City of River Falls
North Kinnickinnic River Monitoring Project

2010 Technical Review

Report prepared by SEH Inc., for the

City of River Falls Engineering Department
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Project Introduction:

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

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

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

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

The City 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, and biological impacts of new development will be undetectable or greatly reduced.

River Falls Precipitation:

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

During the 2010 monitoring season, the Sterling Ponds rain gauge was not functioning properly, and the Rocky Branch Elementary School rain gauge was not functioning at all; so the USGS rain gauge served as the source for daily rainfall data. The USGS rain gauge also provided very helpful information on the timing and intensity of rain events. 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. With the Rocky Branch Weather Station out of commission, the Automated Weather Source weather station at the Hudson Middle School (Hudson, WI) served as the alternate source of daily mean, minimum, and maximum air temperatures in the project area. This weather station is located approximately eight miles north of River Falls.

A total of 33.27 inches of precipitation was recorded in River Falls (at the USGS monitoring station) during the April-September 2010 period, 12.60 inches more than the normal total of 20.67 inches for the April-September time period (Figure 1). Rain fell on 69 days, or 38% of the April-September 2010 period. In comparison, a near-normal total of 19.82 inches of precipitation was recorded in River Falls during the April-September 2004 monitoring period, an above-normal total of 36.45 inches was measured during the April-September 2005 period, a below-normal total of 17.16 inches was measured during the April-September 2006 period, a below-normal total of 18.36 inches was measured during the April-September 2007 period, a near-normal total of 20.01 inches was measured during the April-September 2008 period, and an above-normal total of 24.44 inches was measured during the April-September 2009 period (Figure 1). “Normal” monthly and seasonal rainfall amounts are based upon measurements made by the National Weather Service at the Twin Cites International Airport during the “climate normal period” of 1971-2000. The April-September 2010 period (33.27 inches of rain) was the second-wettest since the start of the North Kinnickinnic River Monitoring Project in 2004, trailing only the April-September 2005 period (36.45 inches of rain).

Daily rainfall amounts during the April-September 2010 period are presented in Figure 2. Monthly rainfall amounts during the April-September 2010 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. All months during the April-September 2010 period were wetter than normal, with monthly rainfall excesses ranging from 0.42 inch to 3.78 inches. April and May were the driest months, while June and September were the wettest months. The combined rainfall in June and September accounted for 44% of the total April-September 2010 precipitation. The largest rain events of the summer occurred on June 25 (2.97 inches), August 10 (2.19 inches), and September 23 (2.58 inches) (Figure 2).

Through September 2009, the North Kinnickinnic River Monitoring Project Area was affected by a region-wide drought that began in early 2006 (see Figure 1). 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 in April and May, combined with an extremely wet June (Figure 3), brought drought conditions to an end by late July 2010. Above-normal precipitation in July and August, combined with a very wet September, kept drought conditions at bay for the duration of the summer (U.S. Drought Monitor, at http://www.drought.unl.edu/dm/index.html).

Besides being wetter than normal, the April-September 2010 monitoring period was warmer than normal. The mean air temperature in River Falls during the April-September 2010 period was 65.6º Fahrenheit (F), 2.4º F higher than the normal mean of 63.2º F for the April-September period, as measured at the Twin Cities International Airport. Monthly mean air temperatures during the April-September 2010 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1971-2000, are presented in Figure 4. The months of April, May, July, and August were all warmer than normal, with April (+7.6º F) and August (+5.3º F) experiencing the greatest departures. The temperature in June was near-normal, while the temperature in September was slightly cooler than normal.

