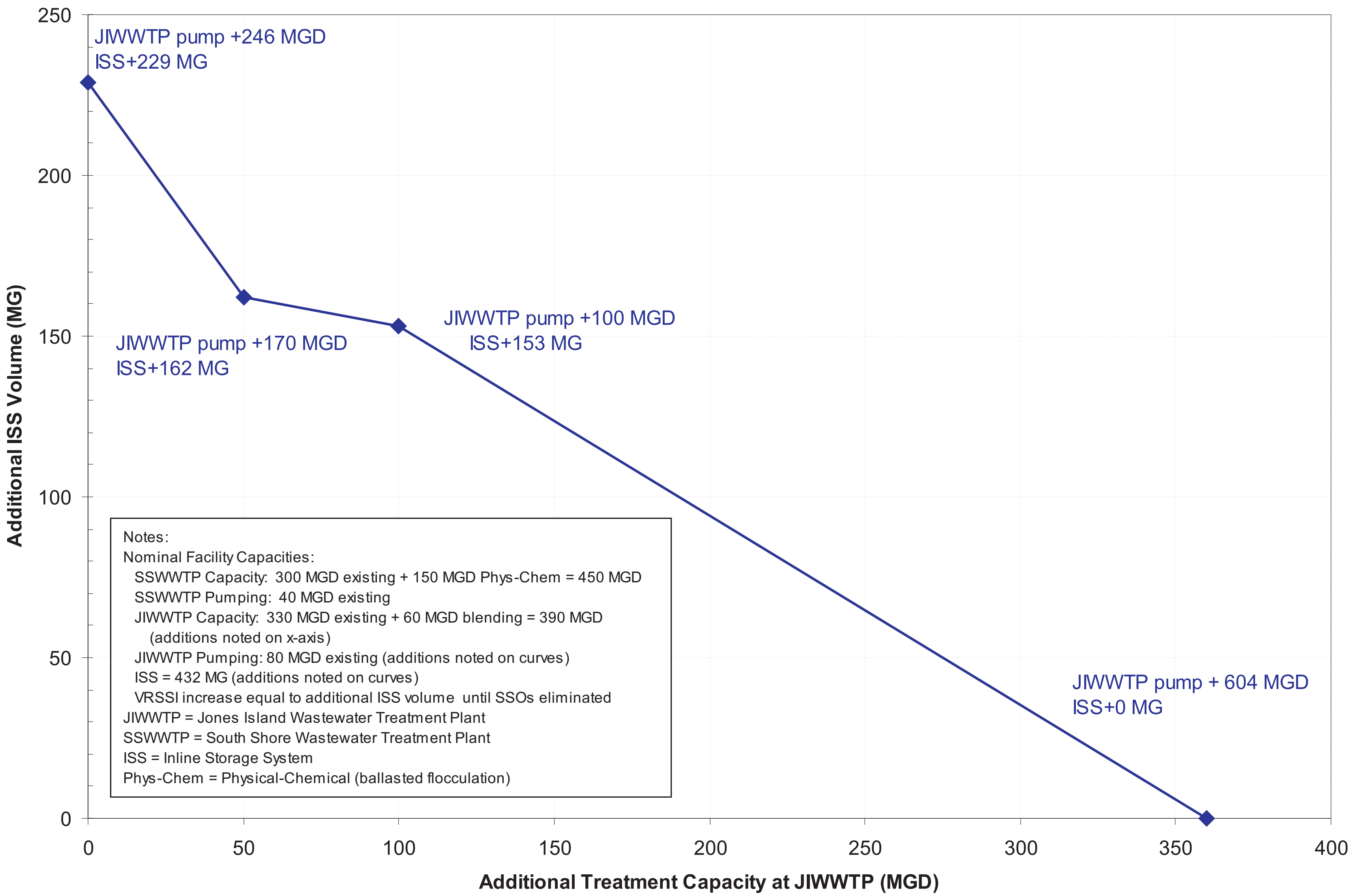

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FIGURE 8-3
SCREENING ALTERNATIVE 1C: TECHNOLOGY COMBINATIONS TO END SSOs
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MACRO Model: Initial Screening and Sensitivity Analysis

This model is a simple volumetric model of the MMSD system that accounts for treatment at the wastewater treatment plants, storage in the ISS, and overflows (both CSOs and SSOs). The model quickly simulates the 64.5-year period of record and tests the sensitivity of the overall system response to the key parameters of treatment capacities, ISS volume, pumping capacities, and operational conditions (such as the ISS volume reserved for separate sewer inflow, VRSSI).

The MACRO model is a screening tool; it was used in the State of the Art Report (SOAR) analysis to develop the production functions and test the relative sensitivity of the overall system response to various technologies. MACRO is not a detailed design tool. Therefore, the MACRO results were used as preliminary indicators of the performance and benefits of the various technologies.

The MACRO model runs indicated that substantial reductions in SSO volume could be achieved by providing additional treatment capacity at SSWWTP; this was also the most cost effective technology. An equal amount of additional treatment capacity at JIWWTP would provide similar reductions in SSOs, but at a higher cost due to additional pumping and the higher cost of land. SSOs could also be removed by additional storage volume in the ISS, but the cost would be higher than treatment at either plant.

To eliminate CSOs, additional storage volume in the ISS would be the most efficient and cost effective technology. This is because the combined sewer area produces intense flow rates during rainfall events. The ISS can accommodate high flow rates of short duration, far in excess of any reasonable treatment capacity. Additional treatment plant capacity, however, is complimentary to the additional storage. For events that are closely spaced, additional treatment plant capacity (along with pumping capacity) helps to dewater the ISS quickly, making more storage volume available for subsequent events that may follow.

Approximately 2,000 million gallons (MG) of additional storage would be required to contain the largest CSO event experienced during the 64.5-year period of record. The additional volume (and the cost) of full elimination of CSOs is very high (estimated at approximately $5 billion for 2,000 MG of storage -1,600 MG of additional storage and the 400 MGD of existing storage). A significant improvement in the simulated frequency of CSOs, however, could be achieved by storing a fraction of the volume required to fully eliminate the most extreme CSO event. The MACRO model continuously simulated the full period of record; therefore, the results reflect the benefits to be achieved over a wide range of hydrologic conditions. The MACRO model, however, lacks the ability to route the flows through the MIS. This is a particular problem when the treatment capacity at SSWWTP is increased. When the model does not limit the peak flow rate to SSWWTP to 300 MGD (that is, when the flow is only limited by the conveyance capacity of the MIS), the MACRO model results are not reliable and the Streamline-MOUSE model must be used to refine the analysis.

Alternative Analysis

It is critical to note that full elimination of SSOs or CSOs in this analysis only applies to the 64.5-year period of record. It is, of course, possible to experience conditions more extreme than those that occurred during this period of record; therefore, it is not possible to assert that a combination of technologies will fully eliminate overflows under all possible conditions. Also, extreme events are rare; therefore, a technology that would provide full elimination of overflows based on the period of record will rarely be used to its full capacity. The cost to eliminate the largest event in the period of record is typically very large.

The analysis of the screening alternatives started with Alternative 1C (SSO control) and progressed to Alternative 1B (CSO and SSO control). Then, Alternative 1A (combined sewer separation) was analyzed; the results are presented in that order. The analysis for Alternative 1D (I/I reduction) was not affected by the other three analyses. Brief summaries of the four analyses are provided below. Detailed descriptions of the analyses are provided in Appendix 9A, *Screening Alternatives* of the *Facilities Plan Report*.

Summary of Alternative 1C - Elimination of Sanitary Sewer Overflows

The goal of Alternative 1C is to eliminate SSOs. Various combinations of treatment and storage were tested in the MACRO program to determine which ones were able to eliminate SSOs and estimate the long term benefit and cost of each. Additional simulations using the Streamline-MOUSE model refined the definition of the capacities and volume needed to achieve the goals of the alternative. Several combinations were simulated in Streamline-MOUSE; these results are compared by cost.

Alternative 1C can be achieved using a combination of treatment and storage. Figure 8-4 shows the cost of various Alternative 1C combinations that achieve the goal of full SSO elimination. The most cost effective combination of technologies to eliminate SSOs is the following:

- 185 MGD of additional treatment at SSWWTP
- 100 MGD of additional treatment at JIWWTP
- 100 MGD of additional pumping from the ISS to JIWWTP
- 153 MG of additional ISS storage

Other combinations were also simulated; the additional facilities needed for each combination are noted on Figure 8-4 beside each data point; these capacities are in addition to the nominal capacities that are noted on the figure. The cost to end SSOs is approximately the same for all of the combinations of technologies, with a range of $1,200 to $1,400 million. The combination that used a forcemain to South Shore was also evaluated; because of the high cost ($1,800 million) this technology was not considered further.

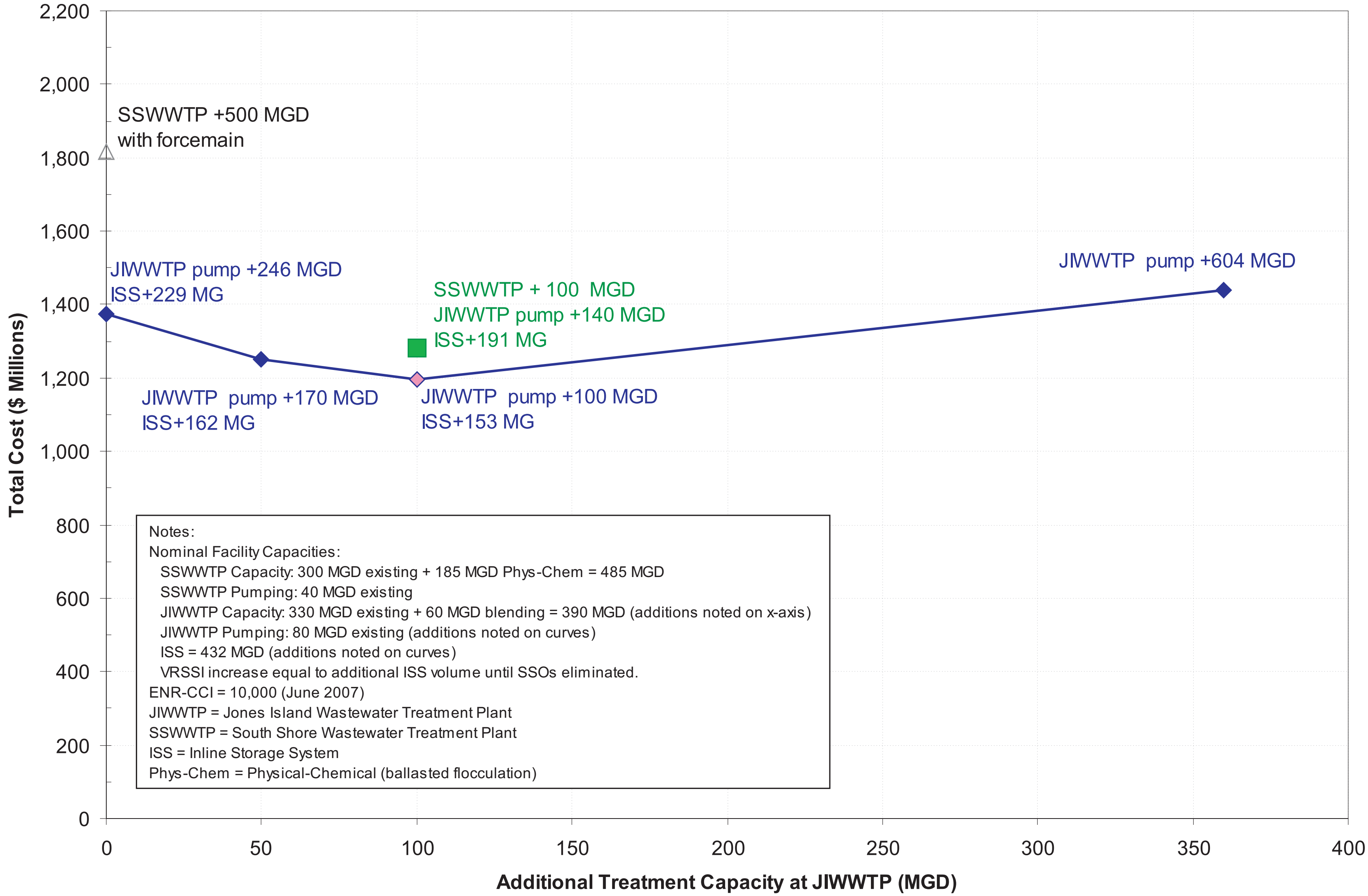

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FIGURE 8-4
SCREENING ALTERNATIVE 1C: COSTS TO END SSOs
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Summary of Alternative 1B - Elimination of Sanitary Sewer Overflows and Combined Sewer Overflows Using Conveyance, Storage and Treatment Technologies

