Lake George Area

Stormwater Treatment Concept Plan

FINAL REPORT

April, 2005

City of River Falls

In cooperation with:

The Wisconsin Department of Natural Resources
The U.S. Army Corps of Engineers – St. Paul District
Trout Unlimited
University of Wisconsin-River Falls

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Executive Summary

This project follows up on the *Water Management Plan for the Kinnickinnic River and Its Tributaries* completed in 1995, and the *Lake George Management Plan* completed in 1996. The 1995 plan identified the reconfiguration of Lake George as a potential project to decrease thermal and other pollutant loads to the river, and to complement possible future efforts by the City to link the City center to the river corridor. The *Lake George Management Plan* recommended converting Lake George to an artificial wetland and stream channel. However, no modeling or scientific studies were completed to quantify the impacts on the river.

The purpose of this project was to develop an overall management strategy for that portion of the Upper Dam Minor Watershed of the Kinnickinnic River watershed, which includes downtown River Falls and Lake George. Two advisory groups helped provide guidance for this project. The first was the Technical Advisory Committee (TAC). These seven individuals serving on the TAC offered water management strategic and technical expertise in scoping and executing the technical analyses and identifying and evaluating the various management options.

The second group was the Stakeholders Committee, comprised of eleven members representing a range of interests in the community. They provided valuable guidance in developing the overall management strategy proposed in this plan. Appendix B of the main report lists participants of each advisory group. These groups held 14 meetings between March 2003 and December 2004 to guide the development of this strategy.

Part of this project involved developing modeling tools to quantify the impacts of various management alternatives. The development of two models helped provide the technical information to evaluate the impact of various alternatives. The CE-QUAL-W2 model for the river between Quarry Road and Rocky Branch Creek helps quantify the thermal impacts of various management alternatives, and the urban runoff model P-8 models total suspended solids loads to the river.

In addition to evaluating reconfiguration alternatives for Lake George, this project examined the 176-acre watershed that drains untreated runoff directly to the river from just above Division Street to the Lake George dam. This examination included an identification and evaluation of watershed treatment practices for possible implementation to help reduce total suspended solids and thermal loads to the river from existing developed areas.

Installing best management practices (BMPs) for several identified projects in the watershed would reduce thermal and total suspended solids loads to the river above Lake George. These projects generally emphasize pre-treating and infiltrating the first flush of runoff carried by storm sewers that serve some of the larger, higher impervious sewersheds in the project area. Located at the lower end of the sewersheds that discharge to the river above Lake George, the projects are intended to fit on land already owned or controlled by the City. The locations of the projects, the sewersheds they would serve, and the type of BMP proposed are shown in Figure ES-1 on page 5.

However, there were a number of high priority sewersheds on the more highly impervious east side of the river for which cost-effective BMPs are not likely to be found given the existing land use patterns. This is mainly because these sewersheds support intensive land uses which back right up to the river and allow little room to install infiltration-oriented BMPs without interfering with those current uses.

In addition to end-of-the-pipe BMPs, it was strongly recommended that smaller scale best management practices such as rainwater gardens (Figure ES-2) to increase runoff infiltration from one or several lots or short street sections be employed in multiple locations throughout one or two targeted sewersheds. These types of practices are usually best suited to residential areas, especially if resident acceptance and cooperation are high.

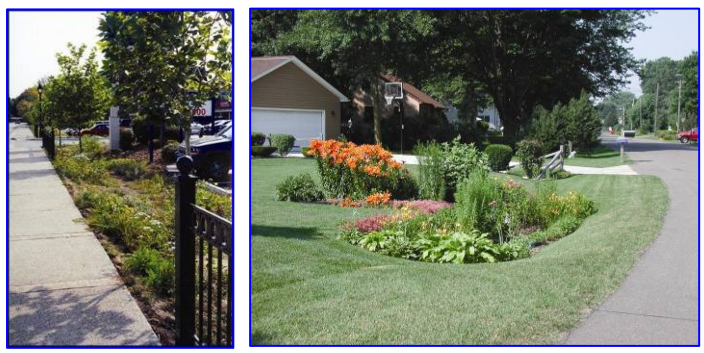

Figure ES-2: Rainwater Gardens Designed to Treat Impervious Area Runoff

The benefits of watershed BMPs in this system have limits, however. First, the watershed BMPs treat runoff from precipitation events. Thus, *watershed BMPs have no significant beneficial impact on baseflow temperatures in the river*. One significant concern is the warming of the system's river water under baseflow conditions during warm weather periods. This is mainly caused by warming of the river water as it passes through the downtown area and the reservoirs (Lake George and Lake Louise). This is an important factor because the baseflow condition is dominant during the summertime period.

A second important consideration is the effect of Lake George on watershed BMP-induced benefits showing up below that reservoir. *Thermal modeling completed for this project shows that thermal benefits of watershed BMP application in the project area above Lake George are virtually eliminated when passing the river water through Lake George in its current configuration*. Nonetheless, it was acknowledged that selectively implementing watershed improvements was desirable because of their overall beneficial impact in reducing the export of common urban pollutants to the river (TSS, heavy metals, phosphorus, etc.) and the likelihood that infiltration-oriented BMPs provide some incremental benefit in improving baseflow.

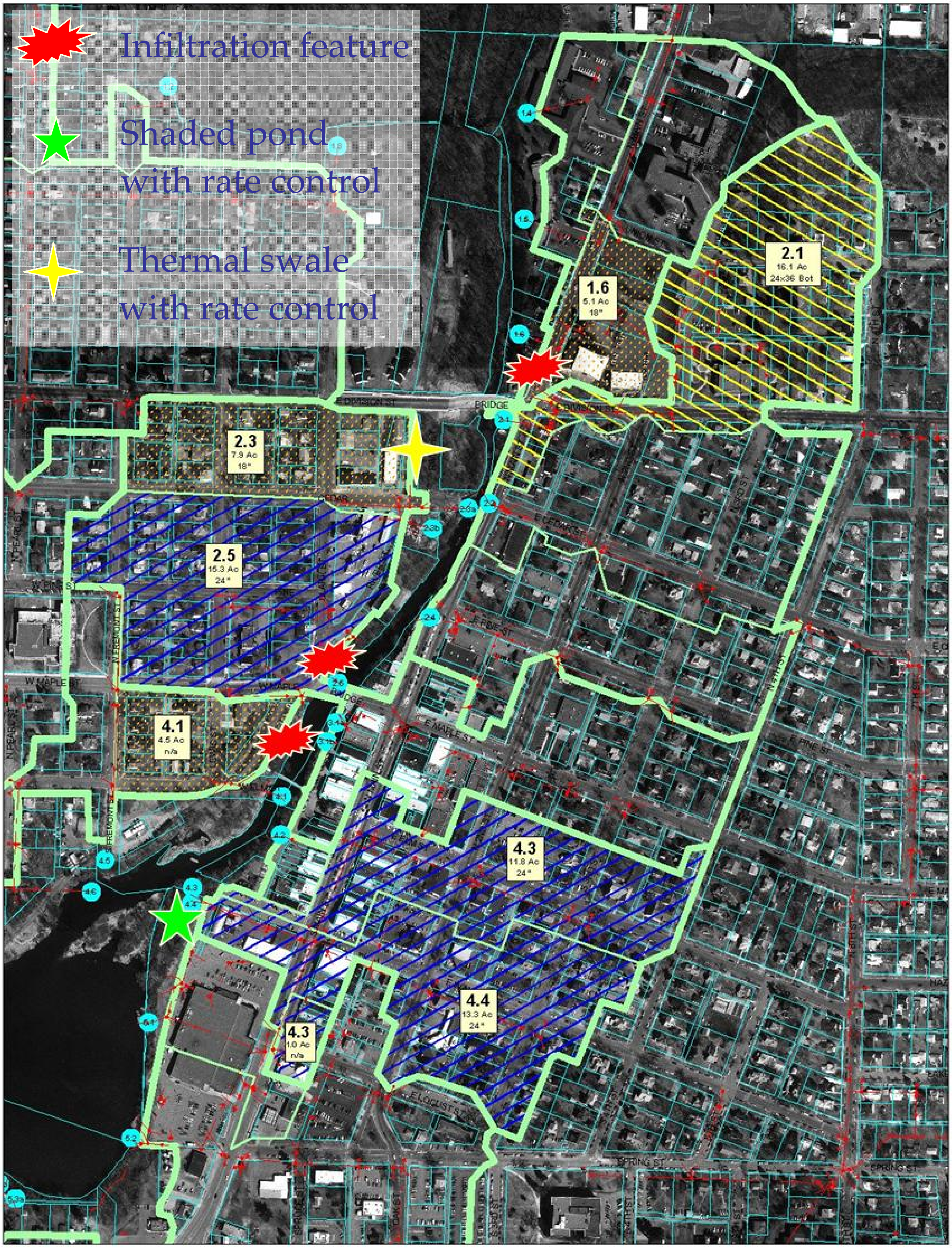

Figure ES-1: Location of Watershed BMP Opportunities

The second phase of this project looked at various options for reconfiguring Lake George itself. There was strong interest in making sure that any reconfiguration alternative selected has a demonstrable positive effect on thermal regimes in the river below Lake George dam under both baseflow and runoff conditions.

All options evaluated included an interceptor pipe extending north from Lake George upstream along the east side of the river as far as Division Street. The interceptor was supported because it can eliminate almost all the total suspended solids and thermal loads to the river above Lake George from the most highly impervious portion of the project area between Division Street and the lake. This raw runoff would be diverted by the interceptor to the Lake George area where the water could be treated and released in a controlled manner back to the river to minimize impact. The interceptor pipe could be capable of capturing runoff from up to 85% of the area of the highest priority sewersheds identified in this study.

After evaluating several alternatives, the reconfiguration alternatives shown in Figure ES-3 were selected as the preferred option. The main features of this alternative are as follows:

- A multi-cell configuration with the smaller northern-most cell to be used as the first (pretreatment) cell in the system to which raw stormwater from the interceptor system would be discharged. Access would be provided to facilitate periodic removal of accumulated sediment.
- Cells would be deepened to a maximum depth of 7-9 feet. Aquatic benches at no steeper than a 10:1 slope for at least 20 feet into each pond cell would be created to provide safety and to support fringe emergent growth. This is consistent with City standards for creating ponds.
- A thermal swale (yellow line) to carry discharge from the last cell of the reduced lake to the river. The cell could be shaded and/or underlain by a rock trench to further cool water discharged from the cell before discharging to the river.
- Piped connections between cells to convey water.
- A piped discharge between the last cell and the river with outlet controls. This pipe could be used to discharge water from the last cell to the river and would be constructed to reach the natural channel if the dam is removed.
- A channel to carry natural spring water (groundwater) discharges directly to the river without mixing with pond discharge water under most conditions. The location and viability of the springs is not known at this time, thus the location of this channel may need to be adjusted once the nature of the spring discharges is better defined.

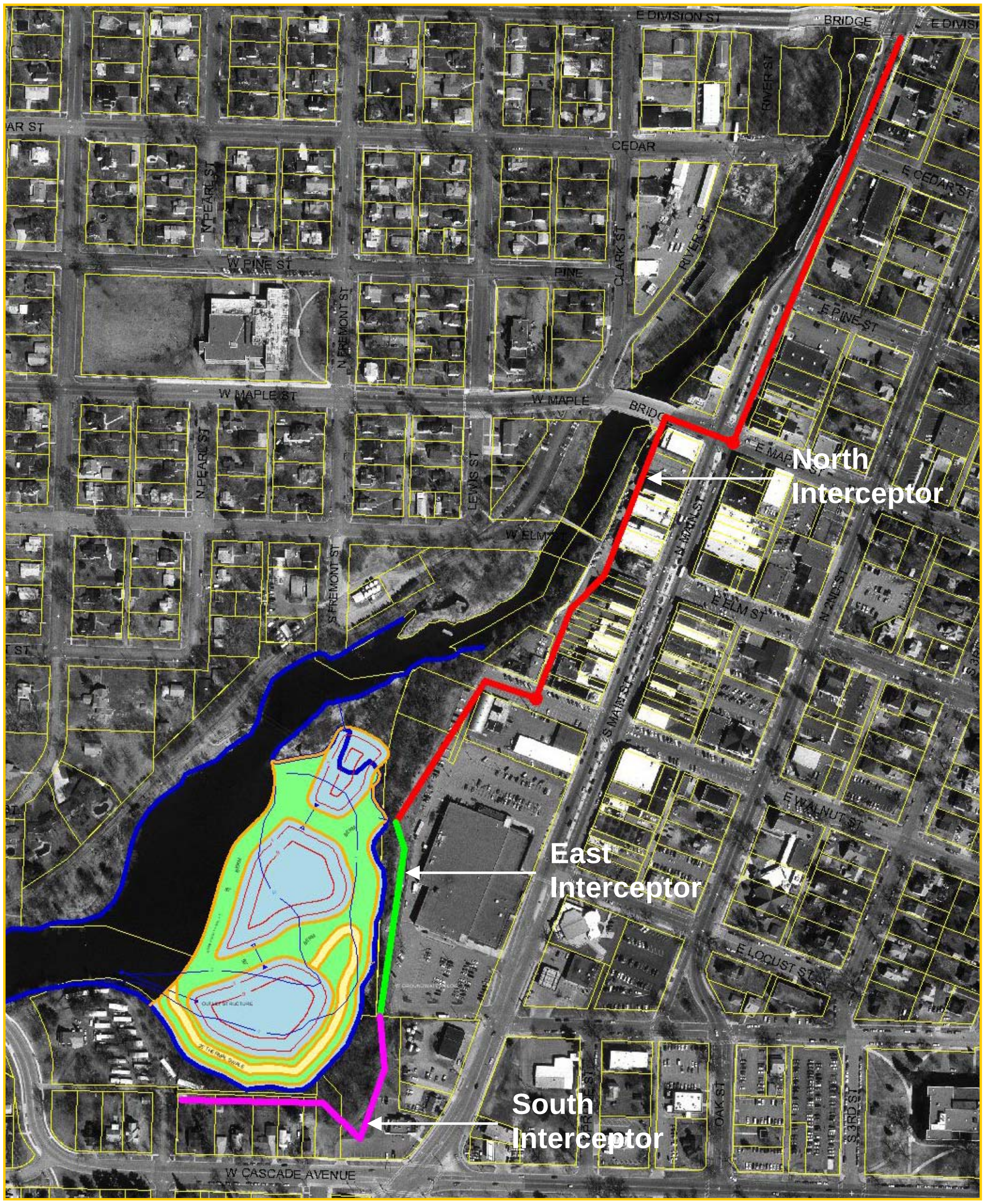

Figure ES-3: Recommended Lake George Reconfiguration Alternative and Local Stormwater Interceptor Pipes

Table ES1 summarizes the estimated benefits and costs of the preferred Lake George reconfiguration alternative along with the interceptor pipes needed to bring runoff from the downtown areas and the areas around Lake George to the upper end of the multi-cell system for treatment.

Table ES1: Summary of Costs for Recommended Lake George Reconfiguration Alternative and Interceptor Pipes

Alternative	Description	TSS and Thermal Benefits			Lake Reconfig Const. Cost	Downtown SS Diversion Const. Cost	Comments
		TSS Red. Benefit [1]	Thermal Benefit [2]				
		Reduction	Baseflow	Runoff Events			
Preferred Alternative	Divert downtown sewersheds, construct primary berm to separate lake from river and multiple internal berms for multi-cell treatment system, add thermal swale as low flow outlet and spring outflow conveyance channel	60-70%	Up to 1° C	<0.5° C w/o watershed improve-ments to 0.5° – 1°C with Priority 1 watershed improve-ments	$515,000 - $1,012,000	North Interceptor $944,000 – 1,200,000 LG East Interceptor $184,000 – 247,000 LG South Interceptor $212,000 – 289,000	Modeled thermal benefits account for rate control of outflows from modified Lake George, do not account for potential benefits of thermal swale, reduced surface area of Lake George

[1] *Estimated at point of discharge to River*

[2] *Estimated at location immediately downstream of Lake George*

On December 16, 2004, a combined meeting of the TAC and the Stakeholders Committee was held to review all information and provide recommendations to the City on an overall strategy. There was consensus that a multi-pronged approach involving strategic execution of both end-of-the pipe and small scale/small site watershed management actions, as well as reconfiguring Lake George and implementing a phased construction of interceptor pipes along the east side of the river was the best strategy to follow.

The critical elements endorsed by the TAC and Stakeholders Committee are as follows:

- Reconfigure Lake George into a multi-cell system separated from the river during baseflow and small to moderate runoff events.
- Construct the east interceptor (which includes capturing runoff from Econo Foods) as well as the first phase of the north interceptor up to Walnut Street.
- Extend the north interceptor as opportunities arise, such as during downtown redevelopment projects or road/alley reconstruction.
- Construct one or more “end-of-pipe” projects designed to infiltrate runoff on existing City-owned land, such as in Heritage Park on the west side of the river.
- Concentrate on one to several storm drainage sewersheds to work with private property owners to find suitable sites for, and install, small scale stormwater treatment features such as rainwater gardens. These efforts could focus on parts of the study area where diverting runoff to a reconfigured Lake George for treatment is not feasible, end-of-the-pipe treatment strategies may not be practical, or neighborhood interest and cooperation may be very high.
- Develop and execute a public education program aimed at building understanding of and support for the overall management strategy and its various components among the general public as well as the business community.

It was also recognized that there are still important actions that need to be undertaken before the concept for the Lake George reconfiguration can be finalized and design completed. The main issues are:

- Collecting reliable bathymetric information on the existing lake
- Locating possible natural spring groundwater discharges to the lake
- Assessing in greater detail the engineering properties of the sediment within the lake
- Beginning the process of identifying and developing the information needed to secure regulatory permits, especially those necessary to work in the bed of the river at Lake George
- Investigating flowage rights and underlying ownership of the lake
- Identifying possible funding sources for implementation

1.0 Introduction

This project centered on assessing and evaluating a portion of the Kinnickinnic River watershed that drains through Lake George and includes downtown and adjacent residential areas between Division Street and the dam. Figure 1 shows the general location of the study area within River Falls, WI.

The primary purpose of the project was to establish the basis for, and recommend, management actions to protect the river. It was the intent of the project to evaluate a broad range of management options, including retrofitting existing drainage systems to reduce thermal and sediment impacts under both baseflow and runoff conditions between Division Street and immediately below Lake George. It was also intended to identify and evaluate alternatives for reconfiguring Lake George to enhance and improve the quality of the river.

This plan provides guidance on executing the improvements that will benefit the river, be compatible with the City's vision of the downtown area, and have a reasonably good chance of being accepted by management agencies and interest groups concerned with the river.

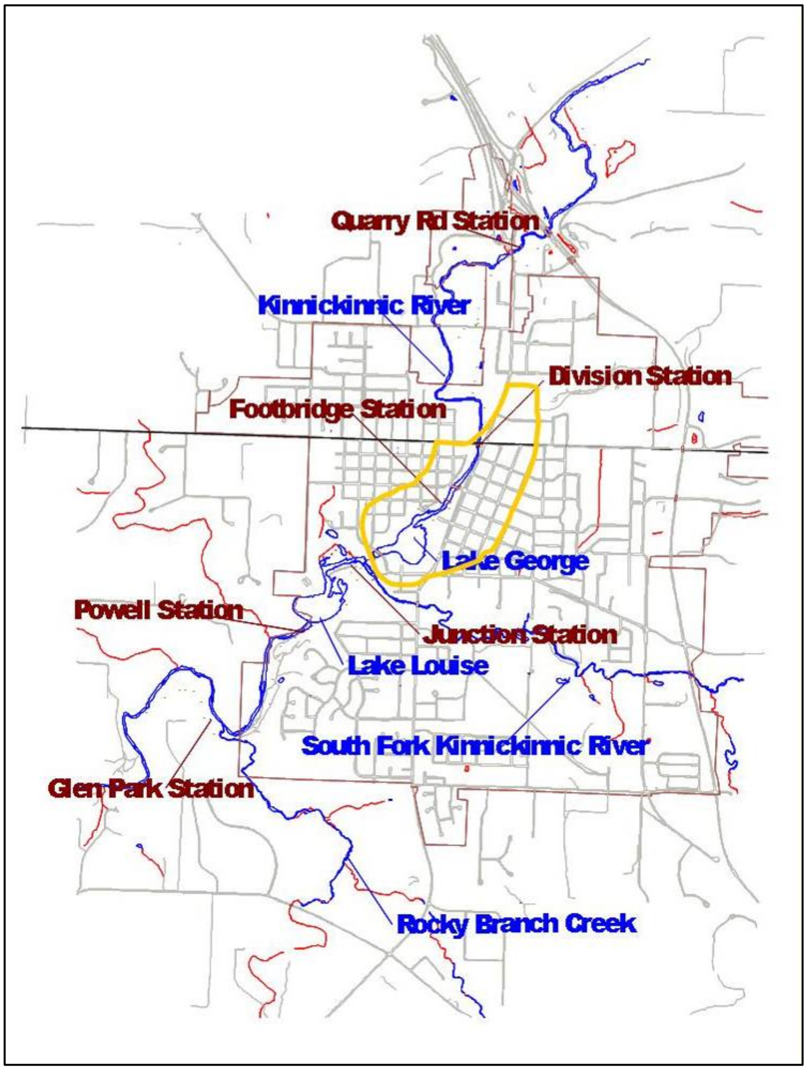

Figure 1: Study Area Location

2.0 Water Quality Primer

The Kinnickinnic River is one of the Upper Midwest's premier trout streams. It is designated a Class I trout fishery by the Wisconsin Department of Natural Resources, meaning that the trout fishery is to be managed as self-sustaining through natural reproduction alone.

Habitat protection is a critical component of protecting the trout fishery, and water quality is a crucial aspect of trout stream habitat protection. Two habitat parameters that are of special interest are temperature and sediment. Temperature is important because trout and many of the organisms they feed on (especially aquatic insects) are temperature sensitive and need a plentiful source of relatively cool water throughout the year to thrive. The most common source of cool, clean water on which trout streams rely is groundwater seepage.

Sediment is a concern because too much fine sediment can bury the gravel and cobble on the stream bottom, smothering the aquatic insects that live on or in the void spaces of these substrates. In addition, trout often use gravel and cobble areas for spawning, so excessive sediment can bury these areas and thus make them unsuitable for egg survival. Finally, other pollutants to which aquatic organisms are sensitive, such as heavy metals, are often attached to sediments and can be carried into the waterway along with the sediment.

Appendix A at the back of this report identifies several papers and books that provide much more detailed and comprehensive technical information on the concerns with these pollutants and the nature of their impacts on aquatic habitat.

Urban stormwater runoff contains a wide range of pollutants that can degrade water quality. In developed areas, impervious coverage (roads, parking lots, rooftops, etc.) is often a key indicator of the mass of pollutant loading that will be generated by a particular land use. In general, the higher an area's impervious coverage, the higher the pollutant load that can be expected from that area.

This is particularly true for temperature and sediment. During warm periods when solar radiation is high, impervious surfaces (especially darker surfaces like asphalt) absorb heat and can reach a temperature significantly higher than the surrounding air. If a rainfall event occurs, the water that runs across these surfaces causes the transfer of a large portion of that heat to the runoff itself. If the runoff discharges directly to a sensitive coldwater resource like the Kinnickinnic River, it can raise the temperature of the receiving water enough to adversely affect its aquatic ecology. The risk is especially acute when the receiving water is already warmer than desirable because of heat it may have absorbed already through the surface of the water.

An example of this type of impact on the Kinnickinnic River as it flows through the downtown River Falls is shown in Figure 2a and 2b. Both graphs show monitored stream temperature data for the river at several locations just before, during, and immediately after a runoff event generated by a 2.2" rainfall between 9 P.M. and 10 P.M.

In Figure 2a, the spike in river temperature at both Division Street and Footbridge caused by the runoff event push the peak temperature close to the "severe stress" temperature threshold of macroinvertebrates that typically colonize the substrate. Macroinvertebrates that frequent trout streams are important as forage to support trout populations. However, they are also particularly vulnerable to thermal and other impacts, partially because they have a relatively narrow range of tolerance, have a low tolerance for rapid changes in temperature, and because of their relative immobility (they can't simply swim to a more favorable environment).

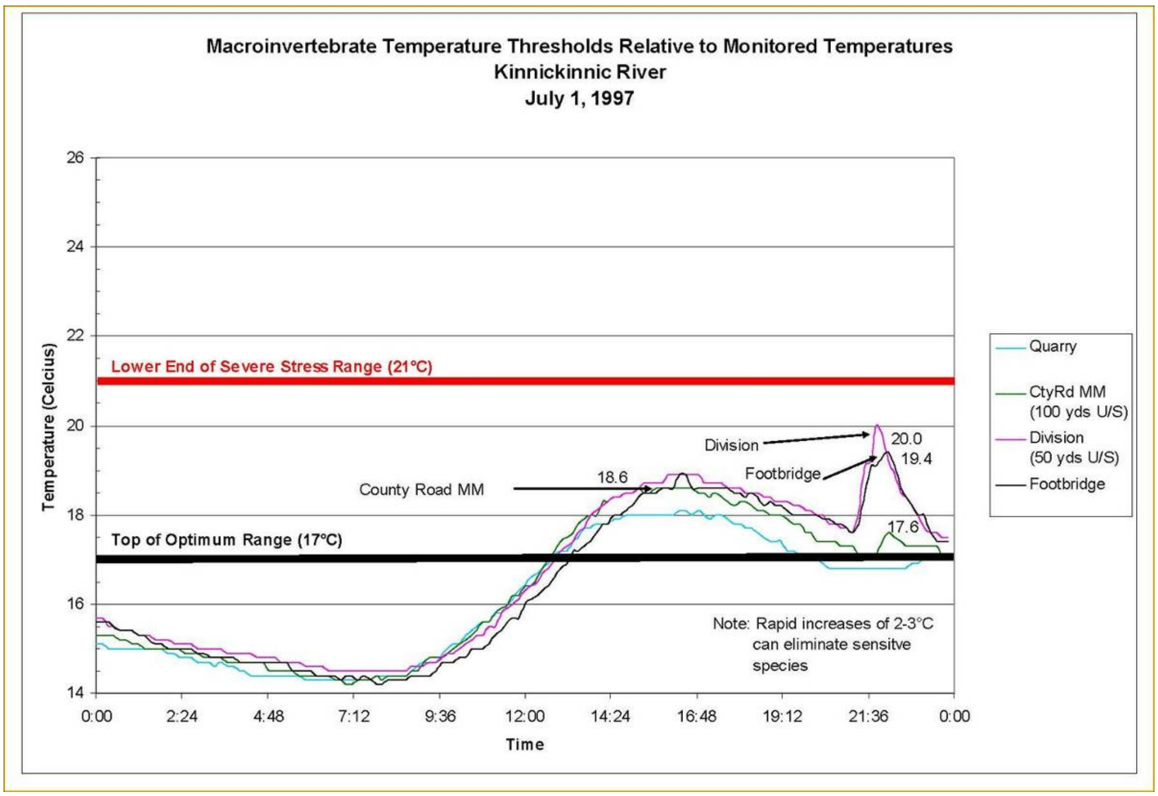

Figure 2a: Runoff-Induced Temperature "Spike" Relative to Temp Tolerances for Macroinvertebrates

The severity of the condition is somewhat less acute for brown trout (Figure 2b), both because of their tolerance to higher temperatures and their mobility. Note, however, that the field examples shown here likely do not represent an extreme condition in the river and that it is very conceivable that conditions do periodically occur that put significantly more stress on the biota in the system than shown in these examples.

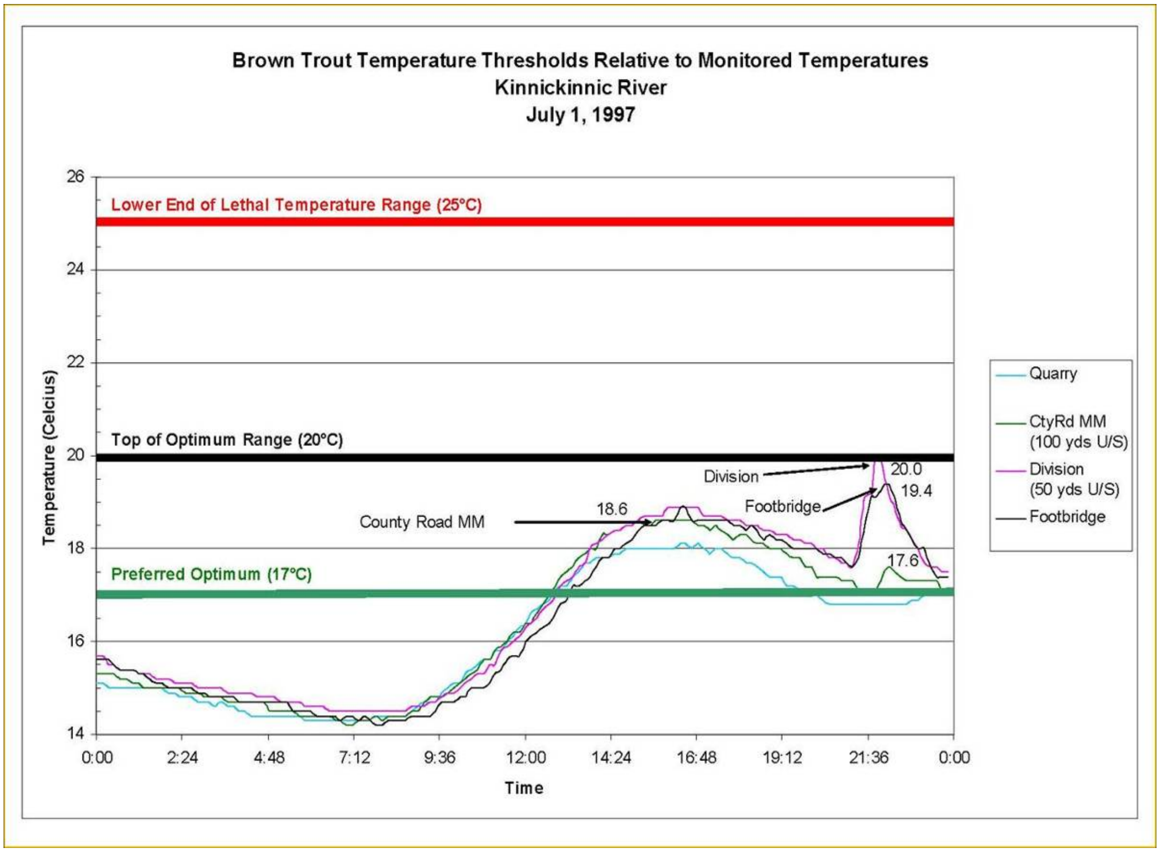

Figure 2b: Runoff-Induced Temperature "Spike" Relative to Temp Tolerances for Brown Trout

Impervious coverage also affects sediment generation and delivery in urban environments. Major sources of sediment in an urban environment include atmospheric deposition, construction site erosion, and vehicle tracking. Once the sediment makes it to an impervious surface that is connected to the storm drainage system, runoff serves as the method of transport that carries that sediment to the downstream receiving water. For much more regarding the impacts of impervious coverage on aquatic systems, see the Center for Watershed Protection publication (March 2003) listed in Appendix A.