The distribution of River Falls daily rainfall amounts during the April-September 2010 period is presented in Figure 5. On 35 (51%) of the 69 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 35 days contributed only 8% of the total April-September 2010 precipitation. Eighteen of these 35 days occurred in the cooler months of April, May, and September (Figure 6). On 10 (14%) of the 69 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 10 days contributed an additional 11% of the total April-September 2010 precipitation. Four of these 10 days occurred in April and May (Figure 6), when air temperatures were cooler. On 8 (12%) of the 69 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 8 days contributed 15% of the total April-September 2010 precipitation, primarily in April and May (Figure 6). On 7 (10%) of the 69 days with measurable precipitation, rainfall amounts ranged from 0.76-1.00 inch. These 7 days contributed 18% of the total April-September 2010 precipitation, primarily in July (2 days) and September (2 days) (Figure 6). On 9 (13%) of the 69 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. These 9 days with the largest rainfall events contributed 49% of the total April-September 2010 precipitation. Rainfall amounts in excess of 1 inch occurred on May 25 (1.72 inches), June 23 (1.44 inches), June 25 (2.97 inches), July 22 (1.67 inches), July 24 (1.16 inches), August 10 (2.19 inches), August 13 (1.39 inches), September 21 (1.25 inches), and September 23 (2.58 inches) (Figures 2 and 6). The 3 largest summer precipitation events, with rainfall amounts in excess of 2 inches, occurred on June 25 (2.97 inches), August 10 (2.19 inches), and September 23 (2.58 inches). The June 25 and August 10 events were produced by convective thunderstorm activity following warm days (high temperatures of 82 and 89° F, respectively). These two rainfall events were characterized by periods of very intense rainfall, with peak rainfall rates of 2.32 inches per hour during the June 25 storm and 1.49 inches per hour during the August 10 storm. The September 23 storm was an all-day event, with a peak rainfall rate of 0.58 inch per hour. These three largest rainfall events in June, August, and September contributed substantially to the above-normal rainfall amounts for these three months. Rainfall events in excess of 0.50 inch occurred on 24 days throughout the April-September 2010 period, with 2 events in April, 4 events in May, 4 events in June, 5 events in July, 4 events in August, and 5 events in September (Figure 2). These rainfall events in excess of 0.50 inch contributed 82% of the total April-September 2010 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 69 days with measurable precipitation during the April-September 2010 period, 64 days (93%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Infiltration of these 64 rain events (22.14 inches) would account for 67% of the total April-September precipitation (33.27 inches). Only the rainfall amounts on May 25 (1.72 inches), June 25 (2.97 inches), July 22 (1.67 inches), August 10 (2.19 inches), and September 23 (2.58 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 five rainfall events, thereby accounting for infiltration of 89% (29.64 inches) of the total rainfall (33.27 inches) that occurred during the April-September 2010 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 2010 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. Rainfall amounts in excess of 1 inch generally had the greatest influence on the April-September 2010 Kinnickinnic River hydrograph (Figure 8).

Abnormally dry conditions prevailed in the North Kinnickinnic River Monitoring Project Area through May 2010, yet above-normal precipitation was evident in both April and May (Figure 3). However, much of this precipitation fell in 18 small rain events (less than 0.50 inch) (Figure 2), which generated no significant runoff and had little influence on the Kinnickinnic River hydrograph (Figure 8), producing peak daily mean flows of 100 cfs or less.

A large rain event on May 25 (1.72 inches) produced the first significant runoff event of the 2010 monitoring season, with a peak daily mean flow of 111 cfs on May 26 (Figure 8). Two large, nearly back-to-back rain events on June 23 (1.44 inches) and June 25 (2.97 inches), followed by a smaller rain event on June 26 (0.80 inch), produced the second significant runoff event of the 2010 monitoring season, with a peak daily mean flow of 192 cfs on June 26 (Figure 8). In spite of 5.21 inches of rain during the June 23-26 period, the magnitude of this June runoff event was tempered by abnormally dry conditions, and partial canopy closure in the agricultural and forested areas of the watershed.

Two large, nearly back-to-back rain events on July 22 (1.67 inches) and July 24 (1.16 inches) produced the third significant runoff event of the 2010 monitoring season, with a peak daily mean flow of 129 cfs on July 24 (Figure 8). In spite of 2.83 inches of rain in 48 hours, only a moderate runoff event occurred, due to the relatively low intensity and extended duration of the larger rain event on July 22, as well as full canopy closure in the agricultural and forested areas of the watershed.

