City of River Falls
North Kinnickinnic River Monitoring Project

2012 Technical Review

SEH

Report prepared by SEH Inc., for the

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North Kinnickinnic River Monitoring Project

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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 is examining 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 uses an "upstream/downstream" approach to determine if storm water management practices in the Sterling Ponds subdivision protect downstream river conditions. We are also taking 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, water quantity, 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 City of River Falls, is an electronic tipping-bucket rain gauge that measures 15-minute precipitation amounts in 0.01-inch increments. This rain gauge is part of an Onset HOBO U30 Weather Station that began operating in December 2010. The weather station is located at the River Falls City Hall (222 Lewis Street), in relatively close proximity to all six North Kinnickinnic River monitoring stations. The City of River Falls weather station also serves as a source of 15-minute air temperature and relative humidity data, thereby allowing determination of daily mean, minimum, and maximum air temperatures in River Falls. A weather station at Rocky Branch Elementary School, on the south side of River Falls, serves as an alternate source of daily rainfall and air temperature 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. In addition, daily precipitation data are available from the United States Geological Survey (USGS) Kinnickinnic River monitoring station (number 05342000) 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. In addition to measuring daily rainfall amounts, the City of River Falls and USGS rain gauges provide very helpful information on the timing and intensity of rain events.

During the 2012 monitoring season, the City of River Falls rain gauge operated quite reliably. The gauge briefly malfunctioned on May 6-7, and was out of service during the May 11-25 period, when it was returned to the manufacturer for repairs. Daily USGS rainfall data were used on these dates. Since the USGS rain gauge is five miles away from River Falls, it does not always accurately reflect rainfall in the North Kinnickinnic River Monitoring Project Area. This tends to be particularly true during larger, convective summer rain events, which can generate very localized and quite variable rainfall patterns. Nonetheless, the USGS rain gauge generally provides a good estimate of rainfall in the project area.

A total of 20.46 inches of precipitation was recorded in River Falls (by the City of River Falls weather station) during the April-September 2012 period, 1.23 inches less than the normal total of 21.69 inches for the April-September time period (Figure 1). Rain fell on 59 days, or 32% of the April-September 2012 period. In comparison, a below-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, a below-normal total of 20.01

inches was measured during the April-September 2008 period, an above-normal total of 24.44 inches was measured during the April-September 2009 period, an above-normal total of 33.27 inches was measured during the April-September 2010 period, and a below-normal total of 20.56 inches was measured during the April-September 2011 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 1981-2010. Although slightly drier than normal, the April-September 2012 period (20.46 inches of rain) was the fifth-wettest April-September period since the start of the North Kinnickinnic River Monitoring Project in 2004. Since project monitoring began, six monitoring years (2004, 2006, 2007, 2008, 2011, and 2012) have been drier than normal, while three monitoring years (2005, 2009, and 2010) have been wetter than normal.

Daily rainfall amounts during the April-September 2012 period are presented in Figure 2. Monthly rainfall amounts during the April-September 2012 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. April, May, and June were all wetter than normal, with a slight rainfall excess of 0.21 inch evident in April, a significant excess of 2.85 inches evident in May, and a moderate excess of 1.24 inches evident in June. The combined rainfall of 14.57 inches in April, May, and June was 4.30 inches above normal, and accounted for 71% of the total April-September 2012 precipitation. In contrast, July, August, and September were all drier than normal. A slight rainfall deficit of 0.30 inch was evident in July, but significant deficits of 2.78 inches and 2.45 inches were evident in August and September, respectively. The combined rainfall of 5.89 inches in July, August, and September was 5.53 inches below normal, and accounted for only 29% of the total April-September 2012 precipitation. The largest rain events of the monitoring year occurred on May 6 (1.40 inches), May 24 (1.61 inches), June 14 (1.79 inches), and June 20 (2.05 inches) (Figure 2).

Through June 2010, the North Kinnickinnic River Monitoring Project Area was affected by a region-wide drought that began in early 2006. With below-normal precipitation during the summers of 2006, 2007, and 2008 (Figure 1), abnormally dry conditions developed in 2006 (Drought Severity Index = D0), and abnormally dry (DSI = D0) to moderate drought conditions (DSI = D1) were apparent in 2007 and 2008. Abnormally dry (DSI = D0) to severe drought conditions (DSI = D2) persisted during the summer of 2009, in spite of above-normal precipitation. Although abnormally dry conditions (DSI = D0) were apparent in May and June 2010, above-normal precipitation during the April-June 2010 period brought drought conditions to an end by late July 2010. Well-above-normal precipitation during the July-September 2010 period and slightly-below-normal precipitation during the summer of 2011 (Figure 1) kept drought conditions at bay through September 2011. However, with an extremely dry September 2011, abnormally dry conditions (DSI = D0) were again apparent in the North Kinnickinnic River Monitoring Project Area by mid-October 2011. These abnormally dry conditions persisted until early May 2012, when above-normal precipitation in May and June (Figure 3) brought drought conditions to an end. However, with a much drier-than normal August 2012 (Figure 3), abnormally dry conditions (DSI = D0) were again apparent in the North Kinnickinnic River Monitoring Project Area by early September

2012. By mid-September, moderate drought conditions (DSI = D1) were evident. With a much drier-than normal September 2012 (Figure 3), severe drought conditions (DSI = D2) developed in the North Kinnickinnic River Monitoring Project Area by early October 2012 (U.S. Drought Monitor, at http://droughtmonitor.unl.edu/).

Besides being slightly drier than normal, the April-September 2012 monitoring period was slightly warmer than normal. The mean air temperature in River Falls during the April-September 2012 period was 65.3º Fahrenheit (F), 1.6º F higher than the normal mean of 63.7º F for the April-September period, as measured at the Twin Cities International Airport. Monthly mean air temperatures during the April-September 2012 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1981-2010, are presented in Figure 4. The months of April, May, June, and July were all warmer than normal, with May (+3.9º F) and July (+3.9º F) experiencing the greatest departures. The months of August and September were both cooler than normal, with temperature departures of -1.1º F and -1.3º F, respectively.

The distribution of River Falls daily rainfall amounts during the April-September 2012 period is presented in Figure 5. On 40 (68%) of the 59 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 40 days contributed only 18% of the total April-September 2012 precipitation. Twenty-one of these 40 days occurred in the cooler months of April, May, and September (Figure 6). On 5 (8%) of the 59 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 5 days contributed an additional 9% of the total April-September 2012 precipitation. Three of these 5 days occurred in April, May, and September (Figure 6), when air temperatures were cooler. On 4 (7%) of the 59 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 4 days contributed 12% of the total April-September 2012 precipitation, in May, June, and July (Figure 6). On 4 (7%) of the 59 days with measurable precipitation, rainfall amounts ranged from 0.76-1.00 inch. These 4 days contributed 17% of the total April-September 2012 precipitation, in May, July, and August (Figure 6). On 6 (10%) of the 59 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. These 6 days with the largest rainfall events contributed 44% of the total April-September 2012 precipitation. Rainfall amounts in excess of 1 inch occurred on April 15 (1.05 inches), May 6 (1.40 inches), May 24 (1.61 inches), June 14 (1.79 inches), June 20 (2.05 inches), and July 21 (1.19 inches) (Figures 2 and 6).

The 3 largest summer precipitation events, with rainfall amounts in excess of 1.50 inches, occurred on May 24 (1.61 inches), June 14 (1.79 inches), and June 20 (2.05 inches). All three rain events were characterized by showers mixed with convective thunderstorm activity, on days with mild to warm air temperatures (high temperatures of 67° F, 68° F and 84° F, respectively). Rainfall on May 24 (1.61 inches) occurred over an extended duration (9 hours), with a low intensity rate that never exceeded 0.50 inch per hour, and was typically much less. According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), a 9-hour rain event of 1.61 inches in West Central Wisconsin has a 9-month recurrence interval. Rainfall on June 14 (1.79 inches) occurred primarily during two waves within a 9-hour period, with peak rainfall rates of 0.25 inch per hour during the first wave (10:30-12:15 CDT) and 0.70 inch per hour during the second wave (16:30-19:30 CDT). According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), a 9-hour rain event of 1.79 inches in West Central Wisconsin has a 1-year recurrence interval. Rainfall on June 20 (2.05 inches) occurred during a 7-hour period (15:00-21:45 CDT); however, the majority of rain (1.78 inches) fell at a very intense rate during a 1-hour period with thunderstorm activity. According to the Rainfall Frequency Atlas of the Midwest, a 7-hour rain event of 2.05 inches in West Central Wisconsin has a 1.6-year recurrence interval; however a 1-hour rain event of 1.78 inches has a 5.5-year recurrence interval. These three largest rainfall events in May and June contributed substantially to the above-normal rainfall amounts for these two months. The May 24 rain event accounted for 26% of the total rainfall for May, and the June 14 and June 20 rain events accounted for 70% of the total rainfall for June.

Rainfall events in excess of 0.50 inch occurred on 14 days throughout the April-September 2012 period, with 1 event in April, 5 events in May, 4 events in June, 3 events in July, and 1 event in August (Figures 2 and 6). These 14 rainfall events in excess of 0.50 inch (24% of the April-September 2012 rain events) contributed 73% of the total April-September 2012 precipitation. Conversely, 45 rainfall events of 0.50 inch or less (76% of the April-September 2012 rain events) contributed only 27% of the total April-September 2012 precipitation.

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 59 days with measurable precipitation during the April-September 2012 period, 56 days (95%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Infiltration of these 56 rain events (15.01 inches) would account for 73% of the total April-September precipitation (20.46 inches). Only the rainfall amounts on May 24 (1.61 inches), June 14 (1.79 inches), and June 20 (2.05 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 95% (19.51 inches) of the total rainfall (20.46 inches) that occurred during the April-September 2012 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 2012 period is presented as a hydrograph in Figure 8. Daily rainfall, as measured at the USGS monitoring station, 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. Daily rainfall amounts in excess of 1 inch and combined rainfall amounts in excess of 1 inch on consecutive (back-to-back) days generally had the greatest influence on the April-September 2012 Kinnickinnic River hydrograph (Figure 8).

The month of April was slightly wetter than normal, with 2.87 inches of rain falling during 12 rain events. With one exception, all of these rain events were less than 0.40 inch in magnitude. A large rain event on April 15 (1.05 inches) produced the first significant (and fourth-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 136 cfs on April 15 (Figure 8).

The month of May was much wetter than normal, and the wettest month of the April-September 2012 monitoring period, with 6.21 inches of rain falling during 12 rain events. A combined 0.94 inch of rain during back-to-back rain events on May 1 (0.77 inch), and May 2 (0.17 inch) produced the second significant (and third-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 155 cfs on May 2 (Figure 8). Shortly thereafter, a combined 2.27 inches of rain during back-to-back rain events on May 5 (0.87 inch), and May 6 (1.40 inch) produced the third significant (and largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 373 cfs on May 6 (Figure 8). The large magnitude of this runoff event was certainly influenced by the antecedent rainfall (1.46 inches) during the May 1-4 period, as well as the lack of canopy closure in the agricultural and forested areas of the watershed. The third-largest rain event of the April-September 2012 monitoring period on May 24 (1.61 inches) produced the fourth significant (and fifth-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 125 cfs on May 24 (Figure 8). The very moderate magnitude of this runoff event was influenced by the extended duration (14.5 hours) and low intensity (0.01- 0.42 inch per hour) of the rain event.

The month of June was also much wetter than normal, with 5.49 inches of rain falling during 9 rain events. A Kinnickinnic River peak daily mean flow of 138 cfs on June 4 (Figure 8) was not related to rainfall and runoff, as it occurred in the middle of a 12-day dry period. This flow aberration may have been related to an abnormal (non-run-of-river) operating condition at the River Falls hydropower facility. The second-largest rain event of the April-September 2012 monitoring period on June 14 (1.79 inches) produced the fifth significant (and seventh-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 121 cfs on June 14 (Figure 8). The very moderate magnitude of this runoff event was influenced by the extended duration (13.0 hours) and low intensity (0.01- 0.69 inch per hour) of the rain event, as well as by partial canopy closure in the agricultural and forested areas of the watershed. Moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch), followed by the largest rain event of the April-September 2012 monitoring period on June 20 (2.05 inches), produced the sixth significant (and second-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 310 cfs on June 21 (Figure 8). In spite of a combined 3.39 inches of rain on June 18-20, the magnitude of this runoff event was tempered by the extended time periods between rain events (27 hours and 33 hours), as well as by partial canopy closure in the agricultural and forested areas of the watershed.

