City of River Falls
North Kinnickinnic River Monitoring Project

2007 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.

To take an active role in 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 new storm water 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. During the April-September 2007 monitoring period, hourly precipitation was measured in 0.01-inch increments with an electronic tipping-bucket rain gauge. The rain gauge, provided by the Wisconsin Department of Natural Resources (WDNR), is located in the Sterling Ponds subdivision at the northwest corner of the City of River Falls. This location places the rain gauge 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.

A total of 18.36 inches of precipitation was recorded in River Falls (at Sterling Ponds) during the April-September 2007 period, 2.31 inches less than the normal total of 20.67 inches for the April-September time period. Rain fell on 67 days, or 37% of the April-September 2007 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, and a below-normal total of 17.16 inches was measured during the April-September 2006 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 2007 period are presented in Figure 2. Monthly rainfall amounts during the April-September 2007 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. Except for August and September, all months during the April-September 2007 period were drier than normal, with monthly rainfall deficits ranging from 0.14 inch to 2.83 inches. The greatest rainfall deficits occurred in June and July, with the lowest monthly rainfall amount (1.33 inches) recorded in July. August was the wettest month (6.93 inches), exceeding the normal monthly rainfall amount by 2.88 inches. September was also a very wet month (4.76 inches), exceeding the normal monthly rainfall amount by 2.07 inches. Until mid-August 2007, the North Kinnickinnic River Monitoring Project Area continued to be affected by a region-wide drought that began in early 2006 (see Figure 1).

Besides being drier than normal, the April-September 2007 monitoring period was warmer than normal. The mean air temperature in River Falls during the April-September 2007 period was 65.4º Fahrenheit (F), 2.2º F higher 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 2007 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1971-2000, are presented in Figure 4. With the exception of April, all months during the April-September 2007 monitoring period were warmer than normal. The months of May and September were nearly 4º F warmer than normal, while the month of June was 3º F warmer than normal. The month of April was slightly colder than normal.

The distribution of River Falls daily rainfall amounts during the April-September 2007 period is presented in Figure 5. Although the 2007 monitoring season was drier than normal, it was characterized by numerous (56) days with rainfall amounts of 0.50 inch or less. On 44 (66%) of the 67 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 44 days contributed only 17% of the total April-September 2007 precipitation. The majority of these 44 days occurred in the cooler months of April, May, June, and September (Figure 6). On 12 (18%) of the 67 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 12 days contributed an additional 22% of the total April-September 2007 precipitation. Three of these 12 days occurred in May and September (Figure 6), when air temperatures were cooler. On 3 (4%) of the 67 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 3 days contributed 10% of the total April-September 2007 precipitation, and occurred in May, August, and September (Figure 6). Only 2 (3%) of the 67 days with measurable precipitation had rainfall amounts in the 0.76-1.00 inch range (Figure 6), contributing 10% of the total April-September 2007 precipitation. On 6 (9%) of the 67 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. These 6 days with the largest rainfall events contributed 42% of the total April-September 2007 precipitation. Rainfall amounts in excess of 1 inch occurred on August 13, 19, 27, and 28, and September 18 and 20 (Figures 2 and 6). On 4 of the 6 days, rainfall amounts ranged from 1.01-1.25 inches. On 2 of the 6 days, rainfall amounts exceeded 1.50 inches. All of these 6 largest rainfall events occurred in August and September, and all but one event (September 18) were produced by convective thunderstorm activity during a warmer than normal summer.

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 67 days with measurable precipitation during the April-September 2007 period, 65 days (97%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Based on that data, only rainfall amounts on August 27 (1.72 inches) and September 18 (1.64 inches) exceeded this criterion. Even so, some infiltration would have occurred under the requirements of the storm water ordinance, thereby accounting for infiltration of approximately 98% (18.00 inches) of the total rainfall (18.36 inches) that occurred during the April-September 2007 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 precipitation 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 Trout Unlimited provide annual cost-share funding for this USGS monitoring station.

The daily mean (average) flow of the Kinnickinnic River at County Highway F during the April-September 2007 period is presented as a hydrograph in Figure 8. Daily rainfall, as measured in River Falls at Sterling Ponds, 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. Prior to the start of the 2007 monitoring season, runoff from rapid snowmelt in mid-March produced a peak daily mean river flow of 2,024 cubic feet per second (cfs) on March 13 (not shown in Figure 8). During the April-September 2007 monitoring period, the highest river flow of 192 cfs on April 1 occurred as a result of heavy rainfall (1.73 inches) on March 30-31.

Numerous small rain events (less than 0.50 inch) in April, May, June, and July had little influence on the Kinnickinnic River hydrograph. Larger rain events on May 23 (0.94 inch) and May 30 (0.88 inch) produced moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 130 cfs and 108 cfs, respectively.