A very large rain event on August 10 (2.19 inches), which continued into August 11 (0.24 inch), produced the fourth significant (and largest) runoff event of the 2010 monitoring season, with a peak daily mean flow of 1,970 cfs on August 11 (Figure 8). A peak instantaneous flow of 4,340 cfs was measured at 05:30 CDT on August 11. The daily mean flow of 1,970 cfs was the highest summer flow recorded at the USGS monitoring station during the 1998-2010 period of record. Although rainfall occurred on two dates, a combined 2.43 inches of rain fell within a 24-hour period at the USGS monitoring station, with a peak rainfall intensity of 1.49 inches per hour. However, rainfall amounts at upstream locations in the Kinnickinnic River Watershed were much greater. As reported by the Minnesota Climatology Working Group (http://climate.umn.edu/), trained National Weather Service (NWS) observers recorded 24-hour rainfall amounts of 3.67 inches in River Falls, 3.46 inches one mile south-southwest of River Falls, and 5.07 inches three miles southeast of River Falls. Although unofficial, a River Falls resident recorded a 24-hour rainfall amount of 5.75 inches near the western edge of the city. According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), a 24-hour rain event of 3.72 inches in West Central Wisconsin has a 5-year recurrence interval, while a 24-hour rain event of 5.28 inches has a 25-year recurrence interval. The heavy rains on August 10-11 produced extensive flash flooding throughout the Kinnickinnic River Watershed, including River Falls. With Kinnickinnic River flow rapidly receding after the August 10-11 rain event, additional heavy rainfall (1.39 inches) on August 13 caused a secondary instantaneous flow peak of 324 cfs at 12:45 CDT on August 13.

Two large, nearly back-to-back rain events on August 31 (0.82 inch) and September 2 (0.88 inch) produced the fifth significant runoff event of the 2010 monitoring season, with a peak daily mean flow of 125 cfs on September 2. The moderate magnitude of this runoff event can be attributed to the relatively low intensity and extended duration of the larger rain event on September 2, full canopy closure, and extensive evapotranspiration in the agricultural and forested areas of the watershed.

Three consecutive days of heavy rainfall on September 21 (1.25 inches), September 22 (0.79 inch), and September 23 (2.58 inches) produced the sixth significant (and second-largest) runoff event of the 2010 monitoring season, with a peak daily mean flow of 656 cfs on September 24 (Figure 8). A peak instantaneous flow of 915 cfs was measured at 23:00 CDT on September 23. The daily mean flow of 656 cfs was the fourth-highest summer flow recorded at the USGS monitoring station during the 1998-2010 period of record. The magnitude of this runoff event can be attributed to the combined 4.62 inches of rain that fell within a 72-hour period. Substantial antecedent rainfall in August and the first half of September (7.35 inches) and very wet soil conditions were also contributing factors. According to the Rainfall Frequency Atlas of the Midwest (Huff and Angel, 1992), a 72-hour rain event of 4.36 inches in West Central Wisconsin has a 5-year recurrence interval.

The Kinnickinnic River hydrograph suggests that six significant runoff events occurred during the April-September 2010 period (Figure 8). Peak daily mean flows for all of these runoff events exceeded 110 cfs.

Two of the six 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. A large rain event on May 25 (1.72 inches) produced a 2-day runoff event (May 25-26), with a peak daily mean flow of 111 cfs. A succession of large rain events on June 23 (1.44 inches), June 25 (2.97 inches), and June 26 (0.80 inches) produced a 7-day runoff event (June 23-29), with a peak daily mean flow of 192 cfs.

Two of the six significant runoff events occurred in July and August, during the two warmest months of the year (Figure 4), when thermal impacts of storm water runoff can be a considerable concern. Nearly back-to-back rain events on July 22 (1.67 inches) and July 24 (1.16 inches) produced a 4-day runoff event (July 22-25), with a peak daily mean flow of 129 cfs. Large rain events on August 10-11 (a combined 2.43 inches) and August 13 (1.39 inches) produced a 6-day runoff event (August 11-16), with a peak daily mean flow of 1,970 cfs.