The goal of Alternative 1B is to eliminate both SSOs and CSOs. To achieve this goal, the Alternative 1B simulations used combinations of treatment, storage, and pumping. Alternative 1B simulations consider that SSOs would first be eliminated by applying the technologies in Alternative 1C, and then additional ISS storage capacity would be provided to eliminate CSOs.

Alternative 1C was used as the starting point for the Alternative 1B simulation because SSOs must be eliminated before CSOs can be addressed. The most cost effective technology for CSO control is ISS storage. Additional treatment at JIWWTP is also effective to partially reduce CSOs, but treatment at SSWWTP is not effective.

Figure 8-5 shows the cost for various technology combinations that satisfy the Alternative 1B goals. All of the cases assumed that the treatment capacity at SSWWTP is equal to the conveyance capacity of the MIS (485 MGD). The additional ISS storage is in the range of 1,500 to 1,700 MG depending on the additional treatment capacity at JIWWTP. The most cost effective configuration is 100 MGD of additional capacity at JIWWTP and approximately 1,600 MG of additional storage. The cost for Alternative 1B is relatively flat for all combinations and is in the range of $4,700 to $5,000 million, which is approximately four times the cost of eliminating the SSOs in Alternative 1C.

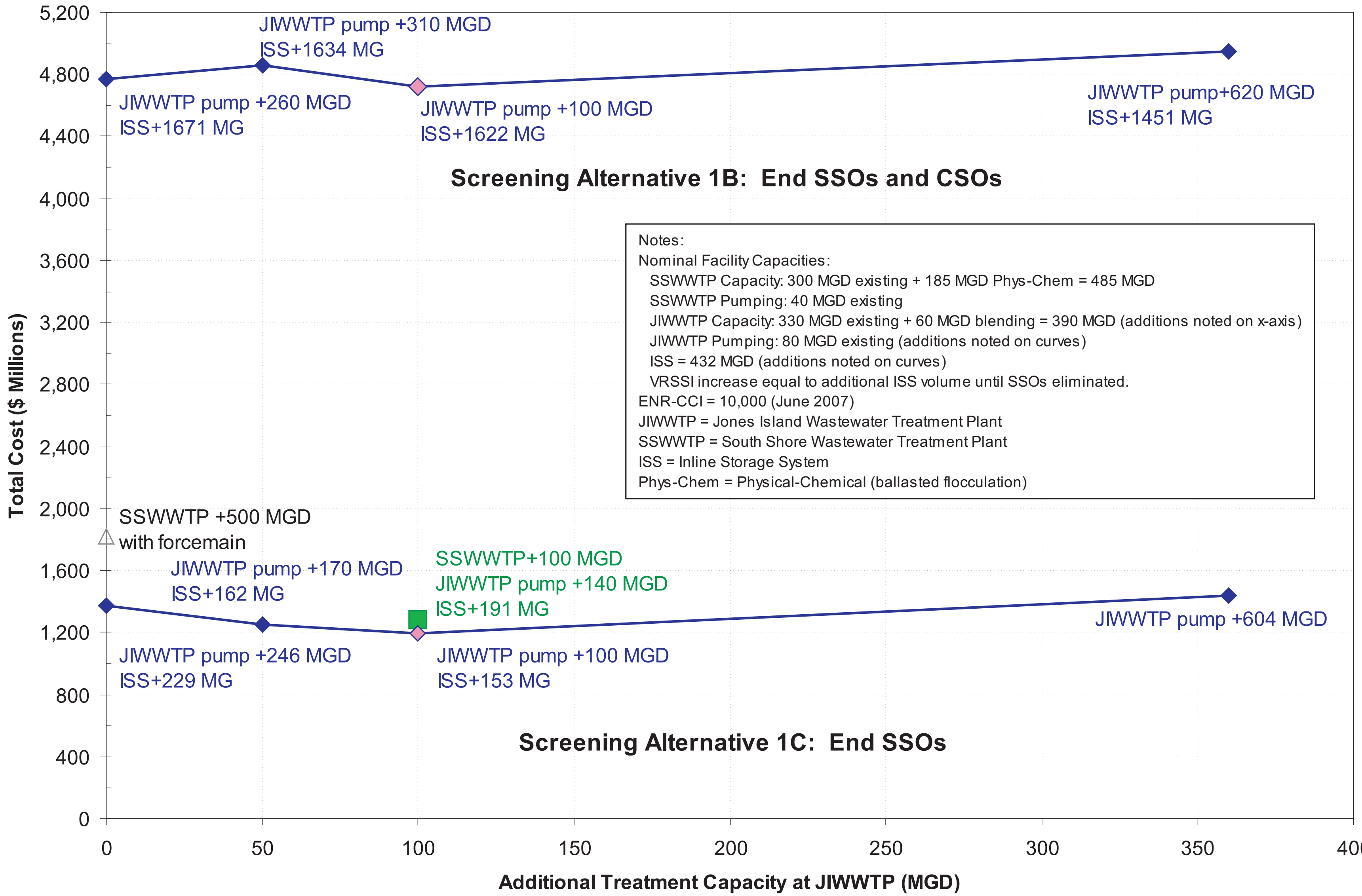

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FIGURE 8-5

SCREENING ALTERNATIVE 1B: COSTS TO END SSOs AND CSOs AND SCREENING ALTERNATIVE 1C: COSTS TO END SSOs

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Summary of Alternative 1D - Infiltration and Inflow Reduction to Eliminate Sanitary Sewer Overflows

The elimination of SSOs using I/I reduction technologies is a two-step process: first eliminate quickly peaking sources that exhibit the characteristics of inflow sources and then address the I/I in priority sewersheds with exceptionally high wet weather flows. The analysis evaluated the benefits of progressive levels of greater reduction. Initial reduction levels focused on sewersheds with high I/I rates. Further levels of reduction would require rehabilitation in greater areas of the separate sewer area.

To achieve zero SSO over the 64.5-year simulation period, I/I reduction efforts would need to reduce I/I in all sewersheds to less than 2,000 gallons per acre per day for the 5-year peak hour flow. The total present worth cost for this reduction is approximately $6,000 million. Achieving such an aggressive goal would require I/I reduction in virtually all sewersheds in the separate sewer area and extensive work on private property sources.

Summary of Screening Alternative 1A – Elimination of Combined Sewer Overflows and Sanitary Sewer Overflows Using Combined Sewer Separation and Conveyance, Storage and Treatment Technologies

Alternative 1A represents less sewer separation, assuming that only the combined area outside of the central business district would be separated. The maximum feasible separation of the combined sewer area represents 89% of the area, leaving the remaining 11% combined. After revising the model accordingly, the SSOs and remaining CSOs were eliminated using combinations of treatment, storage, and pumping. The model assumes capture of the "first flush" of the stormwater from the newly separated areas, with the excess stormwater discharged to waterways.

The cost for this separation plan assumes that the existing combined sewer conveyance system would be used as the stormwater collection system. A new separate sewer system would be built to convey the sanitary flow. The separation assumes that all existing laterals would be connected to the new sanitary system (this includes laterals that connect to foundation drains). It assumes that roof drain downspouts will be disconnected from the collection system. The cost does not include any private property work. The approximate cost for combined sewer separation is $2,400 million, along with additional costs of approximately $1,400 million for the additional storage, treatment and pumping needed to eliminate CSOs and SSOs. Therefore the total present worth cost for this alternative is approximately $3,800 million.

Summary

Table 8-2 summarizes the technology combinations and the costs of each alternative. To fully eliminate CSOs and SSOs, Alternative 1A ($3,800 million) is approximately $900 million less than Alternative 1B ($4,700 million). However, the risks and uncertainties of combined sewer separation are greater. The private property costs are not included in the Alternative 1A cost. A very rough estimate of private property costs (using 50,000 homes at $5,000 per home) for new gutters and downspouts are $250 million. There are likely to be other private property costs, such as replacement of deteriorated laterals that can not be connected to the new sanitary sewer. Furthermore, the performance of a new system is uncertain; in particular, the I/I rates in the new system cannot be predicted with confidence.

TABLE 8-2
SUMMARY OF ALTERNATIVE RESULTS AND COSTS

Alternative	Goals	Approach	Additional Treatment Capacity at SSWWTP (MGD)	Additional Treatment and Pumping Capacity at JIWWTP (MGD)	Additional ISS Storage Volume (MG)	Cost ($ M)
1A	no SSOs / CSOs	Combined Sewer Separation, Treatment and Storage (89% of area)	200	100	234	$3,800
1B	no SSOs / CSOs	Treatment and Storage	185	100	1,622	4,700
1C	no SSOs	Treatment and Storage	185	100	153	1,200
1D	no SSOs	I/I reduction (2000 gpad max)	0	0	0	6,000

CSOs = Combined Sewer Overflows
JIWWTP = Jones Island Wastewater Treatment Plant
SSWWTP = South Shore Wastewater Treatment Plant
ISS = Inline Storage System
SSOs = Separate Sewer Overflows
gpad = gallons per acre per day

Notes:
Alternative 1A: In addition to CS separation, additional facilities are required to end overflows
South Shore PCI = 200 MGD, Jones Island PCI = 100 MGD, Additional ISS Pumping to Jones Island = 100 MGD
Additional ISS storage volume = 160 MG

All costs are escalated using the Engineering News Record Construction Cost Index (ENR-CCI), which was projected to be 10,000 in 2007.

While the cost of Alternative 1B is higher than Alternative 1A, it employs technologies (deep tunnel storage and additional treatment) which have more certain costs and outcomes than sewer separation (see Appendix 3A). In addition, it is possible to substantially reduce the Alternative 1B costs by allowing for infrequent overflows (instead of total CSO elimination). In contrast, Alternative 1A has a large fixed cost for the combined sewer separation and it does not give freedom to define a reasonable level of service to moderate the high costs.