During the August-September period, rainfall amounts in excess of 1 inch generally had the greatest influence on the Kinnickinnic River hydrograph. Rainfall events on August 13 (1.04 inches) and August 19 (1.15 inches) resulted in only moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 101 cfs and 130 cfs, respectively. These moderate runoff events, in spite of rainfall amounts in excess of 1 inch, can be attributed to very dry antecedent conditions during the May-early August period, and full canopy closure in the agricultural and forested areas of the watershed. Large, back-to-back rainfall events on August 27 (1.72 inches) and August 28 (1.04 inches) produced a more significant increase in the Kinnickinnic River hydrograph, with a peak daily mean flow of 149 cfs. Similarly, large, nearly back-to-back rainfall events on September 18 (1.64 inch) and September 20 (1.19 inches) also produced a significant increase in the Kinnickinnic River hydrograph, with a peak daily mean flow of 141 cfs.

The Kinnickinnic River hydrograph suggests that seven significant runoff events occurred during the April-September 2007 period. One of these seven significant runoff events occurred in late March and early April (March 30-April 3), due to early spring rains on March 30-31. With cool air and water temperatures in late March and early April, thermal impacts of storm water runoff are generally not a concern, but water quality impacts can be problematic, due to frozen soils and a lack of vegetative cover in the watershed. Two of the seven significant runoff events occurred in May, when thermal impacts of storm water runoff become a concern due to warmer air temperatures. On May 23, a 0.94 inch rain event resulted in a 3-day runoff event (May 23-25), with a peak daily mean flow of 130 cfs. On May 30, a 0.88 inch rain event produced a 1-day runoff event (May 31), with a peak daily mean flow of 108 cfs. Four of the seven significant runoff events occurred in August and September, during two of the four warmest months of the year (Figure 4), when thermal impacts of storm water runoff can be a considerable concern. On August 13, a 1.04 inch rain event resulted in a 3-day runoff event (August 14-16), with a peak daily mean flow of 101 cfs. On August 19, a 1.15 inch rain event resulted in a 2-day runoff event (August 19-20), with a peak daily mean flow of 130 cfs. On August 27 and 28, back-to-back rainfall events totaling 2.76 inches resulted in a 4-day runoff event (August 27-30), with a peak daily mean flow of 149 cfs. On September 18 and 20, nearly back-to-back rainfall events totaling 2.83 inches resulted in a 5-day runoff event (September 18-22), with a peak daily mean flow of 141 cfs. The six runoff events in May, August, and September should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2007, and are further analyzed in this report.

With drought conditions prevalent during the April-early August 2007 period, Kinnickinnic River base flows steadily decreased from approximately 90 cfs in mid April to approximately 70 cfs in early August, as measured at County Highway F. With higher than normal rainfall amounts in August and September, base flows rebounded to approximately 80 cfs in early September and approximately 90 cfs in late September.

Temperature Monitoring:

In 2007, 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 Kinni 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 2005-2007. 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 is used to measure water temperature at the TU monitoring station at Quarry Road (Site 1A). Onset 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 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 2007 deployment periods (and locations) for the temperature loggers at the ten monitoring stations were as follows:

Site:	Deployment Period:	Location:
Site 1:	May 4-September 30, 2007	Kinnickinnic River
Site 1A:	May 1-September 30, 2007	Kinnickinnic River
Site 2:	May 4-September 30, 2007	Kinnickinnic River
Site 3:	May 4-September 30, 2007	Kinnickinnic River
Site 4:	May 4-September 30, 2007	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2007	Sumner Creek: Mouth
Site 5P:	May 4-September 30, 2007	Sterling Ponds: Wet Pond
Site 5IB:	May 4-September 30, 2007	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 4-September 30, 2007	Sterling Ponds: Wet Pond Outlet
Site 6:	May 4-September 30, 2007	Sumner Creek: Dry Box Culvert

Kinnickinnic River Temperature Monitoring Results:

The May-September (summer) 2007 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 2007 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 2007 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 (13.6 degrees Celsius (°C)) and warmest in July (16.6° C).

At Sites 1, 1A, 2, and 3, river temperatures averaged 15.2° C and ranged from 7.7-21.6° 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 identical at Sites 1 and 2, slightly warmer at Site 1A, but slightly cooler at Site 3, especially during the June-July period.

For the third consecutive year, higher-than-normal river temperatures probably prevailed in the North Kinnickinnic River Project Area during the summer of 2007, since the 2007 summer average air temperature of 20.7º C (69.3º F) was noticeably higher than the normal summer average air temperature of 19.2° C (66.5° F). A comparison of 2004-2007 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 2007 summer average air temperature of 20.7º C and summer average river temperature of 15.2º C were the highest summer average temperatures recorded since the North Kinnickinnic River Monitoring Project began in 2004.

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 2007 (Figures 15-19, respectively). Figures 14-19 indicate that daily maximum temperatures tended to be slightly warmer at Site 1A, due to less canopy cover and shading at this location. Daily minimum temperatures tended to be slightly cooler at Site 1. 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 77% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2007 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 94% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2007 period were ≤ 19° C, which is considered to be the top of the optimum temperature range for brown trout growth (Armour, 1994).