Another water quality issue associated with this reach of the Kinnickinnic River is associated with the impact of the two reservoirs, Lake George and Lake Louise. Reservoirs can have multiple effects on stream water quality, both bad and good.

The primary issue of concern with Lake George and Lake Louise is the warming of the river water that occurs as it moves through the reservoirs during warm periods of the year (usually between June and September). Because the reservoirs have a large surface area and are relatively shallow, the surface water temperature in the reservoirs can rise well above the optimum for trout on days when solar radiation and air temperature are high. Data collected by the Wisconsin Department of Natural Resources (WI DNR) and Trout Unlimited (TU) indicate that increases in stream temperature of 2-4 degrees C are not uncommon from just above Lake George reservoir to just below Lake Louise (Schreiber, 1998).

3.0 Project Background

The City of River Falls is located in western Wisconsin in Pierce County. The population of River Falls was 12,560 according to the 2000 census, an increase of about 18% over the 1990 census population of 10,610. Virtually all of the City of River Falls (approximately 4,000 acres) generates runoff that eventually reaches the Kinnickinnic River.

With the help of a federal Clean Water Planning Grant awarded to the City by the Wisconsin Department of Natural Resources, the City prepared a document entitled *Water Management Plan for the Kinnickinnic River and Its Tributaries.* Completed in 1995, one of the primary objectives of the Plan was to "deliver good quality stormwater runoff to the Kinnickinnic River at acceptable rates and volumes, to reduce pollutant loading and stream bed/stream bank degradation, and maintain a river temperature suitable to support a coldwater fishery."

The *Water Management Plan* identified the need to revise existing City ordinances regarding stormwater management. The City Council adopted a new Stormwater Management Ordinance on April 9, 2002. The purpose of this ordinance is to accommodate anticipated community development and land use practices, while controlling the quality and quantity of stormwater runoff, and properly managing and protecting groundwater resources as well as the physical habitat of the Kinnickinnic River and its tributaries, and set forth stormwater management and erosion control standards which apply to all land development and land disturbing activities.

A key component of these protective measures is the requirement that all new developments incorporate features to infiltrate runoff from up to the 1.5" 24-hour rainfall. This requirement is among the most progressive in the Upper Midwest and shows the City recognizes that:

- The native soils in River Falls are generally of good permeability and suitable for infiltration practices
- Infiltrating runoff into the ground is the best way to protect sensitive resources like trout streams from thermal, total suspended solids and other runoff-generated impacts associated with urban development
- Converting surface runoff to groundwater through managed infiltration also helps sustain the groundwater seepage that provides cool, high quality baseflow essential to trout streams

Many areas of the City of River Falls were developed before the detrimental impact that urban development can have on coldwater resources was widely recognized. Among the areas of highest concern is the downtown area.

This area is of high priority because:

- It contains areas of very high impervious coverage, especially in the commercial area east of the river
- It contains the oldest developed parts of the City and therefore has little in the way of runoff mitigation measures
- Runoff from this area discharges directly to the Kinnickinnic River untreated

Reconfiguring Lake George was identified as a potential project in the *City of River Falls Water Management Plan* (SEH 1995). In 1996, the University of Wisconsin-River Falls, in cooperation with the City of River Falls, obtained a Lake Planning Grant from the Wisconsin Department of Natural Resources to prepare a Lake George Management Plan (Swanson and Huffman 1996). The Lake George Management Plan considered the following four alternatives:

- Alternative I – Do Nothing
- Alternative II – Remove the Lake George Dam
- Alternative III – Complete Dredging of Lake George
- Alternative IV – Construct an Artificial Wetland/Steam Channeling Option

The main recommendation from the project was as follows: "After extensive study, considerable discussion with DNR personnel and others, Alternative IV is the recommended alternative as a management plan for Lake George." However, no scientific studies or modeling were conducted to quantify the impacts on the river.

This project was initiated to address questions and concerns regarding implementing a lake reconfiguration strategy. In addition, this project looked at other watershed-centered alternatives to help identify watershed practices that could help reduce TSS and thermal loads caused by existing development in the project area.

The project area encompasses those areas of the City that discharge directly to the river untreated between approximately Division Street and the Lake George dam. Figure 3 shows the study area overlain on a 2002 air photo.

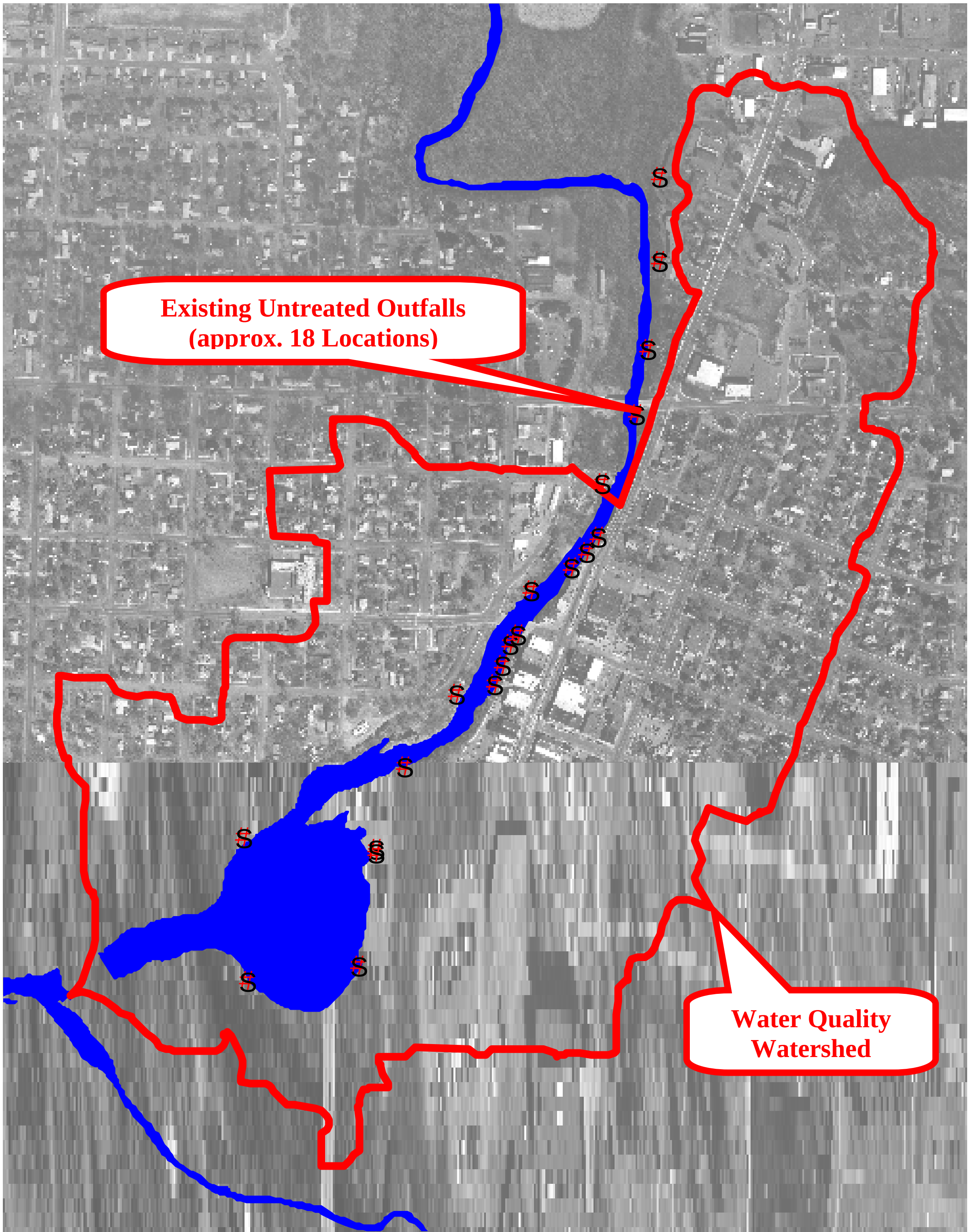

Figure 3: Study Area Boundaries Overlain on 2002 Air Photo

4.0 Approach

This project involved a three-step process. These were:

1. **Identify and evaluate opportunities for watershed management improvements that would benefit water quality in the river**. The improvements should emphasize using infiltration of runoff where practical because of its benefits in reducing thermal and other pollutant loading as well as recharging the shallow aquifer that likely discharges to the river.

2. **Identify and evaluate opportunities for reconfiguring Lake George in a way that benefits the river.** The selected alternative must work whether the Lake George dam stays or is removed, and the reconfiguration must be compatible with the City's ultimate vision of this area as a complement to downtown redevelopment that will turn back toward the river as a high-quality scenic and recreational asset.

3. **Merge the two to form an overall strategy** that has a positive benefit to the river, is cost-effective, and has a reasonable chance of being accepted by the community and permitted by the regulatory agencies.

Two advisory groups were formed to help provide guidance for this project. The first was the Technical Advisory Committee (TAC). This group was comprised of seven representatives from the Wisconsin Department of Natural Resources, Trout Unlimited, the University of Wisconsin River Falls, and City staff. These individuals offered water management strategic and technical expertise in scoping and executing the technical analyses and identifying and evaluating the various management options.

The second group was the Stakeholders Committee, comprised of eleven members representing a range of interests in the community. They provided valuable guidance in developing the overall management strategy proposed in this plan. Participants for each advisory group are listed in Appendix B. Between March 2003 and December 2004, 14 meetings were held with these groups to guide the development of this strategy.

5.0 Study Area Characterization

An early step in this project was to characterize subwatersheds within the study area as a precursor to modeling and identifying management options. Among the most important aspects of this step was the delineation of the areas drained by the 22 storm sewers discharging to this reach of the river as well as characterizing the land use—and thus impervious coverage—within each "sewershed."

A base map was prepared using a digital orthoquad aerial photo (2002) of the study area overlaid with the City's storm sewer system and 2-foot topographic contours. The sewersheds were preliminarily delineated based on topography and curb and gutter flow (catch basins) as well as building placement. All the preliminary sewersheds were field-verified and adjusted where appropriate. The location of the sewershed boundaries were then digitized using GIS. Impervious coverage within each sewershed was then determined.

Digital land use data was obtained from the City for the project area. The land use and sewershed data were manipulated with GIS software to determine the proportion of different types of land use within each drainage area. The 205J plan database was used to determine impervious coverage for particular land uses in the sewersheds. In this manner, the percent of impervious area for each sewershed was determined. The impervious areas of the study area were also field inspected and corroborated with the base map.

The results of this effort are shown in Map 1 (back of the report) and Table 1. Map 1 shows locations of, and labels for, the storm sewer outfalls at the river as well as the main storm sewer lines associated with the outfalls. Boundaries for the area drained by each storm sewer discharging to the river are also shown and the sewershed associated with each outfall labeled. Table 1 (below) shows information on the size and impervious coverage of each sewershed. It also provides a breakdown of the sewersheds by sub-reach within the study area river reach and by side of the river from which the storm sewer discharges.

Table 1 - Project Area Storm Sewershed Characterization

Reach	Sewersheds Discharging from East of River				Sewersheds Discharging from West of River			
	Sewershed #	Total Area (ac.)	Imp. Area (ac.)	% Imp.	Sewershed #	Total Area (ac.)	Imp. Area (ac.)	% Imp.
Above Division St. to Maple St.	1.4	4.1	2.3		2.3	7.9	3.5	
	1.5	8.2	4.3		2.5	15.3	6.3	
	1.6	5.1	1.6					
	2.1	16.1	5.3					
	2.2	14.6	5.3					
	2.4	11.7	6.4					
	Subtotals	59.8	25.2	42%		24.2	9.8	40 %
Maple St. to Footbridge	3.1	15.8	8.2					
	Subtotals	15.8	8.2	52%			~	~
Footbridge to Walnut St.	4.2	1	.9		4.1	4.5	1.2	
	4.3	12.9	8.1		4.5	3.9	1.6	
	4.4	13.3	8.4		4.6	4.5	1.4	
	Subtotals	27.2	17.4	64%		12.9	4.2	33 %
Lake George	5.1	4.2	3.6		5.4	5.8	1.6	
	5.2	17.6	11.1		5.5	1.8	.5	
	5.3	6.3	3.0					
	Subtotals	28.1	17.7	63%		7.6	2.1	28 %
Total for Study Area		130.9	68.5	52%		44.7	16.1	36 %

Following are some key "take home" messages from this information;

- The project study area is approximately 176 acres in size, not including the river and Lake George.
- Of this area, about 85 acres (48% of the study area) are covered by impervious surfaces (mainly roadways, roof-tops, and parking lots).
- The area east of the river contains most of the impervious area within the project area. Approximately 68 acres of impervious area drains to river from the east side compared with 16 acres from the west side.
- The average impervious coverage of subwatersheds draining to the east side of the river is 52% while those that drain from the west average about 36%.

6.0 Approach to Modeling of Pollutant Loads and River Temperatures

Two models were used to help evaluate the various alternatives for both watershed improvements and reconfiguration of Lake George. The urban watershed water quality model P-8 was used to estimate total suspended solids loads to the river. To evaluate thermal impacts to the river, the model CE-QUAL-W2 was used. An overview of both models and their use for this project are described below.

P-8 Urban Watershed Model (Version 2.2): This model, initially developed by developed by W.W. Walker in 1991, is a simulation model used for estimating the generation and transport of a variety of pollutants in stormwater runoff from urban watersheds. The pollutants that can be modeled include total suspended solids (TSS), total phosphorus, total nitrogen, and hydrocarbons as well as some heavy metals.

The P-8 model is geared towards urban landscapes and relies heavily on impervious area information to predict pollutant loads from watersheds. The model simulates pollutant transport and removal in a variety of treatment devices (Best Management Practices) including grassed swales, buffer strips, ponds, and infiltration features. The model is initially calibrated to predict runoff quality typical of that measured under the U.S. EPA's Nationwide Urban Runoff Program (NURP).

Modeling for this assessment was based on the median (as opposed to extreme) runoff concentration profile. Hourly precipitation and temperature data from the Minneapolis/Saint Paul International Airport between 1949 – 1989 was used to provide the base data to run the simulation for estimating average annual TSS loads generated from the various sewersheds.

CE-QUAL-W2 Model Version 3.1.: This model was used to estimate the thermal impacts to the river system under various scenarios. CE-QUAL-W2 version 3.1 is a two-dimensional (longitudinally/vertical), hydrodynamic and water quality model suitable for relatively long and narrow water bodies that exhibit vertical and longitudinal gradients.

The model was adapted to the Kinnickinnic River by the U.S. Army Corps of Engineers under the guidance of the TAC. A detailed description of that modeling effort, including methods and results, is included in the report by Noren (January 2004) in Appendix C. As shown on Figure 1.1 of that document, the model extended well outside the immediate project area, with the upper and lower boundary conditions being Quarry Road gaging station and the Glen Park below the river's confluence with the Rocky Branch.

Inputs to the model included bathymetry data, meteorological data, time-varying in-stream water temperatures and flows, hourly dam releases, and time-varying storm sewer temperatures and flows (generated by a separate thermal model called TURM). In order to run CE-QUAL-W2 on the Kinnickinnic River, several input data sets were needed.

The available data supplied for the study were from the summer of 1996 and 1997. Because of the lack of tributary data from 1996, model runs were completed using only 1997 data. Specifically, data from two 1997 runoff events—the first on July 15 1997 and the second on July 1 1997—were used to develop and help calibrate the model. For the purposes of modeling, the 22 storm sewers discharging between roughly Division Street and the Lake George were represented as three nodes in the CE-QUAL-W2 model.

7.0 Watershed Best Management Practice Evaluation

7.1 Qualitative Evaluation of BMPs

The first step in proposing watershed BMPs for the study area was an identification and qualitative evaluation of individual practices. A summary of that assessment is included in the back of this report as Appendix D.

These practices were broken up into three categories. The first were those practices that were suitable for end-of-the-pipe applications where installation at a small number of sites could be expected to have a relatively large benefit. In the context of the project area, it meant that one or two of these systems could be installed at the lower end of a sewershed to catch and treat the initial flush of runoff that carries the bulk of the thermal and other pollutant loading.

An example of this type of treatment is the installation of a flow-splitter in the main storm sewer line that directs runoff from small frequent storm events to an underground pretreatment unit and infiltration trench (shown schematically in Figure 4).

The appeal of this treatment strategy is that it holds the potential for relatively high cost effectiveness, since pollutant loadings from relatively large areas could be addressed with just one or a few projects. The primary downside is that the area needed for installing the treatment facilities are somewhat large and rely on the availability of City-owned land that could be used for this purpose in a suitable location near the bottom of the sewershed.

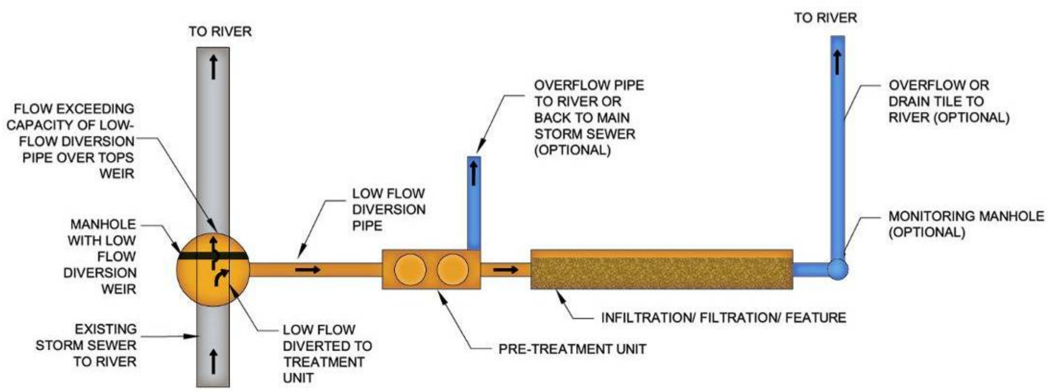

Figure 4: Schematic of Low-Flow Diversion to Pretreatment Unit and Infiltration BMP

The second category included those practices that were considerably smaller in scale, but if done at a large number of sites in a sewershed could have a significant cumulative impact.

Examples include rainwater gardens located in the boulevard areas to catch and infiltrate runoff from small sections if roadway or parking lots (Figure 5), rainwater barrels to catch and hold rooftop runoff, and redirection of downspouts carrying rooftop runoff from impervious areas (Figure 6) to pervious areas where the runoff has a better chance of soaking into the soil.

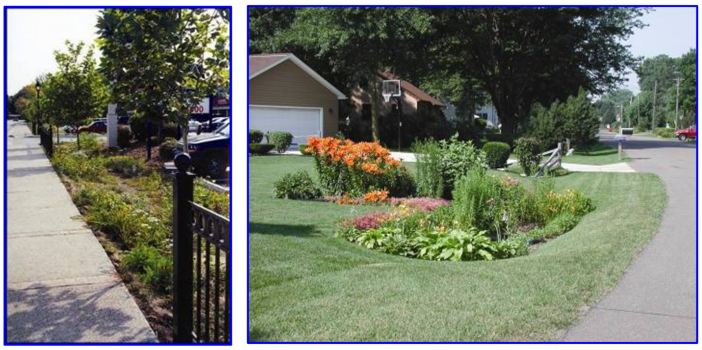

Figure 5: Rainwater Garden Designed to Treat Impervious Area Runoff

Figure 6: Downspout that Could Be Redirected to Pervious Areas

Identifying locations for these BMPs often necessitates a street-by-street and often a lot-by-lot evaluation, and such a detailed evaluation was beyond the scope of this study. However, there was a strong feeling among members of the TAC that these practices should be actively promoted in the project area, with those sewersheds where end-of-pipe treatment is not feasible receiving highest priority.

The third category of BMPs evaluated was a catch-all category that included enhancements to maintenance and education programs. Linking public education efforts with both end-of-the-pipe and small scale projects to promote infiltration was viewed as an especially important strategy to increase public understanding and support for the Category 1 and 2 BMPs.

7.2 Modeling to Identify Priority Sewersheds

The next step in the watershed analysis was to quantify and compare pollutant loadings from the sewersheds within the project area and define those of highest priority to help provide guidance for BMP installation. The P-8 model was used in this process. Though it was used to predict TSS loading from each sewershed, the information can also be used as an indicator of thermal loading as well, since both thermal and TSS loads rise as impervious area and watershed area rise.

A summary of the output from the P-8 model is shown in Table 2. The TSS values represent annual estimated loads under average precipitation conditions and existing land uses that are delivered to the outfall of each sewershed where it discharges to the river. The P-8 model predicted that on an average annual basis, an estimated 53,820 pounds of TSS are washed into the Kinnikinnic River and Lake George from the study area.

The average annual TSS load from the various sewersheds ranged from a low of 190 pounds to a high of 7,010 pounds. This variability is driven by the size of the sewershed as well as the amount of impervious cover.

Table 2 - Estimated TSS Loads Delivered By Individual Sewersheds

	Sewershed	Total	Impervious	Ave. Annual Loading (lbs)	
Reach	I.D.	Acres	Fraction	TSS	TP
Above Division	1.4	4.1	55%	1,430	4.6
	1.5	8.2	53%	2,750	8.9
	1.6	5.1	31%	1,000	3.2
	Total	**17.4**	**47%**	**5,180**	**16.7**
Division to Maple	2.1	16.1	33%	3,370	10.9
	2.2	14.6	36%	3,340	10.8
	2.3	7.9	44%	2,210	7.1
	2.4	11.7	55%	4,080	13.1
	2.5	15.3	41%	3,970	12.8
	Total	**65.6**	**42%**	**16,970**	**54.7**
Maple to Foot Bridge	3.1	15.8	52%	5,220	16.8
	Total	**15.8**	**52%**	**5,220**	**16.8**
Foot Bridge to West Walnut	4.1	4.5	27%	780	2.5
	4.2	1.0	85%	550	1.8
	4.3	12.9	63%	5,150	16.6
	4.4	13.3	63%	5,310	17.1
	4.5	3.9	42%	1,040	3.3
	4.6	4.5	31%	890	2.9
	Total	**40.2**	**59%**	**13,720**	**44.2**
Lake George	5.1	4.2	85%	2,270	7.3
	5.2	17.6	63%	7,010	22.6
	5.3	6.3	47%	1,890	6.1
	5.4	5.8	28%	1,030	3.3
	5.5	1.8	30%	340	1.1
	5.6	1.0	30%	190	0.6
	Total	**36.7**	**45%**	**12,730**	**41.0**

Based on this information, several observations can be made:

- Of the 21 storm sewersheds discharging to the river and Lake George, six—2.4, 2.5, 3.1, 4.3, 4.4, and 5.2—comprising 39% of the total area of all sewersheds contribute 57% of the total estimated TSS load entering the system.
- Eight sewersheds of the 21—all of the above plus sewersheds 2.1 and 2.2—comprising 56% of the total area of all project area sewersheds contribute 70% of the total estimated TSS load entering the system.
- Sewershed 5.2 discharges directly to Lake George while the seven other high priority sewersheds discharge directly to the river above Lake George. It is highly likely that Lake George itself significantly moderates the delivery of TSS as well as other pollutants to the main river channel on the far side of the lake by acting as a treatment basin, especially for sewersheds that drain directly to it.

For the purpose of helping define which areas were most important to evaluate for watershed management controls, initial efforts to look for BMP opportunities then focused on those sewersheds listed above that discharge to the river above Lake George.

Those sewersheds are shown on Figure 7 and identified as either Priority 1 sewersheds (2.4, 2.5, 3.1, 4.3, and 4.4 shown in blue) or Priority 2 sewersheds (2.1 and 2.2 shown in yellow). With the exception of sewershed 2.5, all of the priority sewersheds lie east of the river, have a relatively high impervious coverage (57% for the Priority 1 sewersheds and 34% for the Priority 2 sewersheds), and are relatively large.

Figure 7: Priority 1 and 2 Sewersheds

The CE-QUAL-W2 model was not developed at a fine enough resolution to quantify the input of individual sewershed inputs on the thermal regime in the river. However, urban watersheds with higher impervious coverage and larger area can be expected to generate higher thermal loads, all other factors being equal. Since these factors are also the dominant drivers in TSS loading from urban areas, it is reasonable to assume the sewersheds identified as high priority based on estimated TSS loadings would be of high priority for control of thermal loadings as well.

7.3 BMP Opportunities

After identifying the priority sewersheds, a process occurred to assess these areas for opportunities to implement potential BMP improvements. This process involved evaluating several criteria, including:

- Available space in the urban environment, particularly in the downstream portion of a sewershed
- Adequate infrastructure to maintain a gravity-drained system for any BMP opportunities
- Cursory sizing exercise to evaluate if the footprint of a potential BMP could fit within the anticipated space

Evaluating BMP opportunities first focused on applying the above criteria to the high priority sewersheds shown in Figure 7. After the initial screening for the high priority sewersheds, the search for additional end-of-the-pipe BMP sites was largely opportunity-driven and included virtually all sewersheds discharging to the river above Lake George.

The main factor needed to identify these opportunities was the location and size of City-owned land that could be used to construct a BMP to treat runoff carried by a particular storm sewer. This was driven largely by the City's desire to avoid land acquisition, which can be a potentially large component of overall project costs.

Sizing of BMPs is an important consideration, especially in so-called "retro-fit" applications where the BMP must be fit within existing infrastructure of a built-up area with established elevations and dimensions that cannot be altered without incurring considerable cost. In these applications, it is especially critical to gear the size of the BMP to treat that portion of the runoff volume that carries the greatest pollutant load.

In urban environments, pollutant loading and delivery is largely dictated by the level of impervious coverage and the high delivery efficiency of the stormwater conveyance system. It is generally acknowledged that the early portion of runoff volume from a precipitation event carries a relatively large quantity of pollutants compared to the rest of the event.

In terms of TSS transport and delivery, this is true because the runoff early in a storm washes particles into the conveyance system that have accumulated on impervious surfaces since the last runoff event. For thermal load transfer on a summer day, the temperature difference between hot pavement and rainwater falling on the pavement is greatest at the beginning of the runoff event, so heat transfer between the pavement and the runoff is greatest at the beginning of the event as well.

Capturing the first 0.2" of runoff from an urban watershed will substantially eliminate most of the thermal impacts (Steve Greb-WiDNR, communication to the TAC, April 2003) and significantly reduce TSS loading as well. This figure, approximately equal to capturing the runoff from a 0.5 rainfall event for the downtown area, was the design guideline used to size the end-of-the-pipe BMPs for this portion of the project.

Table 3 presents the results of the watershed BMP assessment and Figure 8 shows the location of some of the BMP opportunities identified, along with estimates of the TSS and thermal load reduction benefits as well as estimated construction costs.

Table 3: Results of Sewershed BMP Assessment

Priority	BMP(s)	Sewersheds Affected			TSS Red. Benefit[1]	Thermal Benefit[2]		Construction Cost	Maint. Cost (Annual)
		Nos.	Total Area (ac.)	Impervious Area (ac.)	Reduction (lbs/yr)	Baseflow	Runoff		
First	Infiltration	2.1, (1.6) 2.5, (4.1)	41	15.7	4,800 (53% red.)	None	<0.1° C	$220,000-320,000	$3,700 – 4,800
Second	Thermal swale, shaded pond	2.3, 4.3, 4.4	34.1	20	5,400 (43% red.)	None	<0.1° C	$90,000-110,000	$1,800-2,100
Third	Small site/small scale BMPs	3.1, 2.4, 2.2	42.1	19.8	Est. 6,000 + (50%+)	None	<0.1° C (Est.)	$60,000 - $120,000 (Est.) just for rainwater gardens (see Comments)	Variable, depending on number and type of BMP
Fourth	Grit Removal	1.4, 1.5, 4.2, 4.5, 4.6	21.7	10.5	2,800 (45% red.)	None	None	$145,000 - $190,000[3]	$3,700 - $4,100

1 *Estimated at point of discharge to river*

2 *Estimated at location immediately downstream of Lake George*

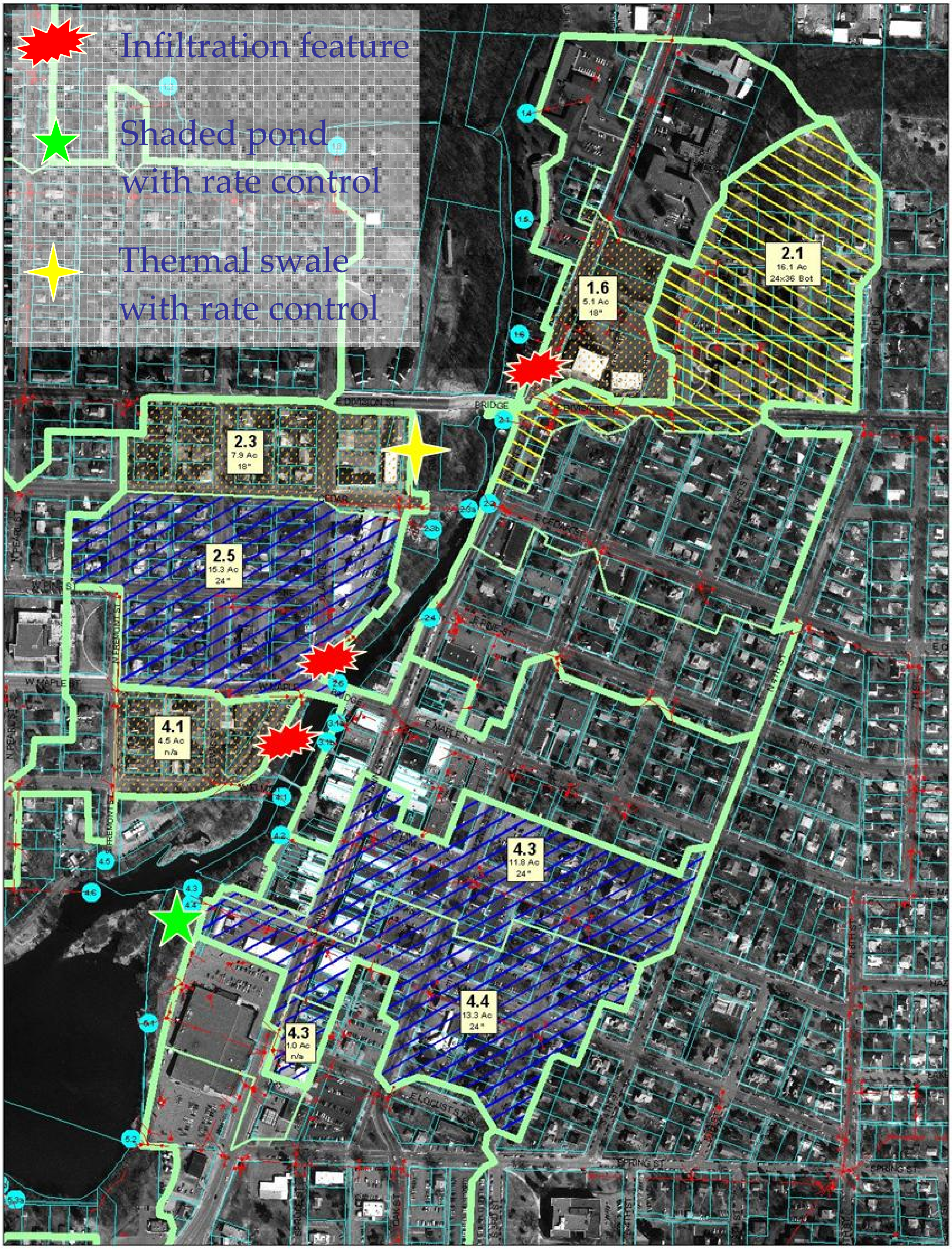

Figure 8: Location of Watershed BMP Opportunities

The BMPs presented in the table are grouped in priority. The BMPs and their priority are explained in more detail below.

