City of River Falls
North Kinnickinnic River Monitoring Project

2009 Technical Review

Report prepared by SEH Inc., for the

City of River Falls Engineering Department
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Project Introduction:

The Kinnickinnic River is one of the premier, naturally sustaining trout fisheries in the Upper Midwest, primarily producing brown trout. There has been a lot of concern about how new development in River Falls may affect the river, especially due to storm water runoff from impervious surfaces in these urbanizing areas. Not only can storm water runoff contribute chemicals from lawns, cars, etc., but the thermal impacts of untreated storm water are also a concern, as described on the North Kinnickinnic River Monitoring Project website (see "The Thermal Impacts of Storm Water").

In 2002, the City adopted a new Storm Water Management Ordinance, which is designed to protect the Kinnickinnic River from the negative impacts of storm water runoff associated with new development. For new development and re-development projects, the City of River Falls Storm Water Management Ordinance requires that, for a 1.5-inch, 24-hour rainfall event, the post-development runoff volume and peak flow rate must not exceed the pre-development runoff volume and peak flow rate. To achieve this requirement, developers must provide on-site infiltration of storm water. Standards adopted under the ordinance require that a safety factor of two be used for designing infiltration areas. The result is that infiltration basins, at the time of acceptance by the City, will be able to infiltrate twice the additional runoff generated by a 1.5-inch rain event.

To take an active role in sustaining the river's health and well-being, the City of River Falls implemented the North Kinnickinnic River Monitoring Project in 2004. The goal of the project is to evaluate the effectiveness of our Storm Water Management Ordinance for preventing degradation of the Kinnickinnic River due to new City development. The project scope includes four primary monitoring elements:

- Temperature Monitoring
- Water Quality Monitoring
- Base Flow Surveys
- Macroinvertebrate Monitoring

The City will examine the long-term results of each of these four monitoring elements to determine whether the storm water management ordinance is protecting the river as new development occurs. The project will use an “upstream/downstream” approach to determine if storm water management practices in the Sterling Ponds subdivision protect downstream river conditions. We will also take a focused look at the performance of the on-site storm water management practices that are incorporated into new developments. Our hope is that, due to the ordinance requirements, the thermal, water quality, and biological impacts of new development will be undetectable or greatly reduced.

River Falls Precipitation:

Due to the major influence of precipitation on river flow, temperature, and water quality, an analysis of seasonal precipitation is conducted as a part of this project. Three rain gauges reside within or near the North Kinnickinnic River Monitoring Project Area. The primary project rain gauge, provided by the Wisconsin Department of Natural Resources (WDNR), is an electronic tipping-bucket rain gauge that measures hourly precipitation amounts in 0.01-inch increments. This gauge is located in the Sterling Ponds subdivision at the northwest corner of the City of River Falls, in very close proximity to all six North Kinnickinnic River monitoring stations. A weather station at Rocky Branch Elementary School, on the south side of River Falls, serves as an alternate source of daily rainfall data. This station is part of an extensive network of local weather stations supported by KSTP-TV in Minneapolis, MN, via the Automated Weather Source. The Rocky Branch Weather Station also serves as a source of daily mean, minimum, and maximum air temperatures in River Falls. In addition, daily precipitation data are available from the United States Geological Survey (USGS) Kinnickinnic River monitoring station at County Highway F, near Kinnickinnic State Park, approximately five miles west of River Falls. The USGS gauge is an electronic tipping-bucket rain gauge that measures 15-minute precipitation amounts in 0.01-inch increments.

During the 2009 monitoring season, the Sterling Ponds rain gauge was not functioning, so the rain gauge at Rocky Branch Elementary School served as the source for daily rainfall data. Occasional gaps in the daily record for the gauge at Rocky Branch Elementary School were filled using daily rainfall data from the USGS gauge. Although five miles removed from the project area, the USGS rain gauge also provided very helpful information on the timing and intensity of rain events.

A total of 24.44 inches of precipitation was recorded in River Falls (at Rocky Branch Elementary School) during the April-September 2009 period, 3.77 inches more than the normal total of 20.67 inches for the April-September time period (Figure 1). Rain fell on 51 days, or 28% of the April-September 2009 period. In comparison, a near-normal total of 19.82 inches of precipitation was recorded in River Falls during the April-September 2004 monitoring period, an above-normal total of 36.45 inches was measured during the April-September 2005 period, a below-normal total of 17.16 inches was measured during the April-September 2006 period, a below-normal total of 18.36 inches was measured during the April-September 2007 period, and a near-normal total of 20.01 inches of precipitation was measured during the April-September 2008 period (Figure 1). "Normal " monthly and seasonal rainfall amounts are based upon measurements made by the National Weather Service at the Twin Cites International Airport during the "climate normal period" of 1971-2000.

Daily rainfall amounts during the April-September 2009 period are presented in Figure 2. Monthly rainfall amounts during the April-September 2009 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. August 2009 was the wettest month (10.84 inches), exceeding the normal monthly rainfall amount by 6.79 inches. The excessive August rainfall accounted for 44% of the total April-September 2009 precipitation. Discounting August, the remainder of the April-September period was drier than normal, with a total rainfall deficit of 3.02 inches. April, May, and September were drier than normal, with monthly rainfall deficits ranging from 0.56 inch to 2.00 inches. The lowest monthly rainfall amounts occurred in April and September. September was very dry, with only 0.69 inch of rain recorded on four days during the final week of the month. In contrast, June and July were slightly wetter than normal, with rainfall surpluses of 0.95 inch and 0.43 inch, respectively.

Until mid-September 2007, the North Kinnickinnic River Monitoring Project Area was affected by a region-wide drought that began in early 2006 (see Figure 1). In April 2008, no drought conditions were apparent in the project area, but lower than normal summer rainfall resulted in abnormally dry conditions (Drought Severity Index = D0) by late August 2008 and moderate drought conditions (DSI = D1) by mid-September 2008. Moderate drought conditions (DSI = D1) still persisted in the project area in early April 2009. With lower than normal rainfall in April and May, severe drought conditions (DSI = D2) were evident by early June. Although June and July were slightly wetter than normal, the severe drought conditions persisted in early August. With very heavy August rainfall, drought conditions abated somewhat by early September, with abnormally dry conditions reported (DSI = D0). However, with much lower than normal rainfall in September, moderate drought conditions (DSI = D1) returned by the end of September (U.S. Drought Monitor, at http://www.drought.unl.edu/dm/index.html).

Besides being wetter than normal, the April-September 2009 monitoring period was slightly cooler than normal. The mean air temperature in River Falls during the April-September 2009 period was 62.5º Fahrenheit (F), 0.7º F lower than the normal mean of 63.2º F for the April-September period, as measured at the Twin Cities International Airport. Monthly mean air temperatures during the April-September 2009 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1971-2000, are presented in Figure 4. The mean air temperature in April (46.6º F) was normal, while the month of May was slightly warmer than normal. The months of June, July, and August were all colder than normal, with July experiencing the greatest departure (5.4º F). The month of September was 4.4º F warmer than normal.

The distribution of River Falls daily rainfall amounts during the April-September 2009 period is presented in Figure 5. On 27 (53%) of the 51 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 27 days contributed only 11% of the total April-September 2009 precipitation. Fifteen of these 27 days occurred in the cooler months of April, May, and September (Figure 6). On 7 (14%) of the 51 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 7 days contributed an additional 10% of the total April-September 2009 precipitation. Three of these 7 days occurred in April and May (Figure 6), when air temperatures were cooler. On 7 (14%) of the 51 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 7 days contributed 18% of the total April-September 2009 precipitation, primarily in June and July (Figure 6). On 6 (11%) of the 51 days with measurable precipitation, rainfall amounts ranged from 0.76-1.00 inch. These 6 days contributed 22% of the total April-September 2009 precipitation, in June (3 days) and August (3 days) (Figure 6). On 4 (8%) of the 51 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. These 4 days with the largest rainfall events contributed 39% of the total April-September 2009 precipitation. Rainfall amounts in excess of 1 inch occurred on June 6 (1.15 inches), July 21 (2.25 inches), August 8 (3.76 inches), and August 25 (2.45 inches) (Figures 2 and 6). The June 6 rainfall event occurred over a 13-hour period on a very cool day (high temperature of 52° F). The 3 largest rainfall events in July and August were produced by convective thunderstorm activity following warm days (high temperatures ranging from 81-86° F). All three of these rainfall events were characterized by periods of very intense rainfall, with peak rainfall rates of 0.55 inch per hour during the July 21 storm, 1.89 inches per hour during the August 8 storm, and 0.57 inch per hour during the August 25 storm. The four largest rainfall events in June, July, and August contributed substantially to the above-normal rainfall amounts for these three months. In contrast, no large rainfall events occurred in April, May, or September, when below-normal monthly rainfall amounts were apparent and drought conditions were emerging. During June, July, and August, 15 of 31 rainfall events exceeded 0.50 inch. In contrast, only 2 of 20 rainfall events exceeded 0.50 inch during April, May, and September (Figure 2).

To achieve the requirements of the City's storm water ordinance, developers must provide on-site infiltration of post-development storm water from 24-hour rainfall events of 1.5 inches or less. Of the 51 days with measurable precipitation during the April-September 2009 period, 48 days (94%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Infiltration of these 48 rain events (15.98 inches) would account for 65% of the total April-September precipitation (24.44 inches). Only the rainfall amounts on July 21 (2.25 inches), August 8 (3.76 inches), and August 25 (2.45 inches) exceeded the 1.5-inch infiltration criterion. Even so, the storm water ordinance would require infiltration of the first 1.5 inches of these three rainfall events, thereby accounting for infiltration of 84% (20.48 inches) of the total rainfall (24.44 inches) that occurred during the April-September 2009 period. Figure 7 depicts the annual effectiveness of the River Falls Storm Water Ordinance for infiltrating storm water runoff generated by rainfall during the April-September period. This figure was prepared for illustrative purposes only, and was created with the assumption that the entire 1.5-inch event is infiltrated. This scenario essentially assumes zero pre-development runoff, which may not necessarily be the case.

Kinnickinnic River Flow:

The flow of the Kinnickinnic River is a reflection of strong ground water (spring) contributions, as well as precipitation-induced storm water runoff from predominantly agricultural and urban land uses throughout the 165-square mile Kinnickinnic River Watershed. The United States Geological Survey (USGS) operates a Kinnickinnic River monitoring station (number 05342000) at County Highway F, near Kinnickinnic State Park, approximately five miles west of River Falls. The station measures river stage (water height) and flow at 15-minute intervals, and 15-minute precipitation amounts in 0.01-inch increments. Because accurate monitoring of river stage and flow entails a significant investment in equipment and labor, no continuous measurement of river flow is currently being conducted within the North Kinnickinnic River Monitoring Project Area. For this reason, the Kinnickinnic River flow information provided by the USGS monitoring station is particularly valuable, as it clearly documents when runoff events are occurring and storm water impacts may be apparent. The City of River Falls, Kinnickinnic River Land Trust, and the Kiap-TU-Wish Chapter of Trout Unlimited provide annual cost-share funding to help support the operation of this USGS monitoring station.