Alternative 1A removes CSOs but, because it separates the sanitary and storm sewers, it creates new stormwater discharges. In effect, the CSOs are not actually eliminated, but rather converted into “stormwater overflows”. Thus, Alternative 1B is the only alternative that eliminates CSOs. Two alternatives were proposed to eliminate all SSOs. Alternative 1C (using a combination of treatment and storage) eliminates SSOs for a cost of $1,200 – $1,400 million. Alternative 1D, using I/I reduction, eliminates SSOs at a cost approximately four times more than Alternative 1C.

These analysis results show the extremely high costs of eliminating all CSOs. The most suitable technology for achieving such a high level of control over CSOs is additional ISS storage. The costs for these alternatives are very high because the goals are extreme - full elimination of overflows for the largest events during the period of record. The level of service that is eventually selected should be guided by the water quality impact of overflows caused by infrequent events.

8.3 Nonpoint Source Technology Analysis

8.3.1 Introduction

The analysis of nonpoint technologies employed different techniques from those used for the point source analysis. The nonpoint analysis started with the list of technologies identified in Chapter 4, *Summary of Nonpoint Source Technology Analysis*. This large number of potential technologies was further refined based on cost-effectiveness and guidance from the Wisconsin Department of Natural Resources (WDNR). The resulting alternatives combine a set of cost-effective techniques with differing implementation strategies. The benefits from each alternative were compared to the relative strengths of the different implementation strategies in order to determine the most effective technology combinations. The steps conducted for this analysis were the following:

- Determine combinations of technologies to:
    - represent the future 2020 condition with NR 151 implementation in urban areas
    - address the goals and objectives for screening alternative 2
    - address the goals and objectives for preliminary alternatives B1, B2, C1 and C2
- Within the Loading Simulation Program in C++ (LSPC) model, represent pollutant reductions corresponding to the combination of technologies and level of implementation selected for each alternative production run
- Run the LSPC model in a full production run (a ten year water quality simulation)
- Use the combination of the LSPC output and the lake/estuary direct discharge as input to the ECOM-RCA model for a production run
- Evaluate the pollutant reductions and associated changes in water quality indicators for each run

Using the water quality indicators discussed in Chapter 2, *Technology/Indicator Analysis*, combinations of technologies that improved most of the water quality indicators were identified.[a]

However, reducing modeled fecal coliform levels presented challenges. Some of these were due to the dynamics involved with fecal coliform, such as die-off and decay rates. Another challenge was the large magnitude of the nonpoint source contributions. In addition, WDNR guidance suggested that NR 151 implementation would provide relatively modest fecal coliform reduction (see Appendix 8B, *NR 151 Implementation Description* of the *Facilities Plan Report*). Additional analysis and optimization of the combination of nonpoint technologies was required to maximize fecal reduction in the model. This process also allowed for the optimization of the technologies that address nutrients and TSS.

[a] See Chapter 2, *Technology/Indicator Analysis* for a description of water quality indicators.

To aid in the optimization of technology implementation, two sensitivity analyses were conducted using the LSPC model – one focusing on an urban land area and one on a rural land area. These sensitivity analyses are discussed below.

8.3.2 Urban Land Use Sensitivity Analysis

To help determine the most effective way to reduce fecal coliform and other pollutant loads from urban sources within the context of the water quality model, a sensitivity analyses was performed on Underwood Creek – a subwatershed of the Menomonee River watershed. This subwatershed was chosen because it is an urban area that does not have CSOs.

Alternative model runs were performed to see how various reduction technologies would impact fecal coliform, TSS, phosphorous and nitrogen loads as well as fecal coliform concentrations. The following technologies were analyzed in these alternatives:

- rain barrels
- rain gardens
- additional infiltration practices
- TSS reduction practices
- disinfection units (DUs)

The sensitivity analysis for Underwood Creek showed that modeled fecal coliform loads are dominated by sources associated with impervious surfaces. Modeled loads from pervious areas and instream processes are significantly lower. In total, existing loads are far above the levels needed to meet water quality targets. One conclusion is that large reductions in impervious surface loads would be required to achieve a significant increase in the number of days during which the fecal coliform concentration criterion is met.

One criterion, the 30-day geometric mean, was found to be particularly sensitive to coliform loads during non-storm conditions (which include sources such as cross connections). It is reasonable to assume that non-storm loads can be reduced through a program of improved sewer system maintenance and illicit connection removal.

The results of the Underwood Creek sensitivity analysis suggest that the greatest potential for reducing coliform loading and concentrations arises from a combination of controls to reduce runoff from urban impervious areas and subsurface discharges (which incorporate potential illicit discharges). Targeted application of DUs is one way to achieve a significant load reduction, yet their ability to achieve the water quality goals is limited by two factors: they can only be deployed in a limited number of locations due to cost, and they can only treat the portion of stormwater that goes through an organized conveyance system to a point of discharge. This analysis indicates that it would be extremely difficult to attain a criterion of 200 colony forming units per 100 milliliter (ml) in urban streams.

A detailed description of this sensitivity analysis is provided in Appendix 8A, *Sensitivity Analysis of Urban BMPs – Underwood Creek* of this chapter.

8.3.3 Rural Sensitivity Analysis

To reduce pollutant loads from rural areas within the context of the water quality model, a series of sensitivity analyses were conducted using the model of the West Branch of the Root River Canal (WBRRC). The following management methods were analyzed:

- Manure and livestock management programs
- Increased riparian buffer width
- Conversion of crop land to wetlands and prairies

The WBRRC was selected for the rural area sensitivity analysis due to the high percentage of rural land use/land cover, the relative lack of riparian buffers, and the lack of upstream drainage in this subwatershed. To locate the WBRRC subwatershed, see Map IX–1 in Chapter IX, *Surface Water Quality Conditions and Sources of Pollution in the Root River Watershed*, of SEWRPC's *Technical Report No. 39, Water Quality Conditions and Sources of Pollution in the Greater Milwaukee Watersheds*.

The analysis showed that modeled fecal coliform loads are dominated by sources associated with impervious surfaces; agricultural load sources are relatively less important. The model was then run without impervious areas to focus on the relative importance of rural management measures. The manure management strategy provided the greatest reduction in modeled fecal coliform concentrations from rural areas, cutting the number of days over the 400 #/100ml standard in half and reducing the average concentration enough for the geomean[b] standard to be met at all times.

The analysis also indicated that converting cropland to forest or wetland areas in the WBRRC has a similar impact to pollutant loads as buffer enhancements, providing significant nutrient reductions roughly equivalent to the percent of the watershed converted to forest or wetlands.

A detailed description of this sensitivity analysis is provided in Appendix 8B, *Sensitivity Analysis of Rural BMPs – West Branch Root River Canal* of this report.

[b] The geometric mean is a measure of central tendency. It is different than the traditional (arithmetic) mean because it uses multiplication rather than addition to summarize data values.

APPENDIX 8A

SENSITIVITY ANALYSIS OF URBAN BEST MANAGEMENT PRACTICES – UNDERWOOD CREEK

2020 Facility Planning Project

Draft Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P2000
Document Name:	Sensitivity Analysis of Urban BMPs – Underwood Creek	HNTB Charge No:	34568-PL-400-115

Date: September 28, 2006

To: Michael Hahn, SEWRPC

Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech, Inc.

Subject: Sensitivity Analysis of Urban BMPs – Underwood Creek (revised)

EXECUTIVE SUMMARY

Reduction of fecal coliform concentrations and loads is a key goal for the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU). To help guide the effort to maximize effectiveness in controlling coliform loads it is useful to perform some sensitivity analyses. This memorandum begins the process, working with the Underwood Creek watershed. This is an urban area within the Menomonee River drainage that does not have CSOs.

The sensitivity analysis for Underwood Creek shows that fecal coliform load predictions are dominated by upland loads from impervious surfaces in the current model configuration. Loads from pervious areas and instream processes have a relatively lesser importance. This is consistent with the understanding that impervious areas are the dominant pathway for accumulation and delivery of pollutants from urban areas. Existing loads are far above the levels needed to meet water quality targets. Therefore, a significant reduction in the number of days during which the fecal coliform concentration criterion is exceeded will not be attained unless large reductions in impervious surface loads are simulated.

Options that show the greatest potential for reducing coliform loading/counts include controls applied to runoff from urban impervious areas and subsurface discharges (which incorporate potential illicit discharges). Disinfection units (DUs) are one way to achieve a significant load reduction, yet their ability to achieve goals is limited by two factors: they can only be deployed in a limited number of locations due to cost, and they can only treat the portion of stormwater that goes through an organized conveyance system to a point of discharge (currently assumed to be 50 percent of the impervious area in a treated subbasin). The use of the DUs is recommended for targeted reduction of loading after all other options have been considered. Indeed, even with all reasonable options considered in the model, attaining a criterion of 200 per 100 ml is extremely difficult in many urban streams and is the reason other urban watersheds have explored site-specific criteria or Use Attainability Analyses.

CONCLUSIONS

The sensitivity analysis for Underwood Creek shows that fecal coliform load predictions are dominated by upland loads from impervious surfaces in the current model prediction, and that instream processes have a relatively smaller importance at the scale of the test watershed. Average concentrations also respond to loads; however, the specification of subsurface loading rates becomes an important component in the prediction of dry weather concentrations and thus 30-day geometric means.

While the sensitivity analysis demonstrated substantial reductions in loads, frequency metrics relative to criteria are relatively insensitive to changes in loads. This occurs primarily because concentrations during washoff events are orders of magnitude greater than the criteria, and very large reductions would be needed to obtain a significant change in the number of days exceeding the criteria. Indeed, attaining a criterion of 200 per 100 ml is extremely difficult in many urban streams and is the reason other urban watersheds have explored site-specific criteria or Use Attainability Analyses.

The 30-day geometric mean criterion is sensitive to subsurface coliform loads (which also include other loads that are independent of surface hydrology). It is reasonable to assume that these loads can be reduced through a program of improved sewer system maintenance and illicit connection removal.

Movement in the other concentration metrics will not be attained unless much larger reductions in impervious surface loads are simulated. DUs are one way to achieve a large load reduction, yet their ability to achieve goals is limited by two factors: they can only be deployed in a limited number of locations due to cost, and they can only treat the portion of stormwater that goes through an organized conveyance system to a point of discharge (currently assumed to be 50 percent of the impervious area in a treated subbasin).

Based on the results in Section 0, the simulated performance of DUs can be improved. Specifically, we recommend the following:

1. DUs should be simulated with a 3-log reduction as this is more technically accurate and leads to a slight increase in performance.
2. It is not necessary to simulate coliform as a decaying constituent within the DUs.
3. A significant increase in performance is obtained by removing the cut on point. This suggests that use of a lower cut on would be advantageous, although the operational cost would increase.

While the application of DUs will result in greater reduction in coliform loads, they will need to be deployed in combination with significant reductions from surface and subsurface loads to be effective.

RECOMMENDATIONS

Results of the smaller scale analysis show that controls will need to combine impervious area controls, sub-surface reductions (through potential removal of illicit discharges), management of pervious land, and targeted application of DUs. We recommend that the Planning Team discuss this memo to determine the most appropriate next steps.

INTRODUCTION

Reduction of fecal coliform concentrations and loads is a key goal for the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU). In some cases model scenarios conducted thus far have not yielded the degree of reduction necessary to meet goals. To help guide the effort to maximize effectiveness in controlling coliform loads it is useful to perform some sensitivity analyses. This memorandum summarizes the results for an urban subwatershed; a separate memorandum addresses key factors in a rural subwatershed. The ultimate intention is to provide an informed basis for representing control measures and selecting and placing BMPs, such as stormwater disinfection units (DUs), to obtain the maximum reduction in criterion violations.