- **Category 1:** These improvements are ranked highest because they serve some of the highest priority sewersheds identified in the previous section with end-of-the-pipe BMPs that emphasize infiltration of the first-flush of stormwater runoff. Both rely on the installation of a structure on the main line(s) of the sewershed that would direct the first flush of stormwater to an underground pretreatment device, which would in turn discharge to an infiltration trench or rainwater garden.

  The pretreatment devices take up relatively little space and therefore are less likely to interfere with existing uses in this heavily developed area of the City. As noted in the table, with minor modifications/expansion of the BMP, small adjacent sewersheds could also be served by the same facility.

- **Category 2:** This category includes two different BMPs that take advantage of available terrain features to divert, catch, and slowly release the first flush of runoff. The first is an existing shaded depression located adjacent to the bottom of sewersheds 4.3 and 4.4 – both of which are high priority sewersheds on the east side of the river –to which runoff would be diverted, held to settle particulates and cool the water, then released back into the river through a controlled outlet.

  The second would serve sewershed 2.3 on the west side of the river by pre-treating the water first with an underground pretreatment device, then discharging the pre-treated water to a shaded thermal swale where it would be cooled and slowly released back to the river through a controlled outlet. While incidental infiltration would probably occur with both, conversion to full infiltration facilities would be significantly more expensive, though technically feasible.

- **Category 3:** This category refers to small-scale, small-site BMPs (such as rainwater gardens) intended to treat stormwater runoff from one or several lots or short street sections and that would be applied in many places throughout one or more targeted sewersheds. As noted in previously in this report, identifying specific locations was beyond the scope of this project, but BMPs emphasizing infiltration of runoff close to where it falls and disconnection of impervious surfaces are of highest priority.

  These types of BMPs were strongly supported by the TAC and, while appropriate for any of the sewersheds in the project area, should probably be targeted at those areas where other treatment options are either infeasible or only marginally desirable/feasible, or where public acceptance and cooperation are exceptionally high.

For comparable cost estimate purposes, sewersheds 3.1, 2.4, and 2.2 were identified, as these are high priority sewersheds for which cost-effective end-of-pipe BMPs have not been identified. However, sewershed 2.3 or one of the other sewersheds west of the river may also be a good test case candidate, since they are largely residential and would thus be expected to have more room to accommodate treatment features.

- **Category 4:** This final category refers to manufactured BMPs like swirl concentrators that could be installed to treat stormwater for TSS. Unlike the BMPs outlined in the first three categories above, these treatment devices by themselves would be ineffective in controlling thermal inputs to the river. Primarily for this reason, they were not recommended for further consideration at this time.

A detailed description of the individual BMPs identified for each of the first and second category groups is presented in Appendix E.

7.4 Summary Comments about Watershed BMPs

Cost-effective applications of BMPs that reduce both TSS and thermal loads from the project area are an important part of the water quality management strategy presented in this report. BMPs that reduce runoff volumes through infiltration deserve priority because they meet the above criteria and likely provide incidental benefits of recharging the shallow groundwater system that helps provide cool baseflow to the river.

The previous sections have outlined some opportunities to install BMPs in the watershed, emphasizing those areas discharging to the live river above Lake George. However, there are a number of high priority sewersheds on the more highly impervious east side of the river (sewersheds 2.2, 2.4, and 3.1) for which cost-effective BMPs are not likely to be found given existing land use patterns.

The difficulty in applying BMPs to mitigate run off impacts from these areas is mainly a consequence of the fact that the sewersheds support intensive land uses which are backed right up to the river and allow little room to install infiltration-oriented BMPs without interfering with those current uses. Redevelopment of this area, if it occurs, should incorporate stormwater treatment features compatible with the new land use patterns.

Another issue that merits more elaboration is the nature of the thermal benefits provided by the watershed BMPs. First, the watershed BMPs address treatment of runoff events. Thus, **watershed BMPs do not inherently have any significant beneficial impact on baseflow temperature regimes in the river** (other than perhaps some relatively small benefit associated with additional groundwater discharge generated by increased infiltration).

Warming of river water in the system under baseflow conditions during warm weather periods has been identified as a significant concern and is acknowledged to be caused mainly by warming of river water as it passes into the downtown area and eventually through the reservoirs (Schreiber, 1998). **This is important because the baseflow condition is usually the dominant condition during the summertime critical period**.

Figure 9 shows the frequency of daily rainfall events between June 1 and September 30 for the period of record 1971-2000. The graphic shows that almost 80% of the days during this time period have no precipitation. Thus, assuming the distribution of precipitation can be used as rough surrogate for stream flow (i.e., when there is no rainfall, stream flows generally reflect the baseflow condition), this information indicates that baseflow conditions dominate the flow regime of the river during the critical summer period.

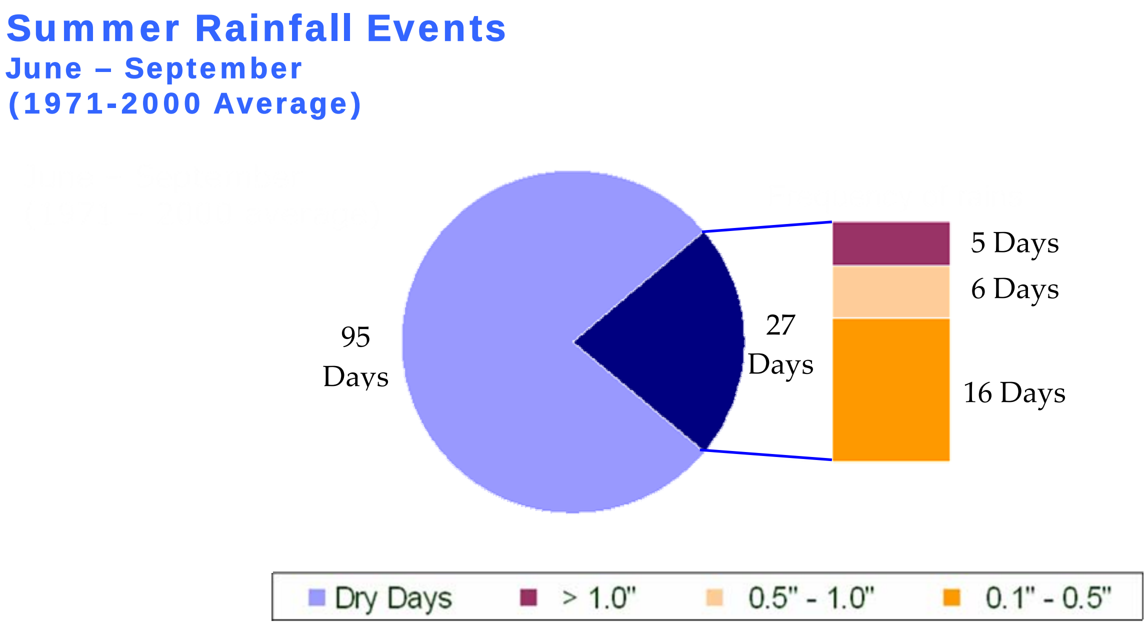

Figure 9: Average Rainfall Frequency June – September (1971-2000)

A second important consideration is the effect of Lake George on watershed BMP-induced thermal benefits showing up below the reservoir. The CE-QUAL-W2 model was used to estimate the effect of eliminating runoff from over 50 acres of the downtown area for the July 1, 1997 storm to approximate the impact of full application of watershed BMPs in the areas proposed.

The outcome of this analysis is discussed in more detail in Section 8.4, but the main conclusion is that while there is some benefit in terms of in-stream temperature reduction at the Footbridge above Lake George, **the thermal benefits of watershed BMP application are virtually eliminated in passing the river water through Lake George in its current configuration.**

Nonetheless, it was acknowledged that selective implementation of watershed improvements was desirable because of their overall beneficial impact in reducing the export of common urban pollutants to the river (TSS, heavy metals, phosphorus, etc.) and the likelihood that infiltration-oriented BMPs provide some incremental benefit in improving baseflow.

8.0 Lake George Reconfiguration

The second phase of this project was to identify and evaluate options for reconfiguring Lake George. Reconfiguration of Lake George is of interest for the following reasons:

- **Reconfiguring Lake George has the potential to significantly benefit water quality in the river.** For example, there is ample documentation that Lake George has a warming effect on the river under both baseflow and runoff conditions during critical parts of the year when water temperatures are already pushing the upper limit of optimum thresholds for some biota (Schreiber, 1998; Johnson, 2004). The TEAC expressed a strong interest that any reconfiguration alternatives selected have a demonstrable positive effect on thermal regimes in the river under both baseflow and runoff conditions.

- **The City is interested in improving the usability of this area by the public.** Downtown revitalization plans are likely to include turning back toward the river as a scenic and recreational resource unique to the City. This area has the potential to be a vital part of the City trail system as well as a place for other passive uses in a quasi-restored natural community.

8.1 Overview of Approach to Evaluating Lake Reconfiguration Alternatives

This phase of the project followed a multi-step approach as well. First, several general reconfiguration options were chosen for qualitative evaluation. After reviewing the results of the qualitative evaluation of options, one or two options were to be selected for more detailed quantitative evaluation, including development of construction cost estimates. The final selected option was then to be combined with the information on watershed BMP evaluation to derive an overall recommended strategy.

The TAC recommended early on that all reconfiguration options include an interceptor pipe that would extend north from Lake George upstream along the east side of the river as far as Division Street. The interceptor was supported because it can eliminate almost all of the TSS and thermal discharges to the river from the most highly impervious portion of the study area between Division Street and the lake, and divert that raw runoff to an area where it can be treated and released back to the river in a controlled manner to minimize impact.

The interceptor pipe would be located to catch and convey runoff from 85% sewershed area in the Priority 1 and 2 sewersheds (the exception being Sewershed 2.5 on the west side of the river). The pipe would be sized to convey runoff from up to a 1 year storm (approximately 2.7" of rainfall in 24 hours) from sewersheds between Lake George and

Division Street, with flow in excess of this amount overflowing to the river through existing outfalls. Runoff captured by the interceptor would be conveyed to a reconfigured Lake George for treatment and be released through a controlled outlet back to the river.

Subsequently, smaller interceptors designed to intercept drainage from other sewersheds discharging along the west and south shores of Lake George were considered as well to convey drainage from these sewersheds to the reconfigured system for treatment. Constructing the interceptor system in phases was also considered.

8.2 Description and Evaluation of Conceptual Reconfiguration Alternatives

Initially, there were four options developed for qualitative evaluation. The options are described below and conceptual drawings of each are shown in Appendix F.

Alternative 1

This alternative involves no reconfiguration of Lake George itself, but rather intercepting and redirecting stormwater from the downtown area east of the river to the lake.

Alternative 2

This alternative is the same as alternative one above, but Lake George would be reconfigured by constructing a low berm to separate the river channel from the remainder of the lake. The berm crest would be approximately three feet above the overflow elevation of the spillway for Lake George and would be constructed of bottom material within Lake George. There would be a reinforced overflow section, either on the berm or on the peninsula to which it is connected, to allow flows from the river during larger runoff events to inundate the lake.

This option could also include gated culverts that could be opened to allow some river flow into the isolated lake for recharge/refreshment if desirable. Flow from the lake to the river would be controlled through one or more culverts in the berm. By restricting the rate at which water from the lake is introduced to the river, the thermal impacts of the lake water on the thermal regime within the river would be much reduced.

Field observations and CE-QUAL-W2 modeling indicates that under the current condition, river and lake water mix indiscriminately and can result in a significant rise in river temperature below Lake George during critical summer periods. This mixing occurs to varying degrees under both baseflow and runoff conditions. Thus, isolating the river from the lake would have thermal benefits to the river for both baseflow and most runoff events.

Alternative 3

This alternative is similar to Alternative 2 above, except that a network of interior berms would be constructed within Lake George to create a multi-celled system. The major benefit of this system is that it would enhance maintenance operations. Under the current proposal, raw runoff from the project area east of the river would be conveyed to Lake George by the various interceptor pipes. Much of the sediment carried in this runoff will settle in the first standing water to which it is discharged.

By diverting the runoff to a single near-shore cell, the heavier sediment which often comprises the bulk of the sediment load can be confined to an area that can be more easily accessed. This facilitates periodic removal of the sediment to reduce the potential for re-suspension and flushing of accumulated sediment into the less easily accessed parts of the treatment system.

Flows between bermed cells would either be through overflow sections on the berms or culverts through the berms. Discharge of the water in the lake to the river would occur as above to minimize the thermal impacts of the stored water.

Alternative 4

The major differences with this alternative are that the surface area of Lake George would be reduced by over half. The change would reduce the quantity of solar radiation the lake absorbs through its surface, an important factor that causes it to warm relative to the river. The intention is to maintain a volume similar to the existing lake by excavating to form a deeper lake with a surface area that is reduced by about 50%.

Other notable features of this conceptual alternative are the use of a thermal swale and/or cooling trench to convey the discharge from the reduced lake to the river in a way that provided further opportunity to cool the water. The rate of discharge into the river would still be controlled, but the swale could be shaded with planted vegetation and underlain with a rock-filled trench to allow water to travel underground to cool it prior to reaching the outlet control at the river.

Table 4 summarizes a qualitative assessment of the four conceptual alternatives described above based on preliminary modeling and technical analysis. The table focuses primarily on water quality benefits to the river for both TSS and temperature.

Table 4: Qualitative Assessment of Lake George Reconfiguration Alternatives

Alternative	Description	TSS and Thermal Benefits			Comments
		TSS Red. Benefit[1]	Thermal Benefit[2]		
		Reduction	Baseflow	Runoff Events	
1	Divert Downtown sewersheds to Lake George, no reconfiguration of lake	Moderate (<50%)	None	Small (<0.5° C)	■ No rate control for outflows from lake to river
2	Same as 1.) but construct single berm to separate lake from river	High (60-70%)	High (~1° C)	Moderate (0.5-1° C)	■ Rate control for outflows from lake to river is key to thermal benefit
3	Same as 1.) but construct multiple berms to separate lake from river	High (60-70%)	High (~1° C)	Moderate (0.5- 1° C)	■ Multi-cell configuration enhances shading slightly, makes periodic maintenance easier ■ Rate control for outflows from lake to river would enhance thermal benefit
4	Same as 1.) but reduce surface area of lake	High (60-70%)	High (~ 1° C)	Moderate (0.5– 1° C)	■ Rate control, possible thermal swale to shade and infiltrate pond discharge from lake to river would enhance thermal benefit

1 Estimated at point of discharge to river

2 Estimated at location immediately downstream of Lake George

8.3 Description and Evaluation of Final Alternative

On October 7, 2004, the Stakeholders Committee met to narrow the list of four conceptual Lake George reconfiguration alternatives described above to one or two for further quantitative analysis and cost estimation. At the end of that meeting, the Stakeholders Committee agreed that the TAC should meet to accomplish that task and present the results of the more detailed assessment at the next Stakeholder Group meeting.

The TAC subsequently developed a single hybrid alternative that combined the features of most of the preliminary concepts. A rendering showing the key features of that plan is shown in Figure 10.

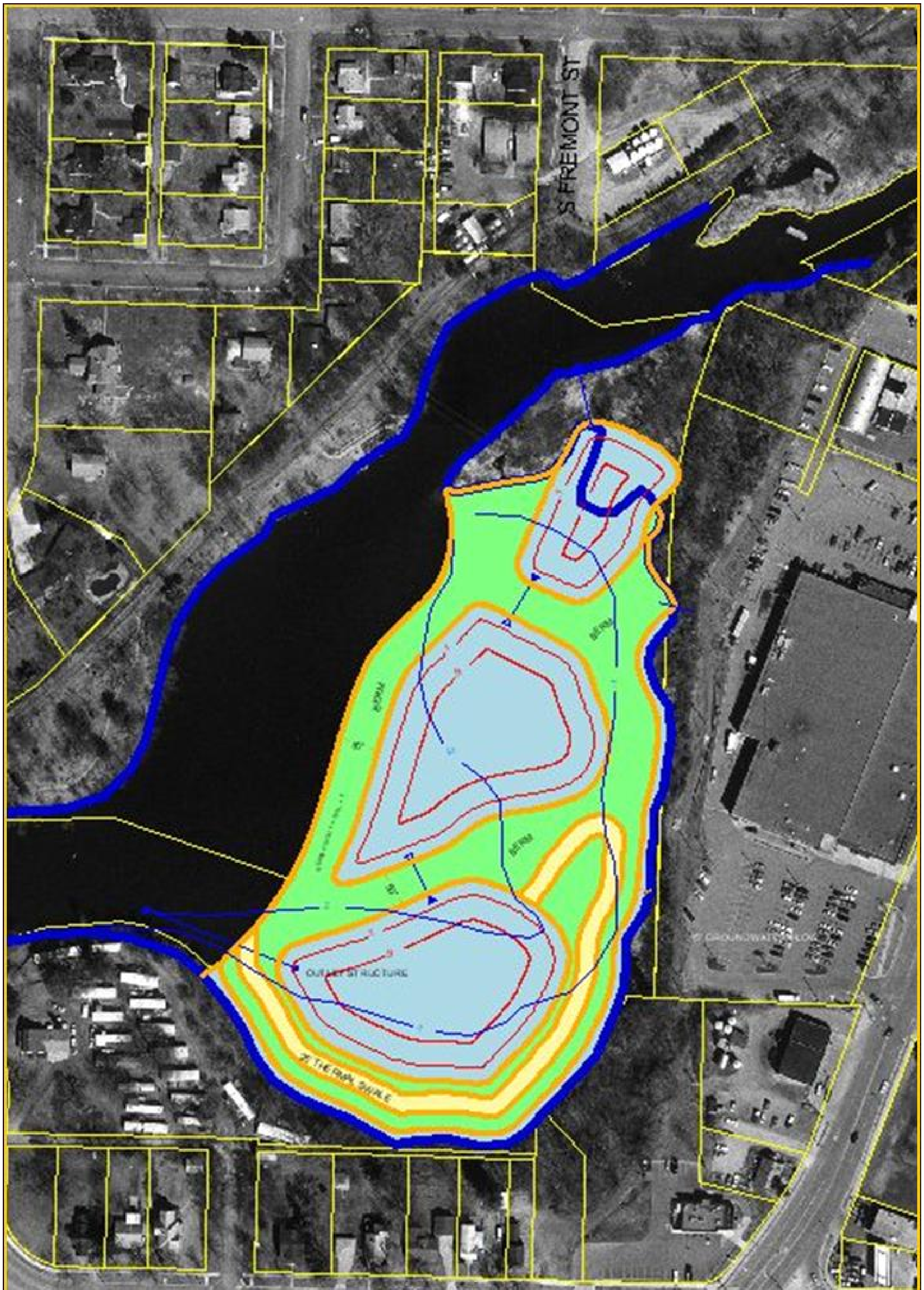

Figure 10: Proposed Lake George Reconfiguration Alternative

The plan contains the following features:

- A multi-cell configuration with the smaller northern-most cell to be used as the first (pretreatment) cell in the system to which raw stormwater from the interceptor system would be discharged. Access would be provided to facilitate periodic removal of accumulated sediment.
- Cells would be deepened to a maximum depth of 7-9 feet. Aquatic benches at no steeper than a 10:1 slope for at least 20 feet into each pond cell would be created for safety and to support fringe emergent growth would be provided at the edge of each cell. This is consistent with City standards for pond creation.
- A thermal swale (yellow line) to carry discharge from the last cell of the reduced lake to the river. As described above, the cell could be shaded and/or underlain by a rock trench to further cool water discharged from the cell before discharged to the river.
- Piped connections between cells to convey water.
- A piped discharge between the last cell and the river with outlet controls. This pipe could be used to discharge water from the last cell to the river and would be constructed to reach the natural channel if the dam is removed.
- A channel to carry natural spring (groundwater) discharges directly to the river without mixing with pond discharge water under most conditions. The location and viability of the springs is not known at this time, thus the location of this channel may need to be adjusted once the nature of the spring discharges is better defined.

Another significant aspect of this plan is the location of the outside toe of the main berm separating the river from the interior cells. This toe has been moved between 80-100 feet to the east to allow for a grade transition area between the toe of the low berm and the natural river channel, should the dam forming Lake George be removed and the river channel return to a pre-impoundment elevation and lateral position.

There is insufficient information to predict accurately where the channel edge would be under this changed condition. However, even with as much as a 15 foot decrease in the elevation of the channel edge from the current impounded water elevation, maintenance of a stable 5:1 slope from the top of the berm to the edge of the stream channel could be accommodated.
Before design and construction of this concept plan can proceed, a more detailed evaluation of the sediment and structural control in this part of the river should be conducted to better estimate the equilibrium position of the channel in the absence of the dam.

8.4 Estimated Benefit and Cost of Final Alternative

The performance of the proposed reconfiguration alternative for Lake George on river temperatures below the Lake George Dam are show in Figures 11 and 12. These graphs reflect the modeled difference in temperatures at this point in the river between the existing condition and the proposed condition for two time periods before, during, and after the June 15 and July 1 1997 rainfall runoff events as estimated using the CE-QUAL-W2 model.

These two time periods were chosen because they contain the runoff events referred to in Section 6.0, but they also show pre-event baseflow conditions. Where the graph is above the horizontal "0" axis, the modeled temperature below the dam is lower/cooler under the reconfiguration scenario than with Lake George in its current configuration. Conversely, if the curve is below the "0" line, the existing configuration generates the cooler temperatures. In both cases for the period shown, the temperature under the reconfigured scenario is show to be consistently above the "0" line (at times showing a cooling benefit of over 1° C) under the conditions leading up to the storm runoff event, but also during and immediately after the event itself.

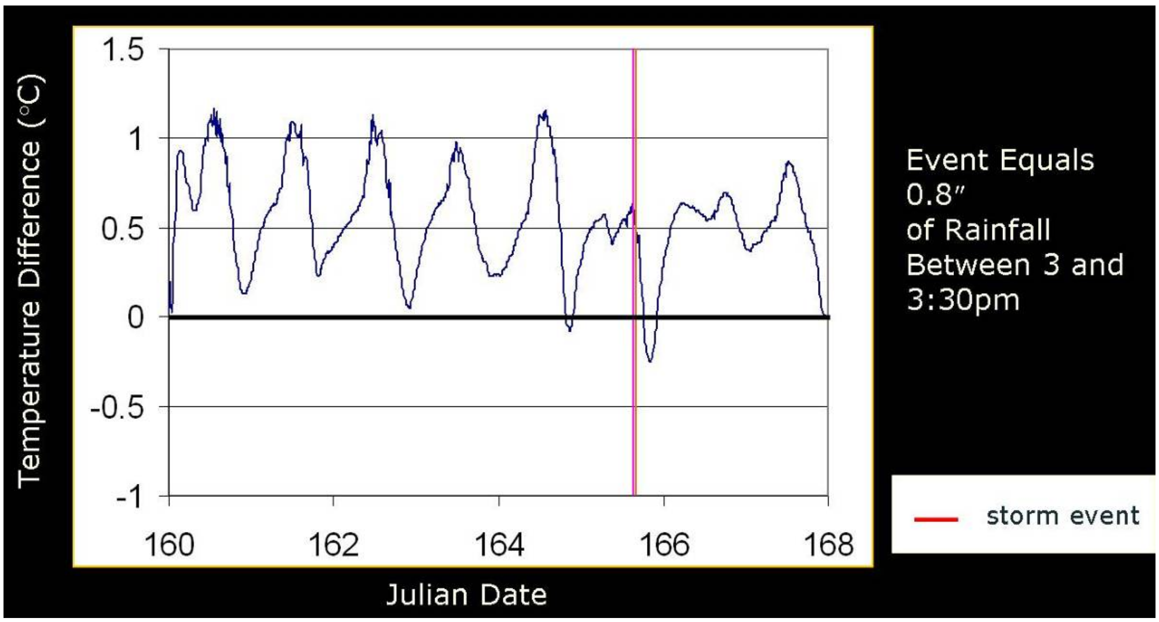

Figure 11: Comparison of Thermal Benefits for Runoff Conditions for Time period Around June 15 1997 Rainfall Event (LG Reconfiguration Alternative vs. Existing Condition)

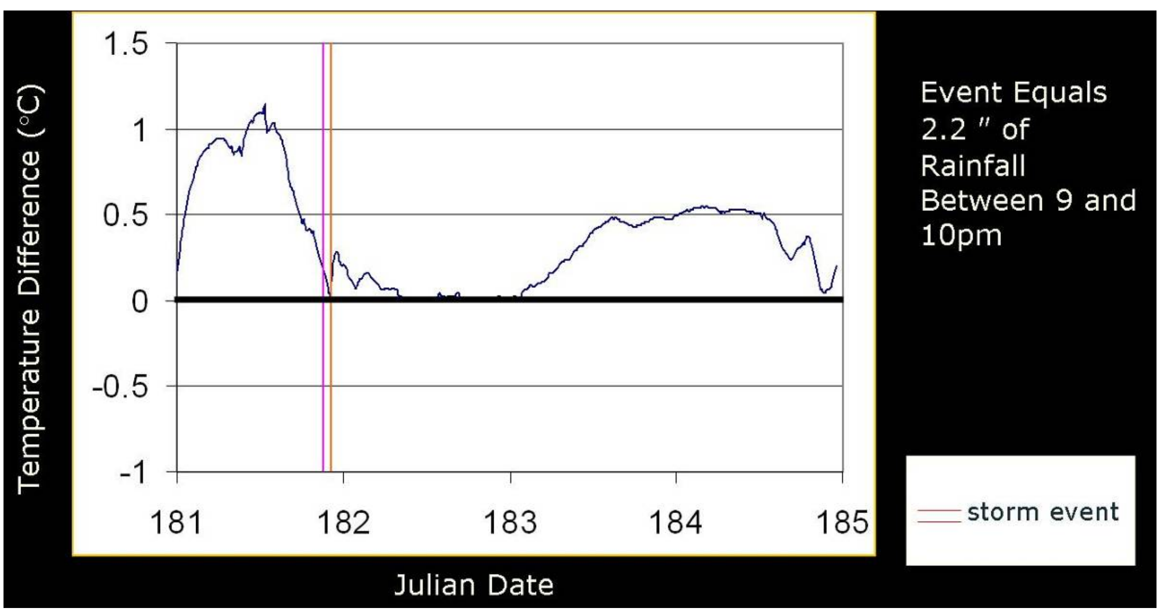

Figure 12: Comparison of Thermal Benefits for Baseflow and Runoff Conditions for Time Period Around July 1 1997 Rainfall Event (LG Reconfiguration Alternative vs. Existing Condition)

The reconfiguration of Lake George also increases the benefit of watershed treatment measures on temperatures below Lake George. Figure 13 shows the difference in modeled temperature in the river under existing conditions at two different locations in the river assuming runoff from approximately 50 acres of the downtown area is removed (i.e. infiltrated instead) for the July 1, 1997 storm.

The blue line (with squares) represents the temperature difference below Lake George under existing lake configuration conditions but without runoff from 50 acres of downtown drainage area, while the red line (with triangles) represents the same condition, but at a location just above Lake George. The graph shows that while there is up to a 0.4° C temperature reduction just above Lake George, the watershed thermal benefits of BMP application are virtually eliminated in passing the river water through Lake George in its current configuration.