The daily mean (average) flow of the Kinnickinnic River at County Highway F during the April-September 2009 period is presented as a hydrograph in Figure 8. Daily rainfall, as measured in River Falls at Rocky Branch Elementary School, is also presented in Figure 8.

Precipitation patterns help explain the changes that occur in the Kinnickinnic River hydrograph, due to runoff events in the watershed. Rainfall amounts in excess of 1 inch generally had the greatest influence on the April-September 2009 Kinnickinnic River hydrograph (Figure 8).

With moderate drought conditions prevailing in early April 2009, and with below-normal precipitation evident in April and May (Figure 3), no significant runoff events occurred during the April-May period (Figure 8). Infrequent (15) small rain events (less than 0.50 inch) throughout this period (Figure 2) had little influence on the Kinnickinnic River hydrograph, producing peak daily mean flows of 100 cfs or less.

Two small runoff events occurred during the first half of June 2009 (Figure 8). A large rain event on June 6 (1.15 inches), followed by back-to-back rain events on June 7-8 (a combined 0.95 inch), produced the first significant runoff event of the 2009 monitoring season, with a peak daily mean flow of 94 cfs on June 8. Nearly back-to-back rain events on June 16 (0.64 inch) and June 18 (0.80 inch) produced the second significant runoff event of the 2009 monitoring season, with a peak daily mean flow of 92 cfs on June 18. In spite of 2.10 inches of rain on June 6-8 and 1.44 inches of rain on June 16-18, the magnitudes of these two June runoff events were tempered by extended rainfall duration (especially during the largest rain event on June 6), relatively low rainfall intensity, dry soil and severe drought conditions, and partial canopy closure in the agricultural and forested areas of the watershed.

A very large and relatively intense rain event on July 21 (2.25 inches) produced the third significant runoff event of the 2009 monitoring season, with a peak daily mean flow of 112 cfs on July 21 (Figure 8). In spite of heavy rainfall, only a moderate runoff event occurred, due to a continuation of dry soil and severe drought conditions in early July, as well as full canopy closure in the agricultural and forested areas of the watershed.

The three largest runoff events of the 2009 monitoring season occurred in August (Figure 8), a month characterized by excessive rainfall (Figure 3) and an active hydrograph. A large rain event on August 7 (0.98 inch), followed by the largest rain event of the year on August 8 (3.76 inches), produced the fourth significant (and largest) runoff event of the 2009 monitoring season, with a peak daily mean flow of 498 cfs on August 8. Although rainfall occurred on two dates, a combined 4.74 inches of rain fell within a 24-hour period, with a peak rainfall intensity rate of 1.89 inches per hour. According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), a 24-hour rain event of this magnitude (4.74 inches) in West Central Wisconsin has a 15-year recurrence interval.

Large back-to-back rain events on August 19 (0.88 inch) and August 20 (0.97 inch), followed by a small rain event on August 21 (0.17 inch), produced the fifth significant runoff event of the 2009 monitoring season, with a peak daily mean flow of 124 cfs on August 21. Although rainfall occurred on three dates, a combined 2.02 inches of rain fell within a 48-hour period, with a peak rainfall intensity rate of 0.43 inch per hour. The moderate magnitude of the second August runoff event can be attributed to an extended rainfall duration, relatively low rainfall intensity, full canopy closure, and extensive evapotranspiration in the agricultural and forested areas of the watershed.

A very large and relatively intense rain event on August 25 (2.45 inches) produced the sixth significant (and second-largest) runoff event of the 2009 monitoring season, with a peak daily mean flow of 171 cfs on August 25 (Figure 8). The greater magnitude of the third August runoff event can be attributed to substantial antecedent rainfall in August

(8.36 inches) and very wet soil conditions.

The Kinnickinnic River hydrograph suggests that six significant runoff events occurred during the April-September 2009 period (Figure 8). Peak daily mean flows for all of these runoff events exceeded 90 cfs. Two of the six significant runoff events occurred in June, when thermal impacts of storm water runoff become a concern due to warmer air and water temperatures. A large rain event on June 6 (1.15 inches), followed by back-to-back rain events on June 7-8 (a combined 0.95 inch), produced a 3-day runoff event (June 6-8), with a peak daily mean flow of 94 cfs. Nearly back-to-back rain events on June 16 (0.64 inch) and June 18 (0.80 inch) also produced a 3-day runoff event (June 16-18), with a peak daily mean flow of 92 cfs.

Four of the six significant runoff events occurred in July and August, during the two warmest months of the year (Figure 4), when thermal impacts of storm water runoff can be a considerable concern. On July 21, a 2.25 inch rain event resulted in a 1-day runoff event (July 21), with a peak daily mean flow of 112 cfs. On August 7 and 8, large back-to-back rain events totaling 4.74 inches resulted in a 2-day runoff event (August 7-8), with a peak daily mean flow of 498 cfs. Large back-to-back rain events on August 19 (0.88 inch) and August 20 (0.97 inch), combined with a small rain event on August 21 (0.17 inch), produced a 3-day runoff event (August 19-21), with a peak daily mean flow of 124 cfs. Finally, on August 25, a 2.45 inch rain event resulted in a 1-day runoff event (August 25), with a peak daily mean flow of 171 cfs.

The six runoff events in June, July, and August should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2009, and are further analyzed in this report.

With moderate drought conditions prevailing in early April 2009, and with below-normal precipitation evident in April and May (Figure 3), Kinnickinnic River base flows steadily decreased from 92 cfs in early April to 75 cfs in late May, as measured at County Highway F (Figure 8). Although June and July were slightly wetter than normal, base flows remained in the 73-77 cfs range until early August. After a much wetter than normal August, Kinnickinnic River base flows rebounded in September, remaining in the 83-89 cfs range despite much lower than normal precipitation.

<u>Temperature Monitoring:</u>

In 2009, temperature monitoring was conducted at six City of River Falls monitoring stations (Sites 1-6) in the North Kinnickinnic River Monitoring Project Area. To evaluate the thermal performance of the storm water management practices at Site 5 in the Sterling Ponds subdivision, temperature monitoring was conducted at three locations: the wet detention pond (Site 5P), the wet detention pond outlet to the infiltration basin (Site 5IB), and the wet detention pond outfall to Sumner Creek (Site 5MHW).

The local Kiap-TU-Wish Chapter of Trout Unlimited (TU) also conducted temperature monitoring at one Kinnickinnic River station (Site 1A) within the project area, between

Sites 1 and 2. The TU monitoring station is located along Quarry Road on the northeast edge of River Falls, just east of the WI Highway 35 bypass, and just upstream of the Sumner Creek confluence. The TU station has been in service during all summer periods (May-September) since 1992. In 2005, as an additional contribution to the North Kinnickinnic River Monitoring Project, TU established a temperature monitoring station in Sumner Creek (Site 4A), approximately 100 feet upstream of the creek confluence with the Kinnickinnic River. This station was in service during the summer periods (May -September) of 2005-2009. The thermal impacts of Sumner Creek on the Kinnickinnic River, including any storm water contributions from Sterling Ponds, can be evaluated at this location.

Onset Computer Corporation's® HOBO Water Temp Pro Loggers are used to measure water temperature at all City of River Falls monitoring stations (Sites 1-6). A Ryan Instruments® RTM 2000 Temperature Logger was used to measure water temperature at the TU monitoring station at Quarry Road (Site 1A) through 2007. In 2008 and 2009, an Onset® StowAway TidbiT Logger was used to measure water temperature at Site 1A. On set Computer Corporation's® Optic StowAway Templogger is used at the TU monitoring station in Sumner Creek (Site 4A). All Onset and Ryan temperature loggers are programmed to record temperatures at 10-minute intervals. Date and time stamps and the 10-minute temperature data are electronically recorded by each logger; and all recorded information is downloaded as necessary. The brief 10-minute time interval was selected so that any rapid temperature increases associated with warm storm water runoff could be readily documented. All temperature loggers were deployed throughout the May-September (summer) period. The thermal impacts of storm water runoff are most likely to occur during this summer period, when air temperatures are highest. The summer 2009 deployment periods (and locations) for the temperature loggers at the ten monitoring stations were as follows:

Site:	Deployment Period:	Location:
Site 1:	May 1-September 30, 2009	Kinnickinnic River
Site 1A:	May 1-September 30, 2009	Kinnickinnic River
Site 2:	May 1-September 30, 2009	Kinnickinnic River
Site 3:	May 1-September 30, 2009	Kinnickinnic River
Site 4:	May 1-September 30, 2009	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2009	Sumner Creek: Mouth
Site 5P:	May 1-September 30, 2009	Sterling Ponds: Wet Pond
Site 5IB:	May 1-September 30, 2009	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 1-September 30, 2009	Sterling Ponds: Wet Pond Outlet
Site 6:	May 1-September 30, 2009	Sumner Creek: Dry Box Culvert

Kinnickinnic River Temperature Monitoring Results:

The May-September (summer) 2009 temperature monitoring data obtained for the Kinnickinnic River at Sites 1, 1A, 2, and 3 are presented as thermographs in Figures 9-12, respectively. Of immediate note in these thermographs is the strong diurnal (daily) temperature pattern in the river. Although cold ground water continually feeds the river via springs along the entire riverway, the temperature of the Kinnickinnic River is greatly influenced by ambient air temperature. During the daylight hours, the river gradually warms and generally reaches a daily maximum temperature in the late afternoon or early evening (4:30-6:30 PM). At night, the river gradually cools and typically reaches a daily minimum temperature just after sunrise (7:30-9:30 AM). These diurnal temperature fluct uations in the river are natural, and the river's residents, including macroinvertebrates and trout, have become accustomed to a constantly but slowly changing temperature regime.

Also of note in the 2009 Kinnickinnic River thermographs are the relatively frequent changes in the daily minimum and maximum river temperatures and daily temperature ranges that are influenced by local weather patterns (cold fronts and warm fronts) and seasonal climate changes. During the summer 2009 period, for example, the monthly mean river temperature in the North Kinnickinnic River Project Area (Sites 1, 1A, 2, and 3) was coolest in May (13.0 degrees Celsius (°C)) and warmest in July (15.2° C).

At Sites 1, 1A, 2, and 3, river temperatures averaged 14.2° C and ranged from 7.5-21.1° C over the course of the summer. Monthly and summer mean temperatures at each of these four monitoring sites are presented in Figure 13. These monthly and summer mean temperatures were nearly identical at Sites 1, 1A, and 2, but slightly cooler at Site 3, especially during the June-August period.