The month of July was slightly drier than normal, with 3.74 inches of rain falling during 11 rain events. All but one of these rain events were less than 1.00 inch in magnitude, with very minimal impacts on the Kinnickinnic River hydrograph. A large rain event on July 21 (1.19 inches) produced the seventh significant (and sixth-largest) runoff event of the 2012 monitoring season, with a peak daily mean flow of 123 cfs on July 21 (Figure 8). The very moderate magnitude of this runoff event was influenced by little antecedent precipitation during the preceding week, a low rainfall intensity rate, and full canopy closure in the agricultural and forested areas of the watershed.

The months of August and September were much drier than normal, with 1.52 inches of rain falling during 9 rain events in August, and only 0.63 inch of rain falling during 6 rain events in September. With very little rainfall, no significant runoff events occurred in August and September. With the exception of a minor runoff event (113 cfs) following a moderate rain event on August 4 (0.80 inch), the Kinnickinnic River hydrograph maintained a steady baseflow condition of 83-98 cfs throughout August and September (Figure 8).

The Kinnickinnic River hydrograph suggests that seven significant runoff events occurred during the April-September 2012 period (Figure 8). Peak daily mean flows for all of these runoff events exceeded 120 cfs.

One of these seven significant runoff events occurred in April. A large rain event on April 15 (1.05 inches), followed by a combined 0.69 inch of rain during the April 16-19 period, produced a 7-day runoff event (April 15-21), with a peak daily mean flow of 136 cfs. With cool air and water temperatures in 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.

Five of the seven significant runoff events occurred in May and June, when thermal impacts of storm water runoff become a concern due to warmer air and water temperatures. Back-to-back rain events on May 1 (0.77 inch) and May 2 (0.17 inch), with a combined 0.94 inch of rain, produced a 3-day runoff event (May 2-4), with a peak daily mean flow of 155 cfs. Shortly thereafter, a combined 2.27 inches of rain during back-to-back rain events on May 5 (0.87 inch) and May 6 (1.40 inch) produced a 5-day runoff event (May 5-9), with a peak daily mean flow of 373 cfs. A very large rain event on May 24 (1.61 inches), followed by a combined 0.81 inch of rain during the May 26-28 period, produced a 5-day runoff event (May 24-28), with a peak daily mean flow of 125 cfs. A very large rain event on June 14 (1.79 inches) produced a 2-day runoff event (June 14-15), with a peak daily mean flow of 121 cfs. A combined 3.39 inches of rain during moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch) and a very large rain event on June 20 (2.05 inches) produced a 7-day runoff event (June 18-24), with a peak daily mean flow of 310 cfs.

One of the seven significant runoff events occurred in July, during the warmest month of the year (Figure 4), when thermal impacts of storm water runoff can be a considerable concern. A large rain event on July 21 (1.19 inches) produced a 2-day runoff event (July 21-22), with a peak daily mean flow of 123 cfs.

With well-below-normal rainfall, no significant runoff events occurred in August and September, when thermal impacts of storm water runoff remain a concern due to warmer air and water temperatures.

The six runoff events in May, June, and July should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2012, and are further analyzed in this report.

As the April-September 2012 period became increasingly drier (Figure 3), Kinnickinnic River base flows, as measured at County Highway F (Figure 8), gradually decreased. Base flows tended to be a bit higher (90-110 cfs) during the wetter-than-normal months of April, May, and June, and a bit lower (83-98 cfs) during the drier-than-normal months of July, August, and September.

Temperature Monitoring:

In 2012, temperature monitoring was conducted at four of the six City of River Falls monitoring stations (Sites 1, 2, 4, and 5) 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 four locations: the wet detention pond inlet (Site 5IN), 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 2005-2012. 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. During the 2008-2011 period, an Onset® StowAway TidbiT Logger was used to measure water temperature at Site 1A, while an Onset® TidbiTv2 Logger was used to measure water temperature at this location in 2012. Onset Computer Corporation's® Optic StowAway Templogger was used at the TU monitoring station in Sumner Creek (Site 4A) during the 2005-2010 period. In 2011, an Onset® StowAway TidbiT Logger was used to measure water temperature at Site 4A, while an Onset® TidbiTv2 Logger was used to measure water temperature at this location in 2012. 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 can 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 2012 deployment periods (and locations) for the temperature loggers at the eleven monitoring stations were as follows:

Site:	Deployment Period:	Location:
Site 1:	May 1-September 30, 2012	Kinnickinnic River
Site 1A:	May 1-September 30, 2012	Kinnickinnic River
Site 2:	May 1-September 30, 2012	Kinnickinnic River
Site 3:	No Deployment	Kinnickinnic River
Site 4:	May 1-September 30, 2012	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2012	Sumner Creek: Mouth
Site 5IN:	May 1-September 30, 2012	Sterling Ponds: Wet Pond Inlet
Site 5P:	May 1-September 30, 2012	Sterling Ponds: Wet Pond
Site 5IB:	May 1-September 30, 2012	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 1-September 30, 2012	Sterling Ponds: Wet Pond Outlet
Site 6:	No Deployment	Sumner Creek: Dry Box Culvert

The Site 3 temperature logger was not deployed in 2012. When established at the start of North Kinnickinnic River Monitoring Project in 2004, Site 3 was intended to be an upstream reference location for determining if River Falls storm water management practices were protecting downstream river conditions as development occurred in the North Kinnickinnic River Monitoring Project area. In 2004, a sizable residential development was envisioned on a 113-acre parcel of land along the Kinnickinnic River corridor, between Site 3 (upstream) and Site 2 (downstream). In July 2010, the Kinnickinnic River Land Trust purchased this parcel, and then donated the property to the Wisconsin Department of Natural Resources, for public ownership and use as a State Wildlife and Fishery Area. Given that future development is no longer possible between Sites 2 and 3, Site 3 is no longer needed as an upstream reference location; and Site 2 now serves this purpose for the monitoring project.

For the third consecutive year, the Site 6 temperature logger was not deployed in 2012. Water rarely flows through the Sumner Creek channel at this location, and several years of monitoring (2004-2009) indicate that intermittent flows during large rain events are very difficult to detect using temperature data alone.

To evaluate the temperature of storm water conveyed from the Sterling Ponds subdivision, a new monitoring location (Site 5IN) was established at the wet detention pond inlet in 2010, and monitoring continued at this location in 2011 and 2012. The monitoring data obtained at this location will provide some insight on storm water temperature variation, as affected by air temperature and rainfall amount, intensity, duration, and timing. The data will also be useful for determining the extent to which the temperature of incoming storm water influences wet pond temperature, as measured at Site 5P.

Kinnickinnic River Temperature Monitoring Results:

The May-September (summer) 2012 temperature monitoring data obtained for the Kinnickinnic River at Sites 1, 1A, and 2 are presented as thermographs in Figures 9-11, 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 fluctuations 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 2012 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 2012 period, for example, the monthly mean river temperature in the North Kinnickinnic River Project Area (Sites 1, 1A, and 2) was warmest in July (17.2 degrees Celsius (°C)) and coolest in September (12.6° C).

At Sites 1, 1A, and 2, river temperatures averaged 14.8° C and ranged from 7.4-21.1° C over the course of the summer. Monthly and summer mean temperatures at each of these three monitoring sites are presented in Figure 12. All monthly mean temperatures and the summer mean temperature were identical at Sites 1A and 2. The monthly and summer mean temperatures were slightly (0.1° C) cooler at Site 1, perhaps due to the cooler water contributed by Sumner Creek, just upstream from Site 1 (see *Sumner Creek*, below).

Higher-than-normal river temperatures probably prevailed in the North Kinnickinnic River Project Area during the summer of 2012, since the 2012 summer average air temperature of 20.3º C (68.6º F) was notably higher than the normal summer average air temperature of 19.4° C (67.0° F). A comparison of 2004-2012 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 2012 summer average air temperature of 20.3º C was the second-highest summer average air temperature recorded in the North Kinnickinnic River Monitoring Project Area during the 2004-2012 period. The 2012 summer average river temperature of 14.8º C was the third-highest summer average river temperature recorded during the 2004-2012 period. The warmest summer average river temperature was recorded in 2007 (15.2º C), while summer average river temperatures in 2004-2006 and 2008-2011 ranged from 13.7º-14.9º 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 downstream summer temperature data at Site 1 to all upstream summer temperature data at Sites 1A and 2 is presented in Figure 13. 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 2012 (Figures 14-18, respectively). Figures 13-18 indicate that daily maximum temperatures tended to be slightly warmer at Site 1A, while the daily minimum temperatures tended to be slightly cooler at Site 1. Figure 12 shows that the monthly mean temperatures in May, June, July, August, and September and the summer mean temperatures were also nearly identical at Sites 1, 1A, and 2. The following should be noted concerning aquatic life in the Kinnickinnic River:

1. Approximately 81% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2012 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 97% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2012 period were ≤ 19° C, which is considered to be the top of the optimum temperature range for brown trout growth (Armour, 1994).

3. Approximately 99% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2012 period were ≤ 20° C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994).

4. With a warmer-than-normal summer (average air temperature of 20.3º C), river temperatures exceeded 20º C on 1 date in June (June 10) and 7 dates in July (July 2-7 and July 16). Maximum air temperatures on these 8 dates were generally very warm-hot, ranging from 31-38º C (87-100° F) and averaging 36º C (96° F). River temperatures at Sites 1 and 1A exceeded 21º C on 2 dates in July (July 4-5). The temperature excursions beyond 21º C in July were short-lived (0.8-1.3 hours), and were caused by hot air temperatures (37º C /99° F on July 4 and 37º C /98° F on July 5).

During six significant rainfall and runoff events in May, June, and July 2012, thermographs at Sites 1, 1A, 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, downstream from Sumner Creek and the Sterling Ponds subdivision.

No thermal spikes were evident at Site 1 in May (Figure 14). Back-to-back rain events on May 1 (0.77 inch) and May 2 (0.17 inch), with a combined 0.94 inch of rain, produced a significant runoff event during the May 2-4 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the May 2-4 runoff event (Figure 19), no thermal spikes were evident at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. The low potential for thermal impacts during the May 1 and May 2 rain events is corroborated by the thermograph at Division Street, where thermal impacts are common due to direct storm water discharges from the downtown area of River Falls. Although thermal spikes were evident at Division Street during the May 1 and May 2 rain events, the magnitudes of these spikes were very small (0.3º C on May 1 and 0.6º C on May 2), due to the mild air temperatures, low rainfall intensities, and extended rain durations.

A combined 2.27 inches of rain during back-to-back rain events on May 5 (0.87 inch) and May 6 (1.40 inch) produced a significant runoff event during the May 5-9 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the May 5-9 runoff event (Figure 20), no thermal spikes were evident at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. As indicated by the Division Street thermograph, the May 5 and May 6 rain events had a low potential for thermal impacts. Although thermal spikes were evident at Division Street during the May 5 and May 6 rain events, the magnitudes of these spikes were very small (0.4º C on May 5 and 0.5º C on May 6), primarily due to the very cool air temperatures.

A very large rain event on May 24 (1.61 inches), followed by a moderate rain event on May 26 (0.52 inch), produced a significant runoff event during the May 24-28 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the May 24-28 runoff event (Figure 21), no thermal spikes were evident at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. As indicated by the Division Street thermograph, the May 24 and May 26 rain events had a low potential for thermal impacts. Although thermal spikes were evident at Division Street during the May 24 and May 26 rain events, the magnitudes of these spikes were very small (0.5º C and 0.6º C on May 24 and 0.6º C on May 26), due to the mild air temperatures, low rainfall intensities, and extended rain durations.

In June, no thermal spikes were evident at Site 1 during a very large rain event on June 14 (1.79 inch) and moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch) (Figure 15). However, the largest rain event of the year on June 20 (2.05 inches) produced a small thermal spike at Site 1 (Figure 15).

The very large rain event on June 14 (1.79 inches) produced a significant runoff event during the June 14-15 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the June 14-15 runoff event (Figure 22), no thermal spikes were evident at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while thermal spikes of 0.4º C and 2.0º C were evident at Division Street during both waves of rainfall in the late morning and late afternoon. The greater magnitude of the second thermal spike on June 14 (2.0º C) can be attributed to higher afternoon air and pavement temperatures, as well as a greater rainfall amount and intensity during the second wave of rain.