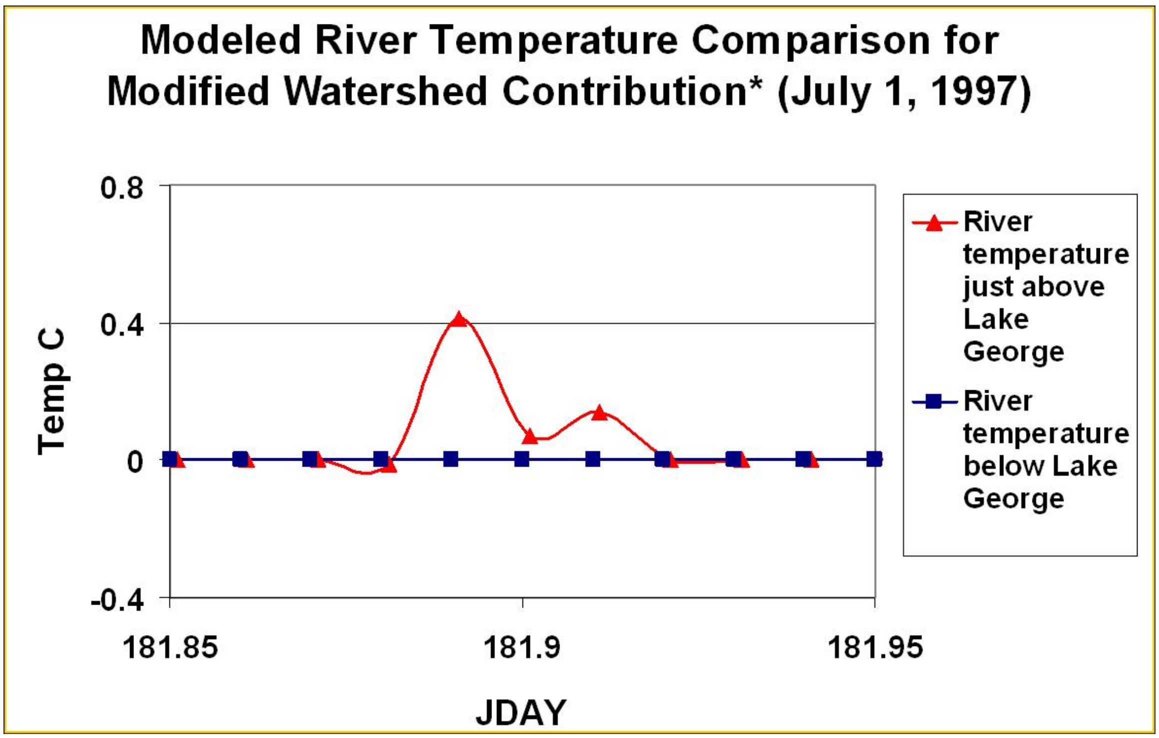

Figure 13: Modeled River Temperature Comparison for Modified Watershed Contribution (July 1, 1997 Storm Event)

The reduction in TSS loading to the river associated with the selected Lake George reconfiguration option will depend on the area diverted to it by the interceptor pipe system. If all three phases of the North interceptor are constructed along with the East interceptor, almost two-thirds of the estimated annual TSS load from the entire study area (33,500 lbs/yr. of a total 53,880 lbs/yr.) would be diverted to the reconfigured Lake George for treatment.

The estimated wet volume of the reconfigured lake is estimated at about 12 acre-feet, significantly above the 8 acre-feet of runoff that would be diverted to the treatment cells by the interceptor system for the 1-year design storm event. Under this condition, an average annual TSS removal rate of 70-80% is very reasonable to expect for the treated runoff, based on NURP sizing criteria. This translates into a reduction of TSS loading to the river of between 23,500 and 26,800 lbs/yr just with these improvements.

The costs of both the stormwater interceptor pipes and the proposed reconfiguration of Lake George are summarized in Table 5 and presented in more detail in Appendix G, while a schematic showing the various segments of the interceptor pipe system and costs are shown in Figure 14.

The costs for reconfiguration of the lake assume that the bulk of the material making up the bottom of the existing Lake George can be used to construct the main and interior berms for the reconfigured lake. The limited historical sediment data that does exist for the lake was done primarily for environmental assessment purposes and not engineering.

The information available on engineering properties of the sediment suggests that use of the material for berm construction is a reasonable technical assumption at this point in the project, but additional investigations will be needed to determine the validity of this assertion.

Table 5: Summary of Costs for Recommended Lake George Reconfiguration Alternative and Interceptor Pipes

Alternative	Description	TSS and Thermal Benefits			Lake Reconfig. Constr. Cost	Downtown SS Diversion Const. Cost	Comments
		TSS Red. Benefit [1]	Thermal Benefit [2]				
		Reduction	Baseflow	Runoff Events			
Preferred Alternative	Divert downtown sewersheds, construct primary berm to separate lake from river and multiple internal berms for multi-cell treatment system, add thermal swale as low flow outlet and spring outflow conveyance channel	60-70%	Up to 1° C	<0.5° C w/o watershed improvements to 0.5° – 1°C with Priority 1 watershed improve-ments	$515,000 - $1,012,000	**North Interceptor** $944,000 – 1,200,000 **LG East Interceptor** $184,000 – 247,000 **LG South Interceptor** $212,000 – 289,000	Modeled thermal benefits account for rate control of outflows from modified Lake George, do not account for potential benefits of thermal swale, reduced surface area of Lake George

1 Estimated at point of discharge to river

2 Estimated at location immediately downstream of Lake George

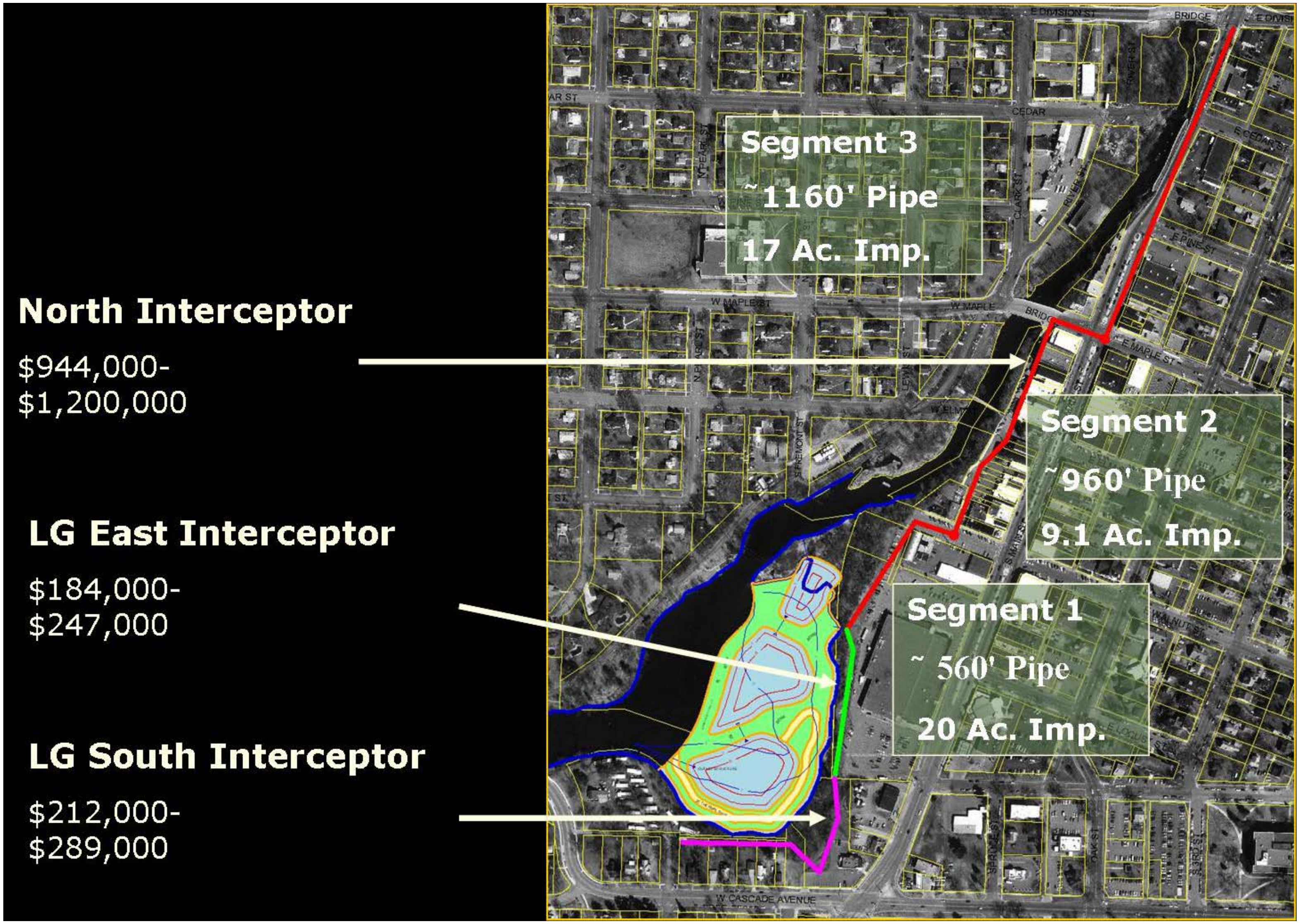

Figure 14: Stormwater Interceptor Pipe System Segments and Estimated Costs

9.0 Overall Strategy/Recommendations

On December 16, 2004, a combined meeting of the TAC and the Stakeholders Committee was held to review all information and provide recommendations to the City on an overall strategy. A detailed summary of that meeting is in Appendix H, including a list of meeting attendees and a detailed accounting of the recommendations and input from the group.

There was consensus that a multi-pronged approach involving strategic execution of both end-of the pipe and small scale/small site watershed management actions as well as reconfiguring Lake George and a phased construction of interceptor pipes along the east side of the river was the best strategy to follow.

The critical elements endorsed by the TAC and Stakeholders Committee are as follows:

- Reconfiguring Lake George into a multi-cell system that is separated from the river during baseflow and small to moderate runoff events.
- Constructing the east interceptor (which includes capture of the runoff from Econo Foods) as well as the first phase of the north interceptor up to Walnut Street.
- Extending the north interceptor as opportunities arise, such as during downtown redevelopment projects or road/alley reconstruction.
- Construction of one or more "end-of-pipe" projects designed to infiltrate runoff on existing City-owned land, such as in Heritage Park on the west side of the river.
- Concentrating on one to several storm drainage sewersheds to work with private property owners to find suitable sites for, and install, small scale stormwater treatment features such as rainwater gardens. It was suggested that these efforts could focus on parts of the study area where diversion of runoff to a reconfigured Lake George for treatment is not feasible, end-of-the-pipe treatment strategies may not be practical, or neighborhood interest and cooperation may be very high.
- Development and execution of a public education program aimed at building understanding of, and support for, the overall management strategy and its various components among the general public as well as the business community.

Yet there are still important actions that need to be undertaken before the concept for Lake George reconfiguration can be finalized and design completed. The main issues are:

- Collecting reliable bathymetric information on the existing lake
- Locating possible natural spring groundwater discharges to the lake
- Assessing in greater detail the engineering properties of the sediment within the lake
- Beginning the process of identifying and developing the information needed to secure regulatory permits, especially those necessary to work in the river bed at Lake George
- Investigate flowage rights and underlying ownership of the lake
- Identifying possible funding sources for implementation

10.0 Literature Cited

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11.0 Glossary

Baseflow: River discharge or flow comprised of ground water drainage and delayed surface drainage. Baseflow is typically characterized as that portion of river flow not related to precipitation-induced runoff. Baseflow is typically measured when the flow is consistent for a period of at least seven days. Typically, baseflow is measured in periods of "low flow" in the middle of winter (January, February) and late summer (August, September).

Bathymetry: The topographic (elevation) contours of the bottom of a lake, river, or other water body. Accurate bathymetry is important for estimating the total volume of water in a lake, the volume of sediment that needs to be removed to achieve a certain desired depth configuration, etc.

Best Management Practice (or BMP): Agricultural and urban land management practices determined to be the most effective, practical means of preventing or reducing pollution from non-point sources.

First-flush: The first portion of runoff generated by a precipitation event that commonly washes a disproportionately high percentage of the pollutants from impervious surfaces into a storm drainage system.

Groundwater: Underground water, generally within the boundaries of an overlying watershed, which fills the internal passageways of porous geologic formations (aquifers). In response to gravity and pressure, aquifers release water via seepage creating coldwater resources such as the Kinnickinnic River. Aquifers also serve as a water source for communities and industries.

Impervious Surfaces: Hard surfaces (rooftops, sidewalks, driveways, streets, parking lots, etc.) that do not allow rain water to infiltrate into the ground. Instead, the rain water runs off these surfaces, picking up heat and other water pollutants that can be transferred to streams, rivers, and lakes, creating water quality problems. Furthermore, these surfaces prevent rain water from infiltrating into the soil to recharge the ground water aquifers that provide spring flow to the Kinnickinnic River.

Macroinvertebrate: An aquatic invertebrate animal large enough to be seen with the naked eye. Macroinvertebrates include aquatic insects and freshwater “shrimp” (which represent an important source of food for trout in the Kinnickinnic River) as well as crayfish, clams, snails, and worms. An analysis of the types and numbers of macroinvertebrates present in a stream, often expressed as a biological “index,” is a very useful indicator of water quality and habitat conditions.

Milligrams per Liter (mg/l): A measure of the concentration of a substance in water. For most measurements of water quality pollutants, 1 mg/l is equivalent to 1 part per million.

NURP: Acronym for Nationwide Urban Runoff Program, undertaken in the early 1980's as the first comprehensive program in this country to describe the quality of urban runoff. The findings of this effort have provided the basis for many of the runoff treatment strategies and BMP designs used to treat urban runoff today.

Pretreatment: Refers to treatment of runoff to remove a portion of the sediment load before the treated water discharges to another part of the overall system for further treatment such as filtration, infiltration, or additional settling and/or biological uptake of pollutants.

Runoff: Rainfall, snowmelt, or irrigation water that runs off the land into streams, rivers, lakes, and wetlands. Runoff frequently picks up natural and human-made pollutants from land surfaces and carries these pollutants into surface waters.

Runoff Event: The response of river flow to precipitation-induced runoff. After a precipitation event, a runoff event is characterized by an increase in flow from the baseflow condition as watershed runoff reaches the river followed by a subsequent decrease in flow to the baseflow condition after watershed runoff passes through the river.

TAC: An acronym for the Technical Advisory Committee that helped in guiding this project. Names of the TAC members for this project are shown in Appendix B of this report.

Total Phosphorus (or TP): Aquatic plants provide food, oxygen, and habitat for aquatic organisms. However, an excess of plant growth can lead to unsightly algae blooms which cause oxygen depletion and odor upon decaying, making the water unpleasant for recreational activities and unsuitable for aquatic life. Phosphorus, a common component of wastewater treatment plant discharges and urban and agricultural runoff, can stimulate excessive plant growth when phosphorus levels in surface waters are too high.

Total Suspended Solids (TSS): The sum total of small particles of soil and organic matter suspended in water.

Storm Sewer: A system of street drains and underground piping that transports rain and snow (stormwater) runoff. Historically, stormwater runoff was transported directly to a stream, river, or lake. Today, it is highly recommended, and often required, that best management practices be used for stormwater management and treatment.

Storm Sewershed: The land area contributing stormwater runoff to a specific storm sewer.

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Kinnickinnic River at River Falls, Wisconsin
Thermal Study

Jim B. Noren

October 2003
U.S. Army Corps of Engineers
St. Paul District
St. Paul, Minnesota

Kinnickinnic River at River Falls, Wisconsin Thermal Study

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Kinnickinnic River at River Falls, Wisconsin Thermal Study

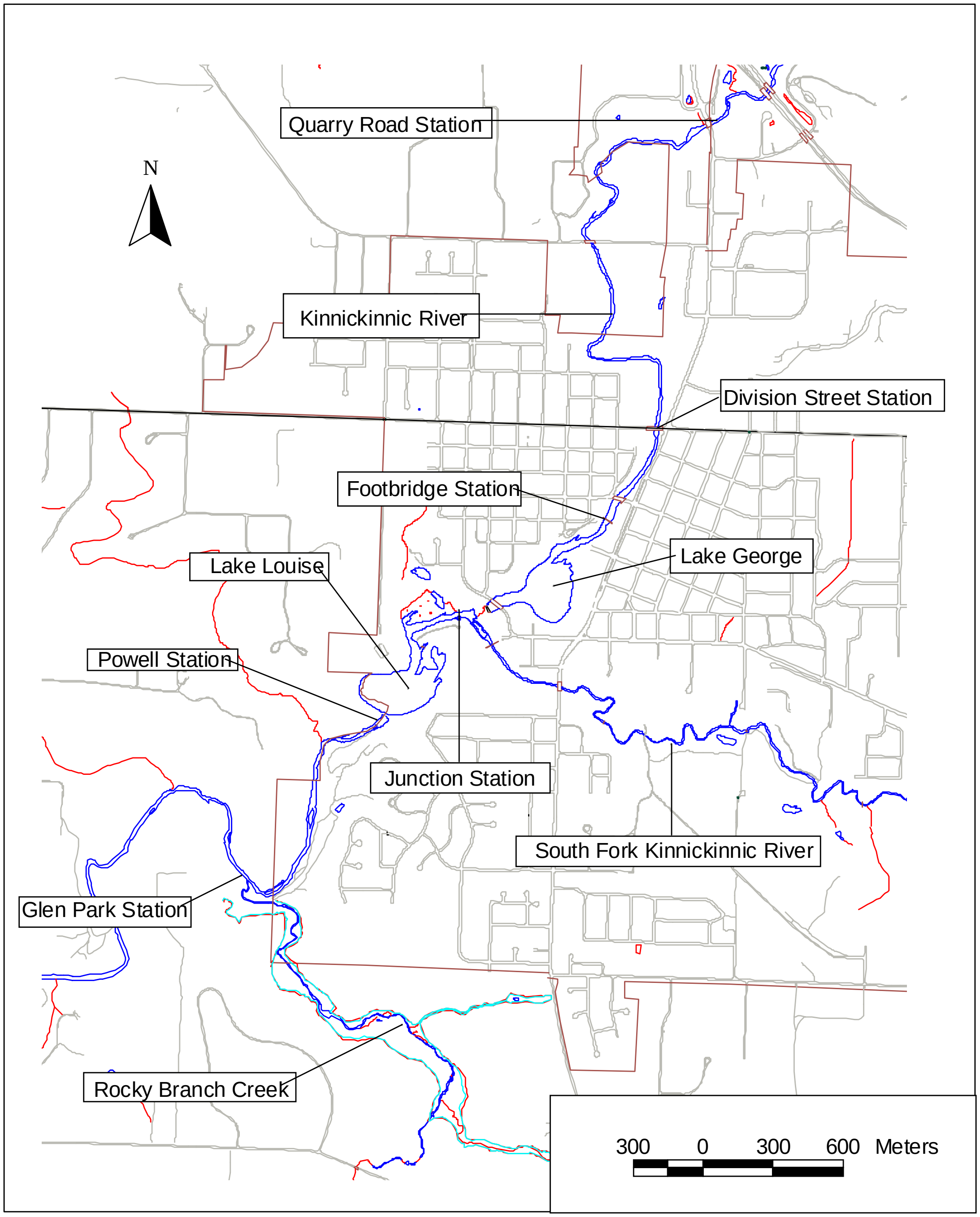
1.0 INTRODUCTION

The purpose of this study was to construct a Kinnickinnic River CE-QUAL-W2 thermal model that would help evaluate the efficacy of different storm runoff management plans currently being developed to manage a cold-water fishery downstream of River Falls, Wisconsin.

The Kinnickinnic River, a premier trout stream known for dense populations of brown trout, is an at-risk resource from the effects of a rapidly growing community (Johnson, 1995). Located in west-central Wisconsin, the City of River Falls (population 12,000) saw a 20 percent population increase in the 1990's. The city's population is projected to grow to 16,500 by the year 2010 (Johnson and Lamberson, 2003). As the community grows and creates more impervious land cover, the Kinnickinnic River would most likely be subjected to increased storm runoff flows and elevated temperatures.

In 1996 and 1997, the Wisconsin Department of Natural Resources (DNR) monitored stream temperatures upstream and downstream of downtown River Falls (Figure 1.1). During that time, flashes of increased stream temperatures downstream of the city's storm sewer effluents were observed during summer storm events. The magnitude of these temperature spikes was pronounced and usually ranged between 2 and 4 degrees C.

Figure 1.1 - Stream monitoring stations- Kinnickinnic River flowing through two impoundments and downtown River Falls



In Figure 1.2, stream temperatures at different points along the Kinnickinnic River are shown for two particular 1997 storms. Both figures depict a stream temperature spike that appeared below Quarry Road, became diminished at Junction Station, and then reappeared below Lake Powell.

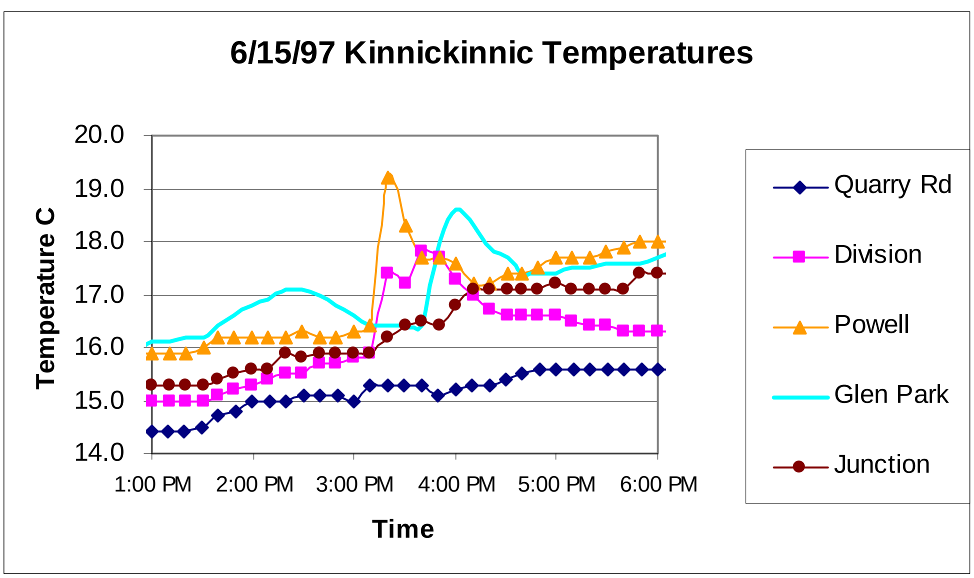
The temperature spikes seen between Quarry Road and Lake George were probably due to storm sewers discharging heated runoff from impervious areas into the river.

The temperature regime seen at Junction Station was primarily an outcome of mixing outflows from Junction Dam and the South Fork Kinnickinnic (Figure 1.3). During the 6/15/97 and 7/1/97 storm sewer runoff periods, the temperatures observed at Junction Station were cooler than the temperatures observed above Lake George at Division Station and at the South Fork Kinnickinnic Station. The dam's discharge at Lake George effectively dampened the temperature spike seen above the reservoir and overwhelmed with much larger flows the warmer temperatures contributed by the South Fork Kinnickinnic at Junction Station.

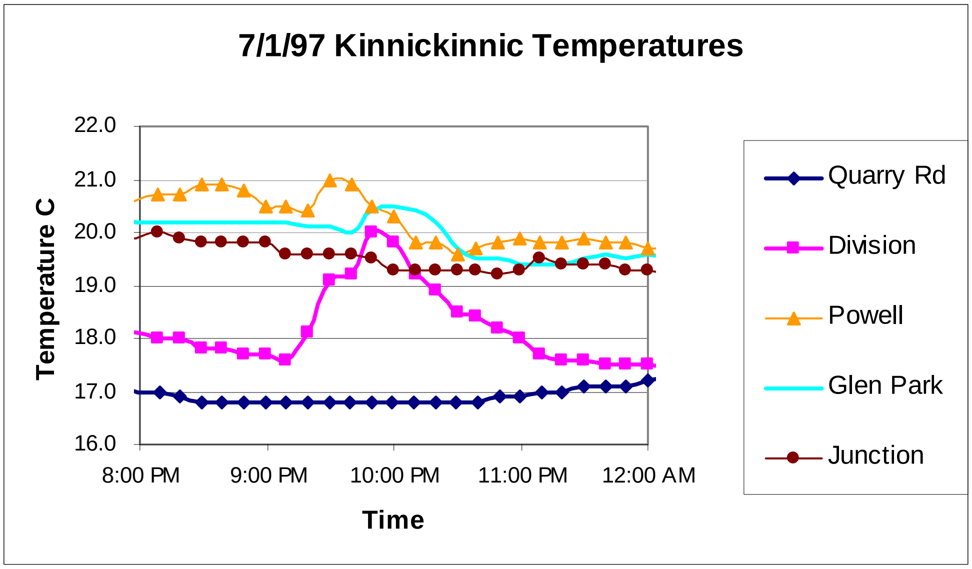
After the storm runoffs flowed through Powell Dam, a temperature spike reappeared at Powell station and at Glen Park for both storm events. Again, the spikes were probably caused by storm sewer discharges into Lake Louise and into the Kinnickinnic River below Powell Dam. The reason that the maximum temperatures seen at Glen Park were less than the maximum temperatures seen at Powell Station was probably due to the relatively cold-water discharge from Rocky Branch into the Kinnickinnic River immediately upstream from Glen Park.

Figure 1.2 - Stream temperatures observed during a) 6/15/97 and b) 7/1/97 at different river stations along the Kinnickinnic River

a)



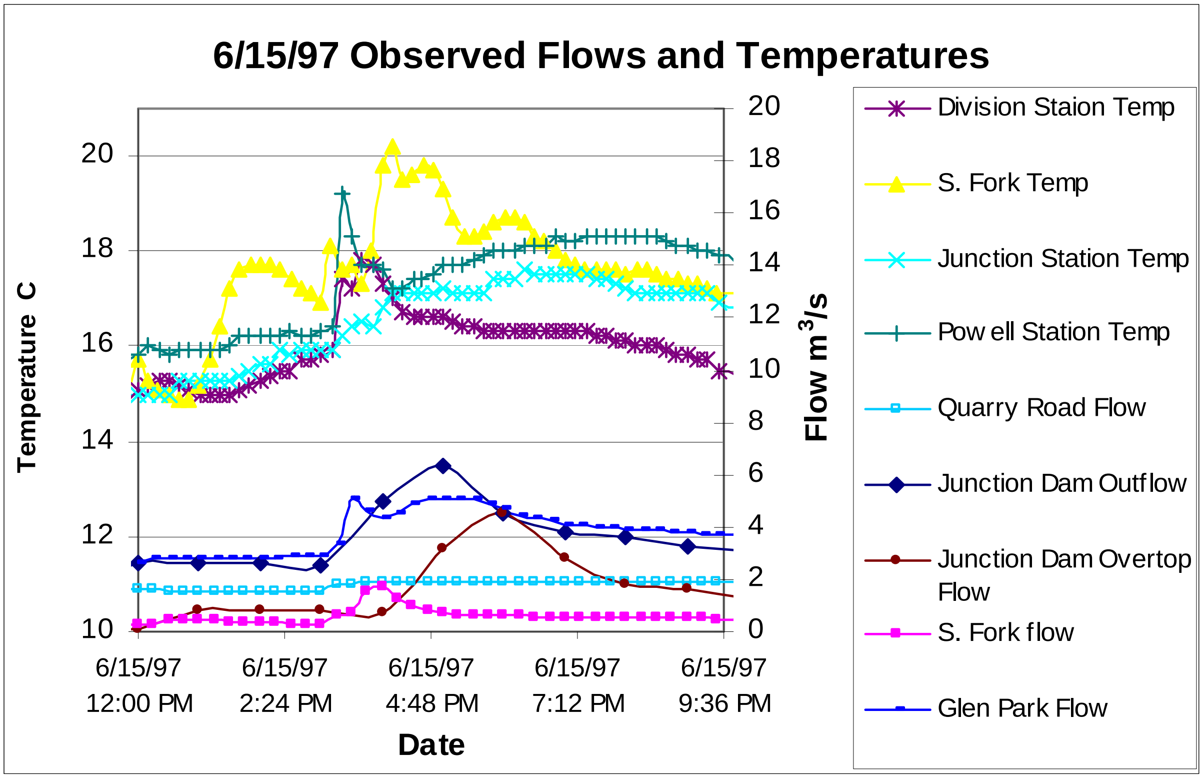
b)



Supported by earlier studies that documented elevated stream temperatures after storm events (Johnson, 1995), a need to address the effects of the city's storm sewer system downstream developed. Utilizing data from these two 1997 rain events and a dry period in August 1997, a CE-QUAL-W2 model was created to simulate the June 15, 1997, and July 1, 1997, storm sewer runoff conditions and the 1997 summer base flow condition. The intended use for the model was to assist water resource managers in evaluating how different storm runoff management plans will alter the temperature and flow regimes observed during these three specific time periods.