Two of the six significant runoff events occurred in September, when thermal impacts of storm water runoff remain a concern due to warmer air and water temperatures. Nearly back-to-back rain events on August 31 (0.82 inch) and September 2 (0.88 inch) produced a 5-day runoff event (August 31-September 4), with a peak daily mean flow of 125 cfs. Three consecutive days of heavy rainfall on September 21 (1.25 inches), September 22 (0.79 inch), and September 23 (2.58 inches) produced an 8-day runoff event (September 21-28), with a peak daily mean flow of 656 cfs.

The six runoff events in May, June, July, August, and September should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2010, and are further analyzed in this report.

With above-normal rainfall throughout the April-September 2010 period (Figure 3), and with drought conditions abating by the end of July 2010, Kinnickinnic River base flows remained very stable throughout the April-September period, generally ranging from 75-85 cfs, as measured at County Highway F (Figure 8). Base flows tended to be a bit lower (75-80 cfs) during the April-July period, and a bit higher (80-85 cfs) during the August-September period, after the two largest runoff events in mid-August and late September.

<u>Temperature Monitoring:</u>

In 2010, 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 2005-2010. The thermal impacts of Sumner Creek on the Kinnickinnic River, including any storm water contributions from Sterling Ponds, can be evaluated at this location.

Onset Computer Corporation's® HOBO Water Temp Pro Loggers are used to measure water temperature at all City of River Falls monitoring stations (Sites 1-6). A Ryan Instruments® RTM 2000 Temperature Logger was used to measure water temperature at the TU monitoring station at Quarry Road (Site 1A) through 2007. In 2008, 2009, and 2010, an Onset® StowAway TidbiT Logger was used to measure water temperature at Site 1A. Onset Computer Corporation's® Optic StowAway Templogger is used at the TU monitoring station in Sumner Creek (Site 4A). All Onset and Ryan temperature loggers are programmed to record temperatures at 10-minute intervals. Date and time stamps and the 10-minute temperature data are electronically recorded by each logger; and all recorded information is downloaded as necessary. The brief 10-minute time interval was selected so that any rapid temperature increases associated with warm storm water runoff could be 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 2010 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, 2010	Kinnickinnic River
Site 1A:	May 1-September 30, 2010	Kinnickinnic River
Site 2:	May 1-September 30, 2010	Kinnickinnic River
Site 3:	Logger Lost	Kinnickinnic River
Site 4:	May 1-September 30, 2010	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2010	Sumner Creek: Mouth
Site 5IN:	May 1-September 30, 2010	Sterling Ponds: Wet Pond Inlet
Site 5P:	May 1-September 30, 2010	Sterling Ponds: Wet Pond
Site 5IB:	May 1-September 30, 2010	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 1-September 30, 2010	Sterling Ponds: Wet Pond Outlet
Site 6:	No Deployment	Sumner Creek: Dry Box Culvert

The temperature logger deployed at Site 3 was lost during the course of the 2010 monitoring season, so no data are available for this site. The Site 6 temperature logger was not deployed in 2010. Water rarely flows through the Sumner Creek channel at this location, and several years of monitoring 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. The monitoring data from 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 storm water temperature influences wet pond temperature.

Kinnickinnic River Temperature Monitoring Results:

The May-September (summer) 2010 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 fluct uations in the river are natural, and the river's residents, including macroinvertebrates and trout, have become accustomed to a constantly but slowly changing temperature regime.

Also of note in the 2010 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 2010 period, for example, the monthly mean river temperature in the North Kinnickinnic River Project Area (Sites 1, 1A, and 2) was coolest in May (13.1 degrees Celsius (°C)) and warmest in July (17.0° C).