3. Approximately 98% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2007 period were ≤ 20° C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). River temperatures exceeding 20º C were not recorded in May and September. With a warmer-than-normal summer, however, daily maximum river temperatures exceeded 20º C on 23 dates during the June-August period. Maximum air temperatures on these 23 dates were generally hot, ranging from 28-37º C (82-98° F) and averaging 32º C (90° F).

During eight significant rainfall events in May, August, and September 2007, thermographs at Sites 1 and 2 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), in spite of two significant rainfall events on May 23 (0.94 inch) and May 30 (0.88 inch). A closer examination of the thermographs for Sites 1 and 2 during the 0.94-inch rainfall event on May 23 (Figure 20) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. During the same rain event, however, the thermograph for the Trout Unlimited temperature monitoring site at Division Street (Figure 20) shows a very prominent thermal spike, due to the thermal impacts of direct storm water discharges from the downtown area of River Falls. Similarly, when the thermographs for Sites 1, 2, and Division Street are compared during the 0.88-inch rainfall event on May 30 (Figure 21), no thermal spike is evident at Site 1, while a slight thermal spike is evident at Division Street.

In August, no thermal spikes were evident at Site 1 (Figure 18), in spite of multiple larger rain events on August 13 (1.04 inches), August 19 (1.15 inches), August 27 (1.72 inches), and August 28 (1.04 inches). A closer examination of the rainfall events on August 13 (Figure 22) and August 19 (Figure 23), and the back-to-back rainfall events on August 27 -28 (Figure 24) indicates that no thermal spikes were apparent at Site 1, while prominent thermal spikes were consistently evident at Division Street. During the August rainfall events, the thermal spikes at Division Street ranged in magnitude from 1.0-3.0º C.

Finally, no thermal spikes were evident at Site 1 in September (Figure 19), in spite of two large, nearly back-to-back rainfall events on September 18 (1.64 inch) and September 20 (1.19 inch). A closer examination of these two rainfall events (Figure 25) indicates that no thermal spikes were apparent at Site 1, while prominent thermal spikes, ranging in magnitude from 0.9-1.8º C were quite evident at Division Street.

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 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, even during the largest runoff events in 2007.

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) 2007 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 12.5° C and ranged from 7.8-17.1° C during the May-September 2007 period. The summer mean temperature of Sumner Creek (12.5º C) was notably colder than the summer mean temperature of the Kinnickinnic River (15.2º 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 2007 period were ≤ 17° C. Temperatures exceeding 17° C were only recorded for a brief period during the largest rainfall event of the summer on August 27 (1.72 inches).

Based upon the summer 2007 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 multiple thermal spikes that occurred at Site 4A during the large rain events in May, August, and September (Figure 26). Several prominent thermal spikes in lower Sumner Creek, ranging from 2.7-4.2° C, occurred during the May 23, August 27, and August 28 rain events. These Sumner Creek thermal spikes were of even greater magnitude than those observed at the Division Street monitoring site on the same dates. In spite of their magnitude, none of these thermal spikes had a discernible impact on Kinnickinnic River temperatures at Site 1, downstream from Sumner Creek. However, thermal spikes of this magnitude and frequency may have detrimental impacts on aquatic life in lower Sumner Creek, especially macroinvertebrates. Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005 and 2006. 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) 2007 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 27. At Site 5P, wet detention pond temperatures averaged 21.4° C and ranged from 13.1-28.9° C during the summer period. Approximately 65% of all summer temperatures exceeded 20° C, and wet pond temperatures continuously remained above 20° C from June 10 until August 19. 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 (21.4° C) was substantially higher than the summer mean temperature of Sumner Creek at Site 4A (12.5º 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 27) 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 2007, 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 eight significant rainfall and runoff events in May, August, and September is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). The August 27 and September 18 events were characterized by rainfall amounts in excess of 1.5 inches, beyond the infiltration requirement of the River Falls Storm Water Management Ordinance.

May

The comparative Sterling Ponds thermographs for May 2007 are presented in Figure 28. The May 1-22 period was warmer than normal and relatively dry, with small rainfall events recorded on only five dates. During this time period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. The five small rain events, ranging from 0.01-0.27 inch and totaling 0.55 inch, were captured in the wet pond, where the water infiltrated or evaporated from the pond.

The comparative Sterling Ponds and Sumner Creek thermographs for the May 23 rain event (0.94 inch) are presented in Figure 29. 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 17:20 CDT (5:20 PM) on May 23, shortly after the onset of rainfall at 17:00 CDT (5:00 PM). Wet pond discharge to the infiltration basin, due to the May 23 rainfall event and several smaller events on May 24 (0.51 inch) and May 26 (0.11 inch), continued for nearly six days, until 10:20 CDT (10:20 AM) on May 29. During this time period, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4. Shortly after the May 23 rain event began, a prominent thermal spike (3.3° C) occurred in lower Sumner Creek at Site 4A. However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause.