Figure 1.3 - Stream temperatures and flows observed during a) 6/15/97 and b) 7/1/97 storms at different river stations along the Kinnickinnic River and South Fork Kinnickinnic River

a)



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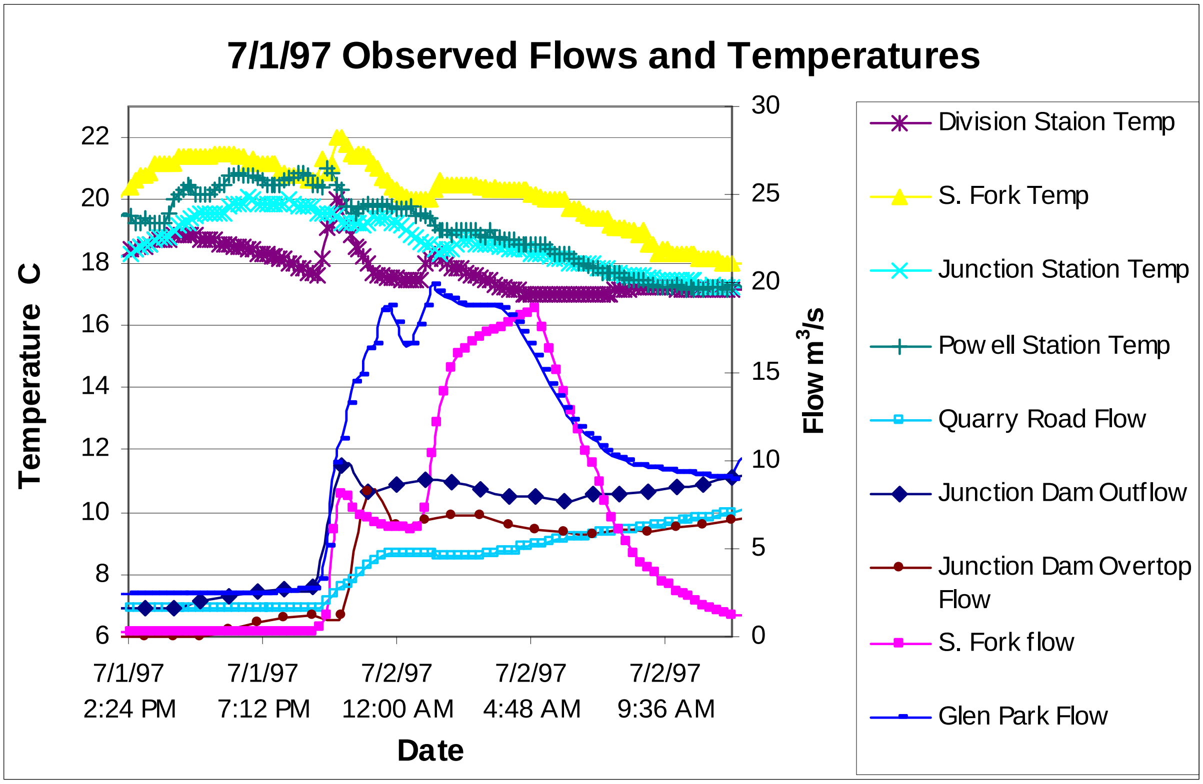
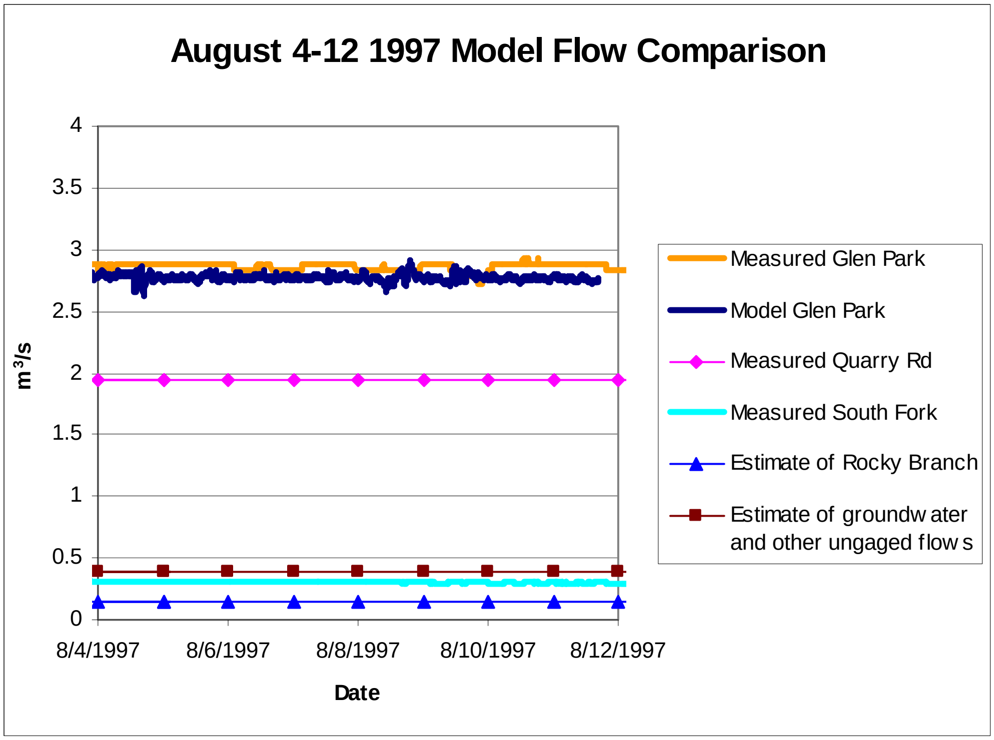


2.0 STUDY AREA

The Kinnickinnic River flows approximately 22 miles from its headwaters in southeastern St. Croix County, Wisconsin, to its confluence with the St. Croix River. On average, it is about 40 feet wide and 2 feet deep. Inside the study area between Quarry Road and Glen Park (Figure 1.1), the Kinnickinnic River runs through two hydroelectric dams that impound Lake George and Lake Louise. Lake George is a relatively shallow reservoir with depths less than 4 feet, except in the old river channel (~ 4 to 8 feet) and immediately upstream of the dam (~ 8 to 20 feet). Lake Louise is of similar shape, but does not have the severe drop-off upstream of its dam as in Lake George. The reported surface area and storage of Lake George at normal pool elevation (865.5 feet) are 16.5 acres and 155 acre-feet, respectively. The reported surface area and storage of Lake Louise at normal pool elevation (821.8 feet) are 19.3 acres and 64 acre-feet, respectively (Ayers, April 1988).

The major tributary entering the Kinnickinnic River is the South Fork Kinnickinnic. The South Fork Kinnickinnic enters just below Lake George and contributes around 5 to 10 percent of the Kinnickinnic River's flows. Just upstream of Glen Park, a smaller tributary, called Rocky Branch, enters the Kinnickinnic River with minimal flows but discharges significantly cooler temperatures. For the 1997 base flow condition (Figure 2.1), the Kinnickinnic River recorded flows averaging around 68.5 cubic feet per second (cfs) at Quarry Road and 100.5 cfs at Glen Park. The South Fork Kinnickinnic averaged about 10.5 cfs and Rocky Branch was estimated at about 3.5 cfs. To balance the flows observed at Glen Park, 14 cfs were distributed into the model. These ungaged flows were assumed to be a combination of groundwater and small drainages that enter the Kinnickinnic River between Quarry Road and Glen Park. The temperatures of these flows were estimated to be a constant 11 degrees C. In Lake Louise, a wastewater treatment plant's effluent was represented in the model with fairly constant flows of 1.4 cfs at 20.5 degrees C.

Figure 2.1 - Stream base flows observed between August 4 and 12, 1997, at different river stations along the Kinnickinnic River and the base flow model flows at Glen Park



3.0 MODEL METHODOLOGY

3.1 Model Description

CE-QUAL-W2 version 3.1 is a two-dimensional (longitudinally/vertical), hydrodynamic and water quality model suitable for relatively long and narrow water bodies that exhibit vertical and longitudinal gradients. The original model was developed by Edinger and Buchak (1975) and was known as LARM (Laterally Averaged Reservoir Model). Since then, the model has been continually updated by the U.S. Army Corps of Engineers Waterways Experiment Station and was renamed CE-QUAL-W2. At its present version 3.1, the model has been shown to be successful in accurately modeling lakes, reservoirs, estuaries, and rivers (Cole and Wells, 2002).

3.2 Model Inputs

In order to run CE-QUAL-W2 on the Kinnickinnic River, several input data sets were needed. The available data supplied for the study were from the summer of 1996 and 1997. Because of the lack of tributary data from 1996, model runs were completed using only 1997 data. Inputs to the model included bathymetry data, meteorological data, time-varying in-stream water temperatures and flows, hourly dam releases, and time-varying storm sewer temperatures and flows (generated by a separate thermal model).

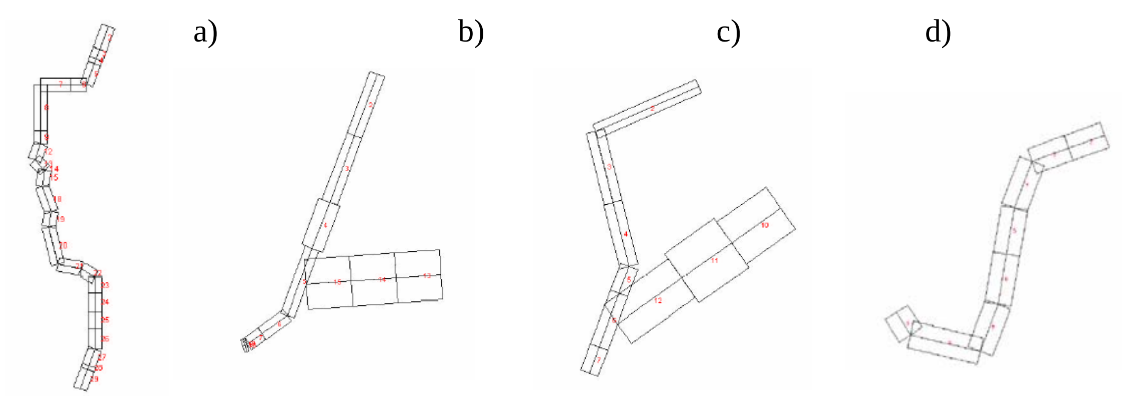
Bathymetry:

For this study, stream temperatures were simulated by splitting the study area into four water bodies:

1) Upper Kinnickinnic (Quarry Road to Lake George)
2) Lake George
3) Lake Louise
4) Lower Kinnickinnic (Lake Louise to Glen Park)

Each water body was divided longitudinally into a number of segments ranging from 5 meters at Junction Dam (Lake George) to over 250 meters along the upper and lower reaches of the river (Figure 3.1). The bathymetry for the river sections was estimated from HEC-2 data files originally developed from cross sections used in the city's flood insurance study (FIS report, 2002). The reservoirs' bathymetries were estimated from several different sources, including cross section surveys, a topographic map of Lake George completed as a school project, and volume and surface area data furnished by the River Falls Municipal Utility. Because of CE-QUAL-W2's assumption of laterally averaged segments, Lake George and Lake Louise were depicted in the model as having side branches. This modification was done to account for flows being heavily influenced by the old river channel and appearing to short-circuit the shallower areas of the reservoirs.

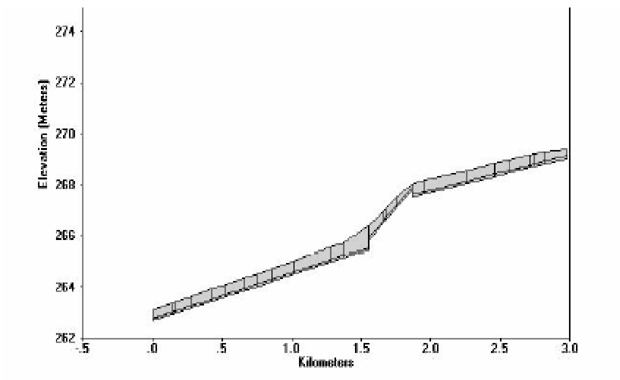
Figure 3.1 - Water body segments: a) Upper Kinnickinnic b) Lake George c) Lake Louise and d) Lower Kinnickinnic



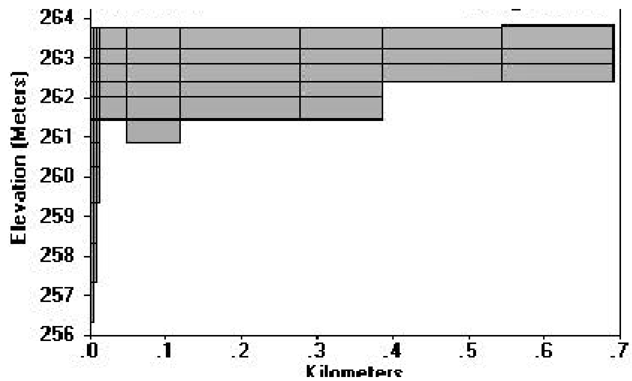
Vertically, the water bodies were divided into 14 layers ranging from 0.1 meter to 1.0 meter (Figure 3.2).

Figure 3.2 - Side view of the four water bodies: a) Upper Kinnickinnic, b) Lake George, c) Lake Louise, and d) Lower Kinnickinnic

a)



b)



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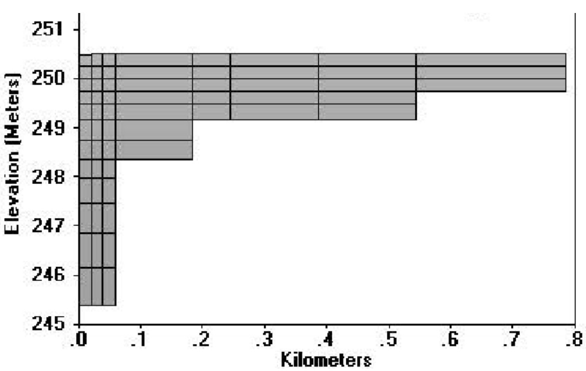

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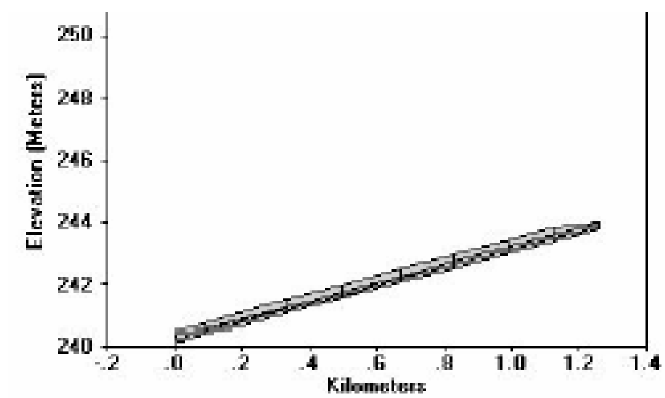


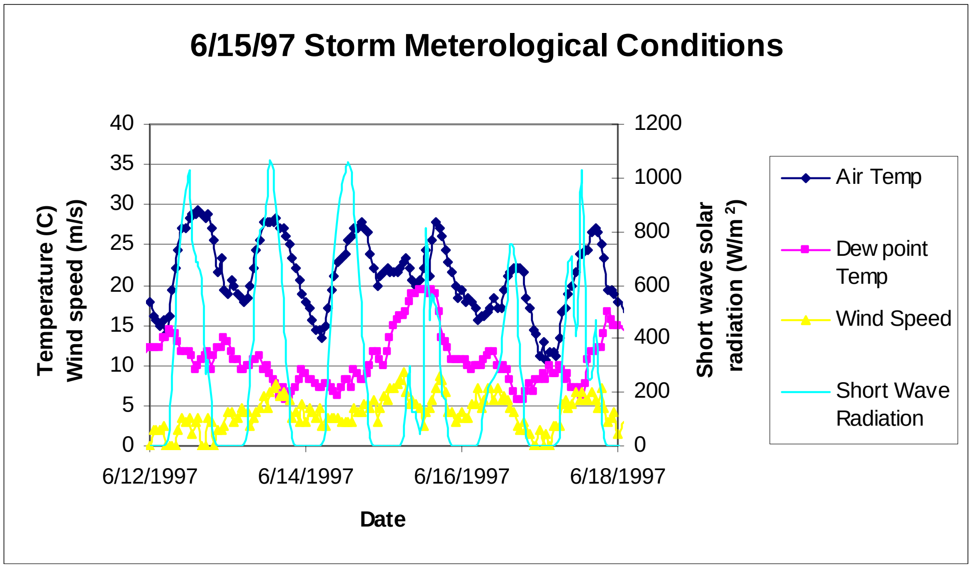
River bottom slopes for the Upper Kinnickinnic and the Lower Kinnickinnic were estimated from water surface levels generated by a HEC-2, 100 cfs steady-state simulation. The Upper Kinnickinnic part of the model grid was divided into three branches with differing slopes. The Lower Kinnickinnic was represented by a single branch and slope. The bottom slopes of the two impoundments were zero.

Meteorological Data:

Types of meteorological data required were air temperature, dew point, wind speed, wind direction, and cloud cover. As an added and more accurate method to measure surface heat exchange, incident short-wave solar radiation was also included from a local source. All other meteorological data were taken from the Minneapolis-St. Paul International Airport, except for cloud cover, which was taken from the Eau Claire, Wisconsin, Airport (Figure 3.3 a-c).

Figure 3.3 - Meteorological Data during the (a) June 15, 1997 storm, (b) July 1, 1997 storm and (c) August 1997 base flow

a)



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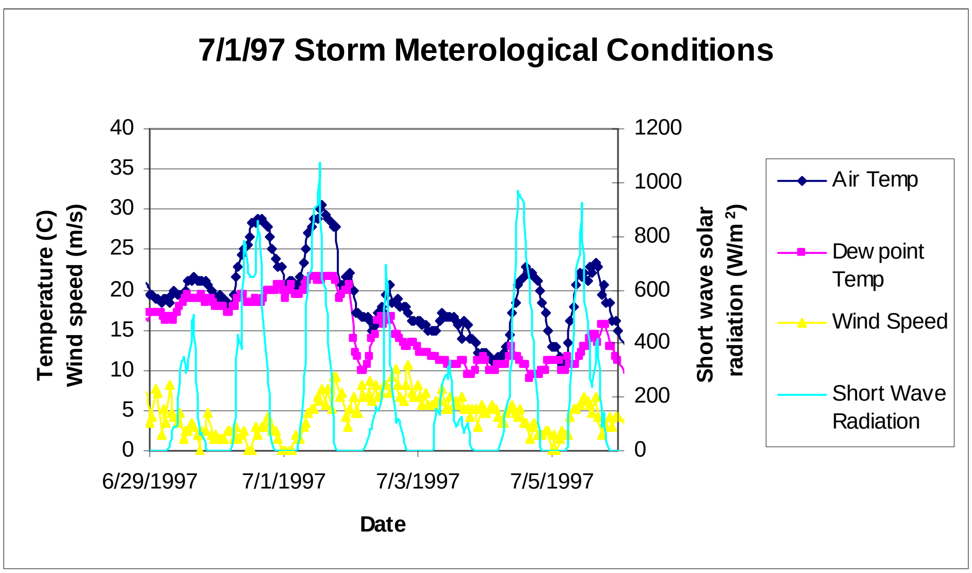
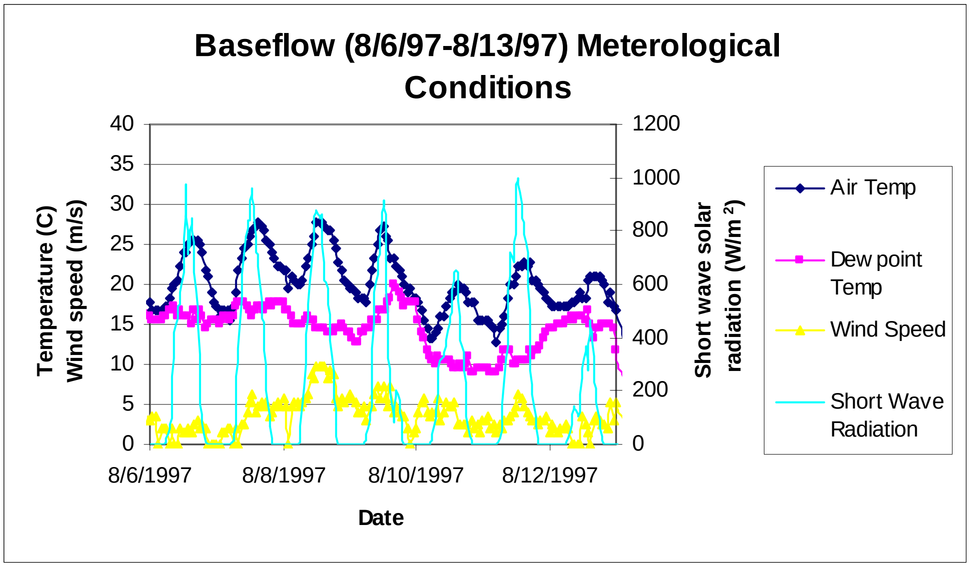


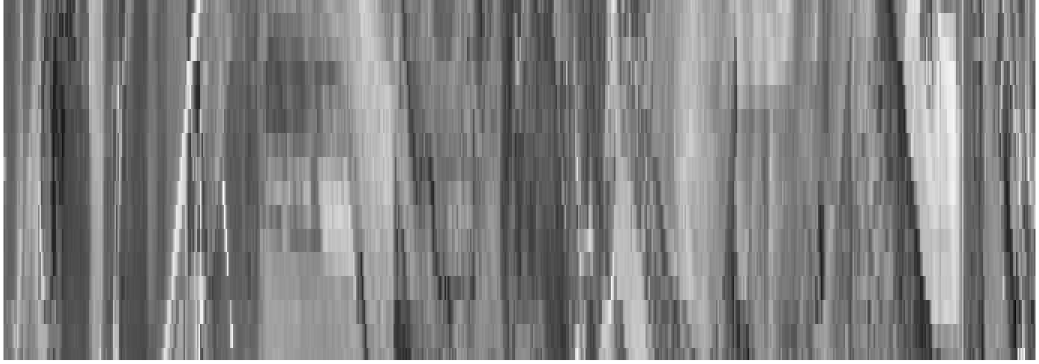
c)

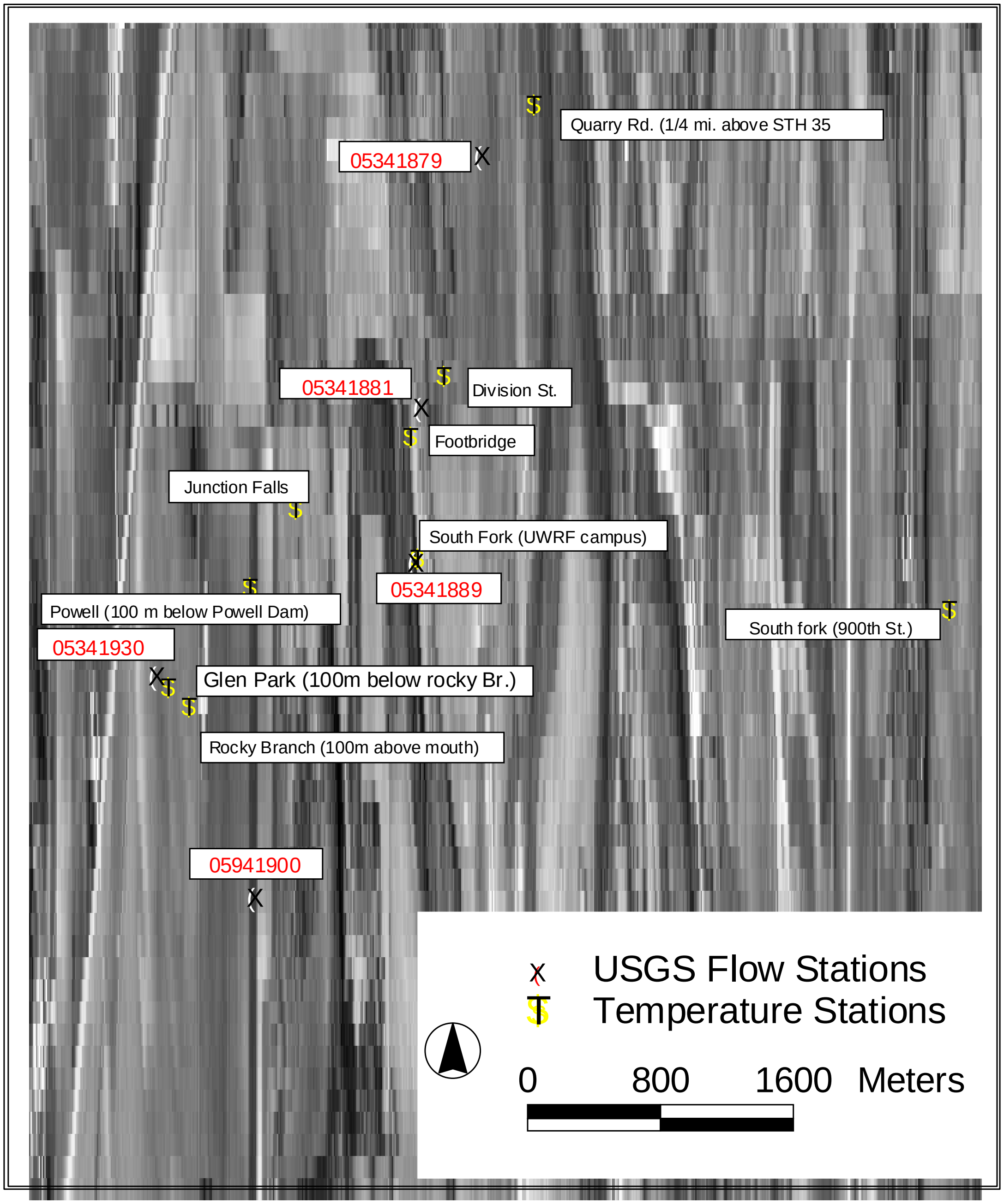


In-stream Water Temperatures and Flows:

At the upper boundary of the model, where storm sewers are largely absent and urbanization of River Falls is not as dramatic as downstream, flow measurements were taken at U.S. Geological Survey (USGS) station #05341870 at 15-minute intervals. Approximately ¼ mile upstream of the USGS station, stream temperatures were recorded with thermisters logging at 10-minute intervals (Figure 3.4).

Model development required the use of time-varying tributary temperature and flow inputs from the South Fork Kinnickinnic, Rocky Branch, and sources not accounted for in the system's water budget (groundwater, overland flow, precipitation, etc.). The South Fork temperature and flow data were collected from the University of Wisconsin-River Falls campus every 10 to 15 minutes. The Rocky Branch temperature data were collected every 10 minutes from just upstream of the creek's confluence with the Kinnickinnic River. Rocky Branch flow data were not available for 1997, but 1996 flow data collected about 50 times during the summer showed an average flow of 0.14 m^3/s (5 cfs). Estimates for the Rocky Branch June 15th and July 1st storm flows were roughly based on the shapes of the corresponding South Fork hydrographs and then were refined through calibration. The Rocky Branch base flow was estimated at 0.1 m^3/s. The River Falls Wastewater Treatment Facility and the Wisconsin DNR collected daily flow and temperature data from the wastewater treatment plant effluent, respectively. To balance the flows the model generated at Glen Park with observed data, 0.396 m^3/s at 11 degrees C were distributed along the study reach (Figure 2.1). These unaccounted flows were probably composed mostly of groundwater.





Quarry Rd. (1/4 mi. above STH 35
05341879
05341881
Division St.
Footbridge
Junction Falls
South Fork (UWRF campus)
05341889
Powell (100 m below Powell Dam)
South fork (900th St.)
05341930
Glen Park (100m below rocky Br.)
Rocky Branch (100m above mouth)
05941900
USGS Flow Stations
Temperature Stations
0
800
1600
Meters

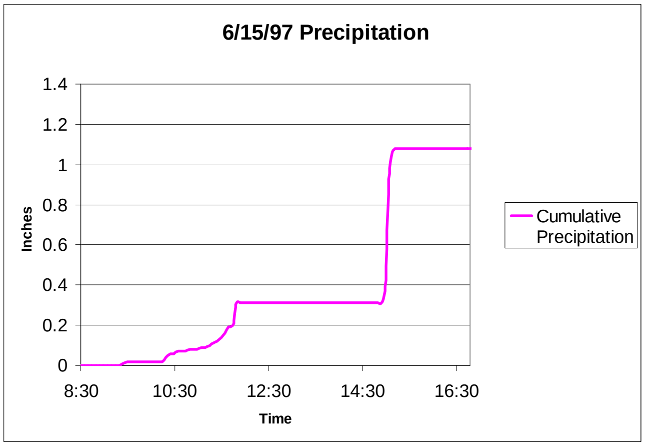
The dam at Lake George is called Junction Dam and the dam at Lake Louise is called Powell Dam. Both dams supply hydropower to the City of River Falls and discharge via a penstock and a weir. The regulation of the dams is structured to simulate the "run of the river," thus trying to maintain a pool elevation equal to the top of the weirs. The penstock discharges and pool elevations are recorded hourly by the municipal utility, and the penstock gate is modified accordingly. The water temperatures discharging from the dam can vary significantly depending on the amount of surface water that is flowing over the dam's weir, the flow through the penstock and the temperature profile at the dam. During storm events, the majority of the water is inevitably released from over the weir. For model inputs, the penstock discharges and the weir discharge/stage parameters were entered for each dam.

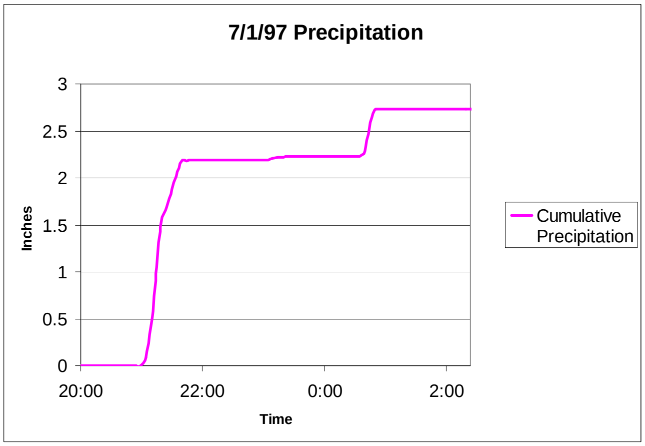
Storm sewer temperatures and flows:

Time-varying flow and temperature measurements from the city's storm sewers were needed as model inputs to accurately simulate the stream temperatures during and after storm events. In lieu of field data, the Wisconsin DNR was able to provide modeled data for two storms. The 6/15/97 storm and the 7/1/97 storm (Fig. 3.5) were selected based on the availability of meteorological, stream flow and stream temperature data.

The two storm's precipitation data (Figure 3.5) were measured by a rain gage located at the City Hall. The June 15th storm occurred during the day with two major downpours totaling over one inch of precipitation. The storm's modeled runoff data was generated from only the second downpour. The precipitation from the July 1st storm was over 2.5 inches and also consisted of two downpours. The storm's first downpour shortly after 9 pm was used to generate the modeled runoff data.

Figure 3.5 - Cumulative rainfall amounts for the June 15 and July 1, 1997, storm events





The Thermal Urban Runoff Model (TURM) (Dane County, WI, 2003) was used to generate the two storm's runoff data. This simple spreadsheet model utilizes net energy flux equations at the impervious surfaces of urban areas to account for the heat transferred to runoff. The runoff temperature is determined as a function of the physical characteristics of the impervious areas, the weather, and the heat transfer between the moving film of runoff and the heated impervious surfaces that commonly exist in urban areas. Key variables affecting the runoff temperature prediction are slope, length and makeup of impervious surfaces, wind speed, air temperature, humidity, solar radiation before and during rain, rainfall intensity, rainfall temperature, fraction of impervious area, and time of concentration associated with pervious areas.