Lower-than-normal river temperatures probably prevailed in the North Kinnickinnic River Project Area during the summer of 2009, since the 2009 summer average air temperature of 18.7º C (65.7º F) was notably lower than the normal summer average air temperature of 19.2° C (66.5° F). A comparison of 2004-2009 summer average air temperatures and river temperatures (at Sites 1, 1A, and 2) can be found in the North Kinnickinnic River Monitoring Project Indicators. Note that the 2009 summer average air temperature of 18.7º C was the lowest summer average air temperature recorded in the North Kinnickinnic River Monitoring Project Area since the summer of 2004. The 2009 summer average river temperature of 14.3º C (at Sites 1, 1A, and 2) was slightly warmer than the summer average river temperatures recorded in 2004 (13.8º C) and 2008 (14.1º C), but slightly cooler than the summer average river temperatures recorded in 2005-2007 (14.4º-15.2º C).

The most direct way to determine if any thermal impacts occurred in the Kinnickinnic River as a result of the Sterling Ponds subdivision is to compare the temperature monitoring data at Site 1, located immediately downstream from Sumner Creek, to the temperature monitoring data at Sites 1A and 2, located immediately upstream from Sumner Creek. These two upstream sites serve as control or reference sites, which are not impacted by Sterling Ponds storm water discharges.

A comparison of all upstream summer temperature data at Sites 1A and 2 to all downstream summer temperature data at Site 1 is presented in Figure 14. This comparison indicates that summer temperatures were nearly identical at these three locations. The temperature similarities at Sites 1, 1A, and 2 are even more evident in the monthly thermographs for May, June, July, August, and September 2009 (Figures 15-19, respectively). Figures 14-19 indicate that daily maximum temperatures tended to be slightly warmer at Site 1, while the daily minimum temperatures tended to be slightly cooler at Site 1A. Figure 13 shows that the monthly and summer mean temperatures at Sites 1, 1A, and 2 were also nearly identical. The following should be noted concerning aquatic life in the Kinnickinnic River:

1. Approximately 90% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2009 period were less than or equal to (≤) 17° C, which is considered to be the top of the optimum temperature range for a healthy coldwater macroinvertebrate community (Galli, 1990). A temperature of 17° C is considered to be the physiological optimum for brown trout survival (Armour, 1994).

2. Approximately 99% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2009 period were ≤ 19° C, which is considered to be the top of the optimum temperature range for brown trout growth (Armour, 1994).

3. Nearly 100% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2009 period were ≤ 20° C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). With a cooler-than-normal summer (average air temperature of 18.7º C), river temperatures exceeding 20º C were not recorded in May, August, and September. However, daily maximum river temperatures exceeded 20º C on 5 dates in June and one date in July. Maximum air temperatures on these 6 dates were generally hot, ranging from 30-35º C (86-95° F) and averaging 33º C (91° F). With the exception of a 30-minute period at Site 1 on June 23, no river temperatures at Sites 1, 1A, and 2 exceeded 21º C during the May-September 2009 period.

During six significant rainfall and runoff events in June, July, and August 2009, thermographs at Sites 1 and 1A can be compared to determine if rapid temperature increases (thermal spikes), which are characteristic of warm storm water discharges, were apparent at Site 1.

No thermal spikes were evident at Site 1 in May (Figure 15), although no significant runoff events occurred during the month. While rain fell on seven dates in May, none of these rain events exceeded 0.50 inch in magnitude, leading to a monthly rainfall deficit of 1.84 inches.

No thermal spikes were evident at Site 1 in June (Figure 16), in spite of two significant runoff events during the June 6-8 and June 16-18 periods. A closer examination of the thermographs for Sites 1 and 1A during the June 6-8 runoff event (with a combined rainfall total of 2.10 inches) (Figure 20) indicates that no thermal spikes occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. Thermal spikes commonly occur at the Trout Unlimited temperature monitoring site at Division Street, due to the thermal impacts of direct storm water discharges from the downtown area of

River Falls. However, no thermal spike was apparent at Division Street during the June 6 rain event (1.15 inches). Lack of a thermal spike is likely due to the extended duration of this rain event (13 hours), in conjunction with very cool air temperatures (7.2-11.1º C), which provided little heating of impervious surfaces. Although a thermal spike was evident at Division Street during the June 8 rain event (0.84 inch), the small magnitude of the spike (0.5º C) can also be attributed to the extended duration of this rain event (5 hours) and cool air temperatures (9.4-13.9º C). When the thermographs for Site 1, Site 1A, and Division Street are compared during the June 16-18 runoff event (Figure 21), no thermal spikes were evident at Site 1, while two small thermal spikes (0.3º C and 1.8º C) were evident at Division Street during the nearly back-to-back rain events on June 16 (0.64 inch) and June 18 (0.80 inch). The greater magnitude of the thermal spike on June 18 (1.8º C) can be attributed to the relatively short duration of the rain event (1 hour) and a warm antecedent air temperature (26.1º C) on June 17.

In July, no thermal spikes were evident at Site 1 (Figure 17), in spite of a very large rainfall event on July 21 (2.25 inches). A closer examination of the thermographs for Site 1, Site 1A, and Division Street during this runoff event (Figure 22) indicates that no thermal spikes occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while two small thermal spikes (1.6º C and 1.0º C) were evident at Division Street during the two waves of rainfall in the early morning and late afternoon.

In August, no thermal spikes were evident at Site 1 during a large rain event on August 7 (0.98 inch), during large back-to-back rain events on August 19 (0.88 inch) and August 20 (0.97 inch), and during a very large rain event on August 25 (2.45 inches) (Figure 18). However, the largest rain event of the year on August 8 (3.76 inches) produced significant thermal spikes at Sites 1, 1A, and 2 (Figure 18).

When the thermographs for Site 1, Site 1A, and Division Street are compared during the August 7 rain event (0.98 inch) (Figure 23), no thermal spike was evident at Site 1, while a small thermal spike was apparent at Division Street. The small magnitude of this spike (0.5º C) can be attributed to the extended duration of this rain event (7 hours) and cool air temperatures (16.1-20.0º C). A supercell thunderstorm during the early morning hours of August 8 produced the largest rain event of the 2009 monitoring season (3.76 inches). Rainfall began shortly after midnight and continued for a 5-hour period, at intensities ranging from 0.64-1.89 inches per hour during the peak of the storm. The August 8 storm was also the largest rain event observed in River Falls since July 2005. This storm, combined with the 0.98-inch rain event on August 7, produced a 24-hour rainfall total of 4.74 inches. A 24-hour rainfall total of this magnitude is a once-in-15-year event. As anticipated, the August 8 rain event produced a very prominent thermal spike (4.0º C) at Division Street (Figure 23). However, thermal spikes were also apparent at all North Kinnickinnic River monitoring sites (Sites 1, 1A, 2, and 3) (Figure 23), due to excessive runoff from nearby watershed areas. Upstream from Sumner Creek and the Sterling Ponds subdivision, the thermal spikes at Sites 1A, 2, and 3 ranged in magnitude from 2.4-3.1º C. Peak temperatures at these three sites occurred in an upstream-to-downstream progression, indicating an upstream source of warm water. The duration of the peak temperature at each site was relatively short (10-40 minutes). Downstream from Sumner Creek and the Sterling Ponds subdivision, a prominent thermal spike (3.1º C) was also evident at Site 1 (Figure 23). However, the thermal spike at Site 1 occurred nearly three hours before the upstream thermal spike occurred at Site 1A, and the duration of the peak temperature at Site 1 (3 hours) was much longer than the durations of the peak temperatures at upstream Sites 1A, 2, and 3 (10-40 minutes). Both of these circumstances suggest that Sumner Creek was a major local contributor of warm water and a primary cause of the thermal spike at Site 1 during the August 8 rain event.

When the thermographs for Site 1, Site 1A, and Division Street are compared during the August 19-21 runoff event (Figure 24), no thermal spikes were evident at Site 1, while two small thermal spikes (1.0º C and 0.6º C) were apparent at Division Street during the back-to-back rain events on August 19 (0.88 inch) and August 20 (0.97 inch). The small magnitudes of these two spikes can be attributed to the extended durations of these rain event (5-9 hours) and cool air temperatures (16.1-20.6º C).

A closer examination of the thermographs for Site 1, Site 1A, and Division Street during the very large rain event on August 25 (2.45 inches) (Figure 25) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while a prominent thermal spike (3.6º C) was evident at Division Street. The magnitude of this thermal spike can be attributed to high initial rainfall intensity (0.57 inch per hour) and a warm antecedent air temperature (27.8º C) on August 24.
Finally, no thermal spikes were evident at Site 1 in September (Figure 19), although no significant runoff events occurred during the month. Rain fell on only four dates in September, with a total monthly rainfall of only 0.69 inch, leading to a monthly rainfall deficit of 2.00 inches.

While the presence of thermal spikes at Division Street is attributed to the thermal impacts of untreated storm water discharges to the Kinnickinnic River, the lack of thermal spikes at Site 1 during all 2009 runoff events (except the largest on August 8) could be attributed to several factors, including effective storm water management at the Sterling Ponds subdivision, or simply a lack of Sterling Ponds storm water discharges and/or storm water conveyance down Sumner Creek.

Sumner Creek and Sterling Ponds Temperature Monitoring Results:

<u>Sumner Creek</u>

Sumner Creek is a low-gradient tributary of the Kinnickinnic River that exhibits only intermittent flow for the majority of its length. Permanent flow begins in the vicinity of the WI Highway 35 bypass, near the creek confluence with the Kinnickinnic River (Site 4A). From this location, the creek drainage way extends upstream to Radio Road on the far northwest corner of River Falls. The upper portion of the Sumner Creek drainage way, including Sites 4 and 6, conveys no flow for the majority of the year. The headwaters area near Site 6 is a dry run. Downstream, however, rather extensive wetland areas are apparent in the Sumner Creek drainage way through the Sterling Ponds subdivision, and for an appreciable distance downstream of Site 4. Anecdotal evidence suggests that flow may occur in the upper portion of Sumner Creek during the spring snowmelt period and perhaps during large summer rain events. During large summer rain events, however, the wetland areas and dry portions of the Sumner Creek channel likely provide considerable water storage, making it very difficult to determine if and when any upstream flow is conveyed all the way downstream to the Kinnickinnic River.

The May-September (summer) 2009 temperature monitoring data obtained for Sumner Creek at Site 4A are presented as a thermograph in Figure 26. Site 4A near the creek mouth was the only Sumner Creek monitoring location with permanent flow throughout the summer. At Site 4A, Sumner Creek temperatures averaged 11.7° C and ranged from 6.7-19.2° C during the May-September 2009 period. The summer mean temperature of Sumner Creek (11.7º C) was notably colder than the summer mean temperature of the Kinnickinnic River (14.2º C) at Sites 1, 1A, 2, and 3, reflecting strong spring activity. Nearly 100% of all temperatures recorded at Site 4A during the May-September 2009 period were ≤ 17° C. Temperatures exceeding 17° C were only recorded for a 20-hour period during and following the largest rainfall event of the summer on August 8 (3.76 inches).