For the purpose of the urban sensitivity analysis we are working with the Underwood Creek watershed. This is an urban area within the Menomonee River drainage that does not have CSOs. Working with only Underwood Creek provides a smaller, more manageable modeling area that is more amenable to sensitivity analysis than the full Menomonee River model.

SOURCES OF COLIFORM LOAD

It is first important to understand where the fecal coliform load originates within the model. Obviously, there is an advantage in focusing on reductions from areas that contribute the largest loads. Figure 1 shows percentage contributions by land area to total external fecal coliform load to Underwood Creek. The summary is for the Alternative 1. Under this alternative, significant amounts of the runoff from impervious areas from ***new*** developed areas are treated by infiltration or extended detention BMPs, reducing coliform loads. A lesser amount of reduction is obtained from existing land uses as a result of NR151 objectives to reduce sediment delivery from such areas.

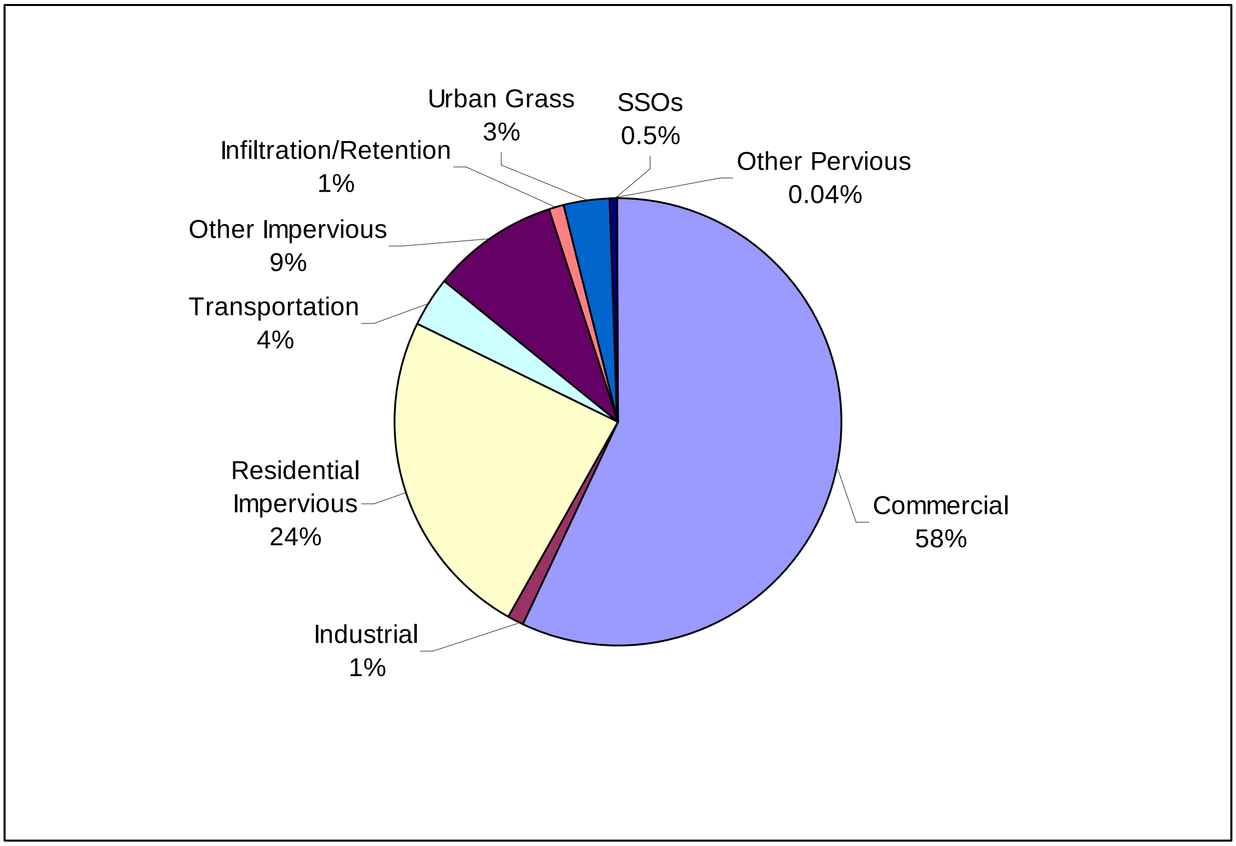

Figure 1. Sources of Fecal Coliform Load to Underwood Creek

Under Alternative 1, the coliform loading is dominated by the impervious runoff from commercial and residential land uses. These are primarily the loads from existing land in those categories. For new residential and commercial land, 70 percent of the impervious runoff is directed to retention or infiltration BMPs. Pervious area contributions are minor. Similar ratios are seen in other watersheds in the Menomonee River. Commercial impervious surfaces account for 40 to 50 percent of the load, and residential impervious surfaces account for 16 to 33 percent of the load.

Loading rates by land use are shown in Figure 2. The impervious loading rates are about two orders of magnitude greater than those from pervious land. Residential impervious surfaces actually have a higher loading rate per acre than commercial land; however, commercial tends to dominate the total load because the percent imperviousness within commercial areas is much higher than in residential areas. It seems obvious that achieving significant reductions in the total fecal coliform loads to Underwood Creek will require additional reductions in loading from existing commercial and residential impervious surfaces.

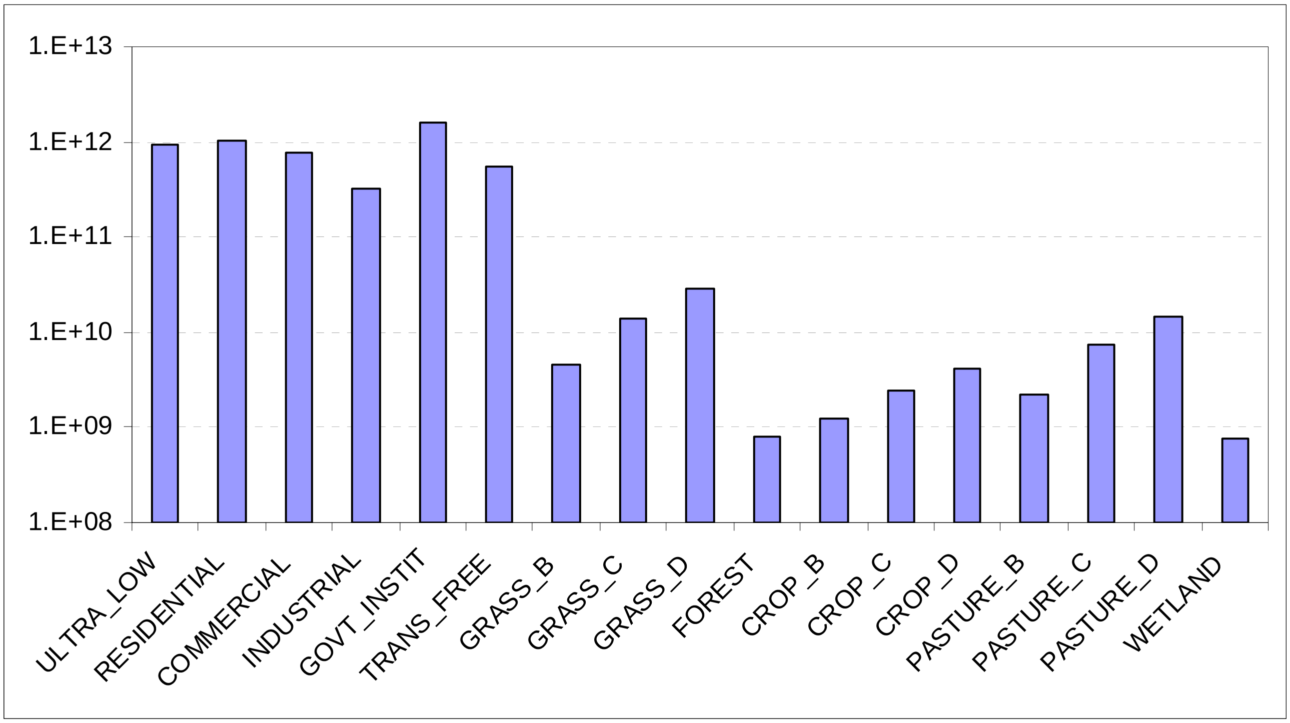

Figure 2. Fecal Coliform Loading Rates (#/ac-yr) for Underwood Creek.

SENSITIVITY ANALYSIS FOR ANNUAL LOADS

Predicted coliform loads at the mouth of Underwood Creek arise from a combination of upland loading rates and instream processes. Sensitivity analyses for loads were undertaken using the Alternative 10 model (old future land use with stormwater disinfection units (DUs) treating impervious runoff in three sub-basins.)

Fecal coliform in the stream is simulated as a general quality constituent that is subject to decay (die-off), and can sorb to sediment in the water column, deposit to the stream bed, and re-release from the stream bed back into the water column. Three decay rates are specified in the model: decay of dissolved/suspended coliform in the water column (FSTDEC), decay of coliform sorbed to particulate matter in the water column (KSUSP), and decay in the sediment bed (KBED). The magnitude of decay rates declines from FSTDEC to KBED. FSTDEC is highest because ultraviolet radiation is a major contributor to bacterial die-off; KBED is lowest because hypoxic conditions in sediment protect bacteria and can even encourage regrowth.

Sensitivity of annual load predictions to a ±25 percent change in each of these decay parameters is summarized in Table 1. An increase in any decay parameter leads to a decline in the transmitted load. Sensitivity of loads to these parameters is greatest for FSTDEC, but in every case is rather small – meaning that we do not need to be unduly worried about exact parameter values, at least in respect to loads.

Table 1. Response of Loads to 25 % Change in Decay Parameters

Parameter	+ 25%	- 25%
FSTDEC	-1.29%	+ 1.35%
KSUSP	-0.19%	+ 0.20%
KBED	-0.01%	+ 0.01%

Changing the KBED decay rate has only a small effect on total load delivery in Underwood Creek. Simulation of coliform as sediment-associated does have an important effect on concentrations (because it causes post-event concentrations to be higher in accordance with observations). It also does have an effect on the total load, even though not sensitive to the exact value of KBED, because residence times in the sediment can be large. If sediment sorption of coliform is turned off in the model, the total coliform load delivery increases by 28.2 percent.

Because of coliform die-off, model predictions should be sensitive to location of coliform load inputs. Loads that have a long time of travel to an evaluation point should have a smaller impact than loads released nearby. This has potential implications for the optimal siting of BMPs such as DUs. To investigate this effect on loads, we added a constant point source (with magnitude $4 \cdot 10^9$ or $4 \cdot 10^{10}$ organisms per hour) at three locations in the stream network and examined the effects on load at the mouth of Underwood Creek. The locations were headwater (Reach 85), middle (Reach 892) and downstream (Reach 905). The effects on the annual load at the mouth (Reach 905) are shown in Table 2.

Table 2. Response of Loads to Added Source Location

Location	Response to Load of $4 \cdot 10^9$ hr^{-1}	Response to Load of $4 \cdot 10^{10}$ hr^{-1}
Headwater	1.63%	+ 16.26%
Middle	2.12%	+ 21.09%
Downstream	2.21%	+ 22.04%

As expected, a source nearer the evaluation point has a greater effect on load. However, the difference between a release at the headwater and downstream is relatively small – indicating that the load results should not be that sensitive to where a DU is placed within a subwatershed. (The relative difference will be greater over longer scales; for instance a DU placed in the downstream portion of the Menomonee would have a much greater impact on reducing loads at the downstream end of the river than a DU applied to similar loads in the upper reaches of the Little Menomonee.)