The River Falls urban basin was broken into subwatersheds and basin attributes such as percent imperviousness and curve number were calculated for each subwatershed. This information was provided by the City of River Falls city engineer's office. Meteorological data was supplied by either WDNR, local school weather station or nearby NOAA weather stations. The runoff water volumes and time series were concurrently calculated with the runoff temperatures within the TURM model. The runoff hydrology is driven by the 5-minute rainfall data, thus the runoff time series is also calculated as a 5-minute time step. The TURM model utilizes a rough approximation method, assuming that the total runoff volume is equal to 90 percent of the impervious area times the rainfall depth during the given measurement time interval. Because the model has no routing capabilities (i.e. rainfall falling on a surface is discharged at the end of the time step), a smoothing function was applied to the output data to more closely simulate urban runoff hydrographs. The form of the equation used was:

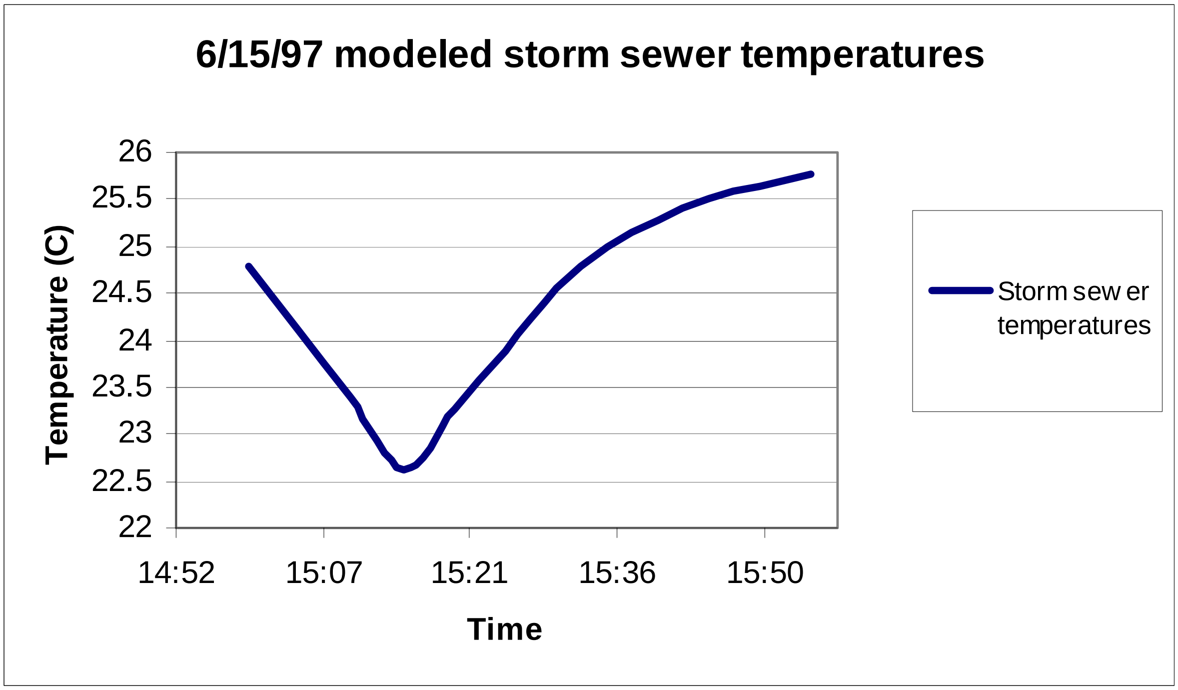
$$Q_t = (Q_{t-2} * \alpha) + (R_t * (1 - \alpha))$$

Where Q=Flow at time step t, α= alpha, smoothing coefficient, R=Rainfall flow (depth*surface area/5 min).

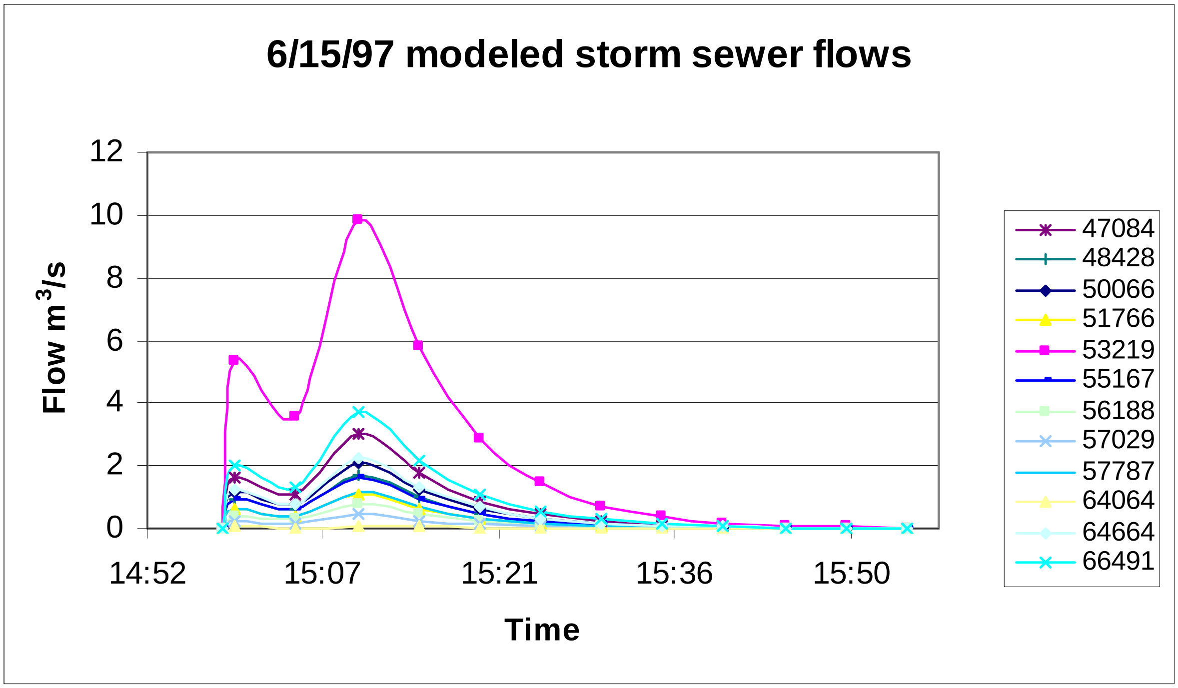
The resulting flows and water temperatures were imputed into the CE-QUAL-W2 model as tributaries. The number of storm sewer pipes discharging to the river was reduced for modeling purposes by combining sewer sheds into 12 discharges to the river (Fig. 3.6). Temperatures for each storm, due to model limitations, were identical for all sewersheds.

Figure 3.6 - a) June 15th modeled storm sewer temperatures, b) June 15th modeled storm sewer flows, c) July 1st modeled storm sewer temperatures, and d) July 1st modeled storm sewer flows

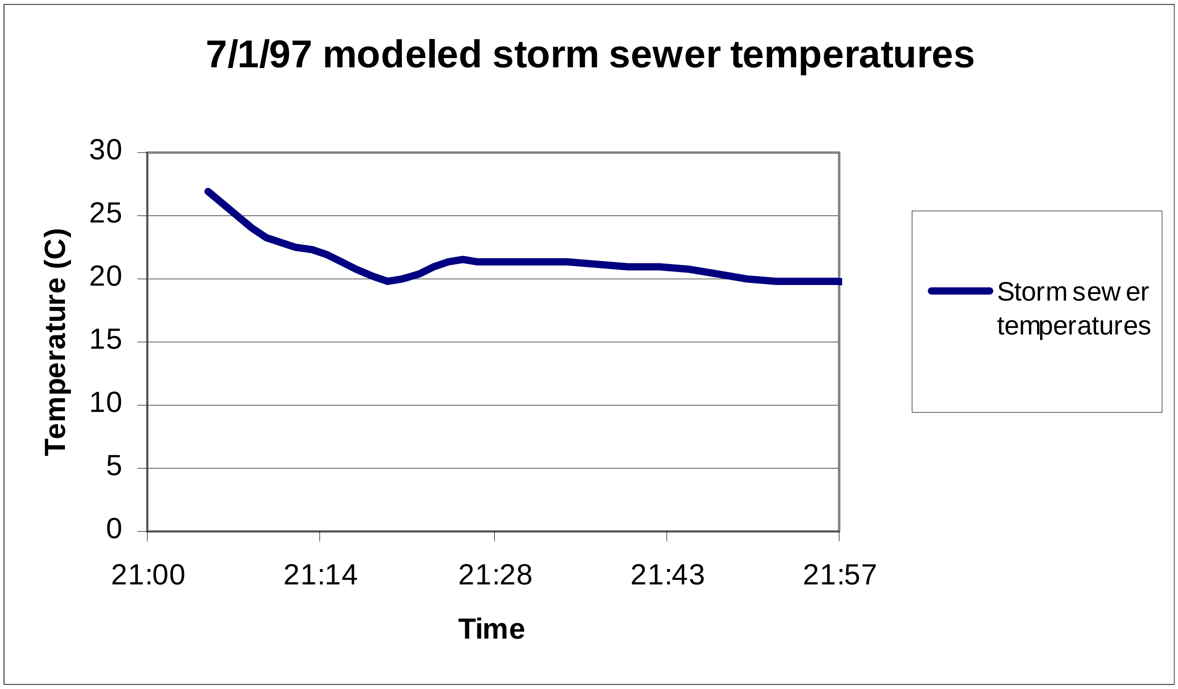
a)



b)



c)


7/1/97 modeled storm sewer temperatures
Temperature (C)
30
25
20
15
10
5
0
21:00
21:14
21:28
21:43
21:57
Time
Storm sew er temperatures

d)

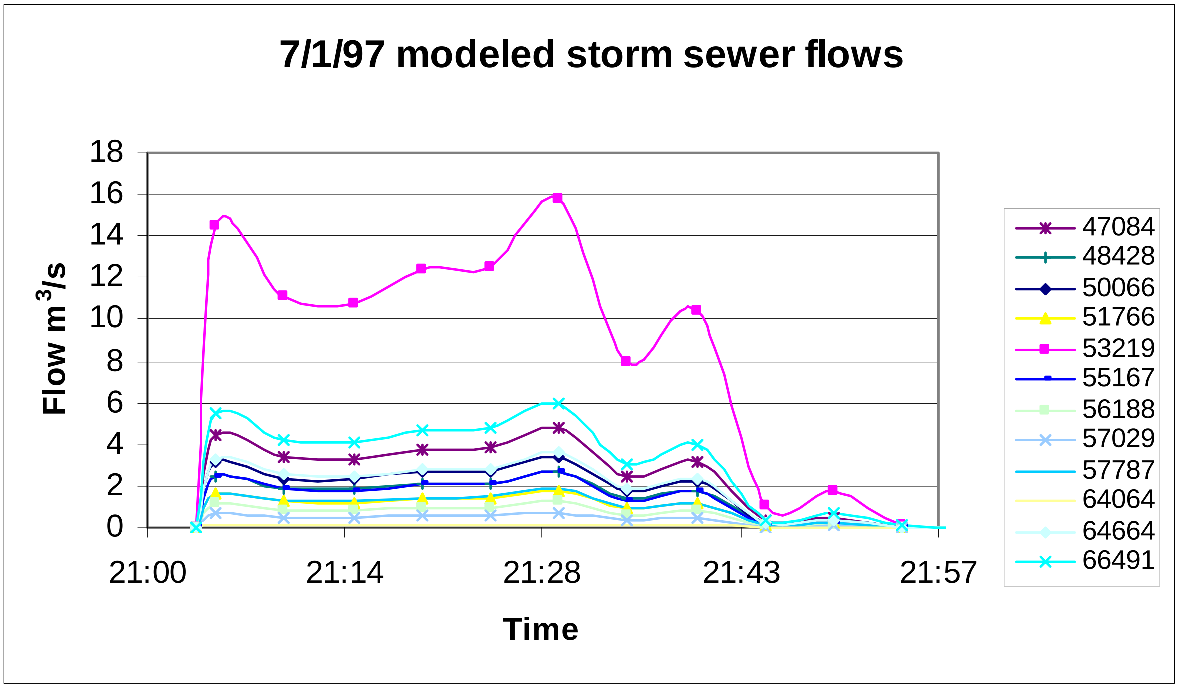
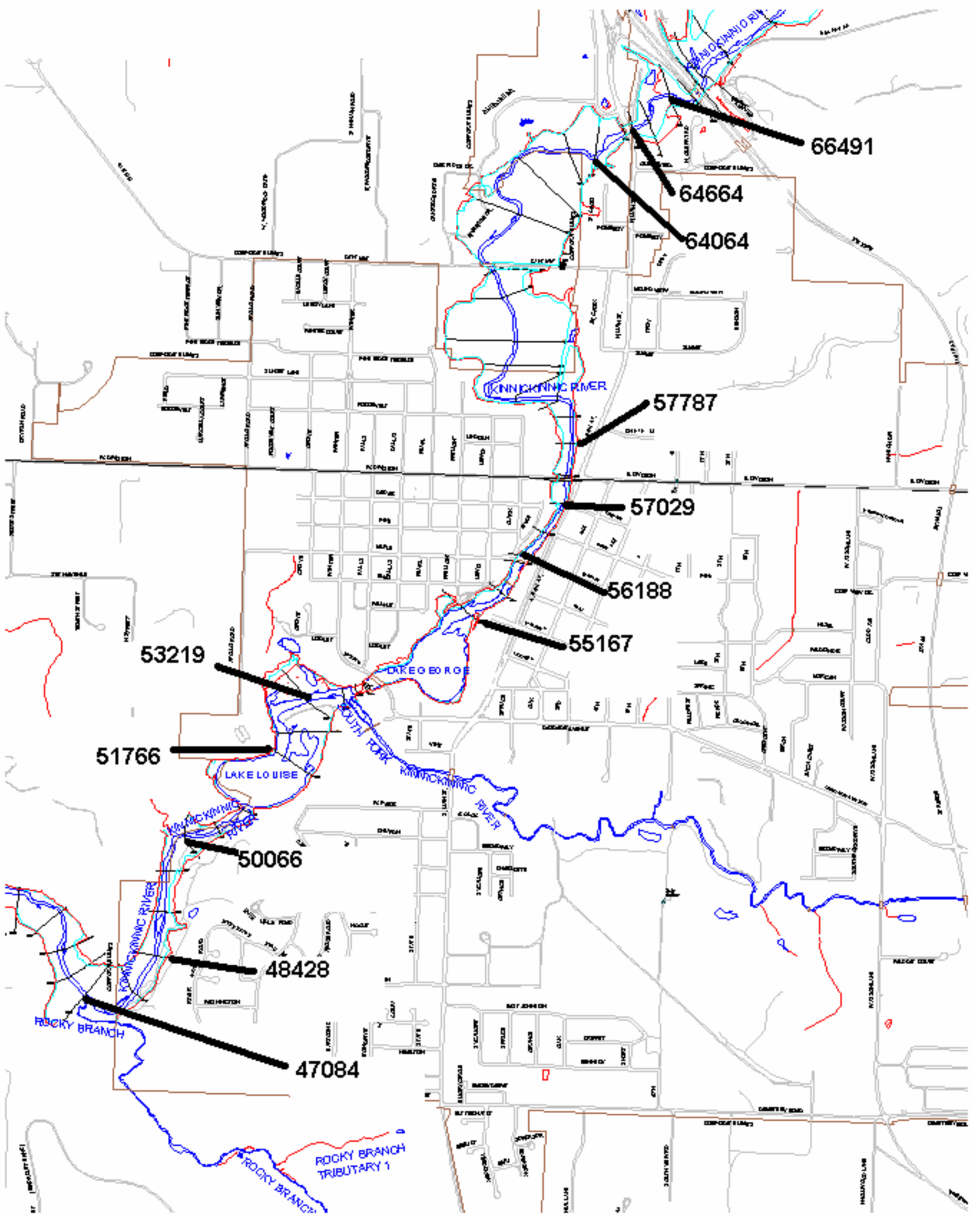

7/1/97 modeled storm sewer flows
Flow m3/s
18
16
14
12
10
8
6
4
2
0
21:00
21:14
21:28
21:43
21:57
Time
47084
48428
50066
51766
53219
55167
56188
57029
57787
64064
64664
66491

Figure 3.6 - Modeled storm sewer discharges to the Kinnickinnic River inputted as tributaries in CE-QUAL-W2



3.3 Model Calibration

Calibration Statistics:

Field data from 1997 were used to calibrate the model's August 4-12 base flow and storm conditions. Three types of error statistics were used to describe the model's performance. Mean Error (ME) was defined as the sum of all the deviations across time at a station divided by the number of deviation measurements. Mean Error was used in the calibration process to give an indication if the model's overall temperature was too warm or cold. Calibration parameters that have a global warming effect like shading or extinction coefficients were used to reduce the mean error. Absolute Mean Error (AME) was defined as the sum of the absolute values for each deviation divided by the number of deviations. Absolute Mean Error gives an average error value for the time period. AME is not affected by the canceling out of negative and positive deviations. Therefore, AME does not show bias, but gives a better indication of an average predictive error than ME. Root Mean Square (RMS) was defined as the root of the sum of squares of the deviations across time for each station. RMS is a more stringent test for replicating observations than AME or ME, since it emphasizes the error of individual predictions, not the average error of all the deviations. RMS is a good statistic to judge the model's ability to replicate the system's diurnal variations.

Calibration Parameters:

Temperature calibration in CE-QUAL-W2 version 3.1 is limited by the accuracy of the input data and the model calculations. Under ideal conditions, few parameters need to be adjusted after input data are taken from the field. Assuming the bathymetry data, meteorological data, shading data, bottom roughness (Manning's n), flow and water temperature data, and parameters that control solar radiation attenuation are correct, the model should come close to predicting observed data without changing the model's default settings (Cole and Wells, 2002). However, in this study, the shading parameter, the light extinction parameters (EXH2O and BETA), the flows and temperatures of the ungaged inflows, the wind sheltering coefficient (WSC) and the fraction of solar radiation reflected by the sediments back into the water column (TSEDF) were not explicitly measured and had to be adjusted during the calibration process. Table 3.1 lists the calibrated values used for the CE-QUAL-W2 model.

Table 3.1- Calibrated values for the Kinnickinnic River W2 model

Coefficient	Upper Kinni	Lake George	Lake Louise	Lower Kinni
WSC	0.25	0.50	0.50	0.25
TSEDF	1.0	0.5	0.5	1.0
Shading	0.50	0.95	0.95	0.75
EXH20	0.45	0.45	0.45	0.45
BETA	0.45	0.45	0.45	0.45
Ungaged Flow (CMS)	0.2	0.066	0.066	0.066
Ungaged Temp (C)	11	11	11	11

Base Flow:

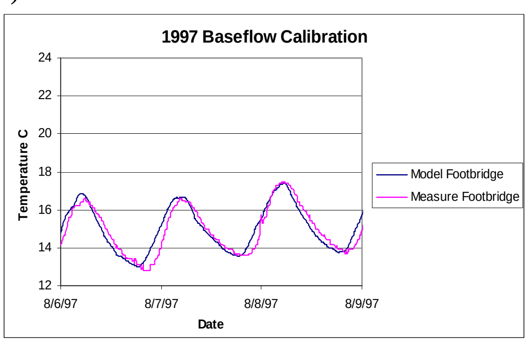
Calibration of the model was evaluated with temperature measurements at four river stations: Foot Bridge, Junction Falls, Below Powell Dam, and Glen Park (Figure 1.1). Using the parameter settings listed in table 3.1, the CE-QUAL-W2 model was calibrated to the August base flow condition to generally accepted standards of less than 1°C AME/RMS error. Table 3.2 shows a statistical summary of the CE-QUAL-W2 model and average travel times at four temperature stations during the August 7 to 11, 1997, time period, and Figure 3.7 graphically compares CE-QUAL-W2 temperatures to field temperatures.

Table 3.2 - Error statistics for the August 7 to 11, 1997 calibration, °C

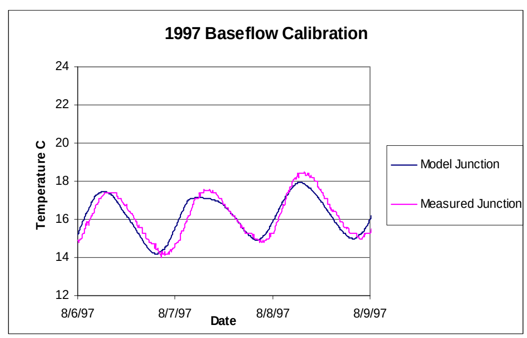
Station	AME, °C	ME, °C	RMS, °C	Count	Ave. Travel Time (Hrs)
FootBridge	0.38	0.02	0.46	505	1.99
Junction Falls	0.41	0.05	0.48	505	10.72
Below Powell	0.35	-0.15	0.42	505	5.43
Glen Park	0.39	-0.22	0.49	505	0.64

Figure 3.7 - CE-QUAL-W2 and observed temperature data at four stations: a) Footbridge, b) Junction Falls, c) Below Powell Dam, and 4) Glen Park.

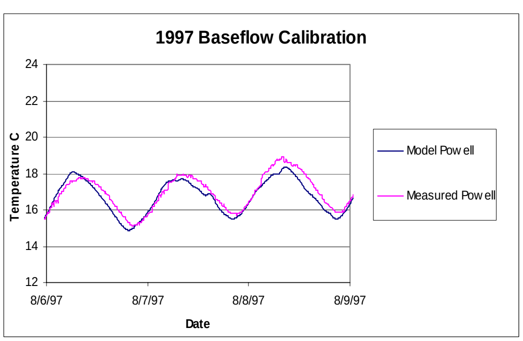
a)



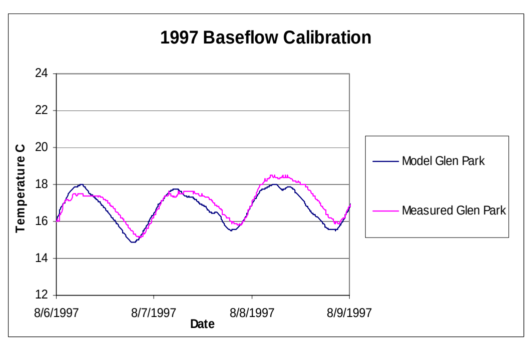
b)



c)



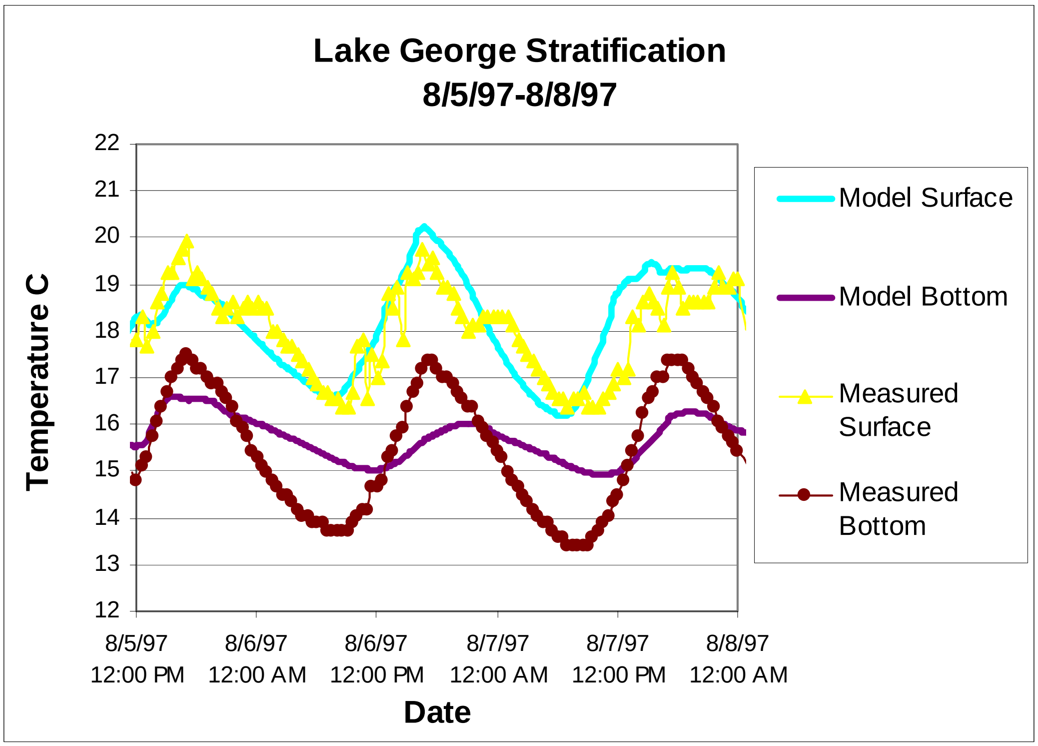
d)



Lake George Stratification:

A further test to see if the model was reproducing field data was to compare model generated temperatures at different depths with August 1997 field data (Figure 3.8). The exact location and bottom elevation of the field data were not documented, but it was assumed that the simulated temperatures taken at the surface and 1.5 meters in the middle of the model's side channel were suitable for comparison. The modeled data showed a stratification of the water column in Lake George that was similar to the observed data, except that the model's bottom temperatures lacked the observed diurnal fluctuations. This difference may be due to the artificial segmentation of the model into a side channel and a main stem, which largely excludes the side channel from the temperature regime of the upstream river water. Nonetheless, the data suggests that the model is reproducing the thermal and hydrodynamics of the system reasonably well.

Figure 3.8 - Modeled and observed data from the surface and bottom of Lake George



Storm Events:

After the model was calibrated to the base flow condition, the model was run for the June 15 and July 1, 1997, storm events with the same parameters. Because observed storm sewer runoff data were not available, storm sewer flow and thermal data derived by TURM were inputted into CE-QUAL-W2 (Figure 3.5). The CE-QUAL-W2 model simulations generated with storm sewer inputs did show an increase in Glen Park discharge flows at the right time periods, but the flows were larger than observed. To correct the flow discrepancies, storm sewer flow inputs were multiplied by 3/5 (Figures 3.9 and 3.10). Statistics comparing flows for the two storms and the August base flow at Glen Park are shown in Table 3.3. After the storm flows compared well between CE-QUAL-W2 output and the measured data, TURM storm sewer temperature data were calibrated for downstream water temperatures. CE-QUAL-W2 outputs demonstrated that 90% of the TURM generated flow temperatures were needed to reproduce observed stream temperatures at each monitoring station.

Figure 3.9 - Comparison of model and observed discharge flows during June 15th with and without storm sewer inputs

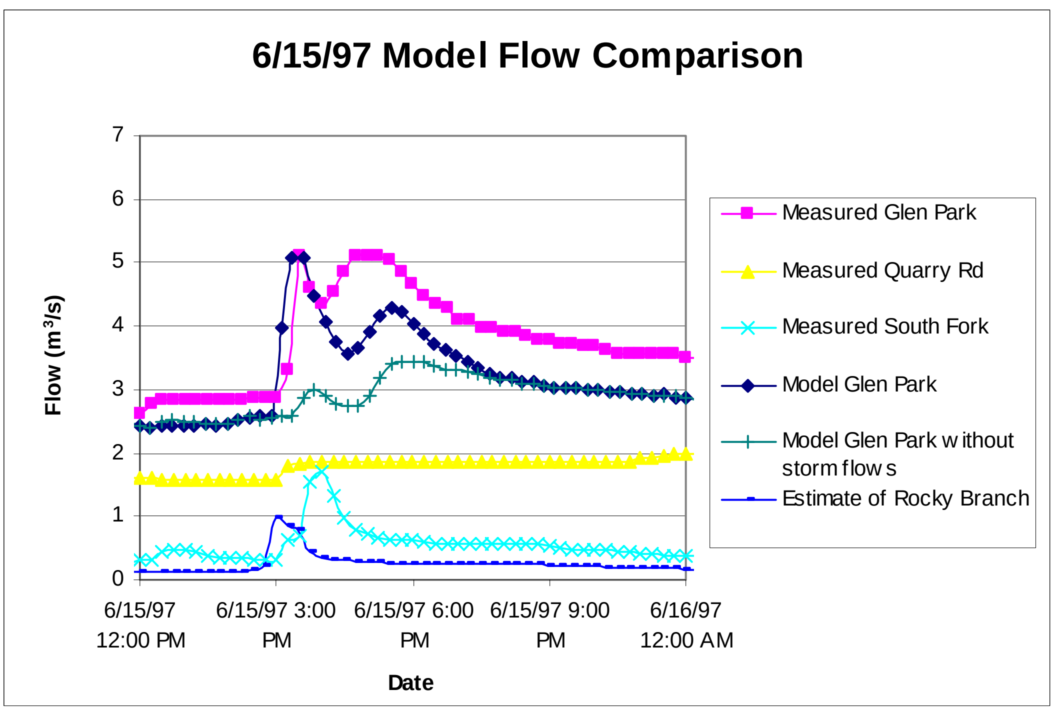


Figure 3.10 - Comparison of model and observed discharge flows during July 1st with and without storm sewer inputs

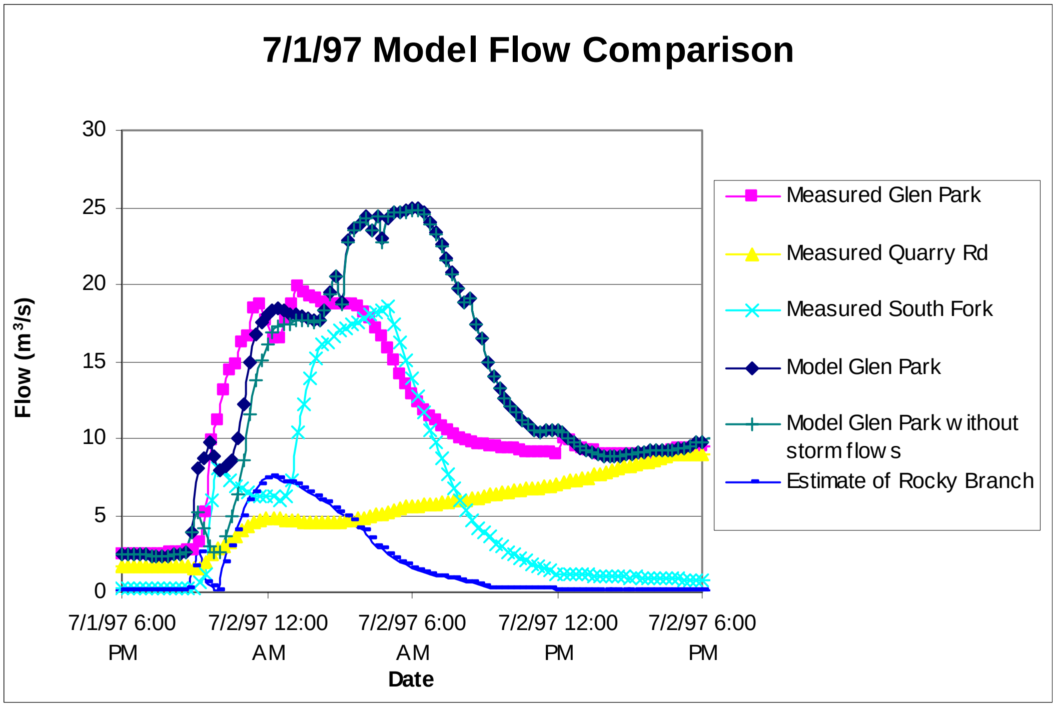


Table 3.3 - Statistical comparison of observed Glen Park flow with CE-QUAL-W2 Glen Park flows for the August base flow and the two storms

Calibration Run	Time Period	AME, m^3/s	ME, m^3/s	RMS, m^3/s	Count
Base Flow	8/3/97 7:15 8/11/1997 16:45	0.09	-0.09	0.09	807
6/15/97 Storm	6/15/97 17:15 6/16/97 5:30	0.66	-0.66	0.66	50
7/1/97 Storm	7/1/97 12:00 7/3/97 11:45	1.79	1.09	3.48	192

On Figures 3.11 and 3.12, temperatures at the four river stations predicted by CE-QUAL-W2 using 90 percent of the computed storm sewer temperatures and their corresponding modified flows are shown along with the observed data for the June 15th and July 1st storms.