Based upon the summer 2009 temperature data, lower Sumner Creek may have potential as a brook trout stream, and is regardless an important contributor of cold water to the Kinnickinnic River. Of concern, however, are several thermal spikes that occurred at Site 4A during two large rain events in August (Figure 26). A very prominent and extended thermal spike (6.8º C) was evident during the August 8 rain event, and a prominent thermal spike (4.1º C) was apparent during the August 25 rain event. These Sumner Creek thermal spikes were of even greater magnitude than those observed at the Division Street monitoring site on the same dates (Figures 23 and 25).

Of the two thermal spikes observed in Sumner Creek during the 2009 monitoring season, only the August 8 thermal spike had a discernible impact on the temperature of the Kinnickinnic River (Figure 27). In Figure 27, note that the profile and timing of the Sumner Creek thermal spike at Site 4A very closely match the profile and timing of the Kinnickinnic River thermal spike at Site 1, immediately downstream from Sumner Creek. Prior to the start of the August 8 rain event, the temperature of Sumner Creek (12.4º C) was notably cooler than the temperature of the Kinnickinnic River (14.4º C). However, within a brief period after the start of the rain event, the temperature of Sumner Creek (19.2º C) was notably warmer than the temperature of the Kinnickinnic River (17.2º C), contributing significantly to the thermal spike evident at Site 1. Warm water from Sumner Creek caused the thermal spike at Site 1 to occur nearly three hours before the upstream thermal spike occurred at Site 1A. Also, the lengthy input of warm water from Sumner Creek resulted in an extended duration of the peak temperature at Site 1 (3 hours), compared with a much shorter duration of the peak temperature at Site 1A (30 minutes) upstream. Overall, Sumner Creek contributed warmer water to the Kinnickinnic River for a 19-hour period during and following the August 8 rain event.

Besides having an occasional impact on the Kinnickinnic River, thermal spikes of the magnitude and frequency observed in Sumner Creek may also have detrimental impacts on aquatic life in lower Sumner Creek, especially macroinvertebrates. A temperature of 17° C is considered to be the top of the optimum temperature range for a healthy coldwater macroinvertebrate community (Galli, 1990). During and following the August 8 rain event, however, the Sumner Creek temperature at Site 4A exceeded 17° C for a 20-hour period.

Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2008. Possible sources contributing to thermal spikes in lower Sumner Creek may include: storm water runoff from WI Highway 35, located immediately upstream from Site 4A; warm water from natural wetland areas in the upper Sumner Creek drainage way; and storm water discharges from the Sterling Ponds subdivision.

Sterling Ponds

The May-September (summer) 2009 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 28. At Site 5P, wet detention pond temperatures averaged 20.2° C and ranged from 11.5-30 .4° C during the summer period. Approximately 55% of all summer temperatures exceeded 20° C, and wet pond temperatures consistently remained above 20° C from June 17 until August 21. Substantial warming of small, shallow ponds such as this can be expected, especially with no shading or canopy cover. The summer mean temperature of the Sterling Ponds wet detention pond (20.2° C) was substantially higher than the summer mean temperature of Sumner Creek at Site 4A (11.7º C), clearly demonstrating the potential for thermal impact when the pond discharges to the creek, and emphasizing the importance of the River Falls Storm Water Management Ordinance, which requires storm water infiltration.

Assessment of Sterling Ponds Storm Water Infiltration and Discharge to Sumner Creek

Temperature data from the three Sterling Ponds monitoring stations (Sites 5P, 5IB, and 5MHW) and the two downstream Sumner Creek monitoring stations (Sites 4 and 4A) can be used to evaluate the effectiveness of the Sterling Ponds storm water management practices for infiltrating storm water and minimizing warm storm water discharges to Sumner Creek. Given the warm and relatively stable thermal regime (Figure 28) in the Sterling Ponds wet detention pond (measured at Site 5P), pond discharges to the infiltration basin can be readily identified when the temperature at Site 5IB closely matches that at Site 5P. Similarly, pond discharges to Sumner Creek can be readily identified when the temperature at Site 5MHW closely matches that at Site 5P. Warm storm water discharges to Sumner Creek may be detectable as thermal spikes at Sites 4 and 4A.

During the summer of 2009, the thermal performance of Sterling Ponds stormwater management practices can be evaluated monthly by comparing the Sterling Ponds and Sumner Creek thermographs. Performance of these stormwater management practices during the six significant rainfall and runoff events in June, July, and August is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). Three of these six significant events were characterized by 24-hour rainfall amounts less than 1.5 inches, and hence would be expected to meet the infiltration requirement of the River Falls Storm Water Management Ordinance. However, the July 21, August 8, and August 25 events were characterized by 24-hour rainfall amounts in excess of 1.5 inches, beyond the infiltration requirement of the ordinance.

May

The comparative Sterling Ponds thermographs for May 2009 are presented in Figure 29. The month of May was slightly warmer and much drier than normal, with small rainfall events (ranging from 0.02-0.46 inch) recorded on seven dates (Figure 2). During the month, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. The entire May rainfall amount of 1.40 inches (Figure 3) was captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

June

The comparative Sterling Ponds thermographs for June 2009 are presented in Figure 30. The month of June was slightly cooler and wetter than normal. Rainfall events (ranging from 0.02-1.15 inches) were recorded on ten dates, with two of the six significant summer rainfall events occurring on June 6-8 and June 16-18 (Figure 2). In spite of considerable rainfall during the June 1-26 period (4.65 inches), no wet pond discharges occurred to either the infiltration basin or Sumner Creek. With below-normal precipitation and very dry antecedent conditions in April and May, it is likely that the Sterling Ponds wet pond had extensive capacity to store all June 1-26 rainfall events, including the significant events on June 6-8 (a combined 2.10 inches) and June 16-18 (a combined 1.44 inches). The regular spacing of rain events during the June 1-26 period provided time for wet pond infiltration and evaporation between events, thereby helping to replenish pond capacity.

The comparative Sterling Ponds and Sumner Creek thermographs for the June 27 rain event (0.64 inch) are presented in Figure 31. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 08:30 CDT (8:30 AM) on June 27, nearly 6 hours after the onset of rainfall at 03:00 CDT (3:00 AM). Wet pond discharge to the infiltration basin, due to the June 27 rainfall event, continued for 1.3 days, until 16:40 CDT (4:40 (PM) on June 28. No wet pond discharge to Sumner Creek was evident during the June 27 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A (Figure 31).

The entire June rainfall amount of 5.29 inches (Figure 3) was captured in the Sterling Ponds wet pond or infiltrated in the Sterling Ponds infiltration basin.

July

The comparative Sterling Ponds thermographs for July 2009 are presented in Figure 32. The month of July was considerably cooler than normal, with slightly above-normal precipitation. Rainfall events (ranging from 0.01-2.25 inches) were recorded on eight dates, with one of the six significant summer rainfall events occurring on July 21 (Figure 2).

The comparative Sterling Ponds and Sumner Creek thermographs for the July 4 rain event (0.55 inch) are presented in Figure 33. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 16:30 CDT (4:30 PM) on July 4, shortly after the onset of heavier rainfall at 15:00 CDT (3:00 PM). Wet pond discharge to the infiltration basin, due to the July 4 rainfall event, continued for 2.0 days, until 16:20 CDT (4:20 PM) on July 6. No wet pond discharge to Sumner Creek was evident during the July 4 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A (Figure 33).

During the July 7-20 period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek (Figure 32). Two small rain events, totaling 0.41 inch, were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

The third of six significant summer rainfall events occurred on July 21. The comparative Sterling Ponds and Sumner Creek thermographs for the July 21 rain event (2.25 inches) are presented in Figure 34. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 06:40 CDT (6:40 AM) on July 21, shortly after the onset of heavier rainfall at 05:00 CDT (5:00 AM). Wet pond discharge to the infiltration basin, due to the July 21 rainfall event and subsequent smaller events on July 22 (0.07 inch) and July 24 (0.61 inch), continued for 5.5 days, until 19:50 CDT (7:50 PM) on July 26. No wet pond discharge to Sumner Creek was evident during the July 21 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 34). The magnitude of the July 21 rain event (2.25 inches) clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet the entire event was captured in the wet pond and infiltrated. The ability to capture and infiltrate such a large event can likely be attributed to a very dry antecedent period (July 7-20), which created adequate storage capacity in the wet pond. After the July 21 rain event began, two small thermal spikes (0.9° C and 1.6° C) occurred in lower Sumner Creek at Site 4A. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause. The initial thermal spike (0.9° C) occurred shortly after the rain event began, and may be attributed to storm water runoff from WI Highway 35, located immediately upstream from Site 4A. A secondary thermal spike (1.6° C) occurred several hours after the first, and may have been caused by a slow release of warm water from natural wetland areas in the upstream Sumner Creek drainage way.

Near the end of the month, two small rain events on July 27 (0.15 inch) and July 30 (0.43 inch) were captured in the Sterling Ponds wet pond, with no wet pond discharges to the infiltration basin (Figure 32).

The entire July rainfall amount of 4.47 inches (Figure 3) was captured in the Sterling Ponds wet pond or infiltrated in the Sterling Ponds infiltration basin.

August

The comparative Sterling Ponds thermographs for August 2009 are presented in Figure 35. The month of August was slightly cooler and much wetter than normal. August rainfall accounted for nearly 50% of the total May-September 2009 precipitation. Rainfall events (ranging from 0.01-3.76 inches) were recorded on thirteen dates, with three of the six significant summer rainfall events occurring on August 7-8, August 19-21, and August 25 (Figure 2).

A small rainfall event on August 1 (0.27 inch) resulted in a relatively brief wet pond discharge to the infiltration basin, starting at 00:00 CDT (midnight) on August 1 and continuing until 18:40 CDT (6:40 PM) on August 1 (Figure 36). A moderate rainfall event on August 3 (0.64 inch) also resulted in a wet pond discharge to the infiltration basin, starting at 00:20 CDT (0:20 AM) on August 3 and continuing for 1.6 days, until 13:40 CDT (1:40 PM) on August 4 (Figure 36).