The key determinant of the delivered load would thus appear to be the source loading, not the instream processes. As already shown above (Figure 1), the majority of the coliform load is derived from commercial and residential impervious surfaces. Table 3 shows the response of loads at the mouth of Underwood Creek to reductions of 25 percent in rates of loading from pervious surfaces, loading via subsurface flow (baseflow loading), and loading from impervious surfaces, respectively. As expected, the loading predictions are most sensitive to reductions in impervious surface loads, with a 25 percent reduction in loading rate leading to a 14.5 percent reduction in total delivered load. In contrast, reductions in loads from pervious surfaces and via subsurface pathways have very little effect on the total load delivery. Impacts on concentrations may, however, be different, as is examined in the next section.

Table 3. Response of Loads to Source Reduction of 25 Percent

Source Reduction	Response
Pervious	-0.80%
Subsurface (Baseflow)	-0.06%
Impervious	-14.50%
Impervious plus Subsurface	-14.56%

SENSITIVITY ANALYSIS FOR CONCENTRATION MEASURES

Determining the sensitivity of total loads is relatively straightforward. However, the primary metrics used to evaluate scenarios are based not on loads but on concentrations – and in particular on the frequency of concentrations greater than various regulatory standards. Measures used include the number of days with maximum concentration greater than 400 per 100 ml (for both full year and recreation season), and the number of days with rolling 30-day geometric mean greater than 200 per 100 ml (again for both full year and recreation season). The response of concentrations is more complex than loads, because concentration depends on the interaction of loads, dilution capacity, and the timing of loading events. Frequency measures introduce another phenomenon, as such measures may not be sensitive to changes in loads if the resulting concentration is smaller, but still above the water quality criterion.

Table 4 examines the sensitivity of concentrations at the mouth to the addition of a constant source at a rate of $4 \cdot 10^9$ organisms per hour (same spatial configuration as used in the load analysis). Addition of such a source leads to increases in the mean and median concentration, and a corresponding increase in the frequency of days on which the criteria are exceeded. Interestingly, the frequency measures are not very sensitive to the placement of the additional source. This occurs because a downstream source does lead to higher concentrations than a headwaters source, but the concentrations are not sufficiently different to have much of an effect on exceedance of fixed criteria. The table includes alternative geometric mean criteria of 400 and 1000 per 100 ml for comparison. Rates of excursion are of course lower for higher criteria; however, the source is sufficiently large that many excursions continue to occur.

Table 4. Sensitivity of Concentration Measures to Added Sources

Measure	Baseline	Headwater Source	Middle Source	Downstream Source
Mean (#/100 ml)	5407	6052	6077	6096
Median (#/100 ml)	142	1155	1285	1312
Mean vs. Existing	0.0%	11.9%	12.4%	12.7%
Median vs. Existing	0.0%	713.4%	804.9%	823.9%
Rec Season Average Days > 400 (#/100 ml)	47	117	136	139
Annual Average Days > 400 (#/100 ml)	168	317	338	340
Annual Average Days w/ 30d Geomean > 200 (#/100 ml)	265	365	365	365
Rec Season Average Days w/ 30d Geomean > 200 (#/100 ml)	103	153	153	153
Annual Average Days w/ 30d Geomean > 400 (#/100 ml)	178	358	365	365
Rec Season Average Days w/ 30d Geomean > 400 (#/100 ml)	43	146	152	153
Annual Average Days w/ 30d Geomean > 1000 (#/100 ml)	97	251	287	294
Rec Season Average Days w/ 30d Geomean >1000 (#/100 ml)	1.2	61	89	95

It was thought that the simulation of coliform as sediment-associated might have an important effect on concentration statistics, as storage and release can change concentrations following an event. This turns out not to be the case for Underwood Creek. Simulating coliform without sorption does lead to an increase in the mean concentration (+ 12.9 %) and a decrease in the median (- 1.6 %) relative to baseline conditions, but essentially no change in the frequency statistics (there is an increase of one day per recreation season for both the 400 per 100 ml daily and 200 per 100 ml geometric mean criteria).

Sensitivity of concentration measures to overall reductions in upland loads is examined in Table 5. Reducing the impervious load (the major component) does reduce the mean significantly, but results in almost no change in frequency statistics – concentrations during events simply remain too high. This is the reason that a small number of DUs has little visible effect on concentration statistics.

Table 5. Sensitivity of Concentration Measures to Source Reduction

Measure	Baseline	25% Reduction Impervious Load	25% Reduction Pervious Surface Load	25% Reduction Baseflow Load	25% Reduction in Impervious and Baseflow Load
Mean (#/100 ml)	5407	4522	5345	5346	4470
Median (#/100 ml)	142	141	142	112	110
Mean vs. Existing	0.0%	-16.36%	-1.15%	-1.14%	-17.34%
Median vs. Existing	0.0%	-0.7%	0.0%	-21.1%	-22.5%
Rec Season Average Days > 400 (#/100 ml)	47	47	47	47	47
Annual Average Days > 400 (#/100 ml)	168	167	166	167	167
Annual Average Days w/ 30d Geomean > 200 (#/100 ml)	265	258	265	240	230
Rec Season Average Days w/ 30d Geomean > 200 (#/100 ml)	103	99	103	82	76
Annual Average Days w/ 30d Geomean > 400 (#/100 ml)	178	167	175	160	150
Rec Season Average Days w/ 30d Geomean > 400 (#/100 ml)	43	35	41	28	22
Annual Average Days w/ 30d Geomean > 1000 (#/100 ml)	97	90	97	93	85
Rec Season Average Days w/ 30d Geomean >1000 (#/100 ml)	1.2	0.8	1.0	0.5	0.4

One other interesting observation emerges from Table 5 regarding baseflow (subsurface) loads. These loads are a minor contributor to total loads, and reducing baseflow loads has only a small effect on the mean concentration. However, reducing the baseflow load by 25 percent has a big effect on the median concentration (-21.7 %). This is because the baseflow loads are the major factor to maintain concentrations during dry weather periods. As a result, reducing the baseflow loads has little effect on the frequency of individual days with concentration greater than 400 per 100 ml, but results in a significant reduction in the frequency of days with geometric mean greater than 200 per 100 ml. The latter measure is thus very sensitive to the specification of baseflow coliform loads. Note that these loads include both true groundwater loads and also other unaccounted load sources that are independent of surface hydrology and contribute at an approximately constant rate (including illicit discharges, leaky sewers, and direct input from animals.)

STORMWATER DISINFECTION CONFIGURATION

One approach to reducing loads from existing impervious areas is through stormwater disinfection, and model simulation of stormwater disinfection units (DUs) has been incorporated into several scenario runs. These units can achieve a high rate of reduction; however, their efficacy in reducing overall loads in practice is limited, as currently implemented, by a number of factors based on design/cost considerations:

- The units are expensive, and are therefore proposed for only a limited number of sub-watersheds in the model.
- In a treated sub-watershed, it is assumed that only 50 percent of the total impervious surface runoff is directed to the disinfection units.
- The DUs have a fixed capacity, and flow exceeding this capacity is bypassed without treatment.
- To reduce operational costs, it is assumed that the DUs do not turn on until a certain flow is reached. This allows additional bypassing during small runoff events, which may contribute a significant portion of the total annual runoff.

There are several questions regarding the current model implementation of DUs. Alternate specifications may provide better performance. We therefore conducted a sensitivity analysis for a DU in watershed 105 of Underwood Creek, and examined the following:

- The original specification sets disinfected stormwater to a constant concentration of 100 organisms per 100 ml. Simulation as a three-log reduction, rather than a constant concentration, is believed to provide a more accurate prediction of unit performance.
- Use of a minimum flow cut on could allow significant loads to bypass during small runoff events. Therefore, the effect of not specifying a cut on point was investigated.
- The model implementation retains a small amount of water between events, which could lead to storage of coliforms and "smearing" of loading predictions. This could be addressed by specifying coliforms within the unit as a rapidly decaying constituent rather than as a conservative constituent. (Addition of a decay rate within the DUs should not have a noticeable effect on concentrations during events, as the hydraulics are simulated such that travel time through the DU is completed in one 15-minute time step.)

Total simulated loads from the DU and its bypass for a 6.6 year period are summarized in Table 6. Simulation with a 3-log reduction, rather than constant concentration, provides a slight improvement in long-term loads. As this representation is believed to be more technically correct, it should be adopted. A much bigger difference occurs with simulation without a cut on. This reduces the total load by about a factor of 3. Use of a decay factor yields results essentially identical to the cut on simulation. This approach reduces loads in residual "drool" from the units, but does nothing to address the loads that are bypassed during small stormwater flow events.

Table 6. Total Loads from Disinfection Unit for Different Configurations (# over 6.6 year simulation period)

	Cut on	No Cut on	Cut on with Decay
Constant C	5.55E+14	1.85E+14	5.55E+14
3-log Reduction	5.52E+14	1.79E+14	5.52E+14

Further detail on the performance of DUs under the different approaches can be obtained by looking at the cumulative distribution of load (#) versus loading rate (#/hr). This is shown, on both arithmetic and logarithmic scale, in Figure 3.