Figure 3.11 - CE-QUAL-W2 storm temperatures generated with 90% of computed storm sewer temperatures and observed temperatures at four river stations for June 15th storm event

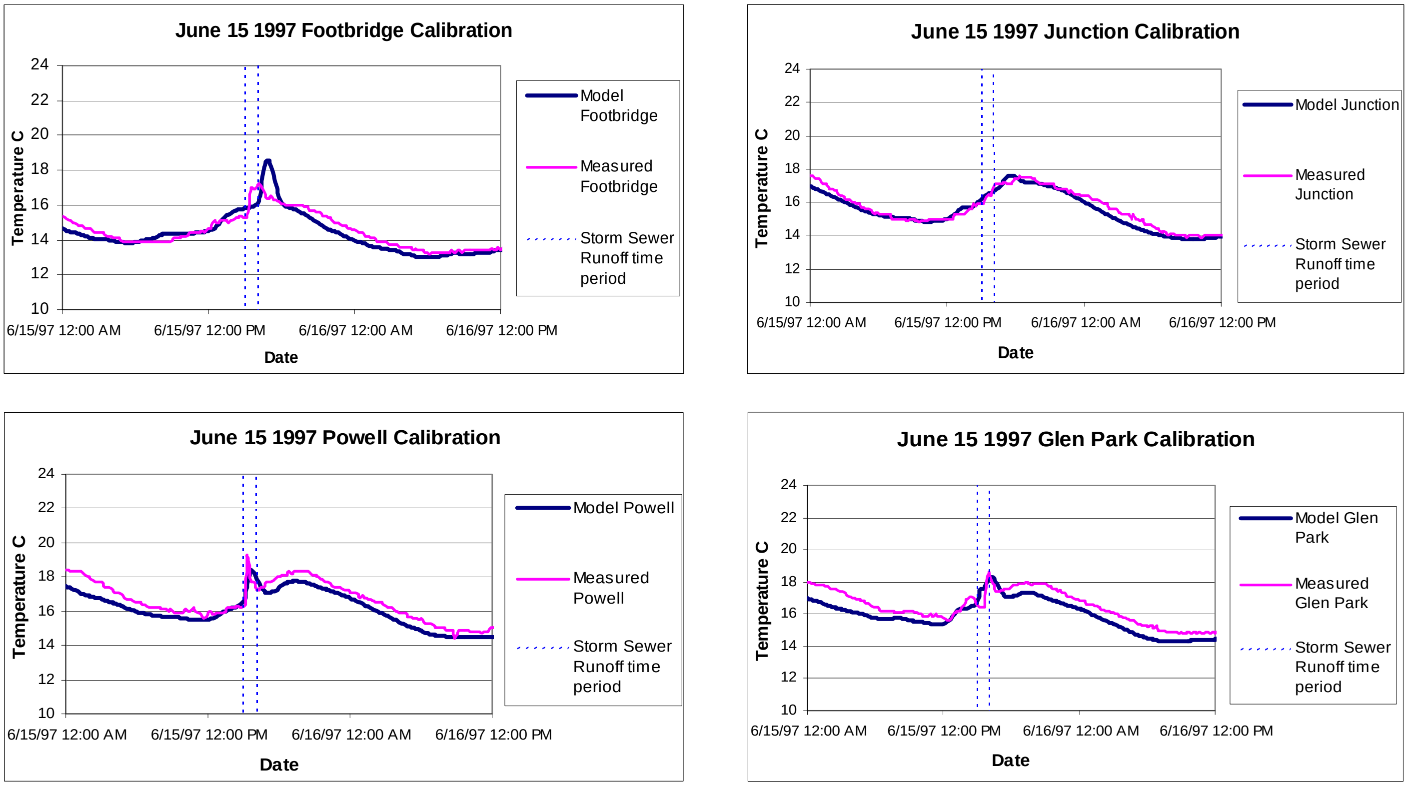
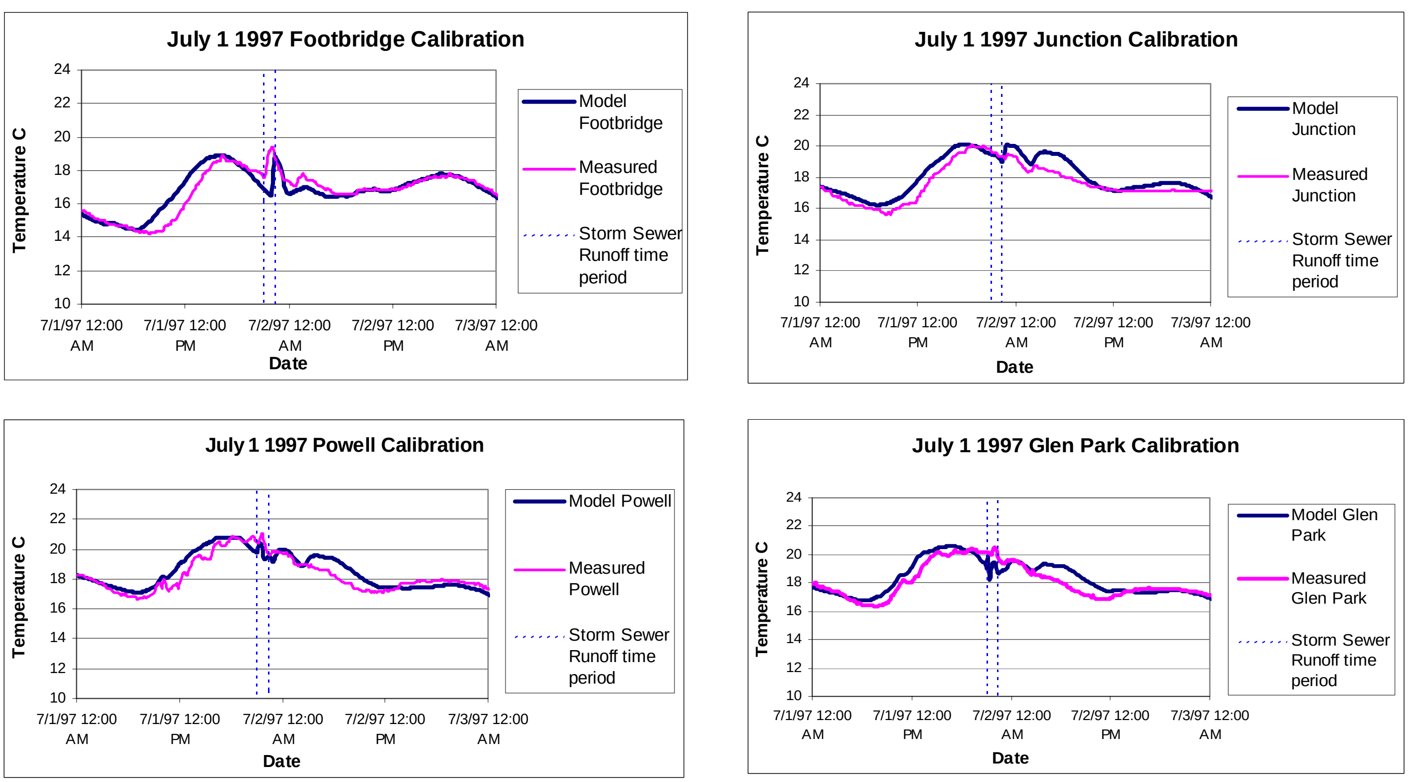


Figure 3.12 - CE-QUAL-W2 storm temperatures generated with 90% of computed storm sewer temperatures and observed temperatures at four river stations for July 1st storm event



4.0 MODEL SENSITIVITY

Determination of the model's sensitivity to different parameters was achieved by first running the model under August 6-10 base flow conditions shown in Table 4.1. By changing one parameter at a time, the model's sensitivity was detailed for wind sheltering (WSC), shading (SHD), solar radiation reflection from the sediment (TSEDF), light extinction coefficients (EXH2O and BETA), and distributed tributary temperatures (Tables 4.1 through 4.5 and Figures 4.1 through 4.5).

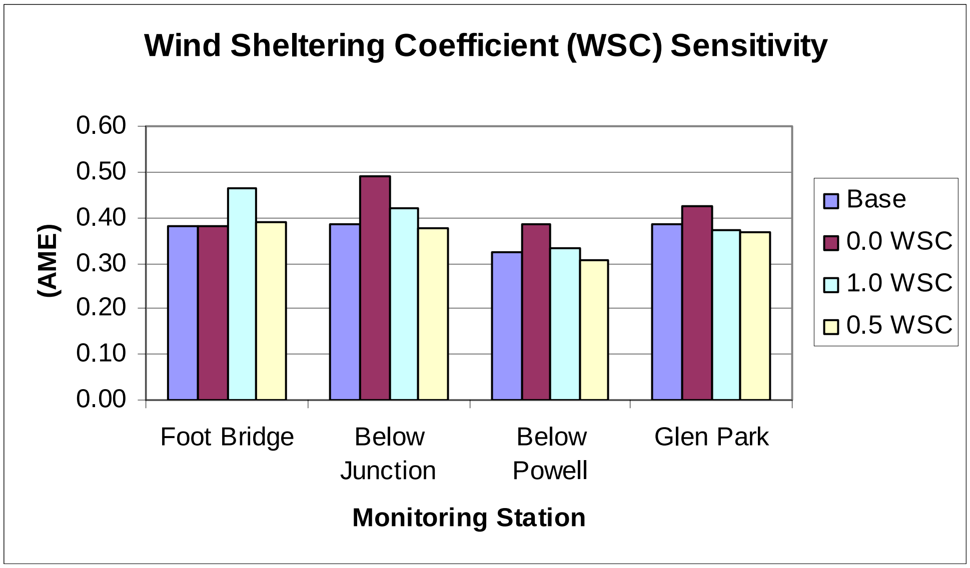
Wind Sheltering Coefficient (WSC):

The Kinnickinnic model is somewhat sensitive to the wind-sheltering coefficient (WSC). The WSC can be adjusted between 0 and typically 1.0; values around 0.5 are used for protected water bodies, and values near 1.0 are used for large open water bodies. This coefficient corrects the wind from the measuring station to a point over the water surface and in some cases can be higher than 1. Because Lake George and Lake Louise are fairly open, but are small and situated in a river valley, a value of 0.50 was used. For the highly protected river sections, a value of 0.25 was used.

Table 4.1- Statistical summary of Wind Sheltering Coefficient (WSC) sensitivity

Scenario	Station	WSC	AME. °C	ME, °C	RMS, °C	Count
base flow	Foot Bridge	0.25	0.38	0.03	0.47	505
	Below Junction	0.50	0.38	-0.03	0.45	505
	Below Powell	0.50	0.32	-0.22	0.38	505
	Glen Park	0.25	0.38	-0.28	0.47	505
1.0 WSC	Foot Bridge	1	0.46	0.24	0.62	505
	Below Junction	1	0.42	0.20	0.53	505
	Below Powell	1	0.33	-0.01	0.39	505
	Glen Park	1	0.37	-0.09	0.45	505
0.5 WSC	Foot Bridge	0.5	0.39	0.08	0.49	505
	Below Junction	0.5	0.38	0.00	0.45	505
	Below Powell	0.5	0.31	-0.19	0.36	505
	Glen Park	0.5	0.37	-0.26	0.45	505
0.0 WSC	Foot Bridge	0	0.38	0.02	0.46	505
	Below Junction	0	0.49	-0.06	0.57	505
	Below Powell	0	0.39	-0.18	0.46	505
	Glen Park	0	0.42	-0.25	0.53	505

Figure 4.1 - Absolute Mean Error (AME) for different Wind Sheltering Coefficients



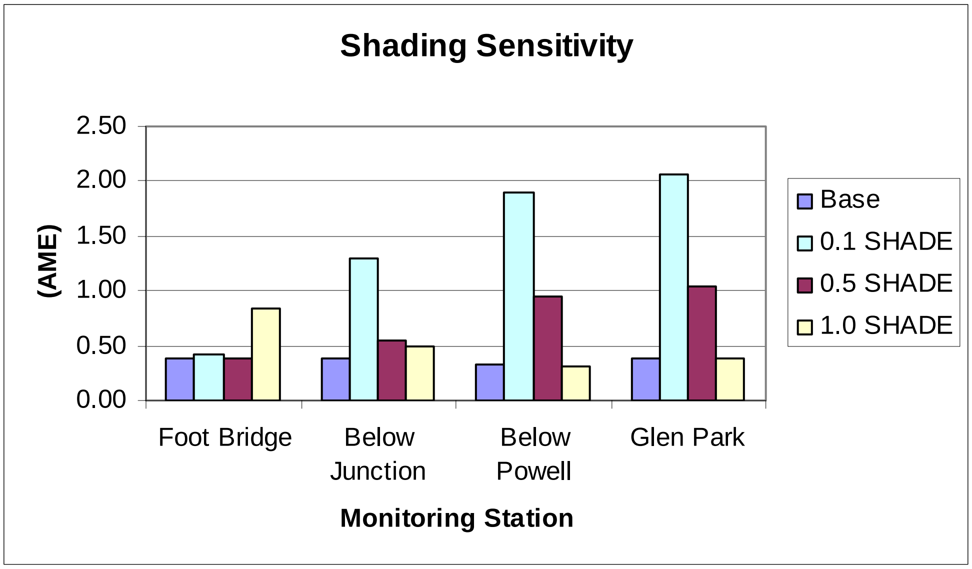
Shading:

Table 4.2 and Figure 4.2 demonstrate that the shading parameter strongly influences the CE-QUAL-W2 thermal calculations. It was apparent that the river sections were shaded from solar radiation more than the reservoirs and that the warming effect of the reservoirs dominates under base flow conditions.

Table 4.2 - Statistical summary of Shading (SHD) sensitivity

Scenario	Station	SHADE	AME. °C	ME, °C	RMS, °C	Count
base flow	Foot Bridge	0.5	0.38	0.03	0.47	505
	Below Junction	0.95	0.38	-0.03	0.45	505
	Below Powell	0.95	0.32	-0.22	0.38	505
	Glen Park	0.75	0.38	-0.28	0.47	505
1.0 SHD	Foot Bridge	1	0.83	0.55	1.12	505
	Below Junction	1	0.49	0.40	0.63	505
	Below Powell	1	0.31	0.20	0.40	505
	Glen Park	1	0.39	0.19	0.48	505
0.5 SHD	Foot Bridge	0.5	0.38	0.03	0.47	505
	Below Junction	0.5	0.54	-0.52	0.62	505
	Below Powell	0.5	0.95	-0.95	0.99	505
	Glen Park	0.5	1.05	-1.05	1.08	505
0.1 SHD	Foot Bridge	0.1	0.42	-0.39	0.50	505
	Below Junction	0.1	1.29	-1.29	1.39	505
	Below Powell	0.1	1.90	-1.90	1.98	505
	Glen Park	0.1	2.06	-2.06	2.14	505

Figure 4.2 - Absolute Mean Error (AME) for different Shading values



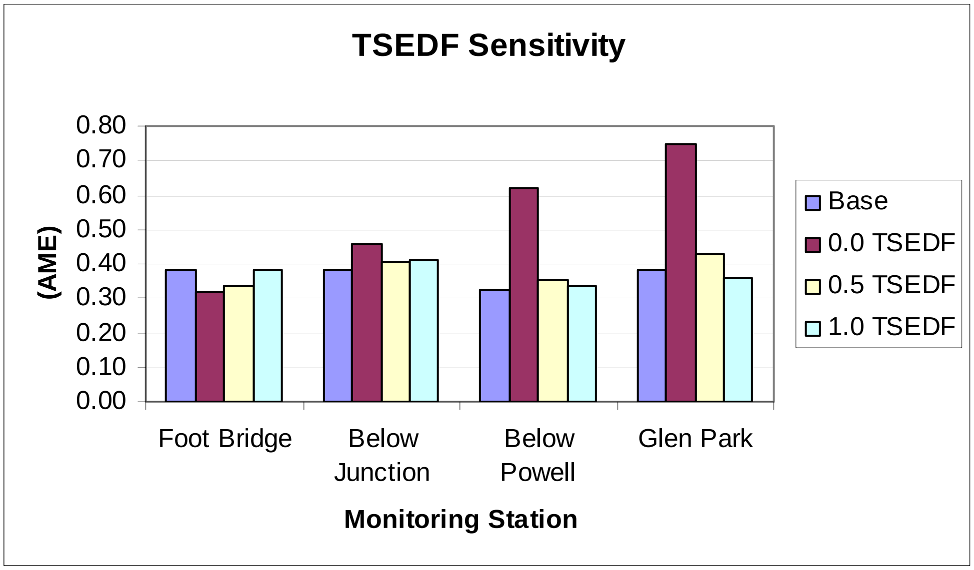
TSEDF:

TSEDF is a coefficient that regulates how much solar radiation is re-radiated as heat after it hits the channel bottom. A value of 1 means 100 percent of the incident short wave solar radiation is re-radiated as heat back into the water column. For the Kinnickinnic thermal model, the TSEDF seems more relevant in the reservoirs (where there is less shading) than in the river segments.

Table 4.3 - Statistical summary of TSEDF

Scenario	Station	TSEDF	AME. °C	ME, °C	RMS, °C	Count
base flow	Foot Bridge	1	0.38	0.03	0.47	505
	Below Junction	0.5	0.38	-0.03	0.45	505
	Below Powell	0.5	0.32	-0.22	0.38	505
	Glen Park	1	0.38	-0.28	0.47	505
1.0 TSEDF	Foot Bridge	1	0.38	0.03	0.47	505
	Below Junction	1	0.41	0.12	0.51	505
	Below Powell	1	0.34	0.08	0.41	505
	Glen Park	1	0.36	-0.01	0.44	505
0.5 TSEDF	Foot Bridge	0.5	0.34	-0.05	0.40	505
	Below Junction	0.5	0.40	-0.09	0.47	505
	Below Powell	0.5	0.35	-0.27	0.42	505
	Glen Park	0.5	0.43	-0.38	0.51	505
0.0 TSEDF	Foot Bridge	0	0.32	-0.13	0.37	505
	Below Junction	0	0.46	-0.30	0.53	505
	Below Powell	0	0.62	-0.62	0.68	505
	Glen Park	0	0.75	-0.75	0.80	505

Figure 4.3 - Absolute Mean Error (AME) for different TSEDF values



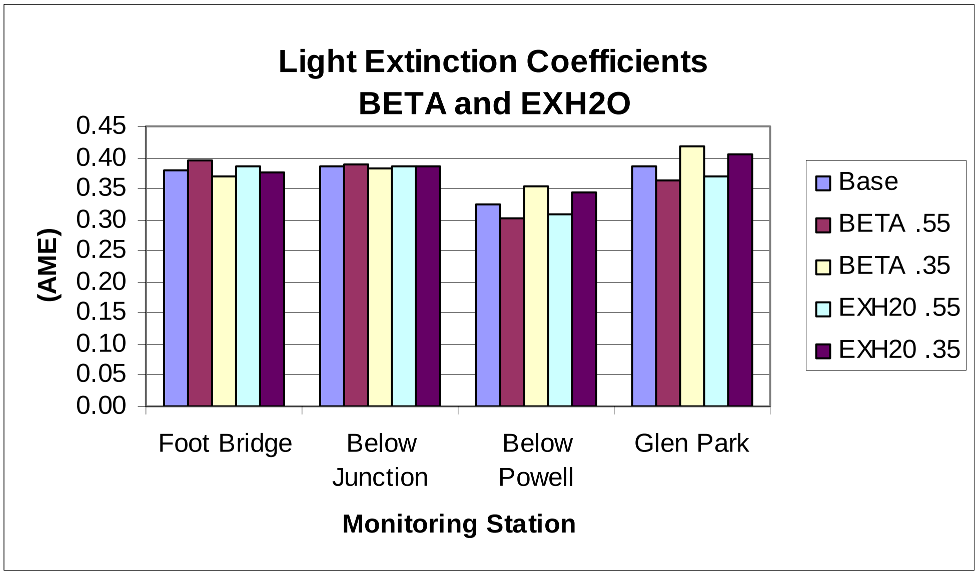
Light Extinction Coefficients:

Both parameters EXH20 and BETA were used for calculating the light extinction through the water column. For this study, light extinction data were not available; therefore, values of 0.45 for EXH20 and 0.45 for BETA were selected on the basis of a sensitivity analysis. To check the sensitivity of the model to these two parameters, 0.35 and 0.55 were run separately for EXH20 and BETA. The model reacted only slightly to the change in the values, but the change may not be so trivial in the deeper sections of the reservoirs where light is limited and stratification occurs.

Table 4.4 - Statistical summaries of Light Extinction Coefficients EXH20 and BETA

Scenario	Station	EXH20/BETA	AME. °C	ME, °C	RMS, °C	Count
base flow	Foot Bridge	0.45/0.45	0.38	0.03	0.47	505
	Below Junction	0.45/0.45	0.38	-0.03	0.45	505
	Below Powell	0.45/0.45	0.32	-0.22	0.38	505
	Glen Park	0.45/0.45	0.38	-0.28	0.47	505
0.55 EXH2O	Foot Bridge	0.55/0.45	0.38	0.04	0.47	505
	Below Junction	0.55/0.45	0.39	0.01	0.46	505
	Below Powell	0.55/0.45	0.31	-0.17	0.37	505
	Glen Park	0.55/0.45	0.37	-0.23	0.45	505
0.35 EXH2O	Foot Bridge	0.35/0.45	0.38	0.03	0.46	505
	Below Junction	0.35/0.45	0.39	-0.07	0.45	505
	Below Powell	0.35/0.45	0.34	-0.27	0.41	505
	Glen Park	0.35/0.45	0.41	-0.33	0.49	505
0.55 BETA	Foot Bridge	0.45/0.55	0.39	0.06	0.49	505
	Below Junction	0.45/0.55	0.39	0.03	0.47	505
	Below Powell	0.45/0.55	0.30	-0.14	0.36	505
	Glen Park	0.45/0.55	0.36	-0.20	0.44	505
0.35 BETA	Foot Bridge	0.45/0.35	0.37	0.01	0.45	505
	Below Junction	0.45/0.35	0.38	-0.08	0.44	505
	Below Powell	0.45/0.35	0.35	-0.29	0.42	505
	Glen Park	0.45/0.35	0.42	-0.36	0.50	505

Figure 4.4 - Absolute Mean Error (AME) for Light Extinction Coefficients EXH20 and BETA



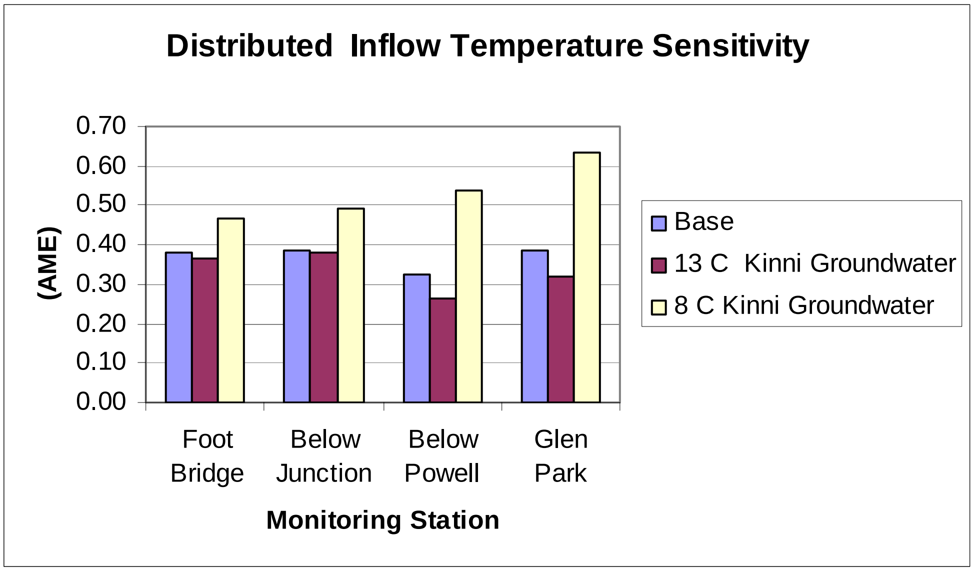
Kinnickinnic Distributed Tributary Temperatures:

Groundwater and other ungaged flows entering the study reach were added in order to maintain observed flows throughout the system. The temperatures of these flows were estimated by performing a sensitivity analysis.

Table 4.5 - Statistical summary of sensitivity of the model to constant distributed tributary temperatures at 8 °C and 13 °C and Quarry Road temperatures

Scenario	Station	Dist. Temp C	AME. °C	ME, °C	RMS, °C	Count
base flow	Foot Bridge	11.00	0.38	0.03	0.47	505
	Below Junction	11.00	0.38	-0.03	0.45	505
	Below Powell	11.00	0.32	-0.22	0.38	505
	Glen Park	11.00	0.38	-0.28	0.47	505
8 C	Foot Bridge	8.00	0.47	-0.23	0.52	505
	Below Junction	8.00	0.49	-0.32	0.56	505
	Below Powell	8.00	0.54	-0.52	0.61	505
	Glen Park	8.00	0.63	-0.62	0.73	505
13 C	Foot Bridge	13.00	0.36	0.21	0.51	505
	Below Junction	13.00	0.38	0.16	0.48	505
	Below Powell	13.00	0.26	-0.01	0.32	505
	Glen Park	13.00	0.32	-0.05	0.38	505

Figure 4.5 - Absolute Mean Error (AME, ^{o}C) for different distributed temperature data sets

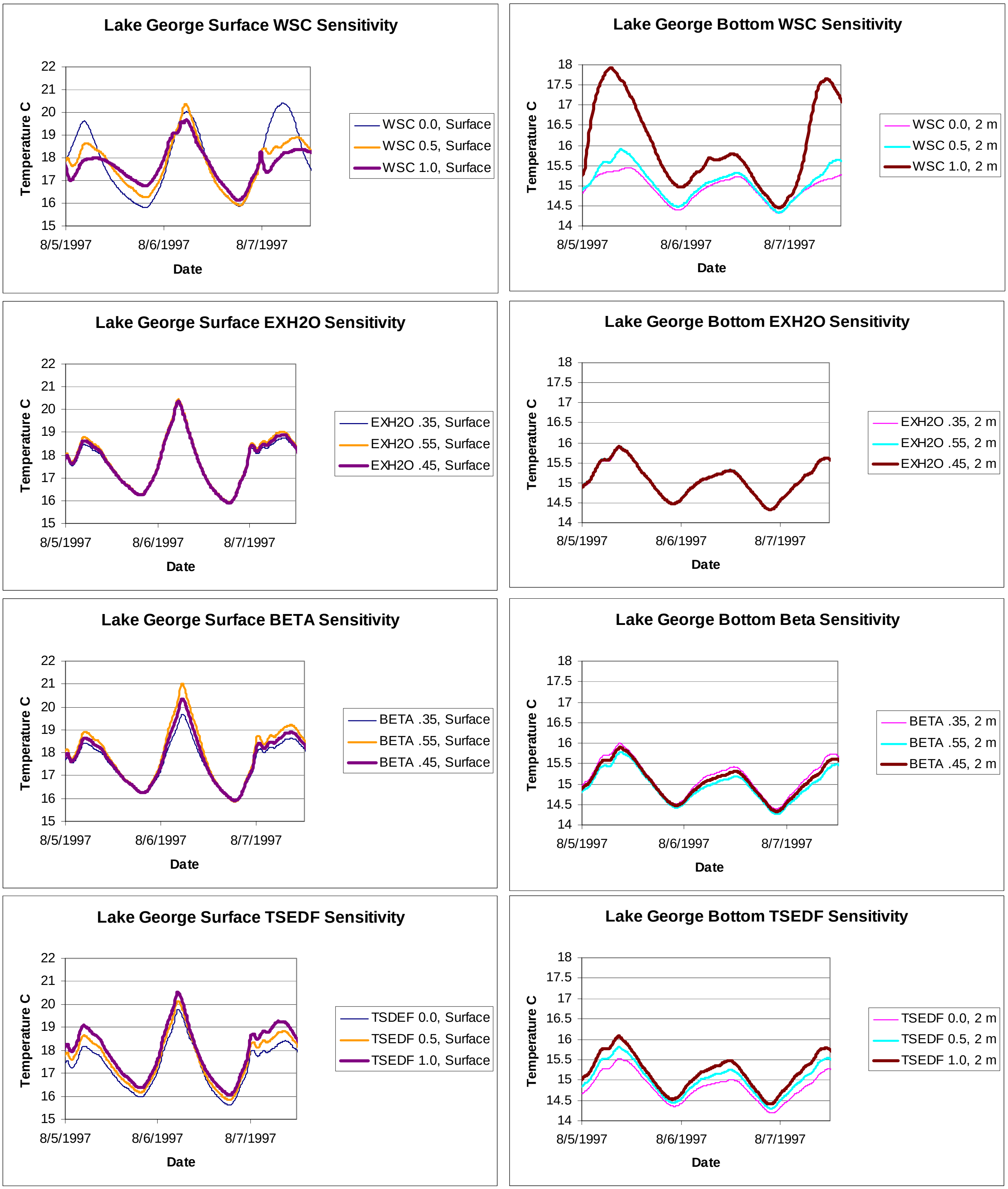


The results of the sensitivity analysis demonstrated that the distributed flow at 13 degrees C produced the lowest AME values. However, distributed flow temperatures of 11 degrees C were used for the model in order to better reproduce stream temperatures during storms and to reflect that the actual temperatures of the groundwater are probably below 10 degrees C.