The fourth (and largest) of the six significant summer rainfall events occurred on August 7-8. A combined total of 4.74 inches of rain fell in a 24-hour period, including 0.98 inch of rain on August 7 and 3.76 inches of rain on August 8. The comparative Sterling Ponds and Sumner Creek thermographs for the August 7-8 rain event are presented in Figure 37. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 10:30 CDT (10:30 AM) on August 7, shortly after the onset of heavier rainfall at 09:00 CDT (9:00 AM). With the wet pond still near maximum capacity and wet pond discharge to the infiltration basin continuing after the August 7 rainfall event, the August 8 rainfall event began at 00:00 CDT (midnight). With very intense rainfall from 00:00-02:00 CDT (midnight-2:00 AM), the Sterling Ponds wet detention pond immediately began discharging to the Sumner Creek drainage way at 00:20 CDT (0:20 AM) on August 8, as indicated by the nearly identical temperatures at Sites 5P and 5MHW (Figure 37). Wet pond discharge to the Sumner Creek drainage way continued for 15 hours, until 15:30 CDT (3:30 PM). During this 15-hour period, the wet pond discharge temperature averaged 19.9º C and ranged from 19.2-21.3º C. Wet pond discharge to the Sumner Creek drainage way was likely influenced by the great magnitude and short duration of the August 8 rainfall event. With the majority of the rain falling in a 4-hour period, and with the wet detention pond already near maximum capacity due to the August 7 rain event, the wet pond was quickly inundated with storm water. Wet pond inflow simply exceeded outflow to the infiltration basin, with the excess water discharged through the outlet structure. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. Field observations during a large rainfall event in July 2008 indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the Sterling Ponds wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. However, a small thermal spike (1.3º C) was apparent downstream at Site 4 in Sumner Creek after the August 8 rain event (Figure 37). Warmer water began flowing at Site 4 at 03:10 CDT (3:10 AM) on August 8 and continued flowing for 1.3 days, until 11:10 CDT (11:10 AM) on August 9. During this 1.3-day period, the temperature of Sumner Creek at Site 4 averaged 21.4º C and ranged from 19.4-23.4º C. The Sterling Ponds wet pond discharge to the Sumner Creek drainage way likely contributed to the warm water flow at Site 4 on August 8. The release of warm water from natural wetland areas in the upstream Sumner Creek drainage way may also have contributed to the warm water flow at Site 4, especially after wet pond discharge to the creek drainage way ceased at 15:30 CDT (3:30 PM) on August 8. The prominent thermal spike (6.8º C) evident near the mouth of Sumner Creek (Site 4A) at 02:10 CDT (2:10 AM) on August 8 (Figure 37) cannot be attributed to the Sterling Ponds storm water discharge, since the spike at Site 4A, located 1.5 miles downstream, occurred shortly after the storm water discharge began, and an hour before the thermal spike was evident at Site 4. It seems apparent that the thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35 and/or warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way. However, the "plug" of warm water passing through Site 4 on August 8 and 9, including the warm water discharged from the Sterling Ponds wet pond on August 8, may have contributed to the extended duration of much warmer-than-normal water at Site 4A until 10:30 CDT (10:30 AM) on August 9. The daily maximum stream temperature at Site 4A on August 8 was 19.2° C, compared to daily maximum temperatures ranging from 13.5-14.9° C during the August 9-12 period, when no rainfall occurred and daily maximum air temperatures were nearly identical to that on August 8. Sterling Ponds wet pond discharge to the infiltration basin, due to the August 7 and 8 rainfall events, continued for 5.0 days, until 11:10 CDT (11:10 AM) on August 12.

Three small rain events on August 13 (0.31 inch), August 15 (0.22 inch), and August 16 (0.15 inch) were captured in the Sterling Ponds wet pond, with no wet pond discharges to the infiltration basin (Figure 35).

The fifth and sixth significant summer rainfall events of the 2009 monitoring season occurred on August 19-21 (a combined 2.02 inches) and August 25 (2.45 inches). All rainfall during the August 19-25 period (a combined 4.47 inches) was captured in the Sterling Ponds wet pond and infiltrated. The comparative Sterling Ponds and Sumner Creek thermographs for these rainfall events are presented in Figure 38. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 14:20 CDT (2:20 PM) on August 19, shortly after the onset of heavier rainfall at 13:00 CDT (1:00 PM). Wet pond discharge to the infiltration basin, due to the August 19 (0.88 inch), August 20 (0.97 inch), August 21 (0.17 inch), and August 25 (2.45 inches) rain events, continued for 11.6 days, until 04:50 CDT (4:50 AM) on August 31. A very small rain event on August 28 (0.03 inch) was also captured in the Sterling Ponds wet pond and infiltrated during the August 19-31 period. No wet pond discharges to Sumner Creek were evident during the August 19-21 and August 25 rain events, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 38). The magnitude of the August 25 rain event (2.45 inches) clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet the entire event was captured in the wet pond and infiltrated. It is possible that a brief dry period on August 22-24 created adequate storage capacity in the wet pond to fully capture the August 25 rain event. During the August 20 rain event, a small thermal spike (1.6° C) occurred in lower Sumner Creek at Site 4A. During the August 25 rain event, a very prominent thermal spike (4.1° C) was apparent at Site 4A. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause, perhaps attributable to storm water runoff from WI Highway 35 and/or warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way.

All rainfall during the August 1-6 and August 13-31 periods (10 events ranging from 0.03 -2.45 inches and totaling 6.09 inches) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the August 7-8 rainfall event (a combined 4.74 inches) was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on August 8, the duration of this discharge was relatively short (15 hours), compared to the duration of discharge to the infiltration basin (120 hours).

September

The comparative Sterling Ponds thermographs for September 2009 are presented in Figure 39. The month of September was much warmer and much drier than normal. Small rainfall events (ranging from 0.01-0.10 inch) and a moderate rainfall event (0.56 inch) were recorded on four dates (Figure 2), making September the driest month during the summer of 2009 (Figure 3). During September, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. The entire September rainfall amount of 0.69 inch (Figure 3) was captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

Effectiveness of Sterling Ponds Storm Water Management Practices:

2009 Performance Assessment

During the May-September (summer) 2009 period, the extent of storm water discharge to the Sterling Ponds infiltration basin could be readily determined, as temperature monitoring of the basin (Site 5IB) was conducted throughout the summer. The extent of storm water discharge to Sumner Creek could be directly determined via temperature monitoring at the wet pond outlet (Site 5MHW) and/or indirectly determined by the presence of thermal spikes in Sumner Creek (Sites 4 and 4A).

With the exception of the large rain events on August 7-8 (a combined 4.74 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River

Falls Storm Water Management Ordinance. These 40 rain events, ranging in magnitude from 0.01-2.45 inches, represent a total of 17.95 inches of precipitation, or 79% of the total summer rainfall amount (22.69 inches). Of these 40 rain events, 27 events, ranging in magnitude from 0.01-1.15 inches and totaling 8.41 inches of precipitation (37% of the total summer rainfall amount) were entirely stored in the Sterling Ponds wet detention pond. The Sterling Ponds wet pond readily stored smaller rain events (less than 0.50 inch), with the storm water infiltrating in the pond or evaporating. The ability of the wet pond to store five moderate-to-large rain events in June (0.64-1.15 inches) can probably be attributed to very dry antecedent conditions in April and May, which created extensive pond capacity for June rainfall. The 13 remaining summer rain events, ranging in magnitude from 0.01-2.45 inches and totaling 9.54 inches of precipitation (42% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin.

All 29 rainfall events in May, June, July, and September were stored in the wet detention pond or diverted to the infiltration basin. These events ranged from 0.01-2.25 inches in magnitude and represented monthly totals of 1.40, 5.29, 4.47, and 0.69 inches, respectively, or 52% of the total summer rainfall amount. Eleven small-to-large rain events in August, ranging from 0.01-2.45 inches and totaling 6.10 inches, were either infiltrated or stored in the wet detention pond. These August rain events represented 27% of the total summer rainfall.

The Sterling Ponds wet detention pond only discharged to Sumner Creek during large back-to-back rain events on August 7-8 (a combined 4.74 inches). This discharge of storm water to Sumner Creek was directly measured at Site 5MHW. Wet pond discharge to the Sumner Creek drainage way was triggered by the extreme magnitude (3.76 inches), high intensity, and short duration of the August 8 rain event. With the majority of the rain falling in a 4-hour period, and with the wet detention pond already near maximum capacity due to the August 7 rain event, the wet pond was quickly inundated with storm water. The wet pond inflow rate simply exceeded outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way.

Although a wet pond discharge to the Sumner Creek drainage way occurred on August 8, it seems likely that the majority of the August 7-8 rainfall event (a combined 4.74 inches) was infiltrated rather than discharged. The duration of the discharge to the Sumner Creek drainage way was relatively short (15 hours), compared to the duration of discharge to the infiltration basin (120 hours). Since the storm water volumes discharged to the infiltration basin and Sumner Creek were not measured, it is not possible to precisely determine the amounts of storm water infiltrated versus discharged.

The temperature data for Site 5P, Site 5IB, and Site 5MHW suggest that the performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 40 summer rain events, ranging in magnitude from 0.01-2.45 inches. All runoff from these events was stored or infiltrated, as required by the River Falls Storm Water Management Ordinance. Of these 40 summer rain events, two rain events on July 21 (2.25 inches) and August 25 (2.45 inches) clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet these two events were entirely infiltrated. Excessive rainfall on August 7-8 caused a storm water discharge to the Sumner Creek drainage way; but the rainfall amount on August 8 (3.76 inches) and the 24-hour rainfall total on August 7-8 (4.74 inches) greatly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance.

Temperature monitoring of all 2005-2009 summer rain events has revealed some performance issues and possible opportunities for improvement of the current Sterling Ponds storm water management practices and/or revision of the storm water management ordinance. Those performance issues are summarized below.

2005-2006 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2005 and 2006 indicated that warm storm water was discharged from the wet pond to Sumner Creek during nine rain events with rainfall amounts ranging from 1.38-4.00 inches. Discharge times ranged from 4-14 hours. Rainfall amounts for six of these rain events (1.63-4.00 inches) were greater than the 1.5-inch ordinance requirement for infiltration, while rainfall amounts for three events (1.38-1.49 inches) were less than the 1.5-inch ordinance requirement. Several performance issues became apparent because of the temperature monitoring information.

When rainfall amounts exceeded the 1.5-inch ordinance requirement, the wet pond began discharging to the Sumner Creek drainage way shortly after it began discharging to the infiltration basin, and the warm storm water discharges likely contributed to pronounced thermal spikes in Sumner Creek. Given the very warm storm water in the wet detention pond, it is important to infiltrate as much pond volume as possible, thereby minimizing warm water discharges to Sumner Creek. At a minimum, it is especially desirable to capture the “first-flush” component of storm water runoff, which generally conveys the greatest thermal impact and highest concentrations of pollutants.

During the summer of 2006, rather lengthy infiltration times (1.5-8.5 days) were evident for a variety of rainfall events (0.33-2.26 inches). An extended infiltration time may be desirable when there is adequate time between rain events, as it also maximizes total suspended solids (TSS) and total phosphorus (TP) removal in the wet pond. However, it certainly limits the available storage volume in the wet pond when the next rain event occurs, possibly causing a premature discharge of storm water to the Sumner Creek drainage way. In 2005 and 2006, this was particularly true for larger, back-to-back rainfall events that occurred within a 24-48 hour period. When daily rainfall amounts exceeded one inch during these back-to-back events, wet pond discharge to the infiltration basin was already underway due to the first rain event, but was not yet complete when the second rain event began. Since infiltration of the first rain event was not yet complete, storage capacity in the wet pond was also limited.