At Sites 1, 1A, and 2, river temperatures averaged 14.9° C and ranged from 6.6-23.8° C over the course of the summer. Monthly and summer mean temperatures at each of these three monitoring sites are presented in Figure 12. These monthly and summer mean temperatures were nearly identical at Sites 1 and 2, but slightly cooler at Site 1A.
Higher-than-normal river temperatures probably prevailed in the North Kinnickinnic River Project Area during the summer of 2010, since the 2010 summer average air temperature of 19.9º C (67.8º F) was notably higher than the normal summer average air temperature of 19.2° C (66.5° F). A comparison of 2004-2010 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 2010 summer average air temperature of 19.9º C was the second-highest summer average air temperature recorded in the North Kinnickinnic River Monitoring Project Area during the 2004-2010 period. Similarly, the 2010 summer average river temperature of 14.9º C (at Sites 1, 1A, and 2) was the second-highest summer average river temperature recorded during the 2004-2010 period. The warmest summer average river temperature was recorded in 2007 (15.2º C), while summer average river temperatures in 2004-2006 and 2008-2009 ranged from 13.8º-14.6º C.

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

A comparison of all upstream summer temperature data at Sites 1A and 2 to all downstream summer temperature data at Site 1 is presented in Figure 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 2010 (Figures 14-18, respectively). Figures 13-18 indicate that daily maximum temperatures tended to be slightly warmer at Site 1, while the daily minimum temperatures tended to be slightly cooler at Site 1A. Figure 12 shows that the monthly and summer mean temperatures at Sites 1, 1A, and 2 were also nearly identical. The following should be noted concerning aquatic life in the Kinnickinnic River:

1. Approximately 76% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2010 period were less than or equal to (≤) 17° C, which is considered to be the top of the optimum temperature range for a healthy coldwater macroinvertebrate community (Galli, 1990). A temperature of 17° C is considered to be the physiological optimum for brown trout survival (Armour, 1994).

2. Approximately 94% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2010 period were ≤ 19° C, which is considered to be the top of the optimum temperature range for brown trout growth (Armour, 1994).

3. Approximately 98% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2010 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 19.9º C), river temperatures exceeded 20º C on 4 dates in May, 3 dates in July, and 4 dates in August. Maximum air temperatures on these 11 dates were generally very warm-hot, ranging from 26-36º C (79-96° F) and averaging 32º C (90° F). River temperatures at Sites 1, 1A, and 2 exceeded 21º C on 2 dates in May, one date in July, and 2 dates in August. The temperature excursions beyond 21º C in May and July were short-lived, ranging from 3-4 hours on each date, and were caused by very warm-hot air temperatures (32-35º C / 89-95° F). Due to very heavy rainfall on August 10 and subsequent flood conditions on August 11-12, river temperatures at Sites 1, 1A, and 2 exceeded 21º C for a 24-hour period on August 11-12. This extended duration of warm water can be attributed to a combination of runoff from the Kinnickinnic River Watershed and hot air temperatures (33-34º C / 92-93° F). Maximum river temperatures on August 11 and August 12 were 23.8º C and 23.6º C, respectively.

During six significant rainfall and runoff events in May, June, July, August, and September 2010, thermographs at Sites 1 and 1A can be compared to determine if rapid temperature increases (thermal spikes), which are characteristic of warm storm water discharges, were apparent at Site 1.

No thermal spikes were evident at Site 1 in May (Figure 14), in spite of heavy rainfall (1.72 inches) and a significant runoff event during the May 25-26 period. A closer examination of the thermographs for Sites 1 and 1A during the May 25-26 runoff event

(Figure 19) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. Thermal spikes commonly occur at the Trout Unlimited temperature monitoring site at Division Street, due to the thermal impacts of direct storm water discharges from the downtown area of River Falls. Although a thermal spike was evident at Division Street during the May 25 rain event, the small magnitude of the spike (0.5º C) can be attributed to the extended duration of this rain event (3 hours) and the timing (late evening, when air and pavement temperatures were cooling).