June

The comparative Sterling Ponds thermographs for June 2007 are presented in Figure 30. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond was already discharging to the infiltration basin on June 1, due to the large rainfall event (0.88 inch) on May 30 (Figure 31). Wet pond discharge to the infiltration basin, due to the May 30 rainfall event and smaller daily rain events during the May 31-June 7 period, began at 19:40 CDT (7:40 PM) on May 30 and continued for nearly nine days, until 18:40 CDT (6:40 PM) on June 8. Rainfall amounts during the May 31-June 7 period ranged from 0.01-0.32 inch and totaled 0.67 inch. During the May 30-June 7 time period, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 31). Shortly after the May 30 rain event began, a small thermal spike (1.1° C) occurred in lower Sumner Creek at Site 4A. However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause.

The remainder of June was very warm and quite dry, with small rainfall events recorded on only six dates. During this time period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek (Figure 30). The six small rain events, ranging from 0.01-0.37 inch and totaling 0.90 inch, were captured in the wet pond, where the water infiltrated or evaporated from the pond. Including infiltration of the May 30 rain event in early June, the entire May rainfall amount of 3.10 inches (11 events ranging from 0.01-0.94 inch) (Figure 6) was captured in the Sterling Ponds wet pond or infiltrated. Similarly, the entire June rainfall amount of 1.51 inches (12 smaller events ranging from 0.01-0.37 inch) (Figure 6) was also captured in the wet pond or infiltrated.

July

The comparative Sterling Ponds thermographs for July 2007 are presented in Figure 32. July was much drier and warmer than normal, with small rainfall events recorded on ten dates. During the month, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. The ten small rain events, ranging from 0.02-0.33 inch and totaling 1.33 inches, were captured in the wet pond, where the water infiltrated or evaporated from the pond. Given the high ambient air and wet pond temperatures in July, evaporation likely accounted for considerable water loss from the pond.

August

The comparative Sterling Ponds thermographs for August 2007 are presented in Figure 33. August was the wettest month of the summer 2007 monitoring season, with 6.93 inches of rain. However, most of this rainfall amount (6.79 inches) occurred during the August 11-28 period.

A moderate rainfall event on August 11 (0.62 inch) and the large rainfall event on August 13 (1.04 inches) caused no Sterling Ponds wet pond discharges to either the infiltration basin or Sumner Creek (Figure 34). With very warm and relatively dry conditions during the June 1-August 10 period, the Sterling Ponds wet pond had adequate capacity to capture both of these rain events. This capacity was gained due to considerable water loss from the pond, via evaporation and possibly some infiltration. After the August 13 rainfall event, no thermal spike was apparent in Sumner Creek at Site 4, but a small thermal spike (1.3° C) occurred in lower Sumner Creek at Site 4A (Figure 34). However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause. Two smaller rain events on August 14 (0.08 inch) and August 18 (0.48 inch) were also captured in the Sterling Ponds wet pond.

Due to the large rainfall event on August 19 (1.15 inches), seven smaller rain events during the August 20-24 period (ranging from 0.01-0.34 inch and totaling 0.66 inch), and large back-to-back rainfall events on August 27-28 (1.72 and 1.04 inches), the Sterling Ponds wet detention pond began discharging to the infiltration basin on August 19 and continued discharging to the infiltration basin through the end of August (Figure 33).
The comparative Sterling Ponds and Sumner Creek thermographs for the August 19 rain event (1.15 inch) are presented in Figure 35. 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 15:50 CDT (3:50 PM) on August 19, shortly after the onset of rainfall at 15:00 CDT (3:00 PM). Wet pond discharge to the infiltration

basin, due to the August 19 rainfall event and the seven smaller rain events during the August 20-24 period (totaling 0.66 inch), continued until the August 27 rain event began. During the August 19-26 period, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4. Shortly after the August 19 rain event began, a small thermal spike (1.7° C) occurred in lower Sumner Creek at Site 4A. However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause.

The comparative Sterling Ponds and Sumner Creek thermographs for the large back-to-back rainfall events on August 27-28 (1.72 and 1.04 inches) are presented in Figure 36. Due to significant rainfall (1.81 inches) during the August 19-24 period, the Sterling Ponds wet detention pond was already discharging to the infiltration basin when the August 27 rain event began at approximately 02:00 CDT (2:00 AM). With heavy, intense rainfall from 02:00-05:00 CDT (2:00-5:00 AM), discharge from the wet pond to the infiltration basin increased (note the small but rapid temperature increase at Site 5IB from 03:10-03:30 CDT). As indicated by the nearly identical temperatures at Sites 5P and 5MHW, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 04:20 CDT (4:20 AM) on August 27 and continued discharging until 08:00 CDT (8:00 AM). During this 4-hour period, the wet pond discharge temperature averaged 19.8º C and ranged from 18.8-20.2º C. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. A small but rapid temperature increase (1.3º C) was apparent downstream at Site 4 in Sumner Creek by 11:00 CDT (11:00 AM) on August 27, and is likely due to the release of warm water (including storm water) from the upstream wetland. In spite of this warm water release, the temperature of Sumner Creek never exceeded 20º C at Site 4 on August 27. The prominent thermal spike (4.1º C) evident near the mouth of Sumner Creek (Site 4A) at 06:00 CDT (6:00 AM) on August 27 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, but well 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.