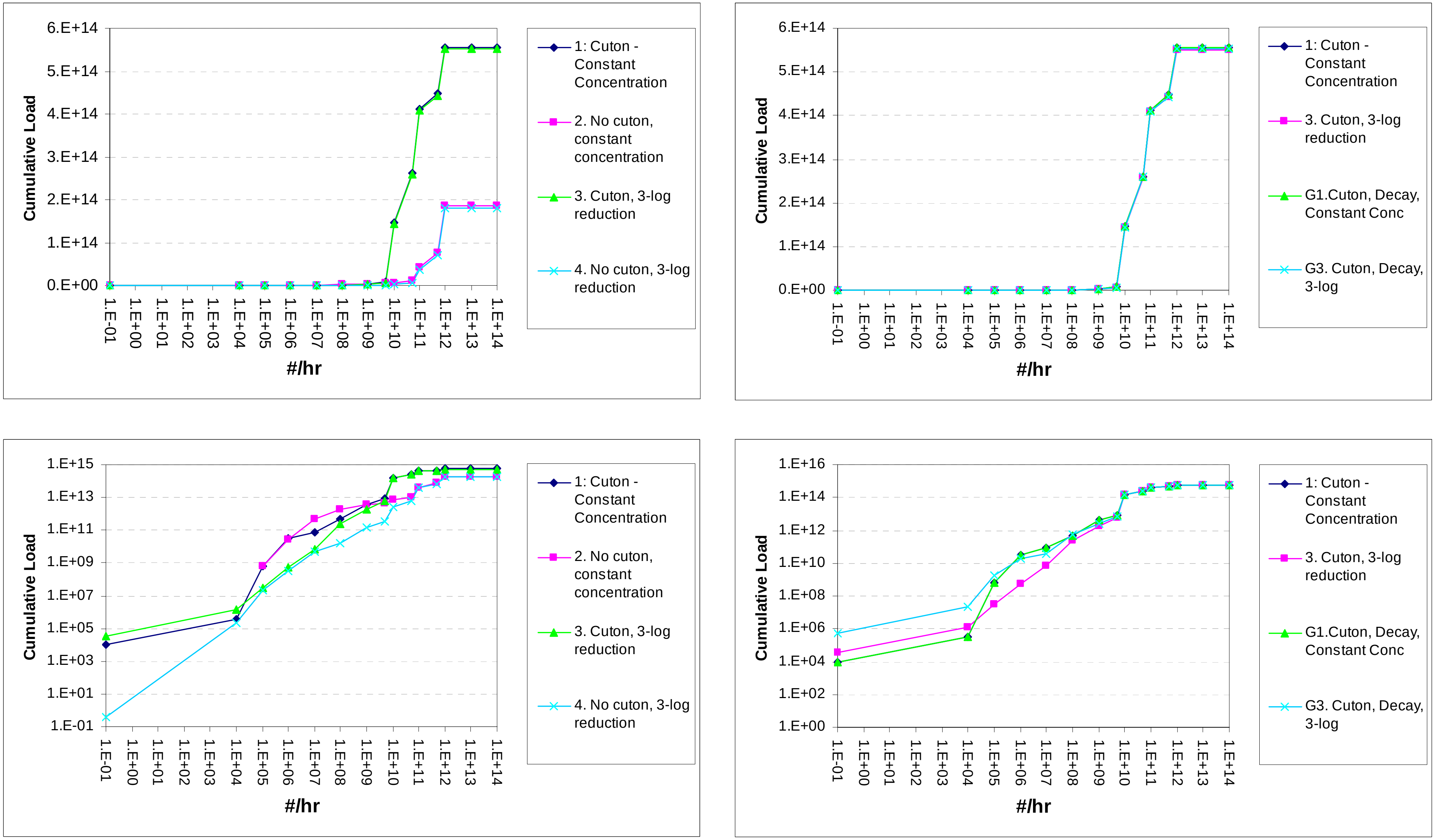

Figure 3. Cumulative Load Distribution for DU Options

Careful examination of these figures shows that the difference between simulations with and without cut on is due to loads in the range of 10^{10} through 10^{11} organisms per hour, representing flows that are large enough to move significant loads, but too low to engage the DU. Use of a 3-log reduction does not appear to result in any degradation in high-load performance; rather the improvement comes at moderate loads where the influent concentration is less than 1000 times the water quality criterion.

ALTERNATIVE 10 ENHANCEMENTS

Alternative 10 as currently implemented represented a suite of BMPs through a combination of loading rate reductions in the NR151 simulation. The loading rates in the NR151 area were reduced by 10% for fecal coliform, 7 % for total phosphorus, and 4 % for total nitrogen to approximate the expected impact of additional BMPs ("10/7/4 reductions").

To examine the impact on fecal coliform and other statistics of explicit implementation (rather than the empirical percentage reductions), we compared results of a more explicit implementation of Alternative 10 for Underwood Creek to the existing Alternative 10 results and the Alternative 1 baseline case.

The following specific management practices were represented in the explicit representation of Alternative 10:

1. Rain barrels and downspout disconnection for volume reduction were applied to 15 % of the residences. We assumed that downspouts serve approximately 50 % of the impervious area on residential lots, so the effective application rate to residential impervious area is 7.5 %. Rain barrels will presumably be used for horticultural irrigation, and the overflow from rain barrels is also supposed to be routed to pervious areas. Therefore, the water routed through rain barrels is assumed to be a lateral surface input on pervious land areas.
2. Rain gardens/bioretention cells and downspout disconnection are assumed to apply to a different 15% of new and existing residences. As with (1) it is assumed that 50 % of the impervious area on the lots is routed to these structures, for an effective application rate of 7.5 %. These are simulated as an infiltration BMP.
3. The criterion for requiring infiltration was reduced from 0.6 to 0.35 in/hr soil infiltration capacity. This results in infiltration being applicable in most new development areas of Underwood Creek.
4. The NR151 infiltration requirement for new development was extended to industrial land uses (exempt under current interpretation of NR151).
5. The TSS reduction target for existing land uses under NR151 was increased from 40 to 50 %.
6. Overflow from infiltration BMPs is assumed to experience another 30 percent reduction in fecal coliform load due to sediment trapping.

In addition, a qualitative request was made to "Control run off volumes beyond NR 151 requirements… Reduce runoff volume from all new (residential, industrial, commercial and institutional) developments, all existing industrial, commercial, and institutional properties, and all redeveloped industrial, commercial, and institutional properties. Compliance could involve porous pavement or other infiltration based technologies…" The objective for new development is assumed to be handled by the options given above. To implement this component for existing industrial, commercial, and institutional development we assumed, as an option in the second run, the following:

7. 25% of the impervious area associated with existing industrial, commercial, and institutional development is routed to infiltration BMPs in subbasins where the soil infiltration capacity is greater than or equal to 0.35 in/hr.

Three subsets of the list of management practices were tested: Option 1 includes BMPs 1 through 6. Option 2 includes BMPs 1 through 7. Option 3 includes only BMPs 1 and 2. In all three options, the empirical "10/7/4" reductions in loading were removed. These options, as well as the original Alternative 10, also differ from the Alternative 1 run in two ways: (1) Streamline Mouse instead of MiniMouse output is used to represent District SSOs; and (2) disinfection units are applied to treat some of the urban stormwater.

The fecal coliform results for Underwood Creek are compared to the base case for Alternative 1 and the existing Alternative 10 below (Table 7 and Table 8). All of the Alternative 10 options produce significant reductions relative to Alternative 1. About half of this reduction is due to the use of stormwater disinfection. Option 1 produces loads that are slightly higher than the existing Alternative 10, while Option 2 achieves more reduction in loads than the existing Alternative 10, although the improvement is limited by the assumptions regarding the hydraulic capacity of the infiltration BMPs, which allows for frequent overflows. Option 3 produces higher loads. The reporting concentration measures show little change between the different variants of Alternative 10, however, because the mean concentrations remain far above the target values (Table 8). Here, the mean concentrations from Option 1 and Option 2 again bracket the results from the "10/7/4" version of Alternative 10. It is important to note that both Option 1 and Option 2 result in slightly higher median concentrations than the "10/7/4" version of Alternative 10 – apparently because some flows are bypassed in the explicit representation – which results in slightly poorer performance on achieving the geometric mean criterion for fecal coliform.

Table 7. Sensitivity of Fecal Coliform Load to Additional BMPs

	Alternative 1	Existing Alternative 10 (10/7/4 Reductions)	Option 1 (Alternative 10 with Explicit Representation of Items 1-6)	Option 2 (Alternative 10 with Explicit Representation of Items 1-7)	Option 3 (Alternative 10 with Explicit Representation of Items 1-2)
Average Annual Load (#/yr)	2.04E+15	1.59E+15	1.61E+15	1.47E+15	1.65E+15
Percent Change Relative to Alternative 1	0.00%	-22.1%	-21.1%	-27.9%	-19.10%

Table 8. Sensitivity of Fecal Coliform Concentration Measures to Source Reduction

Measure	Alternative 1	Existing Alternative 10	Option 1	Option 2	Option 3
Mean (#/100 ml)	6391	5407	5574	5166	5542
Median (#/100 ml)	156	142	153	151	157
Mean vs. Alternative 1	0.00%	-15.4%	-12.8%	-19.2%	-13.3%
Median vs. Alternative 1	0.00%	-9.0%	-1.9%	-3.2%	0.2%
Annual Average Days > 400 (#/100 ml)	168	168	169	168	170
Rec. Season Average Days > 400 (#/100 ml)	47	47	47	47	48
Annual Average Days w/ 30d Geomean > 200 (#/100 ml)	282	265	271	270	279
Rec Season Average Days w/ 30d Geomean > 200 (#/100 ml)	114	103	105	104	111
Annual Average Days w/ 30d Geomean > 400 (#/100 ml)	188	178	184	182	183
Rec Season Average Days w/ 30d Geomean > 400 (#/100 ml)	50	43	47	46	47
Annual Average Days w/ 30d Geomean > 1000 (#/100 ml)	104	97	100	96	98
Rec Season Average Days w/ 30d Geomean >1000 (#/100 ml)	2.0	1.2	1.2	0.8	1.3

Nitrogen and phosphorus show similar behavior for loads, with the “10/7/4” representation falling between the two explicit alternatives. TSS, however, shows additional reductions with full implementation, particularly when infiltration is applied to existing impervious runoff (Option 7).

Table 9. Comparison for Nitrogen and Phosphorus Loads

Change Relative to NR151	FC	TP	TN	TSS
A10: 10/7/4 Reductions	-21.81%	-5.99%	-3.12%	0.00%
A10: Full implementation w/o 10/7/4 Reductions	-27.96%	-6.30%	-7.08%	-12.42%
A10: Options 1-6 w/o 10/7/4 Reductions	-20.78%	-2.64%	-1.93%	-1.75%
A10: Options 1-2 w/o 10/7/4 Reductions	-19.10%	-0.96%	-1.45%	-1.54%

In sum, the “10/7/4” empirical representation of Alternative 10 seems to do a good job of matching the range of loads attained from the two explicit representations of this scenario. This occurs because the empirical representation of Alternative 10 does not include any additional reductions for TSS (the scenario assumptions call for a 10 percent additional reduction in TSS, but only to be applied to the non-NR151 areas).

MORE AGGRESSIVE IMPERVIOUS REDUCTIONS

In the current implementation, the nonpoint fecal coliform loading in the models is dominated by impervious surface loads. Within the urban areas, these rates were increased from the original SLAMM defaults to achieve an approximate match with observed instream concentrations. Representing this load as *associated* with urban runoff appears to work well; however, that does not mean that the load is entirely a surface washoff process. Instead, we expect that much of this (very high) load may be due to leaky sewers, cross-connected discharges (also perhaps leakage from waste handling containing fecal matter sources such as disposable diapers) that tend to pool, then move into the streams with stormwater pulses.

Comparison of the modeling results suggest that we ought to be able to get the loading rate from urban impervious surfaces back down near "default" levels. To evaluate this possibility we evaluated the results of assuming a 50 percent reduction in the impervious surface coliform load as well as other percentage reductions from both impervious and pervious surfaces simultaneously. Results are presented below for the Kinnickinnic (KK) River watershed as the models had previously been run when originally scoping out the Alternative 6 reductions back in January.

For the KK there are plentiful CSOs, SSOs, and point sources, all of which effect conditions at the monitoring locations. Thus, a 50 percent reduction in nonpoint load does not achieve a 50 percent reduction in instream loads – but it comes remarkably close as shown in Table 10. Reducing loads from both pervious and impervious surfaces does better than reducing the load from impervious surfaces only, but it is clear that most of the reduction comes from the impervious surfaces.

It is finally worth noting that a 75 percent reduction in loading rates achieves a big reduction in the average and geometric mean (72 percent reduction on the geometric mean); however, the metric of days exceeding the days exceeding the daily maximum of 400 per 100 ml doesn't change much. That is because the concentrations during washoff events – while much reduced – still exceed this criterion.