Lake George Stratification Sensitivity:

Stratification dynamics in the two reservoirs were important for the model to reproduce to correctly generate dam discharge temperatures. To check the model's stratification sensitivity, the response of Lake George's surface and bottom temperatures to changes in WSC, TSEDF and light extinction coefficients EXH2O and BETA were documented. The wind-sheltering coefficient (WSC) had the most effect on Lake George's surface and bottom temperatures. As Lake George was increasingly exposed to wind, the stability of the reservoir's stratification dramatically decreased. Least visible, changes in EXH2O showed very little difference in the reservoir's surface and bottom temperatures. The other parameters, BETA and TSEDF, were moderately sensitive to changes. Increasing TSEDF had a global effect of increasing the bottom and surface temperatures, whereas, increasing BETA only increased the temperatures at the surface and the bottom during the diurnal temperature peaks (Figure 4.6).

Figure 4.6 – Modeled Lake George surface and bottom temperatures sensitivity to WSC, EXH2O,BETA, and TSEDF.



5.0 DISCUSSION AND RECOMMENDATIONS FOR FURTHER WORK

The predictive ability of this Kinnickinnic CE-QUAL-W2 thermal model was limited to evaluation of the thermal and hydrologic response of different storm water runoff management plans using three specific time periods: the June 15, 1997, storm; the July 1, 1997, storm; and the August 6-10 base flow. Of the three, the base flow model was probably the most reliable. The base flow's primary advantage was that the model did not require storm sewer inputs which were based on several questionable assumptions: 1) uniform rainfall over the basin; 2) simplified runoff routing; and 3) lack of pervious contributions. Also, the base flow model used estimated Rocky Branch flows that were fairly small, steady, and predictable from past data. The Rocky Branch estimated flows used for the two storm models, however, were based on calibration runs, and the tributary's inputs greatly influenced the flows and temperatures seen at Glen Park. In the following sections, other important factors that affected the model's reliability are discussed as suggestions for further work.

Detailed Bathymetry of the Reservoirs:

Lake George, in particular, is an instrumental feature in the model's grid that controls the temperatures downstream. Without a detailed bathymetry and elevation/storage data, it was difficult to simulate the complex hydrodynamics and water temperatures that occurred in the reservoir. Also, an old wooden dam, approximately 30 feet upstream of the current withdrawal structure, was poorly mapped and needs detailing. Any BMPs that involve reconfiguring the reservoir should be based on more reliable bathymetry data.

Storm Sewer Flow and Temperature Field Data:

There is always uncertainty with data derived from models. With this study's focus on the Kinnickinnic River's thermal reaction to storm sewer runoff, field data from the storm sewers would have been preferred over computed data. However, monitoring storm sewers, stream stations, and meteorological conditions for an additional summer were not a part of this study's scope of work.

Tracer Simulation:

To be assured that the model had correct hydrodynamics, a tracer study would have been useful. Besides temperature comparisons at different points along the river, it was difficult to verify that the model had similar transport times and flow patterns. If observed tracer data were available, travel times and hydrodynamics of the system would have been better known.

Shading Data:

Crude estimates of the amount of canopy and shade could be improved by including data that allows CE-QUAL-W2 to utilize its dynamic shading computations. For this study, static coefficients were used to describe the amount of shading on each segment. If for each bank of the river, vegetative type data, topographic data, and leaf growth and leaf fall data for deciduous trees were included, a more accurate dynamic shading coefficient could have been used.

Light Extinction Coefficients:

To estimate the light extinction parameters (GAMMA and BETA), average Secchi depth (Z_s) can be used in the following equations: $\gamma = 1.11Z_s^{-0.73}$, $\beta= 0.27 \ln(\gamma) + 0.61$ (Cole and Buchak, 1995). Without Secchi depths and without modeling water quality and algae in CE-QUAL-W2, these parameters were left at 0.45. During the two rain events, dynamic values for GAMMA and BETA could have been measured to better represent changes in stream turbidity.

Missing Flows:

A large factor in achieving reliable results from the CE-QUAL-W2 model was the inputting of accurate time-varying data for the distributed tributaries. As an estimate of these unaccounted flows, which were assumed to be composed mostly of groundwater, a simple water budget calculation using the hourly or daily upstream flows and downstream flows was made. The temperatures were estimated at a constant 11 degrees C. Without a doubt, a better understanding of these inputs would have improved the model.

Rainfall Data:

For the two storms modeled, rain gage data collected at the City Hall were used in the generation of their corresponding storm sewer inputs. Using one rain gage and assuming a constant rainfall over the entire basin may be a source of significant error for each storm sewer's flow estimation. It is quite likely that these two summer storms were not uniform in rainfall distribution, thus causing individual storm sewers represented in the model to have inaccurate timings and flows. The Kinnickinnic CE-QUAL-W2 model would provide more reliable results during storm events if more rain gages were available in the basin.

6.0 REFERENCES

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7.0 ACKNOWLEDGEMENTS

I would like to express thanks to Ken Schreiber and Steve Greb of the Wisconsin Department of Natural Resources for providing their observed and computed data from 1996 and 1997. Also, I appreciate Tom Cole (USACE) and Scott Wells (Portland State), the developers of CE-QUAL-W2, for their helpful suggestions. Finally, I am grateful to Rich Brasch and Shabana Hameed (Bonestroo, Rosene, Anderlik & Associates) and Reid Wronski and the City of River Falls for their support of this study.

BMP Suite for Reducing Thermal and TSS Impacts of Urban Runoff on Kinnickinnic River

BMP Measure	Description	Benefit		Application Comments
		TSS	Thermal	
Category 1- Larger-scale BMP's suitable for end-of-pipe application. Application at relatively small number of locations can have large beneficial impact, expected to give bigger "bang-for-the-buck"				
Rock Crib/Cooling Trench	Buried rock-filled trench that uses ambient soil temp to cool runoff	Yes	Yes	• Can be installed as buried linear feature having minimal interference with above ground passive uses • Tech analysis suggests 6-7 degree C reduction in runoff temperature for trench designed to hold water for 35 minutes or more • 140 foot long 10" x10" trench (.35 void ratio) needed to contain .2" of runoff from imp area from 12-acre downtown watershed • Desirable to have runoff pre-treatment if flow is concentrated already • Several installed and being monitored in Dane Co WI
Thermal swales	Vegetated surface swale with outlet control at downstream end	Yes	Yes	• Allows cooling of runoff through evaporation and reduction in runoff volume through infiltration • Outflow rate control essential to reduce rate of runoff delivery to stream • Dane Co. WI literature suggests swales 300'-500' in length, 3' deep, with 8" outlet for 100 acre HDR drainage is desirable • Need dedicated surface area to accommodate, • Might enhance effect with shading as long as swale stability is not compromised • Desirable to have runoff pre-treatment if flow is concentrated already
Infiltration Trench	Granular filled trench constructed in permeable soil	Yes	Yes	• Designed to reduce runoff volume through water loss to soil • Can be installed as buried linear feature having minimal interference with above ground passive uses • Need to field check soil suitability

BMP Measure	Description	Benefit		Application Comments
		TSS	Thermal	
				with borings, especially in urban environment • Recommendations for separations from building foundations to avoid seepage issues • Pre-treatment necessary if flow is concentrated (vs. sheet drainage)
Shaded Detention basin	Small shaded surface ponding area where runoff is detained prior to discharge	Yes	Yes	• Best application appears to be use of existing depressions bordered by mature vegetation that shades all or most of area • Main issue is how to get runoff in and out of depression area
Manufactured BMP (swirl concentrators, etc.)	Units installed below grade to catch and treat stormwater to remove trash, oil and grease, and TSS	Yes	No	• Best application for RF may be as pre-treatment for runoff going to another BMP for thermal control • 30-40% TSS reduction expected with proper design and maintenance (3-4 times yearly) • Access to vactor truck needed to do maintenance
Category 2 – Smaller scale BMP's which if done at a large number of sites can have a significant cumulative impact. Often most suitable for incorporation as part of re-development or utility re-construction activities				
Bioretention (such as rainwater garden)	Shallow, landscaped surface depression designed to catch and infiltrate/filter runoff	Yes	Yes	• Best use is to catch and treat sheet drainage from small areas (<1 acre) • One application is if land owner is interested in creating visual amenity that acts as "natural" infrastructure • Good application would be to construct in center medians of roads and along edges of parking lots to catch and treat sheet drainage (e.g. Menard's retail store in Eau Claire, H.B. Fuller Co and Wayzata downtown area in TCMA, etc.)
Porous pavement	Use of specially constructed pavement that transmits water through it to underlying soil	?	Yes	• Benefits are associated with runoff volume reduction • City of Minneapolis has porous pavement pilot project installation that is being monitored

BMP Measure	Description	Benefit		Application Comments
		TSS	Thermal	
Replacement of blacktop	Blacktop would be replaced with lighter, more heat reflective material such as concrete	No	?	• Quantification of benefit during critical period vs. cost would be helpful.
Street-scaping	Use of trees, porticos, etc. to shade impervious areas such as streets, parking lots, and sidewalks	No	Yes	• This could be incorporated into downtown re-development projects
Conversion of overflow parking lot hard surface	Use of concrete cells or flexible plastic grids to replace pavement	Yes	Yes	• Suggested use is for overflow parking lot areas, not high traffic areas
Green roofs	Veneers of living vegetation installed on top of buildings	N/A	Yes	• Mimic hydrologic processes associated with open space • Reduces runoff volume from roofs through ET, cools runoff that does occur • Common practice in Europe • Green roof recently installed on Dakota County park shelter in MN near end of 2003 growing season
Roof-top runoff redirection	Re-direction of downspouts carrying rooftop runoff to pervious areas	N/A	Yes	• Re-direction would be to pervious area to encourage more infiltration
Rain barrels	Located to catch and temporarily hold roof-top runoff	No	Yes	• Mainly for temporary detention of rooftop runoff • Suggested use as source of water for planters/ gardens, etc.
No-mow buffers	Allowing grass to grow to mature height	Yes	Yes	• Un-maintained buffer areas/strips with native vegetation facilitate infiltration/filtration of runoff • Suggested especially for areas close to River and adjacent to parking lots (i.e. the lot north of Division Street and west of Main Street) • Sets good example for residents

BMP Measure	Description	Benefit		Application Comments
		TSS	Thermal	
Category 3 – Enhancements to maintenance and education programs				
High efficiency street sweeping	Use of high efficiency sweeper to supplement or replace mechanical sweeping	Yes	No	• Grain sizes picked up are smaller than those typically removed by manufactured BMP's • Highest priority areas would be high impervious areas draining directly to the river
Storm drain stencils	Messages painted near catch basins draining to priority resources	Yes	No	• Tool to educate public on direct connection of storm drainage system with River • Increase awareness of public on issue of protection of River

East Bank Improvements

Sewershed	Total Area (Ac.)	Imperv. Area (Ac.)	Mean Annual TSS Load (lbs/yr)	Proposed BMP	Mean Annual TSS Reduction	Total Potential Cost Range	Comments
2.1 and 1.6	21.2	6.9	4,370	Infiltration	48% (2,098 lbs/yr)	$110,000 - $140,000	• Deduct approximately $30,000 if only doing 2.1 alone • Assumes a 50' x 50' footprint at the parking lot facility
4.3 and 4.4	26.2	16.5	10,460	Ravine Storage	41% (4,289 lbs/yr)	$60,000	• Could potentially also capture runoff from 1 acre of Econofoods parking lot (add/alt = $45,000 extra) • Assumes 80% efficiency by ponding in shaded ravine parallel to river • Desirable to inventory shade tree locations to prevent mortality
2.1, 2.2.2.4, 3.1, 4.3, 4.4	83.3	41.7	26,470	Stormwater Interceptor	Rough estimate is 60-70% reduction to channel	$420,000 - $500,000 (preliminary estimate)	• Assumes 80% efficiency from ponding in reduced Lake George • Does not include costs for reservoir modification • Thermal model shows peak temperature reduction of 0.3 degree C. for July 1 storm, and 1.0 degrees C for June 15 storm at Footbridge

West Bank Improvements

Sewershed	Total Area (Ac.)	Imperv. Area (Ac.)	Mean Annual TSS Load (lbs/yr)	Proposed BMP	Mean Annual TSS Reduction	Total Potential Cost Range	Comments
2.3	7.9	3.5	2,210	Open Channel	50% (1,105 lbs/yr)	$40,000	• *Feasibility: high* • Open channel would be developed on city-owned property • TSS reductions based on well-vegetated channel in stable condition

West Bank Improvements – Continued

2.5 (north)	11.7	4.8	3,035	Infiltration	49% (1,487 lbs/yr)	$65,000	• City-owned, undeveloped land
2.5 (south) and 4.1	3.6	2.9	1,715	Infiltration and Rainwater Garden (RWG)	69% (1,183 lbs/yr)	$50,000 - $110,000	• *Feasibility: high* • Could be combined with proposed parking lot/trail reconstruction • Two separate infiltration approaches o East of lot, south of Maple o South of lot, diverting storm line from sewershed 4.1 • RWG would treat parking lot runoff at south end of lot.
5.5	5.8	1.6	1,030	Infiltration	47% (484 lbs/yr)	$70,000	• *Feasibility: limited to moderate* • Currently vacant, city-owned lot • Exising slopes would require backfill material to bury infiltration feature.

NOTES AND ASSUMPTIONS

1. Size of all stormwater BMPs can accommodate 0.2” runoff over impervious area of sewershed.
2. Approximately 0.5” rainfall depth is required to generate 0.2” runoff volume, in all scenarios.
3. Infiltration galleries sized assuming 35% void space in storage medium.
4. Allowances:
    a. $20,000 allowance was made for all infiltration galleries to account for a pre-treatment swirl concentrator
    b. Excavation costs were assumed at $5/CY
    c. Mobilization costs were assumed at $10,000 (conservative)
5. Costs include a 30-35% factor for design, construction services and contingency.

RIVER FALLS, WISCONSIN

LAKE GEORGE RECONFIGURATION

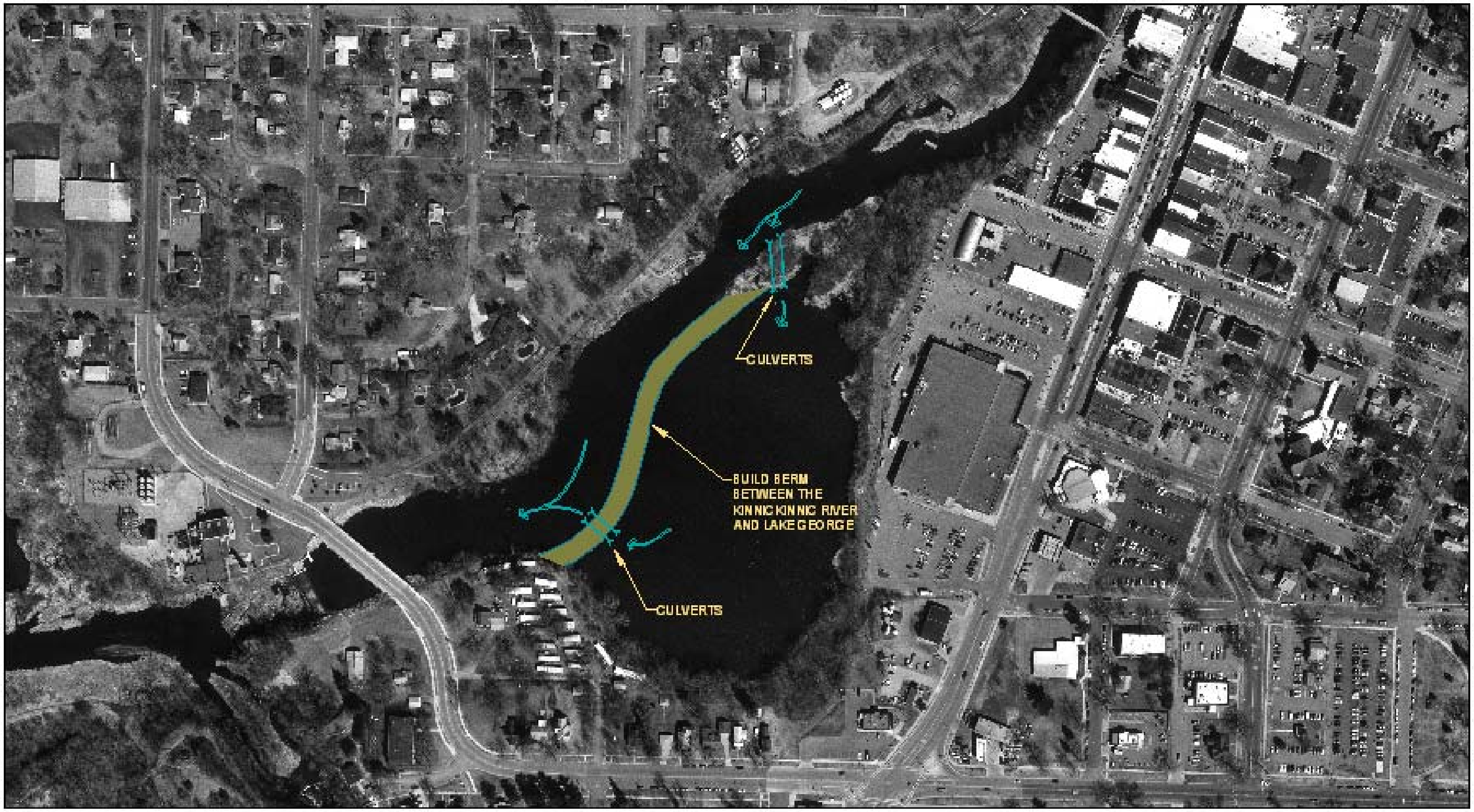
OPTION 1

SEPTEMBER, 2004

0 50' 100' 200'
SCALE: 1" = 200'

Bonestroo
Rosene
Anderlik &
Associates
Engineers & Architects

20603104_LAKE_GEORGE_OPTION1.DWG



RIVER FALLS, WISCONSIN

LAKE GEORGE RECONFIGURATION

OPTION 2

SEPTEMBER 15, 2004

20603104 LAKE GEORGE OPTION2.DWG

Bonestroo
Rosene
Anderlik &
Associates
Engineers & Architects

RIVER FALLS, WISCONSIN
LAKE GEORGE RECONFIGURATION
OPTION3
SEPTEMBER 15, 2004

20603104 LAKE GEORGE OPTION3.DWG

Bonestroo Rosene Anderlik & Associates
Engineers & Architects

RIVER FALLS, WISCONSIN

LAKE GEORGE RECONFIGURATION

OPTION 4

SEPTEMBER 15, 2004

20603104 LAKE GEORGE OPTION4.DWG

SCALE: 1" = 200'

Bonestroo Rosene Anderlik & Associates
Engineers & Architects

Segment 1: Division to Maple

Item	Units	Qty	Unit Price Low End	Unit Price High End	Total Price Low End	Total Price High End
18" RCP storm sewer, 0'-8' deep	LF	310	$30	$45	$9,300	$13,950
24" RCP storm sewer, 0'-8' deep	LF	440	$35	$50	$15,400	$22,000
30" RCP storm sewer, 10'-12' deep	LF	410	$50	$65	$20,500	$26,650
5' diameter manholes	EA	3	$3,000	$4,500	$9,000	$13,500
6' diameter manholes	EA	3	$5,000	$7,000	$15,000	$21,000
Street work (bituminous patching)	SY	1,998	$60	$75	$119,880	$149,850
Traffic Control[a]	LS	1	$15,000	$20,000	$15,000	$20,000
Bedrock Excavation[b]	CY	215	$60	$75	$12,900	$16,125
Mobilization	LS	1	$10,000	$15,000	$10,000	$15,000
Subtotal					$226,980	$298,075
+15% Contingency					$34,047	$44,711
Grand Total					$261,027	$342,786

Segment 2: Maple to Walnut

Item	Units	Qty	Unit Price Low End	Unit Price High End	Total Price Low End	Total Price High End
36" RCP storm sewer, 10'-12' deep	LF	960	$65	$80	$62,400	$76,800
5' diameter manholes	EA	3	$3,000	$4,500	$9,000	$13,500
6' diameter manholes	EA	2	$5,000	$7,000	$10,000	$14,000
Street work (bituminous patching)	SY	2,219	$60	$75	$133,140	$166,425
Traffic Control	LS	1	$15,000	$20,000	$15,000	$20,000
Bedrock Excavation[b]	CY	1,211	$60	$75	$72,660	$90,825
Mobilization	LS	1	$10,000	$15,000	$10,000	$15,000
Subtotal					$312,200	$396,550
+15% Contingency					$46,830	$59,483
Grand Total					$359,030	$456,033

Segment 3: Walnut to Lake George

Item	Units	Qty	Unit Price Low End	Unit Price High End	Total Price Low End	Total Price High End
48" RCP storm sewer, 14'-16'	LF	560	$100	$125	$56,000	$70,000
5' diameter manholes	EA	1	$3,000	$4,500	$3,000	$4,500
6' diameter manholes	EA	3	$5,000	$7,000	$15,000	$21,000
Street work (bituminous patching)	SY	1,195	$60	$75	$71,700	$89,625
Parking lot (bituminous patching)	SY	400	$40	$50	$16,000	$20,000
Traffic Control	LS	1	$15,000	$20,000	$15,000	$20,000
Bedrock Excavation[b]	CY	1,494	$60	$75	$89,640	$112,050
FES, riprap, misc. restoration	LS	1	$5,000	$7,000	$5,000	$7,000
Mobilization	LS	1	$10,000	$15,000	$10,000	$15,000
Subtotal					$281,340	$359,175
+15% Contingency					$42,201	$53,876
Grand Total					$323,541	$413,051

NOTES

a) Assumes a full detour plan for re-routing traffic along Main Street

b) Assumes bedrock starts at depth of 10 feet below grade and follows length and depth of proposed pipe for a uniform width of 10 feet.

Cost Estimate for Construction of ReConfigured Lake George

	LOW				HIGH			
Item	Quantity	Unit	Price	Total	Quantity	Unit	Price	Total
Mobilization	1	LS	$5,000	$5,000	1	LS	$15,000	$15,000
Erosion/Sed Control								
Floating silt curtain	720	LF	$15	$10,800	720	LF	$25	$18,000
Misc. temp ESC	1	LS	$5,000	$5,000	1	LS	$10,000	$10,000
Dewatering	1	LS	$15,000	$15,000	1	LS	$30,000	$30,000
Cut, fill and place for berms	17,780	CY	$5	$88,900	22,225	CY	$10	$222,250
Geotextile fabric (Type V)	18,870	SY	$3	$47,175	18,870	SY	$5	$94,350
Exterior berm protection								
Riprap	3,360	TN	$40	$134,400	3,360	TN	$60	$201,600
Geotextile (Type IV)	3,550	SY	$3	$8,875	3,550	SY	$5	$17,750
Live staking	720	LF	$30	$21,600	720	LF	$60	$43,200
Misc. common excavation	1,000	CY	$6	$6,000	1,500	CY	$10	$15,000
Restoration	9,250	SY	$1	$9,250	9,250	SY	$3	$27,750
Topsoil Borrow	500	CY	$10	$5,000	1,000	CY	$15	$15,000
Overflow structure from river	1	EA	$15,000	$15,000	1	EA	$25,000	$25,000
Inter-cell flow controls	4	EA	$7,500	$30,000	4	EA	$15,000	$60,000
Drawdown pipe for 3rd cell	1	EA	$10,000	$10,000	1	EA	$15,000	$15,000
Subtotal				$412,000				$809,900
Contingency @ 25%				$103,000				$202,475
Construction				$515,000				$1,012,375
Indirect Costs @ 25%				$128,750				$253,094
Total Construction Costs				$643,750				$1,265,469
Feasibility Study				$30,000				$30,000
Permitting				$20,000				$20,000
TOTAL				$693,750				$1,315,469

Lake George/Kinnickinnic River Project
City of River Falls, MN
Stakeholders Advisory Group Meeting #4
Thursday, December 16, 2004

-Meeting Summary-

Meeting Attendees:

Meeting attendees included members of the Technical Advisory Committee, the Stakeholder Committee, and interested citizens. See attached list

Summary of Major Points:

The meeting opened with a review of the recent project meeting progression to date by Rich Brasch of Bonestroo and Associates with the help of other members of the Technical Advisory Committee. Main points were as follows:

- Stakeholder Meeting #2 was held in October 2004. The meeting was largely dedicated to looking at the opportunities for, and the benefits and costs of, applying various watershed management measures in the study area to reduce TSS and thermal loads to the River. At that meeting, the Stakeholders group also reviewed a qualitative comparison of several alternatives for re-configuring Lake George and requested that the Technical Advisory Committee come up with 1-2 alternatives to evaluate in more detail.
- Stakeholder Meeting #3 held on December 2, 2004. This meeting focused on presenting one Lake George re-configuration alternative developed by the Technical Advisory Group, which combined many of the features of the alternatives discussed at the October meeting. The estimated thermal and TSS benefits to the River were presented as were estimated cost ranges for the Lake re-configuration and updated costs for the interceptor pipe system east of the River. Thermal modeling results were presented that showed virtually all of the thermal benefits of watershed management measures were lost at the assessment point below the Lake George dam if Lake George remains in its current configuration. At the conclusion of this meeting, the Stakeholders group was reasonably comfortable with the Lake George re-configuration concept plan presented and believed that the group could move on to the final stage of this phase of the project.

The purpose of this meeting (Stakeholder meeting #4) was to come up with the best way to combine the watershed management and Lake re-configuration elements into an over-all strategy.

Rich Brasch presented information that related monitored temperature data at various points in the River for both baseflow and runoff event conditions to temperature tolerance information for brown trout and macroinvertebrates. The information was intended to illustrate how actual temperatures in the River were approaching some important tolerance thresholds for key aquatic organisms in the River, especially for the macroinvertebrate populations which help sustain the trout. Rich followed with a brief explanation of several schematic drawings of the Lake re-configuration alternative endorsed at the previous stakeholder meeting.

Subsequently, the Stakeholders group was asked to provide guidance on an overall strategy for the River in view of the information presented to date. Following is a summary of the results of that discussion:

- There was consensus that a multi-pronged approach involving strategic execution of both end-of the pipe and small scale/small site watershed management actions as well as re-configuration of Lake George and a phased construction of interceptor pipes along the east side of the River was the best strategy to follow.
- A suggested strategy agreeable to the Stakeholders group should include the following elements (not in any particular order):
    - Re-configuration of Lake George into a multi-cell system that is separated from the River during baseflow and small to moderate runoff events
    - Construction of the east interceptor (which includes capture of the runoff from Econo Foods) as well as the first phase of the north interceptor up to Walnut Street.
    - Extension of the north interceptor as opportunities arise, such as during downtown re-development projects or road/alley re-construction.
    - Construction of one or more “end-of-pipe” projects designed to infiltrate runoff on existing City-owned land, such as in Heritage Park on the west side of the River.
    - Concentrating on one to several storm drainage sewersheds to work with private property owners to find suitable sites for, and install, small scale stormwater treatment features such as rainwater gardens. It was suggested that these efforts could focus on parts of the study area where diversion of runoff to a re-configured Lake George for treatment is not feasible and end-of-the-pipe treatment strategies may not be practical.
    - Development and execution of a public education program aimed at building understanding of, and support for, the overall management strategy and its various components among the general public as well as the business community.
- It was recognized that the technical analysis shows that without a separation of Lake George from the River, the thermal benefits of watershed management actions as measured below the Lake George dam will be negated.
- It was also recognized that watershed management measures should emphasize infiltrating surface runoff and that this is likely to have some as yet unquantifiable benefit in improving cool baseflow to the River.
- In review and discussion of the conceptual plan for re-configuration of Lake George as part of an overall management strategy to protect and enhance the River, the Group recognized that:

- It is important to create a space that will be valued by the community apart from its benefit to the River. Thus, the area should be designed to be as aesthetically pleasing as reasonably possible considering its use to treat stormwater runoff from the downtown areas and should provide trail features and connections.
- One member observed that the changes in the Lake that are being proposed (i.e. dramatically reducing its surface area and isolating it from the River) will significantly change the look of this area in a way which may not be welcomed by some in the community, and that this perception issue will need to be carefully worked through.
- The issues associated with securing regulatory approval for re-configuring the Lake have yet to be resolved, but the outcome of the technical analysis on the benefits of the re-configuration for the River has increased the motivation to work through those issues.
- There are still important actions that need to be undertaken before the concept for re-configuration can be finalized and design completed. The main issues are:
    - collecting reliable bathymetric information on the existing Lake,
    - locating spring discharges, and
    - more detailed assessment of the engineering properties of the sediment within the Lake
    - beginning the process of securing regulatory permits
    - identifying possible funding sources for implementation

  These issues should be addressed in future phases of this project.

(Meeting Summary prepared by Rich Brasch, Bonestroo and Associates on December 27, 2004, modified on January 4, 2005)

Lake George/Kinnickinnic River Project
City of River Falls, MN
Stakeholders Advisory Group Meeting #4
Thursday, December 16, 2004

Name	Representing
Don Richards	Mayor, City of River Falls
Hal Watson	River Falls City Council
Mike Keenan	River Falls Planning Commission and Park Board
Harris Kittelson	River Falls Planning Commission
Karen Voss	WI Department of Natural Resources
Ken Schreiber	WI Department of Natural Resources
Jim Devlin	WI Department of Natural Resources
Kent Johnson	Trout Unlimited
Rick McMonagle	Kinnickinnic River Land Trust
Mark Freeborn	River Falls Municipal Utility
Kerry Keen	UW-River Falls
Aloha Hovde	Citizen
Stan Meyer	Former River Falls Park and Recreation Commission Board member
Reid Wronski	City of River Falls Engineering
Tony Steiner	City of River Falls Planning
Rich Brasch	Bonestroo and Associates