A combined 3.39 inches of rain during moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch) and a very large rain event on June 20 (2.05 inches) produced a significant runoff event during the June 18-24 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the June 18-24 runoff event (Figure 23), no thermal spikes were evident at Site 1 (downstream from Sumner Creek and the Sterling Ponds subdivision) during the moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch). Although thermal spikes were evident at Division Street during both rain events, the magnitudes of these spikes were relatively small (1.2º C on June 18 and 0.8º C on June 19), primarily due to the cool air temperatures when rainfall occurred in the overnight and early morning time periods.

Strong, convective thunderstorm activity during the afternoon of June 20 produced the largest rain event (2.05 inches) of the 2012 monitoring season. When the thermographs for Site 1, Site 1A, and Division Street are compared during the June 18-24 runoff event (Figure 23), a small thermal spike (0.4º C) was evident at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. Shortly after a very intense, 1-hour period of rainfall (1.78 inches) ended at 16:15 CDT, the river temperature at Site 1 began increasing at 16:30 CDT on June 20 and peaked at 16:40-17:00 CDT. No such increase in river temperature was apparent at Site 1A upstream. For a 1.2-hour period, the downstream river temperature at Site 1 was notably higher than the upstream river temperature at Site 1A, perhaps indicating that a warm discharge from Sumner Creek created a downstream thermal impact at Site 1. Indeed, a very prominent thermal spike (6.3º C) was evident at Site 4A (mouth of Sumner Creek) during the June 20 rain event (see *Sumner Creek*, below). When the river temperature at Site 1 peaked (18.5º C) at 16:40-17:00 CDT, Sumner Creek was contributing markedly warmer water (21.0º C) to the Kinnickinnic River, likely accounting for the small temperature spike (0.4º C) evident at Site 1. A very prominent thermal spike (3.5º C) was also apparent at Division Street during the June 20 rain event (Figure 23). The thermal impacts of this rain event can be attributed to the high rainfall intensity, a very warm antecedent air temperature (29º C / 84º F), and the timing of the rain event in mid-afternoon, when pavement temperatures were also very warm.

No thermal spikes were evident at Site 1 in July (Figure 16). A large rain event on July 21 (1.19 inches) produced a significant runoff event during the July 21-22 period. A closer examination of the thermographs for Site 1, Site 1A, and Division Street during this runoff event (Figure 24) indicates that no thermal spikes occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while thermal spikes of 1.4º C and 2.2º C were evident at Division Street during two intense periods of rainfall in the early morning.

With well-below-normal rainfall in August and September, no significant runoff events occurred, and no thermal spikes were evident at Site 1 (Figures 17 and 18).

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 but one runoff event (June 20) in 2012 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. The effectiveness of Sterling Ponds storm water management practices during the summer of 2012 (including the June 20 rain event), and possible downstream impacts on Sumner Creek and the Kinnickinnic River, are discussed below (see *Assessment of Sterling Ponds Storm Water Infiltration and Discharge to Sumner Creek*).

Sumner Creek and Sterling Ponds Temperature Monitoring Results:

Sumner Creek

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 occurs in the upper portion of Sumner Creek during the spring snowmelt period, and past temperature monitoring data at Sites 4 and 6 indicate that flow sometimes occurs 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) 2012 temperature monitoring data obtained for Sumner Creek at Site 4A are presented as a thermograph in Figure 25. 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 12.9° C and ranged from 8.7-21.1° C during the May-September 2012 period. The summer mean temperature of Sumner Creek (12.9º C) was notably colder than the summer mean temperature of the Kinnickinnic River (14.8º C) at Sites 1, 1A, and 2, reflecting strong spring activity. Approximately 99% of all temperatures recorded at Site 4A during the May-September 2012 period were ≤ 17° C. A temperature of 17° C is considered to be the top of the optimum temperature range for a healthy coldwater macroinvertebrate community (Galli, 1990).

Rainfall-related Sumner Creek temperatures excursions beyond 17° C were only recorded during and after the largest rain event of the summer on June 20. During and after this rain event (2.05 inches), the Sumner Creek temperature at Site 4A exceeded 17º C for a 14.7-hour period. The June 20 rain event also produced temperature excursions beyond 20º C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). During and after the June 20 rain event, the Sumner Creek temperature at Site 4A exceeded 20º C for a 5.0-hour period and reached a maximum of 21.1º C.

In spite of the warmer-than-normal summer, heat-related Sumner Creek temperature excursions beyond 17º C were only recorded on June 19, when the maximum air temperature reached 34º C / 93º F in the late afternoon. However, this heat-related excursion was relatively short (1.7 hours), with a very slight magnitude (maximum temperature of 17.2º C). Although heat-related, this June 19 temperature excursion was likely influenced by an early morning (05:00 CDT) rain event (0.60 inch), which increased the early morning Sumner Creek temperature by 1.0º C. With a higher morning baseline temperature, the afternoon heat created a higher-than-normal daily maximum temperature (17.2º C). During a hot and largely rain-free period from June 27-July 6, when daily maximum air temperatures ranged from 91-100º F (33-38º C), daily maximum Sumner Creek temperatures ranged from 14.9-16.7º C. In contrast, daily maximum Kinnickinnic River temperatures at Site 1 ranged from 18.0-21.1º C during the same time period. This marked stream temperature contrast demonstrates the ability of

Sumner Creek to provide a thermal buffer against high summer air temperatures under baseflow conditions, due to strong groundwater contributions.

Based upon the summer 2012 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 the thermal spikes that occurred at Site 4A during 11 rain events throughout the May-August period (Figure 25). These thermal spikes ranged from 0.5-6.3° C in magnitude and were caused by rain events ranging from 0.60-2.05 inches. The Sumner Creek thermal spikes were of even greater magnitude than those observed at the Division Street monitoring site on the same dates (Figures 19-24). The most prominent Sumner Creek thermal spike (6.3º C) occurred on June 20, after the largest summer rain event (2.05 inches) on a warm day (84º F) (Figure 25). As noted above, the June 20 thermal spike peaked at 21.1º C and exceeded optimum temperature thresholds for macroinvertebrates (17º C) and brown trout (20º C). As such, a thermal spike of this magnitude and duration could have a detrimental impact on aquatic life (especially macroinvertebrates) in lower Sumner Creek. The June 20 thermal spike also caused a small temperature spike (0.4º C) in the Kinnickinnic River at Site 1 (Figure 26). The ten additional Sumner Creek thermal spikes were characterized by small to moderate magnitudes (0.5-3.1° C). In spite of their relative frequency during the May-August period, none of these ten thermal spikes exceeded the optimum temperature thresholds for macroinvertebrates and brown trout, and none of these thermal spikes had a discernible impact on Kinnickinnic River temperatures at Site 1, downstream from Sumner Creek (Figures 14-17 and 19-24). This was particularly true during the three very large rainfall events on May 6 (Figure 27), May 24 (Figure 28), and June 14 (Figure 29).

Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2011. 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. On August 12, 2010, the lower Sumner Creek monitoring site (Site 4A) was checked after a very large rain event (2.19" +) and subsequent flood on August 10-11, 2010 (for details, see the "City of River Falls North Kinnickinnic River Monitoring Project 2010 Technical Review"). Field evidence showed that the storm water pond near WI Highway 35 discharged at the southeast corner and flowed directly into Sumner Creek, at a location immediately upstream from Site 4A. This pond likely served as the initial source of warm water causing a very large thermal spike (8.8º C) at Site 4A within three hours after the onset of heavy rainfall on August 10. Similarly, discharges from this storm water pond during other large rain events may have caused some of the thermal spikes apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2012.

Sterling Ponds

The May-September (summer) 2012 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 30.

At Site 5P, Sterling Ponds wet detention pond temperatures averaged 22.4° C and ranged from 11.5-36.3° C during the summer period. Approximately 70% of all summer temperatures exceeded 20° C, and wet pond temperatures consistently remained above 20° C from June 3 until September 8. 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 (22.4° C) was substantially higher than the summer mean temperatures of Sumner Creek at Site 4 (16.0º C) and Site 4A (12.9º 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 30) 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 2012, 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 storm water management practices during the six significant rainfall and runoff events in May, June, and July is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). Two of these six significant events (May 1-2 and July 21) 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 May 5-6, May 24-26, June 14, and June 18-20 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 2012 are presented in Figure 31. The month of May was much warmer (+3.9° F) and wetter (+2.85 inch) than normal. Rainfall events ranging from 0.01-1.61 inches were recorded on twelve dates (Figure 2), with three of the six significant summer rainfall events occurring on May 1-2, May 5-6, and May 24-26.

Due to small rain events on April 28 (0.16 inch) and April 29 (0.22 inch), the Sterling Ponds wet detention pond was already discharging to the Sterling Ponds infiltration basin when the first of six significant summer rainfall and runoff events occurred on May 1-2. The comparative Sterling Ponds and Sumner Creek thermographs for the May 1 (0.77 inch) and May 2 (0.17 inch) rain events, with a combined 0.94 inches of rain, are presented in Figure 32. The May 1-2 rainfall resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin, as indicated by the nearly identical temperatures at Sites 5P and 5IB at 00:10 CDT (12:10 AM) on May 2, shortly after the onset of heavier rainfall at 22:00 CDT (10:00 PM) on May 1. Wet pond discharge to the infiltration basin, due to the May 1-2 rain events and small rain events on May 3 (0.39 inch) and May 4 (0.13 inch), continued for 3.6 days, until the second of six significant summer rainfall and runoff events occurred on May 5-6. No wet pond discharge to Sumner Creek was evident during the May 1-2 event, as documented by the temperature data at Site 5MHW (Figure 32). Small thermal spikes were apparent in Sumner Creek at Site 4 (1.4º C) and Site 4A (1.0º C) after the May 1-2 event; however, these thermal spikes cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have more local causes. The magnitude of the May 1-2 event (a combined 0.94 inch of rain) was less than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; and the entire event was captured in the wet pond and infiltrated, as expected.

The comparative Sterling Ponds and Sumner Creek thermographs for the May 5 (0.87 inch) and May 6 (1.40 inches) rain events, with a combined 2.27 inches of rain, are also presented in Figure 32. The May 5 rainfall resulted in a continuing but reinforced discharge from the Sterling Ponds wet pond to the infiltration basin, as indicated by the identical temperatures at Sites 5P and 5IB at 15:10 CDT (3:10 PM) on May 5, shortly after the onset of heavier rainfall at 14:00 CDT (2:00 PM). Due to the May 5 rain event, wet pond discharge to the infiltration basin was still in progress when the May 6 rain event began at 02:30 CDT (2:30 AM). With very intense rainfall starting at 02:45 CDT (2:45 AM) and 1.07 inches of rain falling in a 30-minute period from 02:45-03:15 CDT, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 03:20 CDT (3:20 AM), as indicated by the rapidly-increasing temperature at Site 5MHW (Figure 32). Wet pond discharge to the Sumner Creek drainage way continued for 14.8 hours, until 18:10 CDT (6:10 PM) on May 6. During this 14.8-hour period, the wet pond discharge temperature averaged 15.0º C and ranged from 14.4-15.7º C. The extended wet pond discharge to the Sumner Creek drainage way was likely influenced by the great magnitude of the May 6 rain event (1.40 inches) and the antecedent rainfall (0.87 inch) on May 5. With the majority of the May 5-6 rainfall (2.27 inches) occurring in a 17-hour period, and with the wet detention pond still discharging to the infiltration basin after the May 1-4 rain events (a combined 1.46 inches), 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. The Sterling Ponds wet pond discharge to the Sumner Creek drainage way may have contributed to a small thermal spike (0.9º C) downstream at Site 4 (Figure 32). This spike occurred at 08:00 CDT (8:00 AM), 4.7 hours after the wet detention pond began discharging to the drainage way. The small thermal spikes evident near the mouth of Sumner Creek (Site 4A) on May 5 (0.7º C) and May 6 (1.4º C) (Figure 32) cannot be attributed to the Sterling Ponds storm water discharge. The May 5 thermal spike occurred at 18:10 CDT (6:10 PM), well before the Sterling Ponds wet pond began discharging to the Sumner Creek drainage way on May 6. The May 6 thermal spike at Site 4A, located 1.5 miles downstream, occurred at 04:10 CDT (4:10 AM), shortly after the Sterling Ponds storm water discharge began, and 3.8 hours before the small thermal spike occurred at Site 4 upstream. It seems apparent that the May 5 and 6 thermal spikes at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35. Given the magnitude of the May 6 rain event, it is likely that warmer water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way also contributed to the May 6 thermal spike at Site 4A. As noted above (*Sumner Creek*), the thermal spike at Site 4A had no downstream thermal impact on the Kinnickinnic River (Figure 27). Sterling Ponds wet pond discharge to the infiltration basin, due to the May 5-6 rain events and a very small rain event on May 11 (0.05 inch), continued for 6.9 days, until 13:10 CDT (1:10 PM) on May 12 (Figure 31). A very small rain event on May 20 (0.01 inch) was captured in the Sterling Ponds wet pond.