Rainfall on August 28 (1.04 inches) occurred in two "pulses", with 0.54 inch measured from 02:00-04:00 CDT (2:00-4:00 AM) and 0.50 inch measured from 11:00-14:00 CDT (11:00 AM-2:00 PM). With the Sterling Ponds wet detention pond already full and discharging to the infiltration basin due to the August 27 rain event, a brief wet pond discharge to Sumner Creek occurred during the second rainfall pulse on August 28. As indicated by the nearly identical temperatures at Sites 5P and 5MHW, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 13:40 CDT (1:40 PM) and continued discharging until 16:20 CDT (4:20 PM). During this 3-hour period, the wet pond discharge temperature averaged 21.5º C and ranged from 21.4-21.7º C. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. In spite of the storm water discharge during the afternoon rain pulse, no thermal spikes were apparent in Sumner Creek at Site 4 on August 28. A moderate thermal spike (2.7° C) occurred in lower Sumner Creek at Site 4A during the early morning rain pulse. However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause.

With rainfall amounts on August 27-28 totaling 2.76 inches, the Sterling Ponds wet detention pond continued discharging to the infiltration basin for another four days, until 21:30 CDT (9:30 PM) on September 1. All rainfall during the August 1-26 period (12 events ranging from 0.01-1.15 inches and totaling 4.17 inches) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the August 27-28 rainfall was infiltrated. Although two brief wet pond discharges to Sumner Creek occurred on August 27 and 28, the combined duration of these discharges was relatively short (7 hours), compared to the duration of discharge to the infiltration basin (138 hours) after rainfall began on August 27.

September

The comparative Sterling Ponds thermographs for September 2007 are presented in Figure 37. September was much wetter and warmer than normal, with 4.76 inches of rain recorded on twelve dates. Most of the September rainfall amount occurred during the September 18-30 period (4.11 inches). As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond was already discharging to the infiltration basin on September 1, due to the large rainfall events on August 27 and 28. However, discharge to the infiltration basin ended at 21:30 CDT (9:30 PM) on September 1. During the September 2-17 period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. Four small rain events during this period, ranging from 0.02-0.44 inch and totaling 0.65 inch, were captured in the wet pond, where the water infiltrated or evaporated from the pond. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond discharged to the infiltration basin during the entire September 18-30 period (Figures 37 and 38), due to eight rainfall events ranging from 0.02-1.64 inches and totaling 4.11 inches.

A lengthy rainfall event on September 18 resulted in the second-highest daily rainfall amount (1.64 inches) recorded during the summer 2007 monitoring season. Rainfall began at 07:00 CDT (7:00 AM) and continued until midnight. The comparative Sterling Ponds and Sumner Creek thermographs for the September 18 rain event 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 13:30 CDT (1:30 PM) on September 18, more than six hours after the onset of rainfall. During the September 18 rain event, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4. Late in the evening, a very small thermal spike (0.7° C) occurred in lower Sumner Creek at Site 4A. This thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause, perhaps warm water released from natural wetland or storage areas in the upstream Sumner Creek drainage way.

On September 20, a thunderstorm with brief but intense rainfall (1.19 inches) occurred from 18:00-20:00 CDT (6:00-8:00 PM). The comparative Sterling Ponds and Sumner Creek thermographs for this rain event are presented in Figure 38. With the Sterling Ponds wet detention pond already discharging to the infiltration basin due to the September 18 rain event, a brief wet pond discharge to Sumner Creek occurred due to the September 20 rain event. As indicated by the nearly identical temperatures at Sites 5P and 5MHW, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 19:00 CDT (7:00 PM) and continued discharging until 24:00 CDT (midnight). During this 5-hour period, the wet pond discharge temperature averaged 17.6º C and ranged from 17.5-17.8º C. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. A very small but rapid temperature increase (0.6º C) was apparent downstream at Site 4 in Sumner Creek by 01:00 CDT (1:00 AM) on September 21, and is likely due to the release of warmer water (including storm water) from the upstream wetland. In spite of this warm water release, the temperature of Sumner Creek never exceeded 20º C at Site 4 on September 20 or 21. The small thermal spike (1.6º C) evident near the mouth of Sumner Creek (Site 4A) by 22:30 CDT (10:30 PM) on September 20 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, but well 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.