Table 10. Response of Fecal Coliform at KK Station RI-12 to Reductions in Nonpoint Load (Results from Scenario 2 Scoping Analyses of February 2006)

Metric	Alternative 1	50 % Reduction in Impervious Load	50 % Reduction in Pervious and Impervious Load	75 % Reduction in Pervious and Impervious Load
Average (/100 ml)	5031	2903	2839	1767
Geometric Mean	567	399	296	161
Days Exceeding 400 /100 ml	191	178	173	161
Days with GeoMean > 200	310	289	223	136

APPENDIX 8B

SENSITIVITY ANALYSIS OF RURAL BEST MANAGEMENT PRACTICES – WEST BRANCH ROOT RIVER CANAL

2020 Facility Planning Project

Draft Memorandum

Project Name:	MMSD – 2020 Facility Planning Project	MMSD Contract No:	M03002P01
DMS Folder Name:	Technology Analysis	MMSD File Code:	M009PE000.P2000
Document Name:	Sensitivity Analysis of Rural BMPs – West Branch Root River Canal	HNTB Charge No:	34568-PL-400-115

Date: September 13, 2006

To: Michael Hahn, SEWRPC

Bill Krill, HNTB

From: Leslie Shoemaker, Tetra Tech, Inc.

Subject: Sensitivity Analysis of Rural BMPs – West Branch Root River Canal (revised)

EXECUTIVE SUMMARY

Rural areas make up a significant portion of the study area of the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU). Management methods such as manure and livestock management programs and increased use of riparian buffers are therefore being considered for reducing pollutant loads to meet water quality objectives. To help guide the effort to maximize the effectiveness of these management measures, it is useful to perform some sensitivity analyses of their performance within the context of the models. The West Branch of the Root River Canal (WBRRC) was selected for the rural area sensitivity analysis due to the high percentage of rural land use/land cover, the relative lack of riparian buffers, and the lack of upstream drainage in this subwatershed.

The analysis for the WBRRC shows that fecal coliform load predictions are dominated by upland loads from impervious surfaces in the current model prediction, and that loads from agricultural areas have a relatively smaller importance. The model was therefore run without impervious areas to allow for a better focus on the relative importance of rural management measures. The results suggest that the manure management strategy provides the most effective means of reducing fecal coliform concentrations from rural areas, cutting the number of days over the 400 #/100mL standard in half and reducing the average concentration enough for the geomean standard to be met at all times.

The analysis also indicates that the general representation of nonpoint source controls used in Alternatives 6, 10, and 11 are approximately equivalent to a more explicit representations of sediment and nutrient removal by stream buffers. The explicit reductions provide estimated TSS and nutrient reduction of approximately 7.7% to 8.1% compared to the

general reductions of 10% for TSS, 7 % for total phosphorus, and 4 % for total nitrogen. Conversion of cropland to forest/wetland areas in the WBRRC had a similar affect as buffer enhancements, providing nutrient reductions relative to the amount of area converted. The proposed landuse conversion recommended in Alternative 11 is estimated to reduce the rural nutrient loads by 13 to 20%.

CONCLUSIONS

The sensitivity analysis for WBRRC shows that the results using the general buffer assumptions provide similar results to using a more explicit representation of buffers. Fecal coliform load predictions are strongly influenced by upland loads from urban surfaces in the current model prediction. When focusing just on the effect of groundwater reductions and manure management, it was seen that manure management had a more significant impact on attaining fecal coliform water quality standards. Conversion of cropland to forest/wetlands had a significant impact on the reduction of rural nutrient loadings roughly equivalent to the percent of the watershed converted to forest/wetlands.

RECOMMENDATIONS

Results of the smaller scale analysis show that rural area controls should focus on manure management efforts for reducing fecal coliform loads. We recommend that the Planning Team discuss this memo to determine the most appropriate next steps.

INTRODUCTION

Reduction of fecal coliform concentrations and loads is a key goal for the 2020 Facility Planning Project and the Regional Water Quality Management Plan Update (RWQMPU). In some cases model scenarios conducted thus far have not yielded the degree of reduction necessary to meet goals. To help guide the effort to maximize effectiveness in controlling coliform loads it is useful to perform some sensitivity analyses. This memorandum provides an evaluation of controls for rural areas; another memorandum addresses urban areas. The ultimate intention is to provide an informed basis for representing control measures and selecting and placing BMPs to obtain the maximum reduction in criterion violations.

For the purpose of the rural sensitivity analysis we are working with the West Branch Root River Canal (WBRRC) watershed. This is a rural area within the Root River drainage. Working with only the WBRRC provides a smaller, more manageable modeling area that is more amenable to sensitivity analysis than the full Root River model.

SOURCES OF FECAL COLIFORM

It is first important to understand where the fecal coliform load originates within the model. Obviously, there is an advantage in focusing on reductions from areas that contribute the largest loads. Table 1 summarizes the loading contributions by land use and the contributing area in the WBRRC. It can be seen that the urban areas provide a significant contribution to the total load in the watershed (Figure 1). The reason for this is due to the relative coliform loading rates as shown in Figure 2. The rural loading rates are often one to two orders of magnitude lower than the urban rates. While rural areas comprise the majority of the land use in the WBRRC watershed, this difference is more than offset by the difference in loading rates. Commercial and residential impervious areas dominate the fecal coliform loading, accounting for two-thirds of the total. Urban pervious areas and cropland are nearly equal and account for most of the remaining third.

The relatively high loading rates associated with impervious areas result in a significant urban related loading in mixed land use watersheds. Even the West Branch Root River has a large proportion of the load associated with urban land uses. The urban impervious areas rates are consistent with the calibrated values derived from the Menomonee River model and represent a combination of different urban fecal coliform sources. To more clearly discern the sensitivity of the rural areas to changes in management, the following sensitivity analysis focused primarily on the agricultural/rural land uses.

Table 1. Summary of West Branch Root River FC Load and Landuse Distribution

Landuse	Load (#/yr)*	Acres
Urban Grass	1.11E+14	2595.8
Residential	2.36E+14	286.3
Commercial	2.64E+14	405.0
Industrial	7.60E+12	28.2
Government/Institutional	3.62E+13	27.0
Forest	2.00E+11	642.9
Cropland	9.96E+13	14301.4
Pasture	1.98E+13	1148.9
Wetlands	3.82E+11	603.1

* Based on loads exported from the land surface. No trapping factor was applied to fecal coliform as was done for other pollutants.

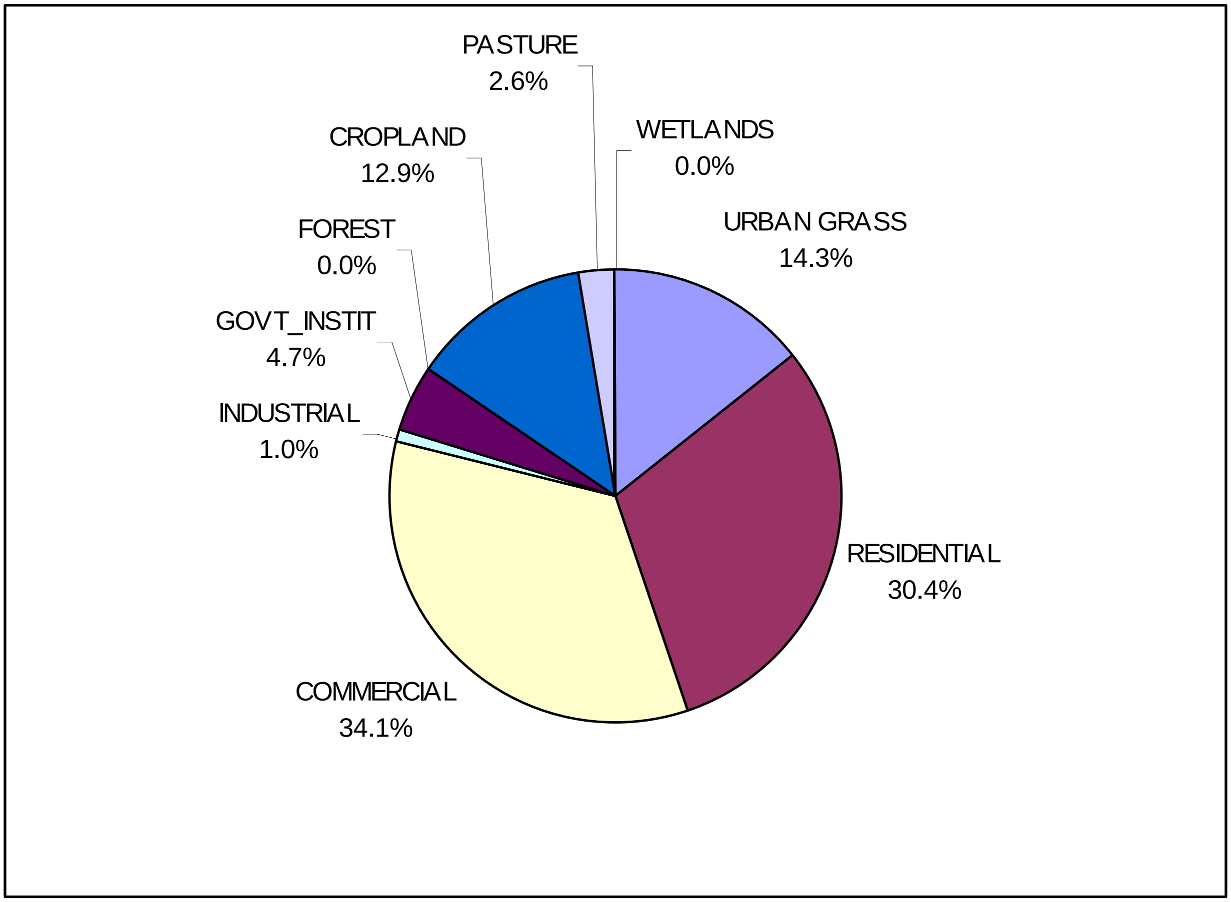

Figure 1. Sources of Fecal Coliform Load to West Branch Root River Canal

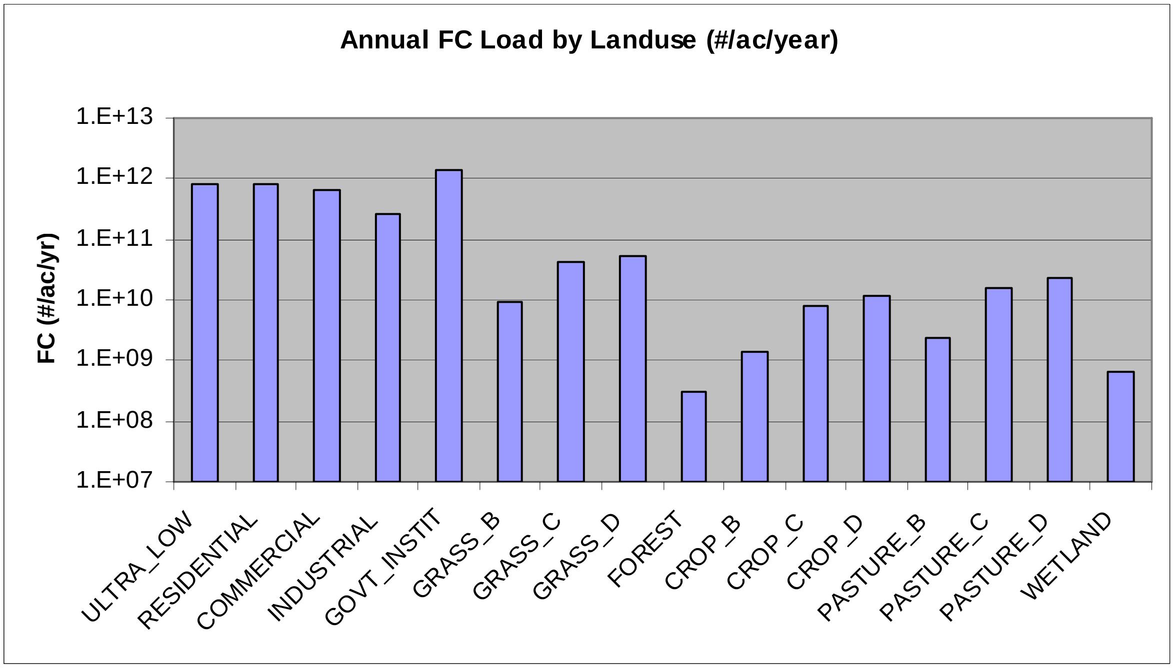

Figure 2. Fecal Coliform Loading Rates (#/ac/yr) for the West Branch Root River

SENSITIVITY ANALYSIS FOR ANNUAL LOADS

Predicted coliform loads at the mouth of the WBRRC arise from a combination of upland loading rates and instream processes. Sensitivity analyses for loads were undertaken by evaluating the relative change in loading rates to various model assumptions.