The third of six significant summer rainfall and runoff events occurred on May 24-26. The comparative Sterling Ponds and Sumner Creek thermographs for the May 24 (1.61 inches) and May 26 (0.52 inch) rain events, with a combined 2.13 inches of rain, are presented in Figure 33. After the onset of heavier rainfall at 07:30 CDT (7:30 AM) on May 24, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 15:40 CDT (3:40 PM) (Figure 33). By this time, 1.51 inches of rainfall had occurred, indicating that the Sterling Ponds wet pond had sufficient capacity to capture the majority of the May 24 rain event before discharge to the infiltration basin began. This capacity was gained via wet pond drawdown (to the infiltration basin) after the May 5-6 rain events, which was complete on May 11 (above). A subsequent 12-day dry period (May 12-23) provided an additional opportunity for wet pond drawdown via water infiltration through the bottom of the pond and/or surface evaporation. Sterling Ponds wet pond discharge to the infiltration basin, due to the May 24-26 rain events, a very small rain event on May 27 (0.05 inch), and a small rain event on May 28 (0.24 inch), continued for 6.9 days, until 13:30 CDT (1:30 PM) on May 31 (Figure 31). No wet pond discharge to Sumner Creek was evident during the May 24 rain event, as documented by the temperature data at Site 5MHW (Figure 33). A very small thermal spike was apparent in Sumner Creek at Site 4A (0.5° C) after the May 24 rain event; however, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause. As noted above (*Sumner Creek*), the thermal spike at Site 4A had no downstream thermal impact on the Kinnickinnic River (Figure 28). Although the magnitude of the May 24 rain event (1.61 inches) was greater than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, the entire event was captured in the wet pond and infiltrated.

In summary for May, the Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the May 1-12 period. Rain events during the May 1-4 period (a combined 1.46 inches) were infiltrated. It seems likely that the majority of the May 5-6 rain events (a combined 2.27 inches) was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on May 6, the duration of the wet pond discharge to Sumner Creek (14.8 hours) was much shorter than the duration of the discharge to the infiltration basin (6.9 days). A very small rain event on May 11 (0.05 inch) was infiltrated, and a very small rain event on May 20 (0.01 inch) was captured in the Sterling Ponds wet pond. The Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the May 24-31 period. A very large rain event on May 24 (1.61 inches), a moderate rain event on May 26 (0.52 inch), a very small rain event on May 27 (0.05 inch), and a small rain event on May 28 (0.24 inch) were all infiltrated.

June

The comparative Sterling Ponds thermographs for June 2012 are presented in Figure 34. The month of June was warmer (+2.5° F) and wetter (+1.24 inches) than normal. Rainfall events (ranging from 0.01-2.05 inches) were recorded on nine dates (Figure 2), with two of the six significant summer rainfall events occurring on June 14 and June 18-20.

The June 1-13 period was dry, and two very small rain events on June 10 (0.02 inch) and June 11 (0.01 inch) were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond. The wet pond did not discharge to the infiltration basin during this time period (Figure 34).

The fourth of six significant summer rainfall and runoff events occurred on June 14. The comparative Sterling Ponds and Sumner Creek thermographs for the June 14 rain event (1.79 inches) are presented in Figure 35. Rainfall on June 14 occurred in two “waves”, from 10:30-12:15 CDT and 16:30-19:30 CDT. The second wave of rain (1.37 inches) accounted for the majority of this event and exhibited a peak intensity of 0.70 inch per hour. Near the end of the second wave of rainfall, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 19:20 CDT (7:20 PM) (Figure 35). By this time, 1.71 inches of rainfall had occurred, indicating that the Sterling Ponds wet pond had sufficient capacity to capture the majority of the June 14 rain event before discharge to the infiltration basin began. This capacity was gained via wet pond drawdown (to the infiltration basin) after the May 24-26 rain events, which was complete on May 31 (above). A subsequent 13-day dry period (June 1-13) provided an additional opportunity for wet pond drawdown via water infiltration through the bottom of the pond and/or surface evaporation. Sterling Ponds wet pond discharge to the infiltration basin, due to the June 14 rain event and small rain events on June 16 (0.12 inch) and June 17 (0.15 inch), continued for 3.3 days, until the fifth of six significant summer rainfall and runoff events began on June 18. No wet pond discharge to Sumner Creek was evident during the June 14 rain event, as documented by the temperature data at Site 5MHW (Figure 35). Small thermal spikes were apparent in Sumner Creek at Site 4 (0.6º C) and Site 4A (1.3º C) after the June 14 event; however, these thermal spikes cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have more local causes. As noted above (*Sumner Creek*), the thermal spike at Site 4A had no downstream thermal impact on the Kinnickinnic River (Figure 29). The magnitude of the June 14 rain event (1.79 inches) was greater than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance. Although the Sterling Ponds wet detention pond was still discharging to the infiltration basin when a subsequent, moderate rain event occurred on June 18, the extended discharge time (3.3 days) prior to the June 18 rain event suggests that the majority of the June 14 event was infiltrated, as were the small rain events on June 16-17 (a combined 0.27 inch).

The fifth of six significant summer rainfall events occurred during the June 18-20 period. Moderate rain events on June 18 (0.74 inch) and June 19 (0.60 inch), followed by the largest rain event of the summer on June 20 (2.05 inches), produced a combined 3.39 inches of rain in a 72-hour period. The June 18 and June 19 rain events were separated by a 27-hour period, while the June 19 and June 20 rain events were separated by a 34-hour period. The comparative Sterling Ponds and Sumner Creek thermographs for the June 18, 19, and 20 rain events are presented in Figure 35.

With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the rain events (a combined 2.06 inches) on June 14, 16, and 17, the June 18 rain event (0.74 inch) resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin, as indicated by the nearly identical temperatures at Sites 5P and 5IB at 02:50 CDT (2:50 AM) (Figure 35), shortly after the onset of heavier rainfall at 00:00 CDT (12:00 AM). Due to the June 18 rain event, wet pond discharge to the infiltration basin was still in progress when the June 19 rain event began at 04:45 CDT (4:45 AM). Generated by convective thunderstorm activity, the June 19 event was brief and intense, with all rain (0.60 inch) falling in a 15-minute period. This event also produced a reinforced discharge from the wet pond to the infiltration basin, as indicated by the nearly identical temperatures at Sites 5P and 5IB at 07:00 CDT (7:00 AM) (Figure 35). No wet pond discharges to Sumner Creek were evident during the June 18 and June 19 rain events, as documented by the temperature data at Site 5MHW (Figure 35). Small thermal spikes were apparent in Sumner Creek at Site 4 (1.0º C) and Site 4A (2.0º C) after the June 18 event, and at Site 4A (1.0º C) after the June 19 event. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have more local causes. Although the Sterling Ponds wet pond was still discharging to the infiltration basin when the June 20 rain event began, it seems likely that the majority of the June 18-19 rainfall (1.34 inches) was infiltrated, given the moderate magnitudes of these rain events and the extended time periods between the June 18-19 and June 19-20 events (27 hours and 34 hours, respectively).

Due to the June 18 and June 19 rain events (a combined 1.34 inches), Sterling Ponds wet pond discharge to the infiltration basin was still in progress when the June 20 rain event (2.05 inches) began at 15:00 CDT (3:00 PM). With very intense rainfall starting at 15:15 CDT (3:15 PM) and 1.67 inches of rain falling in a 45-minute period from 15:15-16:00 CDT, a reinforced discharge from the wet pond to the infiltration basin began at 15:50 CDT (3:50 PM), and the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 16:00 CDT (4:00 PM), as indicated by the rapidly-increasing temperature at Site 5MHW (Figure 35). Wet pond discharge to the Sumner Creek drainage way continued for 19.3 hours, until 11:20 CDT (11:20 AM) on June 21. During this 19.3-hour period, the wet pond discharge temperature averaged 21.5º C and ranged from 20.6-23.8º C. The extended wet pond discharge to the Sumner Creek drainage way was certainly influenced by the great magnitude of the June 20 rain event (2.05 inches). However, the antecedent rainfall (1.34 inches) on June 18-19 was also a likely influence, even though the majority of the June 18-19 rainfall was already infiltrated when the June 20 rain event began. Both antecedent rain events utilized wet pond storage capacity that could have been used to capture a greater proportion of the June 20 rain event, resulting in a reduced wet pond discharge to the Sumner Creek drainage way. Additional wet pond storage capacity would also have been helpful for abatement of any "first-flush" temperature and water quality impacts. With the majority of the June 20 rainfall (1.67 inches) occurring in a 45-minute period, and with the wet detention pond still discharging to the infiltration basin after the June 18-19 rain events, 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. The Sterling Ponds wet pond discharge to the Sumner Creek drainage way may have contributed to a small thermal spike (1.8º C) downstream at Site 4 (Figure 35). This spike occurred at 19:20 CDT (7:20 PM) on June 20, 3.3 hours after the wet detention pond began discharging to the drainage way. The very prominent thermal spike (6.3º C) evident near the mouth of Sumner Creek (Site 4A) at 17:10 CDT (5:10 PM) on June 20 (Figure 35) 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 Sterling Ponds storm water discharge began, and 2.2 hours before the small thermal spike occurred at Site 4 upstream. It seems apparent that the thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35. However, the extended discharge (19.3 hours) of warm storm water from the Sterling Ponds wet pond to Sumner Creek may have contributed to the extended duration (19.3 hours) of warmer-than-normal water at Site 4A, until 10:50 CDT (10:50 AM) on June 21. It is likely that warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way also contributed to the extended presence of warmer water at Site 4A. As noted above (*Sumner Creek*), the thermal spike at Site 4A had a small downstream thermal impact (0.4º C) on the Kinnickinnic River at Site 1 (Figure 26). Sterling Ponds wet pond discharge to the infiltration basin, due to the June 20 rain event and a very small rain event (0.01 inch) on June 21, continued for 6.1 days, until 17:10 CDT (5:10 PM) on June 26 (Figure 34).

In summary for June, no Sterling Ponds wet pond discharges occurred to the Sterling Ponds infiltration basin during the June 1-13 period, and two very small rain events (totaling 0.03 inch) were captured in the wet pond. The Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the June 14-26 period. A very large rain event on June 14 (1.79 inches) event was infiltrated, as were small rain events on June 16-17 (a combined 0.27 inch) and moderate rain events on June 18-19 rainfall (a combined 1.34 inches). It seems likely that the majority of the June 20 rain event (2.05 inches) was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on June 20-21, the duration of the wet pond discharge to Sumner Creek (19.3 hours) was much shorter than the duration of the discharge to the infiltration basin (6.1 days). A very small rain event on June 21 (0.01 inch) was infiltrated.

July

The comparative Sterling Ponds thermographs for July 2012 are presented in Figure 36. The month of July was much warmer (+3.9° F) and slightly drier (-0.30 inch) than normal. Rainfall events (ranging from 0.01-1.19 inches) were recorded on eleven dates (Figure 2), with one of the six significant summer rainfall events occurring on July 21.

During the July 1-17 period, no Sterling Ponds wet pond discharges occurred to the infiltration basin (Figure 36). Very small rain events on July 4 (0.01 inch), July 7 (0.05 inch), and July 14 (0.04 inch) and small rain events on July 3 (0.20 inch) and July 6 (0.21 inch) were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond. A large rain event on July 13 (0.98 inch) was also captured in the wet pond, with no discharge of storm water to the infiltration basin. The ability of the Sterling Ponds wet pond to fully capture the July 13 event was likely due to a 16-day antecedent period (June 27-July 12) with little rainfall (a combined 0.51 inch). This extended dry period provided ample opportunity for wet pond drawdown via water infiltration through the bottom of the pond and/or surface evaporation. Water loss from the wet pond via surface evaporation was probably significant, since daily maximum air temperatures averaged 93° F (34° C) during this time period, and daily maximum wet pond temperatures averaged 90° F (32° C).