Sterling Ponds wet pond discharge to the infiltration basin, due to the large September 18 and 20 rainfall events and five smaller events (ranging from 0.02-0.62 inch and totaling 1.24 inches) during the September 24-30 period, continued through the end of September (Figure 38). During this time period, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A. With the exception of the brief (5-hour) wet pond discharge to Sumner Creek on September 20, all of the September rainfall was captured in the Sterling Ponds wet pond or infiltrated.

Effectiveness of Sterling Ponds Storm Water Management Practices:

During the May-September (summer) 2007 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 three large rain events on August 27 (1.72 inches), August 28 (1.04 inches), and September 20 (1.19 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River Falls Storm Water Management Ordinance. 56 rain events, ranging in magnitude from 0.01-1.64 inches, represent a total of 13.68 inches of precipitation, or 78% of the total summer rainfall amount (17.63 inches). Of these 56 rain events, 29 events, ranging in magnitude from 0.01-1.04 inches and totaling 5.65 inches of precipitation (32% of the total summer rainfall amount) were entirely stored in the Sterling Ponds wet detention pond. With dry conditions and lengthy periods between rain events in May, June, and July, the wet pond readily stored smaller rain events, with the storm water infiltrating in the pond or evaporating. The 27 remaining rain events, ranging in magnitude from 0.01-1.64 inches and totaling 8.03 inches of precipitation (46% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin.

All 33 rainfall events in May, June, and July were stored in the wet detention pond or diverted to the infiltration basin. These events ranged from 0.01-0.94 inch in magnitude and represented monthly totals of 3.10, 1.51, and 1.33 inches, respectively, or 34% of the total summer rainfall amount. Twelve small-to-large rain events in August, ranging from 0.01-1.15 inches and totaling 4.17 inches, were either infiltrated or stored in the wet detention pond. These August rain events represented 24% of the total summer rainfall. Eleven small-to-large rain events in September, ranging from 0.02-1.64 inches and totaling 3.57 inches, were largely infiltrated, with some storage in the wet detention pond. These September rain events represented 20% of the total summer rainfall.

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). These discharges of storm water to Sumner Creek were directly measured at Site 5MHW during all three events, and indirectly measured as thermal spikes at Site 4 after the August 27 and September 20 events. The August 27 rain event was the largest of the summer season, clearly exceeding the River Falls Storm Water Management Ordinance requirement for infiltration of a 1.5-inch, 24-hour rainfall. Given the magnitude of this event, some storm water discharge to Sumner Creek might be expected. Rainfall amounts on August 28 and September 20 were less than the 1.5-inch ordinance requirement. However, the very large, antecedent rain events on August 27 and September 18 (1.64 inches) could be largely responsible for the August 28 and September 20 storm water discharges to Sumner Creek. Due to the August 27 and September 18 rain events, the Sterling Ponds wet detention pond was likely near capacity, and was already discharging to the infiltration basin when the August 28 and September 20 rain events began. With a limited ability to deliver more water to the infiltration basin, the wet pond reached capacity and discharged the excess water to Sumner Creek. The intensity of the September 20 rain event (nearly an inch in an hour) also may have been a factor contributing to the Sumner Creek discharge.

Although the August 27, August 28, and September 20 rain events resulted in brief discharges of storm water to Sumner Creek, it seems likely that the majority of storm water from these three rain events was infiltrated rather than discharged. On August 27 and 28, the combined duration of the Sumner Creek discharges was relatively short (7 hours), compared to the duration of discharge to the Sterling Ponds infiltration basin (138 hours) after rainfall began on August 27. Similarly, the duration of the storm water discharge to Sumner Creek on September 20 was relatively short (4 hours), compared to the duration of discharge to the infiltration basin, which continued through the end of September. 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, nor is it possible to determine if the first 1.5 inches of the largest summer rain event on August 27 (1.72 inches) was fully infiltrated, as required by the storm water ordinance.

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.

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 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.

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 is necessary. Modeling results suggested that the control structure for the wet pond outlet could be raised by 6 inches and still meet performance standards. This adjustment would provide more storm water storage in the wet pond and allow more discharge of 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.

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 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 to the wet pond outlet structure may have provided more storm water 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 to 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.

Summary

Temperature monitoring of the Sterling Ponds storm water practices during the 2005-2007 period indicates that storm water discharges to Sumner Creek are common during rain events larger than 1.5 inches, and during back-to-back rain events, when rainfall amounts exceed one inch and time periods between rain events are less than 48 hours. Modifications made to the control structure for the Sterling Ponds wet pond outlet seemed to improve infiltration capacity for these types of events in 2007. 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. Storm water discharges to Sumner Creek during back-to-back rain events, when rainfall amounts are less than the 1.5-inch ordinance requirement, may need further attention. Climatological data should be analyzed to determine the frequency of back-to-back events of this nature. Modifications to the storm water management ordinance should be made accordingly.