2007 Performance Modeling and Wet Pond Outlet Modification

In early 2007, River Falls Engineering Department staff conducted modeling of the Sterling Ponds storm water management practices, to further investigate performance issues and determine if any corrective action was necessary. Modeling results suggested that the control structure for the wet detention pond outlet should be raised by 6 inches. This adjustment should provide more storm water storage in the wet pond and allow the discharge of more storm water volume to the infiltration basin, without affecting the rate control needed to achieve the target pollutant removal efficiencies (80%) for TSS and TP. The modification to the control structure for the wet pond outlet was made on June 14, 2007, midway through the 2007 monitoring season, but prior to the six largest rain events (all exceeding one inch, with two exceeding 1.5 inches) in August and September.

2007 Performance Issues

After the modification was made to the control structure for the Sterling Ponds wet pond outlet in mid-June, to improve infiltration performance, three rain events in August and September 2007 still delivered warm storm water to Sumner Creek.

The largest rain event of the summer on August 27 (1.72 inches) exceeded the 1.5-inch ordinance requirement for infiltration, as did six rain events in 2005 and 2006 that also delivered storm water to Sumner Creek. During the 2005 and 2006 rain events, the Sterling Ponds wet pond released storm water to Sumner Creek shortly after the onset of discharge to the infiltration basin, with lag times as short as 10 minutes. Storm water discharges to the creek also occurred for extended time periods ranging from 4-14 hours. In contrast, the August 27, 2007 rain event produced a longer lag time (1 hour) and a relatively short discharge time (4 hours). Based upon this single 2007 rain event, it seems that the modification of the wet pond outlet structure may have provided more storm water storage and infiltration, including early in the rain event, when first-flush temperature and water quality impacts are more significant.

Rainfall amounts during the August 28 (1.04 inches) and September 20 (1.19 inches) rain events were less than the 1.5-inch ordinance requirement, yet both events delivered warm storm water to Sumner Creek. These discharges are clearly due to the large, antecedent rain events that occurred on August 27 (1.72 inches) and September 18 (1.64 inches). A 21-hour period separated the August 27 and August 28 rain events, while a 42-hour period separated the September 18 and September 20 events. After the first rain events occurred on August 27 and September 18, the Sterling Ponds wet pond was still discharging to the infiltration basin when the next events occurred on August 28 and September 20. With infiltration of the first events still in progress, the wet pond had a reduced capacity to store the next events, resulting in the discharge of excess storm water to Sumner Creek. During the August 28 rain event, a time lag of 2.5 hours occurred between the onset of wet pond discharge to the infiltration basin and the onset of discharge to Sumner Creek. A time lag of 1 hour was evident during the September 20 event. Durations of discharge to Sumner Creek during the August 28 and September 20 rain events were 3 hours and 5 hours, respectively. As was observed for the August 27 rain event, the longer lag times and shorter discharge times for the August 28 and

September 20 rain events tend to indicate that the modification of the wet pond outlet structure may have provided more storm water infiltration on both the front ends (due to longer lag times) and back ends (due to shorter discharge times) of these events.

2008 Performance Issues

The largest rain event of the summer on July 25 (1.16 inches) was less than the 1.5-inch infiltration requirement in the River Falls Storm Water Management Ordinance. However, this event was not fully infiltrated, as the Sterling Ponds wet pond released warm storm water to Sumner Creek for a 3.3-hour period. Wet pond discharges (to Sumner Creek) during two 2007 rain events of comparable size on August 28 (1.04 inches) and September 20 (1.19 inches) were clearly due to large, antecedent rain events that reduced the storage capacity in the wet detention pond, which was still discharging to the infiltration basin when these events occurred. This was not the case for the July 25, 2008 rain event, which was preceded by a relatively lengthy dry period (6 days). This dry period should have provided adequate time for volume reduction in the Sterling Ponds wet pond, via drainage to the infiltration basin. Indeed, the preceding rain event on July 19 (0.76 inch) was entirely infiltrated by July 22, three days prior to the July 25 event. The performance issue on July 25 seems to be related to the intensity of this event. With 1.06 inches of rain falling in 30 minutes (16:00-16:30 CDT), the wet pond was probably inundated with storm water and quickly reached capacity. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. Evidence of rapid inundation of the wet pond due to the intensity of the event is provided by the very short time lag (20 minutes) between the onset of wet pond discharge to the infiltration basin and the onset of discharge to Sumner Creek. The intensity of the July 25, 2008 rain event (1.06 inches in 30 minutes) was even greater than the intensity of the September 20, 2007 rain event (nearly an inch in an hour). The duration of storm water discharge to Sumner Creek on July 25, 2008 (3.3 hours) was comparable to the discharge times observed during the large rain events in August and September 2007 (3-5 hours). These shorter discharge times, compared to those observed during large rain events in 2005, can probably be attributed to modification (elevation) of the wet pond outlet structure in 2007. More capacity in the wet pond resulted in reduced discharge to Sumner Creek and more post-event discharge to the infiltration basin.

2009 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2009 indicated that warm storm water was discharged from the wet pond to Sumner Creek during large back-to-back rain events on August 7-8 (a combined 4.74 inches within 24 hours). Wet pond discharge to Sumner Creek during the very large rain event on August 8 (3.76 inches) was likely due to several factors. A large, antecedent rain event on August 7 (0.98 inch) significantly reduced the storage capacity in the wet detention pond, which had only been discharging to the infiltration basin for 13.5 hours when heavy rain began on August 8. Other factors triggering wet pond discharge to Sumner Creek include the extreme magnitude (3.76 inches), high intensity, and short (4-hour) duration of the

August 8 rain event. Due to these factors, no time lag occurred between the onset of additional wet pond discharge to the infiltration basin and the onset of discharge to Sumner Creek; hence no first-flush abatement of temperature and water quality impacts was possible for the August 8 event. The excessive rainfall (4.74 inches) within a 24-hour period on August 7-8 (a once in 15-year rain event) contributed to the very lengthy (15-hour) wet pond discharge to Sumner Creek. Given that the rainfall amount on August 8 (3.76 inches) and the 24-hour rainfall total on August 7-8 (4.74 inches) greatly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, given the back-to-back nature of the August 7-8 rain events, and given the intensity of the August 8 rain event, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances. In spite of the great magnitude of the August 7-8 rain events (4.74 inches), wet pond delivery to the infiltration basin (infiltration time) was relatively short (5.0 days), allowing the wet pond to quickly regain the capacity to capture and fully infiltrate the next large rain events on August 19 (0.88 inch) and August 20 (0.97 inch). Also of positive note in 2009 is that the very large rain events on July 21 (2.25 inches) and August 25 (2.45 inches), which clearly exceeded the 1.5-inch ordinance requirement, were both fully infiltrated. The ability to capture and infiltrate these two large events can probably be attributed to modification (elevation) of the wet pond outlet structure in 2007, which created more storage capacity in the wet pond.

Summary

Temperature monitoring of the Sterling Ponds storm water practices during the 2005-2009 period indicates that storm water discharges to Sumner Creek are occurring:

- During rain events larger than 1.5 inches (2005-2007 and 2009);
- During back-to-back rain events, when rainfall amounts range from 1.0-1.5 inches and time periods between rain events are less than 48 hours (2006-2007);
- During very intense rain events, when rainfall amounts range from 1.0-1.5 inches (2008).

A summary of the 2005-2009 Sterling Ponds storm water discharges to Sumner Creek, including discharge dates, rainfall amounts, discharge lags, and discharge times, is provided in Appendix A.

Modifications made to the control structure for the Sterling Ponds wet pond outlet to Sumner Creek seemed to improve storage and infiltration capacity for these types of events in 2007, 2008, and 2009. Rain events larger than 1.5 inches exceed the intent of the River Falls Storm Water Management Ordinance, so storm water discharges to Sumner Creek might be expected. However, storm water discharges to Sumner Creek during back-to-back or very intense rain events, when rainfall amounts are less than the 1.5-inch ordinance requirement, may need further attention. For back-to-back rain events, more rapid delivery of storm water to the infiltration basin may be desirable between rain events, to ensure substantial infiltration of the first rain event within a 24-hour period. This could be accomplished by increasing the diameter of the pipe (currently 8 inches) leading to the infiltration basin. However, the size of the pipe and rate of storm water delivery to the infiltration basin should also be balanced against the need for adequate water residence time in the wet pond, to achieve target removal efficiencies (80%) for total suspended solids (TSS) and total phosphorus (TP). Another option would be to increase wet pond delivery to the infiltration basin, which currently has significant available capacity, at the expense of reduced removal efficiencies for TSS and TP (ordinance permitting). In addition, perhaps some provision should be made in the River Falls Storm Water Management Ordinance to ensure adequate infiltration of back-to-back 1.5-inch, 24-hour rain events. More capacity in the wet pond may be helpful for capturing more storm water volume during very intense rain events, but the increased volume in the pond could require more infiltration time, which may prove problematic when large, back-to-back rain events occur.

While this project is primarily focused on evaluating long-term trends, annual performance information is important as well. With the exception of the large rain events on August 7-8 (a combined 4.74 inches), the storm water management practices at Sterling Ponds prevented thermal impacts on Sumner Creek and the Kinnickinnic River during the May-September (summer) 2009 period. The following should be noted:

- The summer temperature regime in the Kinnickinnic River at Sites 1, 1A, and 2 (above and below the Sumner Creek confluence) was generally excellent for coldwater macroinvertebrate and brown trout communities.
- The performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 40 summer rain events, ranging in magnitude from 0.01-2.45 inches and totaling 17.95 inches (79% of the total summer precipitation). All storm water runoff from these events was infiltrated, as required by the River Falls Storm Water Management Ordinance. Monitoring and analysis of storm water conveyance from the Sterling Ponds wet pond to the infiltration basin will continue in the future, to determine if the intent of the ordinance is being met.
- Smaller rainfall events (less than one inch) caused no thermal impacts on Sumner Creek (see Appendix B). During a large rain event on August 8, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, for an extended time period (15 hours). This warm storm water discharge caused a thermal spike in Sumner Creek at Site 4, and probably contributed to an extended thermal spike observed in lower Sumner Creek, at Site 4A. The presence, intensity, and frequency of thermal spikes will continue to be monitored in the years to come.
- The "first-flush" thermal spike (6.8° C) observed in lower Sumner Creek (Site 4A) during the August 8 rain event was unrelated to the storm water discharge at Sterling Ponds, and seemed to have a more local cause that needs further investigation. The "first-flush" thermal spike (4.1° C) observed at Site 4A during the August 25 rain event also had a local cause.

Based upon the 2005-2009 temperature monitoring results, it appears that the Sterling Ponds storm water management practices are producing long-term positive results that protect the Kinnickinnic River. A summary of the performance of Sterling Ponds storm water management practices during the 2005-2009 period is presented in Figure 40. Note that the number of summer rain events infiltrated far exceeds the number of rain events (partially) discharged to Sumner Creek each year. Also note that the minimum percentage of summer rainfall infiltrated ranged from 60-92% during the 2006-2009 period. Beyond 2009, these same trends will be monitored from year to year, to determine if favorable results are apparent in the future.