After a small rain event on July 18 (0.12 inch), the Sterling Ponds wet detention pond began discharging to the Sterling Ponds infiltration basin at 18:20 CDT (6:20 PM), as indicated by the rapidly-increasing temperature at Site 5IB (Figure 37). Given the small magnitude of this rain event, wet pond discharge to the infiltration basin seems like an unusual circumstance. Rainfall on July 18 occurred during convective thunderstorm activity, which can produce significantly variable rain amounts in short distances. Small rain amounts were recorded by the City of River Falls rain gauge (0.12 inch) and the USGS rain gauge (0.17 inch), located five miles west of River Falls. However, a substantially greater amount of rain was measured in Hudson, Wisconsin (0.95 inch), seven miles northwest of River Falls. With a southeasterly track, the thunderstorm cell may have produced more rainfall at Sterling Ponds than was measured at the River Falls City Hall, approximately one mile to the south. Furthermore, the large, antecedent rain event on July 13 (0.98 inch) reduced the capacity of the Sterling Ponds wet pond, making it more susceptible to discharge to the infiltration basin after the July 18 rain event. Wet pond discharge to the infiltration basin, due to the July 18 rain event, continued for 2.6 days, until a subsequent rain event occurred on July 21.

The sixth (and final) of six significant summer rainfall and runoff events occurred on July 21. The comparative Sterling Ponds and Sumner Creek thermographs for the July 21 rain event (1.19 inches) are presented in Figure 37. With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the July 18 rain event, the July 21 rain event resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin, as indicated by the identical temperatures at Sites 5P and 5IB at 08:00 CDT (8:00 AM) (Figure 37), shortly after the onset of heavier rainfall at 07:00 CDT (7:00 AM). 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 spike was apparent in Sumner Creek at Site 4 (Figure 37). A moderate thermal spike (3.1º C) was evident at Site 4A after the July 21 rain event (Figure 37); however, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause. The magnitude of the July 21 event (1.19 inches of rain) was less than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; and the entire event was captured in the wet pond and infiltrated, as expected. Wet pond discharge to the infiltration basin, due to the July 21 rain event, a moderate rain event on July 24 (0.54 inch), a very small rain event on July 28 (0.01 inch), and a moderate rain event on July 29 (0.39 inch), continued for 11.1 days, until 09:40 CDT (9:40 AM) on August 1.

In summary for July, no Sterling Ponds wet pond discharges occurred to the Sterling Ponds infiltration basin during the July 1-17 period. Very small rain events on July 4 (0.01 inch), July 7 (0.05 inch), and July 14 (0.04 inch), small rain events on July 3 (0.20 inch) and July 6 (0.21 inch), and a large rain event on July 13 (0.98 inch) were all captured in the Sterling Ponds wet pond. The wet detention pond continuously discharged to the infiltration basin during the July 18-31 period. A small rain event on July 18 (0.12 inch), a large rain event on July 21 (1.19 inches), a moderate rain event on July 24 (0.54 inch), a very small rain event on July 28 (0.01 inch), and a moderate rain event on July 29 (0.39 inch) were all infiltrated.

August

The comparative Sterling Ponds thermographs for August 2012 are presented in Figure 38. The month of August was slightly cooler (-1.1° F) and much drier (-2.78 inches) than normal. Rainfall events (ranging from 0.01-0.80 inch) were recorded on nine dates (Figure 2). Six of these rain events were very small, with rainfall amounts ≤0.02 inch. None of the six significant summer rainfall events occurred in August.

Due to a moderate rain event on August 4 (0.80 inch), the Sterling Ponds wet detention pond began discharging to the Sterling Ponds infiltration basin at 01:10 CDT (1:10 AM), shortly after the onset of heavier rainfall at 00:00 CDT (12:00 AM) (Figure 38). No wet pond discharge to Sumner Creek was evident during the August 4 event, as documented by the temperature data at Site 5MHW (Figure 38). A moderate thermal spike (1.6º C) was evident at Site 4A after the August 4 rain event (Figure 25); however, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause. Wet pond discharge to the infiltration basin, due to the August 4 rain event, continued for 2.6 days, until 15:40 CDT (3:40 PM) on August 6.

The August 7-31 period was dry, with eight rain events producing a combined 0.72 inch of rainfall. All eight rain events, ranging from 0.01-0.43 inch, were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond. The wet pond did not discharge to the infiltration basin during this time period (Figure 38).

In summary for August, a moderate rain event on August 4 (0.80 inch) was infiltrated in the Sterling Ponds infiltration basin. The Sterling Ponds wet pond did not discharge to the infiltration basin during the August 7-31 period. During this time period, eight rain events, ranging from 0.01-0.43 inch and producing a combined 0.72 inch of rainfall, were all captured in the Sterling Ponds wet pond.

September

The comparative Sterling Ponds thermographs for September 2012 are presented in Figure 39. The month of September was cooler (-1.3° F) and much drier (-2.45 inches) than normal. Rainfall events (ranging from 0.06-0.21 inch) were recorded on only six dates (Figure 2), with none of the six significant summer rainfall events occurring in September. All six rain events in September (a combined 0.63 inch) were captured in the Sterling Ponds wet pond, with no wet pond discharges to the infiltration basin (Figure 39).

Effectiveness of Sterling Ponds Storm Water Management Practices:

2012 Performance Assessment

During the May-September (summer) 2012 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 a large rain event on May 6 (1.40 inches) and a very large rain event on June 20 (2.05 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River Falls Storm Water Management Ordinance. These 45 rain events, ranging in magnitude from 0.01-1.79 inches, represent a total of 14.14 inches of precipitation, or 80% of the total summer rainfall amount (17.59 inches). Of these 45 rain events, 23 events, ranging in magnitude from 0.01-0.98 inch and totaling 2.88 inches of precipitation (16% of the total summer rainfall amount) were entirely stored in the Sterling Ponds wet detention pond, with the storm water infiltrating in the pond or evaporating. The 22 remaining summer rain events, ranging in magnitude from 0.01-1.79 inches and totaling 11.26 inches of precipitation (64% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin. Due to below-normal rainfall (-1.44 inches) and a reduced frequency of rainfall during the May-September (summer) 2012 period, the Sterling Ponds wet detention pond discharged to the infiltration basin for 46 days, or 30% of the summer period.

Eleven rainfall events in May were stored in the Sterling Ponds wet detention pond or diverted to the Sterling Ponds infiltration basin. These events ranged from 0.01-1.61 inches in magnitude and represented a monthly total of 4.81 inches, or 27% of the total summer rainfall amount. Eight rain events in June, ranging from 0.01-1.79 inches and totaling 3.44 inches, were either infiltrated or stored in the wet detention pond. These June rain events represented 20% of the total summer rainfall. Eleven rain events in July, ranging from 0.01-1.19 inches and totaling 3.74 inches, were either infiltrated or stored in the wet detention pond. These July rain events represented 21% of the total summer rainfall. Nine rain events in August, ranging from 0.01-0.80 inch and totaling 1.52 inches, were either infiltrated or stored in the wet detention pond. These August rain events represented 9% of the total summer rainfall. All six rain events in September, ranging from 0.06-0.21 inch and totaling 0.63 inch, were stored in the wet detention pond. These September rain events represented 4% of the total summer rainfall.

The Sterling Ponds wet detention pond only discharged to Sumner Creek during a large rain event on May 6 (1.40 inches) and a very large rain event on June 20 (2.05 inches). These discharges of storm water to Sumner Creek were directly measured at Site 5MHW.

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on May 6 was triggered by the great magnitude of the May 6 rain event (1.40 inches), the high rainfall intensity near the start of the event (1.07 inches of rain in a 30-minute period), and the antecedent rainfall (0.87 inch) on May 5. With the majority of the May 5-6 rainfall (2.27 inches) occurring in a 17-hour period, and with the wet detention pond still discharging to the infiltration basin after the May 5 rain event, the wet pond was quickly inundated with storm water on May 6. 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. The lengthy wet pond discharge to the Sumner Creek drainage way (14.8 hours) was likely influenced by the great magnitude of the May 6 rain event and the antecedent rainfall on May 5. The 10.5-hour period separating the two rain events did not provide sufficient time to fully infiltrate the May 5 event before the May 6 event commenced. Although an extended wet pond discharge to the Sumner Creek drainage way occurred on May 6, the duration of this discharge was relatively short (14.8 hours), compared to the duration of discharge to the infiltration basin (6.9 days). 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. A total of 2.27 inches of rain fell in a 17-hour period on May 5-6, which significantly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance.

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on June 20-21 was primarily triggered by the great magnitude of the June 20 rain event (2.05 inches) and the very high rainfall intensity near the start of the event (1.67 inches of rain in a 45-minute period). With the majority of the June 20 rainfall (1.78 inches) occurring in a one-hour period, the wet pond was quickly inundated with storm water. 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. The extended wet pond discharge to the Sumner Creek drainage way (19.3 hours) was certainly influenced by the great magnitude of the June 20 rain event (2.05 inches). However, the antecedent rainfall on June 18-19 (a combined 1.34 inches) was also a likely influence. Although the Sterling Ponds wet pond was still discharging to the infiltration basin when the June 20 rain event began, it seems likely that the majority of the June 18-19 rainfall (1.34 inches) was infiltrated, given the moderate magnitudes of these rain events and the extended time periods between the June 18-19 and June 19-20 events (27 hours and 34 hours, respectively). However, both antecedent rain events utilized wet pond storage capacity that could have been used to capture a greater proportion of the June 20 rain event, resulting in a reduced wet pond discharge to the Sumner Creek drainage way. Additional wet pond storage capacity would also have been helpful for abatement of any “first-flush” temperature and water quality impacts. Although an extended wet pond discharge to the Sumner Creek drainage way occurred on June 20-21, the duration of this discharge was relatively short (19.3 hours), compared to the duration of discharge to the infiltration basin (6.1 days). 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 wet pond discharge to Sumner Creek on June 20-21 was not entirely unexpected, as the magnitude of the June 20 rainfall event (2.05 inches) clearly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance.

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 45 summer (May-September) rain events, ranging in magnitude from 0.01-1.79 inches. All runoff from these events was stored or infiltrated. A large rain event on May 6 (1.40 inches) and a very large rain event on June 20 (2.05 inches) caused storm water discharges to the Sumner Creek drainage way; but the 24-hour rainfall amounts for these two storms (a combined 2.27 inches on May 5-6 and 2.05 inches on June 20) were greater than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance.

Temperature monitoring of all 2005-2012 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 the 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.

2010 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2010 indicated that warm storm water was discharged from the Sterling Ponds wet pond to Sumner Creek during a moderate rain event on August 8 (0.55 inch) and very large rain events on June 25 (2.97 inches), August 10-11 (a combined 2.43 inches), and September 23 (2.58 inches).

The great magnitude of rainfall on June 25 (2.97 inches), August 10-11 (2.43 inches), and September 23 (2.58 inches) was a major factor contributing to the wet pond discharges to Sumner Creek during these rain events. National Weather Service (NWS) observer reports indicate that rainfall amounts near River Falls (3.46-5.07 inches) on August 10-11 were even higher than the amount recorded at the USGS monitoring station (2.43 inches). Given that the 24-hour rainfall amounts on these dates greatly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances. Although the rainfall amount on August 8 could not be accurately determined, a combination of USGS and NWS observer information suggests that the magnitude of this event may also have exceeded the 1.5-inch infiltration standard. According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), the June 25, August 10-11, and September 23 rain events have recurrence intervals of 2 years, 5-25 years, and 1-2-years, respectively.

In addition to great rainfall magnitudes, high rainfall intensity rates and short rainfall durations also contributed to the wet pond discharges to Sumner Creek during the June 25, August 8, and August 10-11 rainfall events. All three rain events were characterized by convective thunderstorm activity that produced periods of very intense rainfall, with peak rainfall rates of 1.90 inches per hour during the June 25 storm and 1.49 inches per hour during the August 10 storm. Rainfall durations were relatively short, including 2.5 hours on June 25, 0.75 hour and 1.5 hours during two waves of rainfall on August 8, and 7.0 hours on August 10-11. These high-intensity, short-duration storms rapidly delivered storm water to the Sterling Ponds wet pond, quickly overwhelming the capacity of the pond. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged to Sumner Creek.