No thermal spikes were evident at Site 1 in June (Figure 15). Large rain events on June 23 (1.44 inches) and June 25 (2.97 inches), and a smaller rain event on June 26 (0.80 inch) produced a significant runoff event during the June 23-27 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during the June 23-27 runoff event (Figure 20), no thermal spikes were evident at Site 1, while thermal spikes of 0.9º C, 2.7º C, and 1.4º C were evident at Division Street during the June 23, June 25, and June 26 rain events, respectively. The greater magnitude of the thermal spike on June 25 (2.7º C) can be attributed to a very warm antecedent air temperature (28º C / 82º F) and the timing of the event in the early evening, when air and pavement temperatures were still very warm.

No thermal spikes were evident at Site 1 in July (Figure 16). Large, nearly back-to-back rain events on July 22 (1.67 inches) and July 24 (1.16 inches) produced a significant runoff event during the July 22-24 period. A closer examination of the thermographs for Site 1, Site 1A, and Division Street during this runoff event (Figure 21) indicates that no thermal spikes occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while thermal spikes of 2.5º C and 1.3º C were evident at Division Street during the July 22 and July 24 rain events, respectively.

In August, no thermal spikes were evident at Site 1 during a moderate rain event on August 8 (0.55 inch) and during a large rain event on August 13 (1.39 inches) (Figure 17). However, the largest rain event of the year on August 10-11 (a combined 2.43 inches) produced significant thermal spikes at Sites 1, 1A, and 2 (Figure 17).

When the thermographs for Site 1, Site 1A, and Division Street are compared during the August 8 rain event (0.55 inch) (Figure 22), no thermal spikes were evident at Site 1, while very prominent thermal spikes (4.5º C and 2.9º C) were apparent at Division Street during two waves of rainfall in the early morning and late evening. The large magnitudes of these spikes can be attributed to short rainfall durations during both waves and very warm antecedent air temperatures on August 7 (32º C / 89º F) and August 8 (36º C / 96º F).

A supercell thunderstorm during the late evening hours of August 10 and the early morning hours of August 11 produced the largest rain event of the 2010 monitoring season. Rainfall began shortly before 19:30 CDT on August 10 and continued for a 5-hour period, until shortly after midnight. A peak rainfall intensity of 1.49 inches per hour was measured at the USGS monitoring station. A combined 2.43 inches of rain fell within a 24-hour period at the USGS monitoring station; however, trained National Weather Service (NWS) observers recorded 24-hour rainfall amounts of 3.67 inches in River Falls, 3.46 inches one mile south-southwest of River Falls, and 5.07 inches three miles southeast of River Falls. A 24-hour rain event of 3.72 inches in West Central Wisconsin has a 5-year recurrence interval, while a 24-hour rain event of 5.28 inches has a 25-year recurrence interval. A storm event of similar magnitude, with a 24-hour rainfall total of 4.74 inches, occurred on August 7-8, 2009. As anticipated, the August 10-11 rain event produced a very prominent thermal spike (3.6º C) at Division Street (Figure 22). However, thermal spikes were also apparent at all North Kinnickinnic River monitoring sites (Sites 1, 1A, and 2) (Figure 22), due to excessive runoff from nearby and upstream watershed areas. The heavy rainfall on August 10-11 produced extensive flash flooding throughout the Kinnickinnic River Watershed, including the North Kinnickinnic River Monitoring Project Area in River Falls. The Kinnickinnic River was deluged with warm water from the landscape, overwhelming the normal cold water regime present under base flow conditions. The very warm antecedent air temperature on August 10 (32º C / 89º F) was a significant factor contributing to the warmth of the runoff. Kinnickinnic River temperatures at all three monitoring locations began to rise simultaneously at 23:00 CDT on August 10, and initial thermal spikes (1.8º C, 0.9º C, and 2.7º C at Sites 1, 1A, and 2, respectively) occurred simultaneously at 24:00 CDT. These initial thermal spikes were likely due to runoff in the immediate vicinity of each monitoring site. Secondary thermal spikes (1.8º C, 2.6º C, and 1.0º C at Sites 1, 1A, and 2, respectively) occurred nearly simultaneously at 04:30 CDT on August 11. The secondary thermal spikes were likely due to runoff via an intermittent tributary which enters the Kinnickinnic River just upstream of Site 3. Warm runoff from this tributary caused the secondary thermal spike at the upstream site (Site 2) first, at 04:20 CDT, before affecting the two downstream sites (Sites 1A and 1) at 04:50 CDT. Tertiary thermal spikes (all 3.0º C) occurred nearly simultaneously at Sites 1, 1A, and 2 from 18:00-19:30 CDT on August 11, due to runoff from the remainder of the upstream watershed. River temperatures at Sites 1, 1A, and 2 peaked at 23.7º C, 23.6º C, and 23.8º C, respectively. Although watershed runoff was the major cause of the very warm river temperatures on August 11, a very warm air temperature (34º C / 93º F) likely contributed as well. River temperatures at all three monitoring sites remained above 20º C for 42 consecutive hours, above 21º C for 23 consecutive hours, above 22º C for 19 consecutive hours, and above 23º C for 12 consecutive hours. The thermographs at Sites 1, 1A, and 2 show no evidence that runoff from the Sterling Ponds subdivision and/or discharge from Sumner Creek created a downstream thermal impact at Site 1 during the August 10-11 rain event, since temperatures at all three sites were nearly identical throughout the duration of this event. Although Sumner Creek conveyed significant runoff, and a very prominent thermal spike (8.8º C) was evident at Site 4A during the August 10-11 rain event (see *Sumner Creek*, below), it is likely that the major flooding and warm water inundation on the mainstem of the Kinnickinnic River overwhelmed any thermal contribution from Sumner Creek.