While this project is primarily focused on evaluating long-term trends, annual information is important as well. The storm water management practices at Sterling Ponds prevented thermal impacts on the Kinnickinnic River during the May-September (summer) 2007 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 56 summer rain events, ranging in magnitude from 0.01-1.64 inches and totaling 13.68 inches (78% of the total summer precipitation). All storm water runoff from these events was infiltrated, as required by the River Falls Storm Water Management Ordinance. We will continue to monitor and analyze how storm water from the Sterling Ponds wet pond is conveyed to the infiltration basin, to determine if it is meeting the intent of the ordinance.
- Smaller rainfall events (less than one inch) caused no thermal impacts on Sumner Creek (see Appendix A). However, during three large rain events in August and September, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, often for extended periods (3-5 hours). These warm storm water discharges likely contributed to notable thermal spikes in Sumner Creek at Site 4, but were not responsible for the thermal spikes observed in lower Sumner Creek, at Site 4A. We will watch for these thermal spikes in the years to come and monitor their intensity and frequency.
- The "first-flush" thermal spikes (0.7-4.1° C) observed in lower Sumner Creek (Site 4A) during the eight largest summer rain events appear unrelated to the storm water discharges at Sterling Ponds, and seem to have a more local cause that needs further investigation.

We hope the Sterling Ponds storm water management practices produce long-term positive results that protect the Kinnickinnic River. Beyond 2007, these same trends will be monitored from year to year, and we hope to find similar results in the future.

<u>Water Quality Monitoring:</u>

No runoff event-based water quality monitoring was conducted in 2007. With below-normal precipitation during the April-September period (Figure 1) and very dry conditions in April, June, and July (Figure 3), very few significant runoff events occurred in the North Kinnickinnic River Monitoring Project Area. Numerous small rain events (less than 0.50 inch) in April, May, June, and July had little influence on the Kinnickinnic River hydrograph (Figure 8). Larger rain events on May 23 (0.94 inch) and May 30 (0.88 inch) produced only moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 130 cfs and 108 cfs, respectively. Due to very dry antecedent conditions and full canopy closure in the agricultural and forested areas of the watershed, the larger rain events on August 13 (1.04 inches), and August 19 (1.15 inches) also produced very moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 101 cfs and 130 cfs, respectively. Large, back-to-back rain events on August 27-28 (2.76 inches) and large, nearly back-to-back rain events on September 18 and September 20 (2.83 inches) produced more significant increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 149 cfs and 141 cfs, respectively. However, no water quality samples were obtained during these two runoff events. Given more normal precipitation and runoff conditions, the water quality monitoring component of the North Kinnickinnic River Monitoring Project will be initiated in 2008.

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 was 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 base flow of approximately 70-90 cfs at County Highway F. Real-time and recent (31-day) stage, flow, and precipitation data for this monitoring station are web-accessible at:

http://waterdata.usgs.gov/wi/nwis/uv?dd_cd=02&format=gif&period=7&site_no=05342000

In the spring and autumn of 2007, 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 2007 base flow surveys were conducted using a SonTek® FlowTracker handheld Acoustic Doppler Velocimeter (ADV).

The spring 2007 base flow survey was conducted on May 3. These spring 2007 survey results are presented in Figure 39, with a comparison to the spring 2006 survey results. In spring 2007, Kinnickinnic River base flows were identical at Sites 2 (48 cfs) and 3 (48 cfs) and slightly higher at Site 1 (55 cfs). Sumner Creek provided a small contribution (0.6 cfs) to the Kinnickinnic River, just upstream of Site 1. An additional 31% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (72 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (4 cfs). The spring 2007 Kinnickinnic River base flows in the project area (Sites 1-3) were reduced by 11-26%, compared to spring 2006, likely due to below-normal precipitation during the intervening year. The greatest base flow reduction (26%) was apparent at Site 2. In Sumner Creek, the spring 2007 base flow was 25% less than the spring 2006 base flow. In spring 2007, a 30% base flow decrease was apparent in Rocky Branch Creek, and a 26% decrease was evident in the Kinnickinnic River at County Highway F.

The autumn 2007 base flow survey was conducted on October 26. These autumn 2007 survey results are presented in Figure 40, with a comparison to the autumn 2005 and autumn 2006 survey results. In autumn 2007, Kinnickinnic River base flows increased slightly from upstream to downstream, with flows of 51 cfs, 53 cfs, and 55 cfs measured at Sites 3, 2, and 1, respectively. Sumner Creek provided a small contribution (0.5 cfs) upstream of Site 1. An additional 76% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (97 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (4 cfs). The autumn 2006 and autumn 2007 Kinnickinnic River base flows in the project area (Sites 1-3) were reduced by 12-28%, compared to autumn 2005, likely due to below-normal precipitation during the summers of 2006 and 2007 (Figure 1). The greatest reduction (28%) was apparent at Site 1. In Sumner Creek, the autumn 2007 base flow was 58% less than the autumn 2005 and autumn 2006 base flows. In Rocky Branch Creek, the autumn 2005 and autumn 2007 base flows were 28% and 35% less, respectively, than the autumn 2006 base flow. Like Rocky Branch Creek, the Kinnickinnic River at County Highway F had a higher autumn base flow in 2006.