Wet pond discharges to Sumner Creek during the June 25, August 10-11, and September 23 rain events were also affected by large, antecedent rain events on June 23 (1.44 inches), August 8 (>0.55 inch), and September 21-22 (2.04 inches). These antecedent rain events significantly reduced the storage capacity in the wet detention pond, and provided only short periods of time for storm water discharge to the infiltration basin before the onset of additional rainfall.

In spite of great rainfall magnitudes, high rainfall intensity rates, short rainfall durations, and/or considerable antecedent rainfall, discharge lags ranging from 30 minutes to 2 hours were apparent during the June 25, August 8, and August 10-11 rain events (Appendix A). These discharge lags, defined as the time lag between the onset of discharge to the infiltration basin and the onset of discharge to Sumner Creek, provided a limited opportunity for first-flush abatement of temperature and water quality impacts. Even so, the average temperatures of storm water discharged to Sumner Creek during the June 25, August 8, and August 10-11 rain events were 22.6° C, 24.8° C, and 25.0° C, respectively. These temperatures were much higher than pre-rainfall temperatures in Sumner Creek (Site 4A) on June 25 (12.6° C), August 8 (13.0° C), and August 10 (13.8° C), indicating the potential for downstream thermal impacts, which were evident as thermal spikes at Sites 4 and 4A during the August 10-11 rain event. Due to the large amount of antecedent rainfall on September 21-22 (2.04 inches), no discharge lag was apparent during the September 23 rain event (Appendix A). The Sterling Ponds wet pond was already near maximum capacity as heavy rainfall began on September 23, and the pond immediately discharged to Sumner Creek, providing no opportunity for first-flush abatement of temperature and water quality impacts. The average temperature of storm water discharged to Sumner Creek during the September 23 rain event was 17.2° C, compared to a pre-rainfall temperature of 13.3° C in Sumner Creek (Site 4A). As such, the September 23 wet pond discharge to Sumner Creek contributed to the thermal spikes evident at Sites 4 and 4A.

Wet pond discharge times to Sumner Creek during the August 10-11 and September 23 rain events were 20 hours and 34.5 hours, respectively (Appendix A), the longest discharge times observed during the 2005-2011 monitoring period. The extended wet pond discharge time during the August 10-11 rain event (20 hours) can be attributed in part to antecedent rainfall on August 8, but primarily to the great magnitude of rainfall (3.46-5.07 inches) that inundated the wet pond. The extended wet pond discharge time during the September 23 rain event (34.5 hours) can be attributed to the considerable antecedent rainfall (2.04 inches) on September 21-22, the great magnitude of rainfall (2.58 inches) on September 23, and the very extended (all-day) rainfall duration.

On a positive performance note in 2010, very large rain events on May 24 (1.72 inches) and July 22 (1.67 inches) were both fully infiltrated. The magnitudes of these two rain events clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance.

2011 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2011 indicated that warm storm water was discharged from the Sterling Ponds wet pond to Sumner Creek during a moderate rain event on July 16 (0.71 inch) and very large rain events on June 21 (2.46 inches) and August 16 (1.78 inches).

The great magnitude of rainfall on June 21 (2.46 inches) and August 16 (1.78 inches) was a major factor contributing to the wet pond discharges to Sumner Creek during these rain events. Given that the 24-hour rainfall amounts on these dates exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances. Past monitoring has documented that wet pond discharges to Sumner Creek commonly occur when 24-hour rainfall amounts exceed 1.5 inches (Appendix A). During the 2005-2011 monitoring period, wet pond discharges occurred during 14 rain events ranging from 1.63-4.00 inches. On average, two such rain events occur each summer.

In addition to great rainfall magnitudes, high rainfall intensity rates and short rainfall durations also contributed to the wet pond discharges to Sumner Creek during the June 21 and August 16 rain events. Both rain events were characterized by convective thunderstorm activity that produced periods of very intense rainfall, with peak rainfall rates of 1.21 inches per hour during the June 21 storm and 0.91 inch per hour during the August 16 storm. Rainfall durations were relatively short, including 1.5 hours and 2.75 hours during two waves of rainfall on June 21, and 2.75 hours on August 16. These high-intensity, short-duration storms rapidly delivered storm water to the Sterling Ponds wet pond, quickly overwhelming the capacity of the pond. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged to Sumner Creek.

Wet pond discharges to Sumner Creek during the June 21 and August 16 rain events were also affected by large, antecedent rain events during the June 14-19 period (a combined 1.94 inches), and on August 13 (1.03 inches). These antecedent rain events significantly reduced the storage capacity in the wet detention pond, and provided relatively short periods of time for storm water discharge to the infiltration basin before the onset of additional rainfall. As such, the Sterling Ponds wet detention pond was still discharging to the infiltration basin when the June 21 and August 16 rain events began.

In spite of great rainfall magnitudes, high rainfall intensity rates, short rainfall durations, and/or considerable antecedent rainfall, discharge lags of 17.5 hours and 1.5 hours were apparent during the June 21 and August 16 rain events, respectively (Appendix A). Discharge lags, defined as the time lag between the onset of discharge to the infiltration basin and the onset of discharge to Sumner Creek, provide a limited opportunity for first-flush abatement of temperature and water quality impacts. For this reason, longer discharge lags are desirable when rain events ≥1.5 inches result in Sterling Ponds wet pond discharges to Sumner Creek. During the 2005-2011 monitoring period, wet pond discharge lags ranging from none (instantaneous) to 17.5 hours were associated with the 14 rain events ranging from 1.63-4.00 inches (Appendix A). Although the discharge lags associated with the June 21 and August 16 rain events were relatively lengthy, the average temperatures of storm water discharged to Sumner Creek on June 21-22 and August 16-17 were 20.9° C and 22.5° C, respectively. These temperatures were much higher than pre-rainfall temperatures in Sumner Creek (Site 4A) on June 21 (15.2° C) and August 16 (14.4° C), indicating the potential for downstream thermal impacts, which were evident as thermal spikes at Sites 4 and 4A during both rain events. The 17.5-hour discharge lag during the June 21 rain event was the longest recorded during the 2005-2011 monitoring period. This very extended discharge lag can be attributed to two waves of rainfall during early morning and late evening thunderstorms. The early morning storm (0.71 inch of rain) likely filled the Sterling Ponds wet pond and resulted in a reinforced storm water flow to the infiltration basin at 04:00 CDT (4:00 AM). With the wet pond still near capacity when the larger, late evening storm (1.75 inches of rain) began, the discharge to Sumner Creek commenced at 21:30 CDT (9:30 PM). This extended discharge lag on June 21 provided a significant opportunity for first-flush abatement of the temperature and water quality impacts associated with the first wave of rainfall.

Sterling Ponds wet pond discharge times to Sumner Creek during the June 21 and August 16 rain events were 18.2 hours and 16.0 hours, respectively (Appendix A). During the 2005-2011 monitoring period, wet pond discharge times ranging from 2.5-34.5 hours were associated with the 14 rain events ranging from 1.63-4.00 inches (Appendix A). For these rain events ≥1.5 inches, reduced wet pond discharge times are clearly more desirable than extended discharge times. The extended wet pond discharge times associated with the June 21 and August 16 rain events can be primarily attributed to the great magnitude of rainfall that inundated the wet pond. However, antecedent rainfall also played a role by reducing the capacity of the wet pond before these large rain events occurred. The wet pond discharge times associated with the June 21 and August 16 rain events were amongst the longest recorded during the 2005-2011 monitoring period, and were even longer than the discharge times associated with the two largest rain events on July 8, 2005 (14 hours for 4.00 inches of rain) and August 8, 2009 (15 hours for 3.76 inches of rain) (Appendix A). Given that the extended wet pond discharges associated with the June 21 and August 16 rain events were a somewhat unusual occurrence, it is possible that the wet pond outlet to the infiltration basin may have been partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin. In this event, reduced storm water flow to the infiltration basin would result in extended storm water flow to Sumner Creek (also see discussion of the July 16 rain event below).

The moderate rain event on July 16 (0.71 inches) was much 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 14.7-hour period (Appendix A). Given the moderate magnitude of the July 16 rain event, the wet pond discharge to Sumner Creek was an unusual occurrence, as was the extended duration of the discharge. This discharge may have been influenced by the short duration (2 hours) and relatively high intensity of rainfall on July 16, as well as antecedent rainfall (0.60 inch) on July 15. However, even with antecedent rainfall on July 15, the magnitude of the July 15-16 rain event (a combined 1.31 inches of rain in 21.7 hours) was still less than the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. Furthermore, the Sterling Ponds wet pond was not discharging to the infiltration basin when rainfall began on July 15, so the wet pond should have had adequate capacity to store incoming storm water. Indeed, the preceding large rain event on July 10 (1.09 inches) was entirely infiltrated by July 12, three days prior to the July 15 rain event. However, the extended duration (9.5 hours) and low intensity of the July 15 rain event may have slowly re-filled the wet pond to capacity, in spite of ongoing wet pond discharge to the infiltration basin during this rain event. It is also possible that wet pond discharge to the infiltration basin during the intervening 10.2-hour dry period between the July 15 and July 16 rain events did not sufficiently increase wet pond capacity to fully store the July 16 rain event. With 0.71 inch of rain falling in two hours, 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 is provided by the relatively short time lag (40 minutes) between the onset of intense rainfall and the onset of discharge to Sumner Creek on July 16 (Appendix A). Given the very unusual performance of the Sterling Ponds storm water management practices during the July 16 rain event, especially the extended duration (14.7 hours) of the wet pond discharge to Sumner Creek, it is possible that the wet pond outlet to the infiltration basin may have been partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin. In this event, reduced storm water flow to the infiltration basin would result in extended storm water flow to Sumner Creek (also see discussion of the June 21 and August 16 rain events above).

2012 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2012 indicated that warm storm water was discharged from the Sterling Ponds wet pond to Sumner Creek during a large rain event on May 6 (1.40 inches) and a very large rain event on June 20 (2.05 inches). The circumstances contributing to these wet pond discharges to Sumner Creek are detailed in the *2012 Performance Assessment* above.

While rainfall on May 6 (1.40 inches) was less than the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance, the total rainfall in a 17-hour period on May 5-6 (2.27 inches) substantially exceeded the 1.5-inch infiltration standard. The great magnitude of rainfall on May 5-6 (2.27 inches) and June 20 (2.05 inches) was a major factor contributing to the wet pond discharges to Sumner Creek during these rain events. Given that the 24-hour rainfall amounts on these dates exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances.

Past monitoring has documented that wet pond discharges to Sumner Creek commonly occur when 24-hour rainfall amounts exceed 1.5 inches (Appendix A). During the 2005-2012 monitoring period, wet pond discharges occurred during 16 rain events ranging from 1.63-4.00 inches. On average, two such rain events occur each summer.

In addition to great rainfall magnitudes, high rainfall intensity rates and short rainfall durations also contributed to the wet pond discharges to Sumner Creek during the May 5-6 and June 20 rain events. Both rain events were characterized by convective thunderstorm activity that produced periods of very intense rainfall, with peak rainfall rates of 1.13 inches per hour during the May 6 storm and 1.78 inches per hour during the June 20 storm. Rainfall durations during these two rain events were relatively short. The majority (1.66 inches) of the combined May 5-6 rainfall (2.27 inches) occurred during a 45-minute period on May 5 (0.59 inch) and a 30-minute period on May 6 (1.07 inches). The majority (1.78 inches) of the June 20 rainfall (2.05 inches) occurred during a one-hour period. These high-intensity, short-duration storms rapidly delivered storm water to the Sterling Ponds wet pond, quickly overwhelming the capacity of the pond. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged to Sumner Creek.

Wet pond discharges to Sumner Creek during the May 5-6 and June 20 rain events were also affected by antecedent rainfall during the May 1-4 period (a combined 1.46 inches) and the June 18-19 period (a combined 1.34 inches). These antecedent rain events significantly reduced the storage capacity in the wet detention pond, and provided relatively short periods of time for storm water discharge to the infiltration basin before the onset of additional rainfall. As such, the Sterling Ponds wet detention pond was still discharging to the infiltration basin when the May 5-6 and June 20 rain events began.