When the thermographs for Site 1, Site 1A, and Division Street are compared during the large rain event (1.39 inches) on August 13 (Figure 22), no thermal spike was evident at Site 1, while a moderate thermal spike (1.7º C) was apparent at Division Street. The magnitude of this spike can be attributed to the short rainfall duration and very warm antecedent air temperature on August 12 (33º C / 92º F).

No thermal spikes were evident at Site 1 in September (Figure 18), in spite of two significant runoff events. Large, nearly back-to-back rain events on August 31 (0.82 inch) and September 2 (0.88 inch) produced a significant runoff event during the August 31-September 2 period. A closer examination of the thermographs for Site 1, Site 1A, and Division Street during this runoff event (Figure 23) indicates that no thermal spikes occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while thermal spikes of 1.9º C and 1.4º C were evident at Division Street on August 31 and September 2, respectively. Three consecutive days of heavy rainfall on September 21 (1.25 inches), September 22 (0.79 inch), and September 23 (2.58 inches) produced a significant runoff event during the September 21-24 period. When the thermographs for Site 1, Site 1A, and Division Street are compared during this runoff event (Figure 24), no thermal spikes were evident at Site 1, while thermal spikes ranging from 0.5º C - 2.8º C were apparent at Division Street.

While the presence of thermal spikes at Division Street is attributed to the thermal impacts of untreated storm water discharges to the Kinnickinnic River, the lack of thermal spikes at Site 1 during all 2010 runoff events (except the largest on August 10-11) could be attributed to several factors, including effective storm water management at the Sterling Ponds subdivision, or simply a lack of Sterling Ponds storm water discharges and/or storm water conveyance down Sumner Creek.