Water Quality Monitoring:

No runoff event-based water quality monitoring was conducted in 2009, due to ongoing logistical and technical difficulties with the automated monitoring equipment at Kinnickinnic River Sites 1 and 2, and at the Sterling Ponds wet detention pond outlet (Site 5MHW). If these equipment difficulties can be resolved, the water quality monitoring component of the North Kinnickinnic River Monitoring Project will be initiated in 2010. At a minimum, it seems likely that automated monitoring can be conducted at Site 5MHW, to characterize the water quality of any Sterling Ponds wet pond discharges to Sumner Creek in 2010.

Base Flow Surveys:

The USGS stream flow gauge located at County Highway F, as described earlier in this report, was used to determine when a base flow condition existed in the North Kinnickinnic River Monitoring Project Area. When 3-4 days of "flat-line" flow were observed at this station, the river was assumed to be in a base flow condition. During dry periods between runoff events, the Kinnickinnic River maintained a summer 2009 base flow of 72-91 cfs at County Highway F. Real-time and recent (60-day) stage, flow, and precipitation data for this monitoring station are web-accessible at:

http://waterdata.usgs.gov/wi/nwis/uv/?site_no=05342000&PARAmeter_cd=00065,00060

In the spring and autumn of 2009, instantaneous measurements of base flow were obtained at Sites 1-3 in the Kinnickinnic River and at the mouth of Sumner Creek (Site 4A) within the North Kinnickinnic River Monitoring Project Area. The 2009 base flow surveys were conducted using a handheld SonTek® FlowTracker Acoustic Doppler Velocimeter (ADV).

The spring 2009 base flow survey was conducted on May 22. These spring 2009 survey results are presented in Figure 41, with a comparison to the spring 2006-2008 survey results. In spring 2009, Kinnickinnic River base flows in the project area increased gradually from upstream to downstream, with flows of 39 cfs, 41 cfs, and 47 cfs measured at Sites 3, 2, and 1, respectively. Sumner Creek provided a very small contribution (0.5 cfs) to the Kinnickinnic River, just upstream of Site 1. An additional 70% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (80 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (2.5 cfs). The spring 2009 Kinnickinnic River base flows in the project area (Sites 1-3) decreased notably (by 18-22%), compared to spring 2008, likely due to moderate drought conditions in early April and below-normal precipitation in April and May (Figure 3). In Sumner Creek, however, the spring 2009 base flow was 150% higher than the spring 2008 base flow. The spring 2009 base flows in Rocky Branch Creek and in the Kinnickinnic River at County Highway F decreased by 50% and 7%, respectively, compared to the spring 2008 base flows at these locations. The spring 2007-2009 base flows at all monitoring sites in the North Kinnickinnic River Monitoring Project Area were less than the spring 2006 base flows, which were probably influenced by much wetter than normal conditions in 2005 (Figure 1). Within the project area, the spring 2009 base flows were the lowest recorded since monitoring began in 2006. The low spring 2009 base flows and a downward trend in spring base flows since 2006 may be attributed to three consecutive summers of below-normal precipitation (2006-2008) and a continuation of drought conditions.

The autumn 2009 base flow survey was conducted on September 21. These autumn 2009 survey results are presented in Figure 42, with a comparison to the autumn 2005-2008 survey results. In autumn 2009, Kinnickinnic River base flows increased slightly from upstream (40 cfs at Site 3) to downstream (47 cfs at Site 1) in the project area. Sumner Creek provided a small contribution (0.8 cfs) upstream of Site 1. An additional 77% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (83 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (3.2 cfs). The autumn 2009 Kinnickinnic River base flows in the project area (Sites 1-3) decreased notably (by 8-23%), compared to autumn 2008, likely due to moderate drought conditions and below-normal precipitation in September (Figure 3). In Sumner Creek, Rocky Branch Creek, and the Kinnickinnic River at County Highway F, the autumn base flows were identical in 2008 and 2009. The autumn 2006-2009 base flows at all monitoring sites in the North Kinnickinnic River Monitoring Project Area were less than the autumn 2005 base flows, which were probably influenced by much wetter than normal conditions in 2005 (Figure 1). Within the project area, the autumn 2009 base flows were the lowest recorded since monitoring began in 2005. The low autumn 2009 base flows and a downward trend in autumn base flows since 2005 may be attributed to three consecutive summers of below-normal precipitation (2006-2008) and a continuation of moderate-severe drought conditions throughout the summer of 2009, in spite of above-normal precipitation.

Based upon several years of base flow survey data, it seems apparent that climatic variability can cause significant annual changes in spring and autumn base flows within the North Kinnickinnic River Monitoring Project Area. Below-normal rainfall during the summers of 2006-2008 resulted in markedly reduced base flows during the autumns of 2006-2008, compared to the autumn of 2005, which was preceded by a summer with above-normal rainfall. In contrast, spring 2009 base flows were nearly identical to autumn 2009 base flows at all monitoring sites, in spite of above-normal summer precipitation. This may be explained in part by high runoff and reduced infiltration rates during the three largest summer rain events in July and August, which accounted for 42% of the summer precipitation.

One goal of the River Falls Storm Water Management Ordinance is to maintain strong base flow conditions in the Kinnickinnic River by requiring storm water management practices that promote infiltration of rainfall, thereby maintaining shallow aquifer levels, as well as the springs that provide cold water for the river. Since 2005, proportionately similar decreases in spring and autumn base flows have occurred at all sites within the project area, including those upstream (Sites 2 and 3) and downstream (Site 1) of Sumner Creek and the Sterling Ponds subdivision. Given consistent base flow diminution across all sites since 2005, it is likely that a regional factor is contributing, rather than a lack of storm water infiltration at Sterling Ponds. Three consecutive summers of below-normal precipitation (2006-2008) and a continuation of moderate-severe drought conditions throughout this period are the likely cause of the observed base flow reduction. Conversely, performance monitoring at Sterling Ponds has demonstrated that the storm water management practices have provided excellent infiltration capacity since 2004, thereby helping to sustain groundwater recharge during an extended dry period.

Annual spring and autumn base flow surveys will provide an ongoing measure for determining if base flow conditions will be sustained in the future as development progresses in the North Kinnickinnic River Monitoring Project Area.

Macroinvertebrate Monitoring:

Biotic indicators such as macroinvertebrates (aquatic insects and crustaceans) are often used to complement physical and chemical measurements in stream monitoring programs. Biological data add a significant dimension to monitoring procedures because they provide an analysis that measures long-term phenomena. Because many aquatic organisms live in the stream environment for a year or more, they are excellent indicators of past as well as present water quality conditions. Annual macroinvertebrate samples are collected at Sites 1-3 within the North Kinnickinnic River Monitoring Project Area. Sampling is generally conducted in late May. After collection, the organisms are identified and counted in the laboratory, and various biological indices can then be calculated for each monitoring site. The index values are indicative of water quality, depending upon the pollution tolerances of the macroinvertebrates collected at the monitoring sites.

The use of benthic (bottom-dwelling) macroinvertebrates was initiated in Wisconsin with the work of W. L. Hilsenhoff at the University of Wisconsin-Madison, and has been modified and refined (Hilsenhoff 1982, 1987). The Hilsenhoff Biotic Index (HBI) is particularly useful for determining the influence of organic pollution on macroinvertebrates. The Wisconsin Department of Natural Resources has used this index for many years in long-term stream monitoring programs.

Macroinvertebrate HBI determinations follow a sequence of field sample collection, laboratory sorting, identification and enumeration, and index calculation. All macroinvertebrates in each sample are identified to the lowest practical taxon, typically genus, but also species where possible. Each macroinvertebrate taxon has been assigned a specific tolerance value at the genus or species level. These values range from 0 (extremely intolerant of organic pollution) to 10 (extremely tolerant of organic pollution).

The Hilsenhoff Biotic Index (HBI) is calculated for each macroinvertebrate sample, as follows:

$$HBI = \sum T_1 \times TV_1 \ldots. T_n \times TV_n \; / \; N$$

Where:

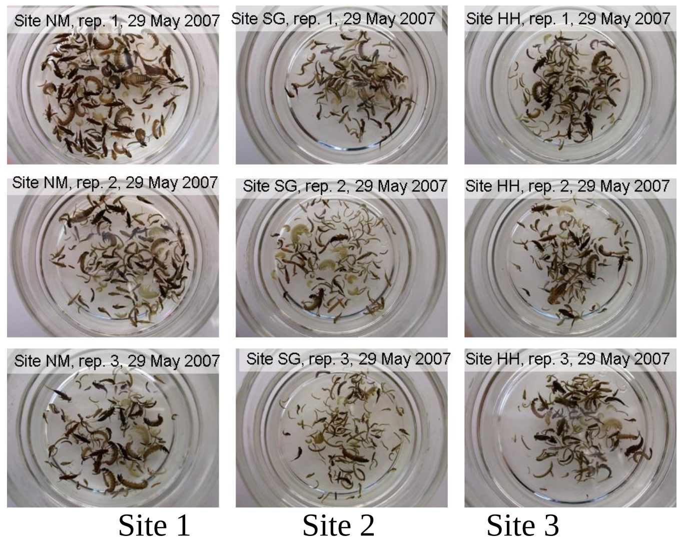
T = number of individuals in the taxon
TV = tolerance value of the taxon
n = number of taxa
N = total number of individuals in the sample

The more intolerant taxa that are present in a macroinvertebrate sample, the lower the biotic index, indicating better water quality, as shown in the table below.

HBI Value	Water Quality	Degree of Organic Pollution
0.00-3.50	Excellent	No apparent organic pollution
3.51-4.50	Very Good	Slight organic pollution
4.51-5.50	Good	Some organic pollution
5.51-6.50	Fair	Fairly significant organic pollution
6.51-7.50	Fairly Poor	Significant organic pollution
7.51-8.50	Poor	Very significant organic pollution
8.51-10.00	Very Poor	Severe organic pollution

HBI values provide the observer with quantitative data that can be used for comparing water quality at various river sites. Additionally, the work yields supplementary metrics useful for further analysis. These metrics include: taxa richness, numerical dominance, and proportions of sensitive groups (Ephemeroptera, Plecoptera, Trichoptera, i.e., EPT index).

The 2004-2007 macroinvertebrate HBI values for triplicate samples collected at Sites 1-3 in the North Kinnickinnic River Monitoring Project Area are presented in Table 1 (below). The mean 2004-2007 macroinvertebrate HBI values at Sites 1-3 are also presented in Figure 43. The 2004-2007 data establish a baseline for assessing the long-term health of the macroinvertebrate community within the project area.