An extended discharge lag (12.2 hours) was apparent during the May 5-6 rain event; however, a very short discharge lag (10 minutes) was evident during the June 20 rain event (Appendix A). Discharge lags, defined as the time lag between the onset of discharge to the infiltration basin and the onset of discharge to Sumner Creek, provide a limited opportunity for first-flush abatement of temperature and water quality impacts. For this reason, longer discharge lags are desirable when rain events ≥1.5 inches result in Sterling Ponds wet pond discharges to Sumner Creek. During the 2005-2012 monitoring period, wet pond discharge lags ranging from none (instantaneous) to 17.5 hours were associated with the 16 rain events ranging from 1.63-4.00 inches (Appendix A). The 12.2-hour discharge lag during the May 5-6 rain event was the second-longest recorded during the 2005-2012 monitoring period. This very extended discharge lag can be attributed to separate thunderstorms on May 5 and 6, with an intervening 10.5-hour period between these two storms. The mid-afternoon storm on May 5 (0.87 inch of rain) likely filled the Sterling Ponds wet pond and resulted in a reinforced storm water flow to the infiltration basin at 15:10 CDT (3:10 PM). With the wet pond still near capacity when the early morning storm (1.40 inches of rain) began on May 6, the discharge to Sumner Creek commenced at 03:20 CDT (3:20 AM). The extended discharge lag on May 5-6 provided a significant opportunity for first-flush abatement of the temperature and water quality impacts associated with the first storm on May 5. In contrast, the discharge lag during the June 20 rain event was very short (10 minutes). This very short lag time can be attributed to the great rainfall magnitude on June 20 (2.05 inches), a high rainfall intensity rate (1.78 inches per hour), a short rainfall duration (1 hour), the timing of heavy rainfall at the front end of the storm, and considerable antecedent rainfall on June 18-19 (1.34 inches), which reduced the capacity of the Sterling Ponds wet pond before the June 20 rain event began. The very short discharge lag on June 20 provided no opportunity for first-flush abatement of temperature and water quality impacts.

Sterling Ponds wet pond discharge times to Sumner Creek during the May 5-6 and June 20 rain events were 14.8 hours and 19.3 hours, respectively (Appendix A). During the 2005-2012 monitoring period, wet pond discharge times ranging from 2.5-34.5 hours were associated with the 16 rain events ranging from 1.63-4.00 inches (Appendix A). For these rain events ≥1.5 inches, reduced wet pond discharge times are clearly more desirable than extended discharge times. The extended wet pond discharge times associated with the May 5-6 and June 20 rain events can be primarily attributed to the great magnitude of rainfall that inundated the wet pond. However, antecedent rainfall also played a role by reducing the capacity of the wet pond before these large rain events occurred. The wet pond discharge time (19.3 hours) associated with the June 20 rain event (2.05 inches) was the third-longest recorded during the 2005-2012 monitoring period, and was even longer than the discharge times (2.5-18.2 hours) associated with six larger rain events (2.27-4.00 inches) during the 2005-2012 period (Appendix A). Given that the extended wet pond discharge associated with the June 20 rain event was a somewhat unusual occurrence, it is possible that the wet pond outlet to the infiltration basin may have been partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin. In this event, reduced storm water flow to the infiltration basin would result in extended storm water flow to Sumner Creek.

As observed in 2012, the seasonal timing of Sterling Ponds wet pond discharges to Sumner Creek can greatly influence the potential for downstream thermal impacts. The May 5-6 and June 20 rain events were both characterized by convective thunderstorm activity. On May 5-6, air temperatures were very cool, ranging from 12-15° C (53-59° F). As such, the temperature of the wet pond discharge to Sumner Creek on May 6 averaged 15.0º C and ranged from 14.4-15.7º C during the 14.8-hour discharge period. In contrast, air temperatures on June 20 were much warmer, ranging from 18-29° C (64-84° F). As a result, the temperature of the wet pond discharge to Sumner Creek on June 20-21 was also much warmer, averaging 21.5º C and ranging from 20.6-23.8º C during the 19.3-hour discharge period. The average wet pond discharge temperatures on May 6 (15.0º C) and June 20-21 (21.5º C) were notably higher than pre-rainfall temperatures in Sumner Creek (Site 4A) on May 6 (10.7° C) and June 20 (14.8° C), indicating the potential for downstream thermal impacts during both rain events. However, given the much higher wet pond discharge temperature on June 20-21 and the substantial difference (6.7° C) between this temperature and the Sumner Creek temperature, the June 20-21 wet pond discharge exhibited a greater potential for downstream thermal impacts on Sumner Creek. In fact, the May 6 wet pond discharge caused a small thermal spike (0.9º C) downstream at Site 4, while the June 20-21 wet pond discharge contributed to a somewhat larger thermal spike (1.8º C) at Site 4.

On a positive performance note in 2012, very large rain events on May 24 (1.61 inches) and June 14 (1.79 inches) were both fully infiltrated. The magnitudes of these two rain events clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance. The Sterling Ponds wet pond had sufficient capacity to capture the majority of the May 24 and June 14 rain events before discharge to the infiltration basin began. This capacity was gained via wet pond drawdown (to the infiltration basin) of the large, antecedent rain events that occurred on May 5-6 and May 24-26. Extended dry periods (May 12-23 and June 1-13) in advance of the May 24 and June 14 rain events provided an additional opportunity for wet pond drawdown via water infiltration through the bottom of the pond and/or surface evaporation.

The extended time (11.1 days) needed to infiltrate a large rain event on July 21 (1.19 inches) and subsequent, very small-moderate rain events during the July 24-29 period (a combined 0.94 inch) also suggests that the wet pond outlet to the infiltration basin may have been partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin, or perhaps by organic material in the pipe itself.

Summary

Temperature monitoring of the Sterling Ponds storm water management practices during the 2005-2012 period indicates that storm water discharges to Sumner Creek are occurring:

- During rain events larger than 1.5 inches (2005-2007 and 2009-2012);
- During back-to-back rain events, when rainfall amounts range from 0.7-1.5 inches and time periods between rain events are less than 48 hours (2006-2007 and 2011);
- During very intense rain events, when rainfall amounts range from 1.0-1.5 inches (2008).

A summary of the 2005-2012 Sterling Ponds storm water discharges to Sumner Creek, including discharge dates, rainfall amounts, discharge lags, and discharge times, is provided in Appendix A.

In June 2007, River Falls Engineering Department staff conducted modeling of the Sterling Ponds storm water management practices, to further investigate these 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. As such, the modification should be beneficial for the back-to-back rain events and very intense rain events ≤1.5 inches that are occasionally causing wet pond discharges to Sumner Creek. More storm water storage capacity in the wet pond should also increase discharge lags and reduce the discharge times associated with rain events larger than 1.5 inches.

The modification 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, but was not particularly helpful for the very large rain events (8 events ≥1.5 inches) that occurred in 2010, 2011, and 2012. 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 potential expense of reduced removal efficiencies for TSS and TP (ordinance permitting). The impacts of such modifications (increasing the rate and amount of storm water delivery to the infiltration basin between large rain events) on wet pond pollutant removal efficiencies could be directly determined by monitoring TSS and TP concentrations at Sites 5IN and 5IB during targeted rain events in the 1.0-1.5-inch range (see "**Water Quality Monitoring**", below). 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.

Given the frequent number of rain events ≥1.5 inches during the 2004-2012 monitoring period (22), including 16 that resulted in wet pond discharges to Sumner Creek during the 2005-2012 period, perhaps an ordinance amendment should be considered to require infiltration of all 24-hour rain events ≤2.0 inches. Such an ordinance modification would have covered 9 (41%) of the 22 rain events ≥1.5 inches during the 2004-2012 monitoring period, and potentially would have resulted in 5 fewer rain events with wet pond discharges to Sumner Creek.

Two lines of evidence (the extended Sterling Ponds wet pond discharge time to Sumner Creek after the June 20 rain event and the extended wet pond discharge time to the infiltration basin after rain events during the July 21-29 period) suggest possible partial plugging of the pipe conveying wet pond storm water to the infiltration basin. Unusually long wet pond discharges to Sumner Creek were also noted during three rain events in 2011 (Appendix A). Given these circumstances in 2011-2012, maintenance work may be needed to clear the pipe between the wet pond and the infiltration basin. The wet pond end (entrance) of the pipe should be checked to ensure that it is not partially plugged by pond vegetation or other organic material. In addition, it may be beneficial to flush the entire length of the pipe.

While this project is primarily focused on evaluating long-term trends, annual performance information is important as well. With the exception of the two very large rain events on May 5-6 (2.27 inches) and June 20 (2.05 inches), the storm water management practices at Sterling Ponds prevented thermal impacts on Sumner Creek and the Kinnickinnic River during the May-September (summer) 2012 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 45 rain events, ranging in magnitude from 0.01-1.79 inches and totaling 14.14 inches of precipitation (80% of the total summer precipitation). All storm water runoff from 43 rain events ≤1.5 inches was infiltrated, as required by the River Falls Storm Water Management Ordinance. Although not required by the ordinance, all storm water runoff from two rain events ≥1.5 inches was also infiltrated. 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). However, during very large rain events on May 5-6 and June 20, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, for extended time periods (14.8 and 19.3 hours, respectively). The warm storm water discharges during these two rain events caused small thermal spikes in Sumner Creek at Site 4, and the June 20 rain event probably contributed to the extended thermal spike observed in lower Sumner Creek, at Site 4A. However, these warm storm water discharges had no discernible impact on Kinnickinnic River temperatures at Site 1, downstream from Sumner Creek. The presence, intensity, and frequency of thermal spikes will continue to be monitored in the years to come.
- Numerous "first-flush" thermal spikes were observed in lower Sumner Creek (Site 4A) during 11 rain events throughout the May-August period. These thermal spikes ranged from 0.5° C - 6.3° C in magnitude and were caused by rain events ranging from 0.60-2.05 inches. All of these "first-flush" thermal spikes seemed to have a local cause. Possible sources contributing to these thermal spikes may include storm water runoff from WI Highway 35, located immediately upstream from Site 4A, and/or warm water from natural wetland areas located a short distance upstream in the upper Sumner Creek drainage way.

Based upon the 2005-2012 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 2005-2012 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 2006-2012 period. Beyond 2012, these same trends will be monitored from year to year, to determine if favorable results are apparent in the future.

Water Quality Monitoring:

At the outset of the North Kinnickinnic River Monitoring Project in 2004, water quality monitoring was envisioned at Kinnickinnic River Sites 1 and 2, to assess any water quality impacts related to storm water runoff from the Sterling Ponds subdivision. Due to technical difficulties with the automated monitoring equipment and the complexity of open-channel monitoring, no runoff event-based water quality monitoring has been conducted at Sites 1 and 2 to date. However, the results of temperature and macroinvertebrate monitoring at these locations have consistently demonstrated that Sterling Ponds storm water impacts on the Kinnickinnic River have been very minimal. With these two key monitoring components in place, water quality monitoring is probably not necessary at Sites 1 and 2.

Rather, to obtain water quality information on the performance of the Sterling Ponds storm water management practices, the automated monitoring equipment at Sites 1 and 2 has been re-located to Sites 5IN (Sterling Ponds wet detention pond inlet) and 5MHW (Sterling Ponds wet detention pond outlet). Along with automated sampling at these two locations, grab sampling will be conducted at Site 5IB (Sterling Ponds infiltration basin). Water samples will be analyzed by a certified laboratory, to determine concentrations of total suspended solids (TSS) and total phosphorus (TP). By comparing these pollutant concentrations at Site IN to concentrations at Site IB, Sterling Ponds wet pond pollutant removal efficiencies can be determined for TSS and TP and compared to the target removal efficiencies (80%). In addition, pollutant concentrations at Site 5MHW can be evaluated to better characterize the water quality impacts of any Sterling Ponds wet pond discharges to Sumner Creek. Finally, potential impacts on pollutant removal efficiencies can be determined, if Sterling Ponds storm water management practices are adjusted to provide improved storm water infiltration capability (see "***Effectiveness of Sterling Ponds Storm Water Management Practices: Summary"***, above). Large rain events (>1.0 inch) of various magnitudes will be targeted for this Sterling Ponds water quality monitoring work, beginning in 2013.