Based upon several years of base flow survey data, it seems apparent that climatic variability can cause significant annual changes in base flows within the North Kinnickinnic River Monitoring Project Area. Below-normal rainfall during the summers of 2006 and 2007 resulted in markedly reduced base flows during the autumns of 2006 and 2007, compared to the autumn of 2005, which was preceded by a summer with above-normal rainfall.

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. Annual spring and autumn base flow surveys will provide a baseline 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 efforts.

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:

$$HBI = \sum T_1 \text{ x } TV_1 \ldots . \; T_n \text{ x } TV_n \; / \; N$$

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

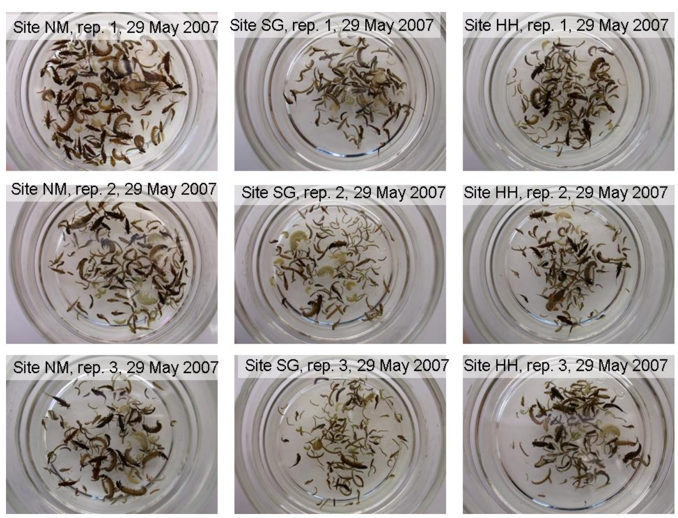
The more intolerant taxa that are present in a macroinvertebrate sample, the lower the biotic index, indicating better water quality, as shown in the table below.

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 and 2005 macroinvertebrate HBI values for triplicate samples collected at Sites 1-3 in the North Kinnickinnic River Monitoring Project Area are presented in Table 1. The mean 2004-2005 macroinvertebrate HBI values at Sites 1-3 are also presented in Figure 41. These 2004 and 2005 data were generated to establish a macroinvertebrate-based water quality baseline at the start of this monitoring project. In 2004 and 2005, mean HBI values at Site 1 were indicative of 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. Macroinvertebrate monitoring was again conducted in May 2006 and May 2007, 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.



Site 1 Site 2 Site 3

Triplicate macroinvertebrate samples collected at Sites 1-3 in 2007

Table 1. Macroinvertebrate HBI Values in the Kinnickinnic River: 2004-2005

Sampling Site	Sampling Location	2004 HBI Values	2005 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
	Mean of 3 reps:	2.87	3.00
Site 2: Swinging Gate (STH 65)	Approx. 1.1 mile 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
	Mean of 3 reps:	4.01	4.48
Site 3: Hebert (Hebert-Hagen)	Approx. 0.4 mile downstream from Quarry Rd. Lat. 44°53'22.2", Long. 92°36'19.5"	3.37 4.04 3.60	3.65 3.55 3.13
	Mean of 3 reps:	3.67	3.44

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 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
- 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 2004-2007 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

Reasons why small rainfall events (less than one inch) caused no storm water impacts at Sterling Ponds in 2007

Smaller rainfall and runoff events can cause 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 2007. 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 2007, due to several factors:

1. Building progress remained somewhat limited in the Sterling Ponds subdivision in 2007, 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, 37 single-family housing units were built by year-end 2006 and 53 single-family housing units were built by year-end 2007.

   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, 6 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 80 units.

   Maps of Sterling Ponds build-out progress in 2003, 2004, 2005, 2006, and 2007 are available on the project website ("What We Monitored"). With 53 of approximately 150 single family units (35%) complete in the southeast quadrant, 80 of approximately 150 family units (53%) complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2007, 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, with some capacity for storing storm water runoff from the existing impervious areas, especially during smaller rain events. Three of the four infiltration basins paired with the wet storm water detention ponds were not yet functional in 2007. However, the fourth infiltration basin serving the southeast quadrant of Sterling Ponds was functional throughout the April-September 2007 period (see 2007 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 southeast wet detention pond and infiltration basin should have provided effective storm water treatment for the southeast quadrant of Sterling Ponds in 2007, as required by the ordinance. Indeed, monitoring of these southeast storm water management practices in 2007 demonstrated excellent infiltration for 56 summer rain events, ranging in magnitude from 0.01-1.64 inches and totaling 13.68 inches (78% 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 basin.

Monitoring at Sterling Ponds in 2007 capably evaluated ordinance effectiveness and identified the storm water impacts related to several rainfall events 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.