Triplicate macroinvertebrate samples collected at Sites 1-3 in 2007

During the 2004-2007 period, mean HBI values at Site 1 were indicative of very good-excellent water quality, mean HBI values at Site 2 were indicative of very good water quality, and mean HBI values at Site 3 were indicative of very good-excellent water quality. Mean annual HBI values at Site 1 have been increasing slightly (Figure 43), indicating a slight degradation of water quality. However, the 2006-2007 values were still indicative of very good water quality. In spite of some apparent degradation during the 2004-2007 period, the mean annual HBI values at Site 1 are all less than or comparable to the mean annual HBI values at Sites 2 and 3, indicating slightly better water quality at Site 1. Mean annual HBI values at Site 2 decreased in 2006 and 2007, indicating improving water quality. However, all annual values during the 2004-2007 period were indicative of very good water quality. Mean annual HBI values at Site 3 were relatively consistent during the 2004-2007 period, and generally indicative of very good water quality.

The comparability of mean annual macroinvertebrate HBI values at Sites 1-3 during the 2004-2007 period indicates that no storm water impacts were apparent at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. The 2004-2007 macroinvertebrate monitoring results nicely corroborate the 2004-2007 Kinnickinnic River and Sterling Ponds temperature monitoring results, which indicated that the summer temperature regimes in the Kinnickinnic River at Sites 1-3 were generally excellent for coldwater macroinvertebrate communities, and the Sterling Ponds storm water management practices were effectively treating storm water, as intended by the River Falls Storm Water Management Ordinance.

Macroinvertebrate monitoring was again conducted in May 2008 and May 2009, but the taxonomic analysis has not yet been completed by the University of Wisconsin-Stevens Point laboratory. Annual HBI values and other macroinvertebrate indices will continue to be posted as they become available, and long-term trends in these indices will continue to be evaluated, to assess the ongoing health of the Kinnickinnic River macroinvertebrate community.

Table 1. Macroinvertebrate HBI Values in the Kinnickinnic River: 2004-2007

Samp g Site	**Sampling Location**	**2004 HBI Values**	**2005 HBI Values**	**2006 HBI Values**	**2007 HBI Values**
Site 1: North Main	50 yards upstream from North Main Street Bridge, River Falls, WI Lat. 44°52'32.1", Long. 92°37'15.6"	2.77 2.86 2.99	3.17 3.04 2.79	3.57 3.57 3.62	3.64 3.85 4.07
	Mean of 3 reps:	2.87	3.00	3.59	3.85
Site 2: Swinging Gate (STH 65)	Approx. 1.1 miles upstream from North Main Street Bridge, River Falls, WI Lat. 44°53'12.9", Long. 92°36'40.9"	4.20 3.99 3.85	4.30 4.67 4.45	4.01 3.91 4.13	3.85 3.84 3.62
	Mean of 3 reps:	4.01	4.47	4.02	3.77
Site 3: Hebert-Hagen	Approx. 0.4 mile downstream from Quarry Rd., River Falls, WI Lat. 44°53'22.2", Long. 92°36'19.5"	3.37 4.04 3.60	3.65 3.55 3.13	3.88 3.72 3.89	3.65 3.86 3.74
	Mean of 3 reps:	3.67	3.44	3.83	3.75

North Kinnickinnic River Monitoring Project Indicators:

As a part of the North Kinnickinnic River Monitoring Project, key physical and biological indicators have been monitored to evaluate the effectiveness of the River Falls Storm Water Management Ordinance for preventing degradation of the Kinnickinnic River due to development-related storm water impacts. These ten key indicators, which have been monitored since the onset of the project in 2004, include:

- Total rainfall in River Falls during the April-September period
- % April-September rainfall infiltrated, per the River Falls Storm Water Management Ordinance
- Number of summer (May-September) rain events infiltrated and % summer rainfall infiltrated, as measured by monitoring at Sterling Ponds
- Summer (May-September) average air temperature in River Falls
- Summer (May-September) average temperatures in the Kinnickinnic River and Sumner Creek

- % of the summer Kinnickinnic River temperatures favorable for biota
- % of the summer Sumner Creek temperatures favorable for biota
- Spring base flow conditions in the Kinnickinnic River and Sumner Creek
- Autumn base flow conditions in the Kinnickinnic River and Sumner Creek
- Kinnickinnic River macroinvertebrate HBI values

The North Kinnickinnic River Monitoring Project Indicators for the 2004-2009 period can be found on the project website. As monitoring continues in the future, these indicators can evaluate the annual effectiveness of the River Falls Storm Water Management Ordinance and track long-term trends that document protection of the Kinnickinnic River.

Appendix A

Sterling Ponds: Wet Pond Discharges to Sumner Creek
2005-2009

2005:
During six summer rain events in excess of one inch, the Sterling Ponds wet detention pond discharged warm water (17.9-27.2º C) to the Sumner Creek drainage way, often for extended periods (5-14 hours). Three of these rain events (June 11, July 25, and September 21) were less than 1.5 inches.

Date	Rainfall Amount	Discharge Lag	Discharge Time
June 8	1.76 inches	No Data	11 hours
June 11	1.43 inches	No Data	13.5 hours
July 8	4.00 inches	No Data	14 hours
July 25	1.38 inches	No Data	9 hours
Sept 21	1.49 inches	30 minutes	5 hours
Sept 24-25	2.49 inches	No Data	14 hours

2006:
During three summer rain events in excess of 1.5 inches, the Sterling Ponds wet detention pond discharged very warm water (23.4-26.5º C during the July 24 event) to the Sumner Creek drainage way, often for extended periods (4 hours during the July 24 event).

Date	Rainfall Amount	Discharge Lag	Discharge Time
July 24	1.80 inches	10 minutes	4 hours

August 2*	2.26 inches	No Data	No Data
August 24*	1.63 inches	No Data	No Data

*Antecedent rain events occurred on August 1 (1.04 inches) and August 23 (0.71 inches)

2007:
The Sterling Ponds wet detention pond only discharged to Sumner Creek during the large, back-to-back rain events on August 27 (1.72 inches) and August 28 (1.04 inches), and during the large, intense rain event on September 20 (1.19 inches).

Date	Rainfall Amount	Discharge Lag	Discharge Time
August 27	1.72 inches	1 hour	4 hours
August 28	1.04 inches	2.5 hours	3 hours
Sept 20*	1.19 inches	1 hour	5 hours

*An antecedent rain event occurred on September 18 (1.64 inches)

2008:
The Sterling Ponds wet detention pond only discharged to Sumner Creek during the large, intense rain event on July 25 (1.16 inches).

Date	Rainfall Amount	Discharge Lag	Discharge Time
July 25	1.16 inches	20 minutes	3.3 hours

2009:
The Sterling Ponds wet detention pond only discharged to Sumner Creek during the large, intense rain event on August 8 (3.76 inches).

Date	Rainfall Amount	Discharge Lag	Discharge Time
August 8	3.76 inches	None	15 hours

*An antecedent rain event occurred on August 7 (0.98 inches)

Discharge Lag is defined as the time lag between the onset of discharge to the infiltration basin and the onset of discharge to Sumner Creek. **Discharge Time** is the length of time that discharge occurs to Sumner Creek.

Appendix B

Reasons why small rainfall events (less than one inch) caused no storm water impacts at Sterling Ponds in 2009

Smaller rainfall and runoff events can have significant storm water impacts on the Kinnickinnic River, as was evident by the numerous thermal spikes (Figures 20-25) caused by direct (untreated) storm water discharges upstream from the Division Street monitoring site in 2009. However, storm water runoff from the Sterling Ponds subdivision caused no impacts on the Kinnickinnic River during these smaller rainfall events (less than 1 inch) in 2009, due to several factors:

1. Building progress remained somewhat limited in the Sterling Ponds subdivision in 2009, and has largely occurred in the southeast and northeast quadrants of the subdivision.

   In the southeast quadrant, only 3 single-family housing units were built by year-end 2003, 19 single-family housing units were built by year-end 2004, 33 single-family housing units were built by year-end 2005, 36 single-family housing units were built by year-end 2006, 48 single-family housing units were built by year-end 2007, 56 single-family housing units were built by year-end 2008, and 58 single-family housing units were built by year-end 2009.

   In the northeast quadrant, 2 duplex units were complete by year-end 2005, and 2 multi-family (8-plex) units were under construction. By year-end 2006, 1 single-family unit, 2 duplex units, 3 multi-family 8-plex units, and 2 multi-family 10-plex units were complete, for a total of 49 units. By year-end 2007, 3 single-family units, 5 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 77 units. By year-end 2008, 11 single-family units, 8 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 91 units. By year-end 2009, 12 single-family units, 9 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 94 units.

A build-out total of 600 units is projected for Sterling Ponds. By year-end 2009, a total of 152 units (25% of build-out) were complete in the southeast and northeast quadrants of Sterling Ponds.

Maps of Sterling Ponds build-out progress in 2004, 2005, 2006, 2007, 2008, and 2009 are available on the project website ("Annual Reports"). With 58 of approximately 150 single family units (39%) complete in the southeast quadrant, 94 of approximately 150 family units (63%) complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2009, impervious surfaces (rooftops, sidewalks, driveways, and streets) still account for a relatively small proportion (??%) of the overall Sterling Ponds subdivision area.

2. Four wet storm water detention ponds were already in place in 2009, with some capacity for storing storm water runoff from the existing impervious areas, especially during smaller rain events. Two of the four infiltration basins paired with the wet storm water detention ponds were not yet functional in 2009. However, the third infiltration basin (serving the northeast quadrant of Sterling Ponds) and the fourth infiltration basin (serving the southeast quadrant of Sterling Ponds) were functional throughout the April-September 2009 period (see 2009 build-out map). These infiltration basins were designed and constructed to meet the current River Falls Storm Water Management Ordinance infiltration requirements. The Sterling Ponds infiltration basins remained off-line throughout 2004, so that percolation testing could be conducted and native vegetation had an opportunity to become established. The northeast and southeast wet detention ponds and infiltration basins should have provided effective storm water treatment for the northeast and southeast quadrants of Sterling Ponds in 2009, as required by the ordinance. Indeed, monitoring of the southeast storm water management practices in 2009 demonstrated excellent infiltration for 40 summer rain events, ranging in magnitude from 0.01-2.45 inches and totaling 17.95 inches (79% of the total summer precipitation) (see ***Effectiveness of Sterling Ponds Storm Water Management Practices***).

3. The Sterling Ponds subdivision is approximately 1.5 miles from the Kinnickinnic River, with a connection via Sumner Creek. Sumner Creek is a low-gradient tributary that typically exhibits only intermittent flow during larger rain events. Downstream wetland areas that are part of the Sumner Creek drainage way and the Sumner Creek channel itself likely provide some storage of any Sterling Ponds storm water discharges, especially during larger rain events that may exceed the capacity of the wet detention ponds and the functional infiltration basins.

Monitoring at Sterling Ponds in 2009 capably evaluated ordinance effectiveness and identified the storm water impacts related to one large rainfall event in excess of 1 inch (see ***Effectiveness of Sterling Ponds Storm Water Management Practices***). Ongoing annual monitoring and evaluation will be especially important as the Sterling Ponds subdivision continues to develop and impervious area increases.