Base Flow Surveys:

The USGS stream flow gauge located at County Highway F, as described earlier in this report, is used to determine when a base flow condition exists in the North Kinnickinnic River Monitoring Project Area. When 3-4 days of “flat-line” flow are observed at the USGS station, the river is assumed to be in a base flow condition. During dry periods between runoff events, the Kinnickinnic River maintained a summer 2012 base flow of 85-110 cfs at County Highway F (Figure 8). As the April-September 2012 period became increasingly drier (Figure 3), Kinnickinnic River base flows gradually decreased. Base flows tended to be a bit higher (90-110 cfs) during the wetter-than-normal months of April, May, and June, and a bit lower (83-98 cfs) during the drier-than-normal months of July, August, and September. Real-time and recent (120-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 2012, 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 2012 base flow surveys were conducted using a handheld SonTek® FlowTracker Acoustic Doppler Velocimeter (ADV).

The spring 2012 base flow survey was conducted on June 8. These spring 2012 survey results are presented in Figure 41, with a comparison to the spring 2006-2011 survey results. In spring 2012, Kinnickinnic River base flows in the project area increased gradually from upstream (flows of 48 cfs and 50 cfs at Sites 3 and 2, respectively) to downstream (69 cfs at Site 1). Sumner Creek provided a very small contribution (0.4 cfs) to the Kinnickinnic River, just upstream of Site 1. An additional 36% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (94 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (5.4 cfs). Within the North Kinnickinnic River Monitoring Project Area, the spring 2012 Kinnickinnic River base flows at Sites 2 and 3 were notably lower (by 18% and 24%, respectively) than the spring 2011 base flows at these two locations; however, the spring 2012 base flow was nearly identical to the spring 2011 base flow at Site 1. In Sumner Creek, the spring 2012 base flow was identical to the spring 2011 base flow. The spring 2012 base flow in Rocky Branch Creek decreased slightly (by 7%), while the spring 2012 base flow in the Kinnickinnic River at County Highway F decreased by 15%, compared to the spring 2011 base flows at these locations. The decrease in spring 2012 base flows at most locations can be attributed to below-normal precipitation during the April-September 2011 period (especially in September), as well as below-normal antecedent winter snowfall. The spring 2007-2010 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). The low spring 2010 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), a summer with slightly above-normal precipitation (2009), and a continuation of drought conditions, which persisted until July 2010. With wetter than normal conditions returning in 2010, the spring 2011 base flows were amongst the highest recorded since monitoring began in 2006. However, with abnormally dry conditions again apparent in the North Kinnickinnic River Monitoring Project Area from October 2011 until May 2012, the spring 2012 base flows receded slightly.

The autumn 2012 base flow survey was conducted on October 10. These autumn 2012 survey results are presented in Figure 42, with a comparison to the autumn 2005-2011 survey results. In autumn 2012, Kinnickinnic River base flows increased notably (29%) from upstream (38 cfs at Site 2) to downstream (49 cfs at Site 1) in the project area. Sumner Creek provided a very small contribution (0.7 cfs) upstream of Site 1. An additional 92% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (94 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (4.3 cfs). Within the North Kinnickinnic River Monitoring Project Area, the autumn 2012 Kinnickinnic River base flows at Sites 1 and 2 were notably lower (by 26% and 30%, respectively) than the autumn 2011 base flows at these two locations. In Sumner Creek, the autumn 2012 base flow was notably higher (250%) than the autumn 2011 base flow. However, this base flow variability may simply be due to the difficulty of measuring very low stream flows (≤1 cfs) with a high degree of accuracy. The autumn 2012 base flow in Rocky Branch Creek decreased slightly (by 12%), while the autumn 2012 base flow in the Kinnickinnic River at County Highway F decreased by 20%, compared to the autumn 2011 base flows at these locations. The decrease in autumn 2012 base flows at most locations can be attributed to below-normal precipitation during the April-September 2012 period, especially in August and September (Figure 3). The autumn 2006-2012 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). With above-normal precipitation in 2010 and only slightly below-normal precipitation in 2011 (Figure 1), Kinnickinnic River autumn base flows rebounded in 2010-2011, reversing a downward trend that had been occurring since 2005, due to three consecutive summers of below-normal precipitation (2006-2008) and a continuation of moderate-severe drought conditions throughout the summer of 2009. However, with much-reduced rainfall in August and September 2012 (Figure 3), severe drought conditions developed in the North Kinnickinnic River Monitoring Project Area by early October 2012, causing decreased autumn 2012 base flows.

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, autumn 2009 base flows were nearly identical to spring 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. In 2010, base flows in the project area increased by 8-37% from spring (May) to autumn (November), due to much higher-than-normal precipitation during the May-September period. In 2011, base flows in the project area decreased slightly (6-13%) from spring (June) to autumn (October), due to slightly lower-than-normal precipitation (a 7% reduction) during the June-September 2011 period. In 2012, base flows in the project area decreased notably (24-29%) from spring (June) to autumn (October), due to below-normal precipitation (a 27% reduction) during the June-September 2012 period.

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. During the 2005-2009 period, proportionately similar decreases in spring and autumn base flows 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 this consistent base flow diminution across all sites, it is likely that a regional factor was 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 are the likely causes of the observed base flow reductions through 2009. With above-normal precipitation during the summer of 2010 and only slightly below-normal precipitation during the summer of 2011, base flows rebounded at all sites in the project area. The decreased autumn 2012 base flows in the North Kinnickinnic River Monitoring Project Area were caused by much-reduced rainfall in August and September 2012 and the severe drought conditions that developed by early October 2012. 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 any extended dry periods.

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. Macroinvertebrate samples are collected annually 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.

Site 1 Site 2 Site 3

Triplicate macroinvertebrate samples collected at Sites 1-3 in 2007

The use of benthic (bottom-dwelling) macroinvertebrates to evaluate stream water quality was initiated in Wisconsin with the work of W. L. Hilsenhoff at the University of Wisconsin-Madison. The Hilsenhoff Biotic Index (HBI), which has been modified and refined over a number of years (Hilsenhoff 1977, 1982, 1987), 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 tolerance 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 2004-2009 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 2004-2009 macroinvertebrate HBI values at Sites 1-3 are also presented in Figure 43. The 2004-2009 data establish an ongoing baseline for assessing the long-term health of the macroinvertebrate community within the project area.

Table 1. Macroinvertebrate HBI Values in the Kinnickinnic River: 2004-2009

	Sampling Location	**2004 HBI Values**	**2005 HBI Values**	**2006 HBI Values**	**2007 HBI Values**	**2008 HBI Values**	**2009 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	2.89 3.95 3.78	4.04 3.85 3.89
	Mean of 3 reps:	2.87	3.00	3.59	3.85	3.54	3.93
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	5.41 4.18 4.52	4.14 4.08 3.66
	Mean of 3 reps:	4.01	4.47	4.02	3.77	4.70	3.96
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	4.44 3.89 3.78	3.66 3.74 3.26
	Mean of 3 reps:	3.67	3.44	3.83	3.75	4.04	3.55

During the 2004-2009 period, mean HBI values at Site 1 were indicative of very good-excellent water quality, mean HBI values at Site 2 were indicative of good-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 2006-2009 values were still indicative of very good water quality. In spite of some apparent degradation during the 2004-2009 period, the mean annual HBI values at Site 1 are generally 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 have been relatively consistent; but values increased in 2005 and 2008, indicating a slight degradation of water quality. However, with the exception of 2008, all annual values during the 2004-2009 period were indicative of very good water quality. Mean annual HBI values at Site 3 were relatively consistent during the 2004-2009 period, and generally indicative of very good water quality.

The comparability of mean annual macroinvertebrate HBI values at Sites 1-3 during the 2004-2009 period indicates that no storm water impacts were apparent at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. In fact, the mean

2004-2009 macroinvertebrate HBI values at Sites 1-3 indicate that the best water quality was evident at Site 1. The mean 2004-2009 macroinvertebrate HBI value at Site 1 (3.46) was indicative of excellent water quality, while the mean 2004-2009 macroinvertebrate HBI values at Site 2 (4.16), and Site 3 (3.71) were indicative of very good water quality. The 2004-2009 macroinvertebrate monitoring results nicely corroborate the 2004-2009 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 also conducted in May 2010, May 2011, and May 2012, but the taxonomic analysis of these samples 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.

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 2004-2012 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
2005-2012

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 very 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)

2010:
The Sterling Ponds wet detention pond discharged to Sumner Creek during three very large summer rain events in excess of 1.5 inches, and twice during a rain event of unknown magnitude on August 8.

Date	Rainfall Amount	Discharge Lag	Discharge Time
June 25*	2.97 inches	50 minutes	2.5 hours
August 8	Unknown	40 minutes	12.5 hours
August 8	Unknown	30 minutes	2.7 hours
August 10-11*	2.43 inches	2 hours	20.0 hours
Sept. 23*	2.58 inches	None	34.5 hours

*Antecedent rain events occurred on June 23 (1.44 inches), August 8 (>0.55 inch), and September 21-22 (2.04 inches)

2011:
The Sterling Ponds wet detention pond discharged to Sumner Creek during two large summer rain events in excess of 1.5 inches, and during a moderate rain event (0.71 inch) on July 16.

Date	Rainfall Amount	Discharge Lag	Discharge Time
June 21*	2.46 inches	17.5 hours	18.2 hours
July 16*	0.71 inch	40 minutes	14.7 hours
August 16*	1.78 inches	1.5 hours	16.0 hours

*Antecedent rain events occurred on June 14-19 (a combined 1.94 inches), July 15 (0.60 inch), and August 13 (1.03 inches)

2012:

The Sterling Ponds wet detention pond discharged to Sumner Creek during two large summer rain events in excess of 1.5 inches.

Date	Rainfall Amount	Discharge Lag	Discharge Time
May 5-6*	2.27 inches	12.2 hours	14.8 hours
June 20*	2.05 inches	10 minutes	19.3 hours

*Antecedent rain events occurred on May 1-4 (a combined 1.46 inches) and June 18-19 (a combined 1.34 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 2012

Smaller rainfall and runoff events can have significant storm water impacts on the Kinnickinnic River, as was evident by the numerous thermal spikes (Figures 19-24) caused by direct (untreated) storm water discharges upstream from the Division Street monitoring site in 2012. 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 2012, due to several factors:

1. Building progress remained very limited in the Sterling Ponds subdivision in 2012, and has only occurred in the southeast and northeast quadrants of the subdivision during the 2004-2012 period.

   In the southeast quadrant, 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. No additional single family units were built in 2010 and 2011, leaving the year-end totals at 58 units. In 2012, 1 additional single family unit was built, leaving the year-end total at 59 units.

   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. In 2010, only two single-family units were built, leaving the year-end total at 96 units, as follows: 14 single-family units, 9 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units. No additional housing units were built in 2011 and 2012, leaving the year-end totals at 96 units.

   A build-out total of 600 units is projected for Sterling Ponds. By year-end 2012, a combined 155 units (26% 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, 2009, 2010, 2011, and 2012 are available on the project website ("Annual Reports"). With

59 (39%) of approximately 150 single family units complete in the southeast quadrant, 96 (64%) of approximately 150 family units complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2012, impervious surfaces (rooftops, sidewalks, driveways, and streets) still account for a relatively small proportion of the overall Sterling Ponds subdivision area. For example, the percent impervious area in the storm watershed draining to Site 5 in the southeast quadrant of Sterling Ponds (see 2012 build-out map) was only 11.8% (7.9 acres of 66.8 acres) in 2012, reflecting a build-out rate of 35.8% (53 of 148 lots). The percent impervious area and percent build-out rate for each of the nine project years are as follows:

2004:	7.9% Impervious	10.8% Build-out
2005:	9.1% Impervious	18.2% Build-out
2006:	9.5% Impervious	20.9% Build-out
2007:	11.1% Impervious	31.8% Build-out
2008:	11.5% Impervious	33.8% Build-out
2009:	11.7% Impervious	35.1% Build-out
2010:	11.7% Impervious	35.1% Build-out
2011:	11.7% Impervious	35.1% Build-out
2012:	11.8% Impervious	35.8% Build-out

2. Four wet storm water detention ponds were already in place in 2012, 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 2012. 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 2012 period (see 2012 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 2012, as required by the ordinance. Indeed, monitoring of the southeast storm water management practices in 2012 demonstrated excellent infiltration for 45 summer rain events, ranging in magnitude from 0.01-1.79 inches and totaling 14.14 inches (80% 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 2012 capably evaluated ordinance effectiveness and identified the storm water impacts related to five large 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.