Exceedances of the fecal coliform water quality standards occur during both wet and dry weather conditions. To evaluate the dry weather exceedances, further analysis was conducted on the significance of subsurface loads of fecal coliform since these were used to represent a number of potential fecal coliform sources in rural areas, including failing septic systems and direct discharges (such as livestock and wildlife in the streams). Simulations representing a 10%, 50% and a 99% reduction in subsurface concentrations were performed by assuming uniform reductions in subsurface loads from all pervious lands.

The response of the model to manure storage and handling assumptions was also addressed. The calibration of the model simulates the buildup of fecal coliform from agricultural areas based on animal counts, typical manure characteristics, and standard handling practices. Data on these issues are input to the Fecal Coliform Loading Estimation spreadsheet, which then produces monthly buildup and washoff rates. The potential benefits of enhanced cattle fencing and manure composting were investigated by revising these monthly buildup and washoff rates. For example, it was assumed that all manure was collected and composted prior to application. Research by

Larney et. al. (2003) found reductions up to 99% in fecal coliform concentrations from composted manure and this level of reduction was applied to all fecal concentrations for beef and dairy manure. Furthermore, the composted manure was applied only two months per year (May and October) instead of being applied throughout the year as was the uncomposted manure.

The results of the subsurface and manure management sensitivity analyses are summarized in Table 2. Loads at the mouth of WBRRC responded slightly to reductions in the rates of subsurface flow loading from pervious surfaces and more significantly from the incorporation of enhanced cattle and manure management (Table 2).

Fecal coliform in the stream is simulated as a general quality constituent that is subject to decay (die-off), and can sorb to sediment in the water column, deposit to the stream bed, and re-release from the stream bed back into the water column. One potential reason for the insensitivity to subsurface loads is that high fecal loads delivered to the streams during storm events may sorb to bed sediments. The sorbed coliform is then re-released to the water column causing elevated levels for many days after an event. Therefore subsurface contributions provide only part of the overall fecal coliform seen during low flow conditions.

Table 2. Response of Rural Loads to Source Reductions

Source Reduction	**Response in Fecal Coliform Load at Outlet of WBRRC**
-10% Subsurface Load	-0.91%
-50% Subsurface Load	-4.59%
-99% Subsurface Load	-9.04%
Enhanced Manure Management	-74.52%

SENSITIVITY ANALYSIS FOR CONCENTRATION MEASURES

Determining the sensitivity of total loads is relatively straightforward. However, the primary metrics used to evaluate scenarios are based not on loads but on concentrations – and in particular on the frequency of concentrations greater than various regulatory standards. Measures used include the number of days with maximum concentration greater than 400 per 100 ml (for both full year and recreation season), and the number of days with rolling 30-day geometric mean greater than 200 per 100 ml (again for both full year and recreation season) (see Table 3). The response of concentrations is more complex than loads, because concentration depends on the interaction of loads, dilution capacity, and the timing of loading events. Frequency measures introduce another phenomenon, as such measures may not be sensitive to changes in loads if the resulting concentration is smaller, but still above the water quality criterion.

Table 3. Sensitivity of Concentration Measures for Rural Landuses to Source Reduction

Measure	Baseline	10% Reduction Subsurface	50% Reduction Subsurface	99% Reduction Subsurface	Enhanced Manure Management
Mean (cfu/100 mL)	165	163	155	144	102
Median (cfu/100 mL)	51	48	39	28	29
Mean vs. Baseline	0.0%	-1.3%	-6.6%	-13.0%	-38.4%
Median vs. Baseline	0.0%	-4.5%	-22.7%	-45.5%	-41.9%
Rec Season Average Days > 400 (days)	28	28	27	27	19
Annual Average Days > 400 (days)	63	63	62	61	34
Annual Average Days w/ 30d Geomean > 200 (days)	22	21	18	14	0
Rec Season Average Days w/ 30d Geomean > 200 (days)	9	9	7	6	0
Annual Average Days w/ 30d Geomean > 400 (days)	3	3	2	2	0
Rec Season Average Days w/ 30d Geomean > 400 (days)	1	1	1	1	0

Note: these results exclude loading from urbanized areas

The baseflow reductions of fecal coliform have a limited affect on the statistics used to evaluate achievement of the water quality standards. The 50% reduction in baseflow loads do show a nearly 23% decrease in median concentrations as compared to the baseline, but this does not translate into a similar decrease in meeting the water quality standards. The manure management strategy, however, cuts the median value by over 40% which is sufficient to reduce the number of days over the 400 #/100mL standard in half. Even more significantly, this approach reduces the average concentration enough for the geomean standard to be met at all times (keeping in mind that this run only evaluated the agricultural contributions of fecal coliform).

BUFFER POLLUTANT REMOVAL EFFECTIVENESS

Alternatives 6, 10, and 11 as currently implemented represented a suite of BMPs through a combination of loading rate reductions. The loading rates in rural areas were reduced by 10% for TSS, 7 % for total phosphorus, and 4 % for total nitrogen to approximate the expected impact of additional BMPs ("10/7/4 reductions").

In order to more explicitly evaluate the effects of buffers on agricultural areas, SEWRPC provided an estimate of riparian corridor lengths and existing buffers in four width categories. It was then assumed that efforts would be made to improve these buffers, bringing them up to the next category in the future. Buffers in the highest class (>75') would remain as they currently exist. It was also assumed that the buffers would treat adjacent areas equal to approximately 20 times their width. Table 4 provides the estimates of the current area in the WBRRC and the additional area that converted to buffer area.

Table 4. Summary of Buffer Improvement Calculations

Category	Category 1 (0-25 ft)	Category 2 (25-50 ft)	Category 3 (50-75 ft)	Category 4 (>75 ft)	Total
Length (ft)	156,965	112,480	21,410	70,957	361,812
Current area (ac)	45.0	96.8	30.7	162.9	335.5
Affected area (ac)	900.9	1,936.6	614.4	3,257.9	6,709.8
% of cropland	5.8%	12.5%	4.0%	21.1%	43.4%
% of watershed	4.5%	9.7%	3.1%	16.3%	33.5%
Additional area converted to buffer	90.1	64.6	18.4	0.0	173.1

Information provided by SEWRPC suggested that enhancing buffers would create new buffer areas in the lowest class and increase buffer widths from one category to next highest. It was assumed that the buffers currently in Category 1 provide limited water quality benefits. These areas will be considered as new buffer areas and given an estimated 75% reduction in TSS, TN, and TP loadings. Areas which currently have buffers greater than 25 feet already provide some level of pollutant reduction. For this reason, it was assumed that the enhanced areas would only provide an additional 15% reduction. The buffer effectiveness assumptions are summarized in Table 5. These effectiveness estimates were then multiplied by the ratio of the treated area to the total area. An additional benefit is seen during the buffer enhancement process as agricultural areas are converted to forested riparian buffers. The area estimated to be converted was multiplied by the ratio of cropland and forest areas to estimate the magnitude of this conversion. If it is assumed that the buffers would affect only cropland and pasture, buffer improvements would result in a reduction of 11.8% to 12.9% of TSS, TP, and TN of the crop and pasture load. If the same buffer area applies to all landuse, the surface load reduction from the entire watershed would be approximately 7.7% to 8.1% as shown in Table 6. From this table it can be seen that the “10/7/4” empirical representation seems to fairly approximate the range of loads attained from the more explicit representations of buffers, although perhaps slightly underestimating the potential benefits. It should be noted that these estimates use the same reduction rates for all parameters whereas TN and TP may have slightly lower reductions from riparian buffer areas.

Table 5. Summary of Buffer Pollutant Removal Effectiveness

Category	Category 1 (0-25 ft)	Category 2 (25-50 ft)	Category 3 (50-75 ft)	Category 4 (>75 ft)
TSS	75	15*		
TN	75	15*		
TP	75	15*		

* Percent Reduction above Existing Buffer Effectiveness

Table 6. Percent Reductions from Buffer Categories and Landuse Conversion

Category	Category 1 (0-25 ft)	Category 2 (25-50 ft)	Category 3 (50-75 ft)	Category 4 (>75 ft)	Landuse Conversion	Total
Crop/Pasture only Reduction						
TSS	4.4%	1.9%	0.6%	3.2%	1.8%	11.8%
TN	4.4%	1.9%	0.6%	3.2%	2.7%	12.7%
TP	4.4%	1.9%	0.6%	3.2%	2.8%	12.9%
Entire Watershed Reduction						
TSS	3.4%	1.4%	0.5%	2.4%	0.02%	7.7%
TN	3.4%	1.4%	0.5%	2.4%	0.1%	7.8%
TP	3.4%	1.4%	0.5%	2.4%	0.4%	8.1%

CONVERSION OF CROPLAND TO WETLANDS OR PRAIRIES

Alternative 11 as currently implemented represents the conversion of croplands to wetlands and/or prairies. The primary benefit of this is related to the significantly lower loading rates expected from the forest or wetland landuses. These areas could potentially be converted to natural prairie areas. It is assumed that these prairies would have similar loading rates as the natural forested areas.

As seen in Figure 2, forest and to a lesser extent wetlands have a significantly lower loading rate compared to croplands. Conversion of cropland to forest or wetlands would therefore reduce the initial load generation. In addition, selective conversion of croplands to forest or wetlands could be used to enhance buffer effectiveness as shown in Section 8. While the individual impact of each of these measures is small, they could be a useful component of an integrated management approach.

Results for the Alternative 1 baseline and Alternative 11 were compared to determine the reduction in total loadings as a result of shifting landuse from cropland to wetland/forest areas. Approximately 3,053 acres (15.1%) were converted to wetland/forest areas under Alternative 11 resulting in pollutant reductions ranging from 13 to 20 percent as shown in Table 7.

Table 7. Watershed Scale Reduction Resulting from Landuse Conversion

	Total P (lbs)	TSS (tons)	Fecal Coliform(#)	Total N (lbs)	BOD (lbs)
Load Reduction	1,429.2	1,027.1	2.51E+13	43,705.7	75,073.1
Percent Reduction	13%	20%	18%	18%	16%

Note: these results exclude loading from urbanized areas

REFERENCES

Larney, F. J., L.J. Yanke, J.J. Miller, and T.A. McAllister. 2003. Fate of Coliform Bacteria in Composted Beef Cattle Feedlot Manure. Journal of Environmental Quality. 32:1508-1515 (2003).