Sumner Creek and Sterling Ponds Temperature Monitoring Results:

<u>*Sumner Creek*</u>

Sumner Creek is a low-gradient tributary of the Kinnickinnic River that exhibits only intermittent flow for the majority of its length. Permanent flow begins in the vicinity of the WI Highway 35 bypass, near the creek confluence with the Kinnickinnic River (Site 4A). From this location, the creek drainage way extends upstream to Radio Road on the far northwest corner of River Falls. The upper portion of the Sumner Creek drainage way, including Sites 4 and 6, conveys no flow for the majority of the year. The headwaters area near Site 6 is a dry run. Downstream, however, rather extensive wetland areas are apparent in the Sumner Creek drainage way through the Sterling Ponds subdivision, and for an appreciable distance downstream of Site 4. Anecdotal evidence suggests that flow 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) 2010 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 12.2° C and ranged from 6.7-22.5° C during the May-September 2010 period. The summer mean temperature of Sumner Creek (12.2º C) was notably colder than the summer mean temperature of the Kinnickinnic River (14.9º C) at Sites 1, 1A, and 2, reflecting strong spring activity. Approximately 99% of all temperatures recorded at Site 4A during the May-September 2010 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). Temperatures exceeding 17° C were recorded during rain events on June 25, July 14, July 22, August 8, August 10-11, August 13, and August 31. The temperature excursions beyond 17º C were short-lived during six rain events, ranging from 2-8 hours. However, due to very heavy rainfall on August 10-11 and subsequent flood conditions on August 11-12, the Sumner Creek temperature at Site 4A exceeded 17º C for a 25-hour period on August 10-12. The stream temperature exceeded 22º C for a 6-hour period on August 11 and reached a maximum of 22.5º C.

Based upon the summer 2010 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 numerous thermal spikes that occurred at Site 4A during 15 rain events throughout the May-September period (Figure 25). These thermal spikes ranged from 2.8-8.8° C in magnitude and were caused by rain events ranging from 0.42-2.97 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 thermal spike (8.8º C) occurred on August 10-11, during the largest rain event of the 2010 monitoring season. Large rain events on June 25 and August 8 also produced significant thermal spikes of 5.5º C and 7.2º C, respectively. In spite of their frequency and magnitude, none of these thermal spikes had a discernible impact on Kinnickinnic River temperatures at Site 1, downstream from Sumner Creek (Figures 14-18). This was particularly true during the two largest runoff events of the 2010 monitoring season, on August 10-11 (Figure 26) and September 22-23 (Figure 27). However, thermal spikes of this frequency and magnitude may have detrimental impacts on aquatic life (especially macroinvertebrates) in lower Sumner Creek, as noted above.

Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2009. 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 the very large flood event on August 10-11. 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 the 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 2005-2010.

Sterling Ponds

The May-September (summer) 2010 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 28. At Site 5P, wet detention pond temperatures averaged 21.7° C and ranged from 10.5-30 .3° C during the summer period. Approximately 64% of all summer temperatures exceeded 20° C, and wet pond temperatures consistently remained above 20° C from June 17 until September 3. Substantial warming of small, shallow ponds such as this can be expected, especially with no shading or canopy cover. The summer mean temperature of the Sterling Ponds wet detention pond (21.7° C) was substantially higher than the summer mean temperature of Sumner Creek at Site 4A (12.2º C), clearly demonstrating the potential for thermal impact when the pond discharges to the creek, and emphasizing the importance of the River Falls Storm Water Management Ordinance, which requires storm water infiltration.

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

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

During the summer of 2010, the thermal performance of Sterling Ponds stormwater management practices can be evaluated monthly by comparing the Sterling Ponds and Sumner Creek thermographs. Performance of these stormwater management practices during the six significant rainfall and runoff events in May, June, July, August, and September is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). Only one of these six significant events (August 31-September 2) was characterized by a 24-hour rainfall amount 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 25, June 25, July 22, August 10, and September 23 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 2010 are presented in Figure 29. The month of May was slightly warmer and wetter than normal. Rainfall events (ranging from 0.01-1.72 inch) were recorded on fourteen dates, with one of the six significant summer rainfall events occurring on May 25 (Figure 2).

Due to a series of smaller rain events (0.02-0.55 inch) during the last week in April, the Sterling Ponds wet detention pond was already discharging to the Sterling Ponds infiltration basin on May 1. After a very small rain event on May 1 (0.01 inch), wet pond discharge to the infiltration basin continued until 13:10 CDT (1:10 PM) on May 1. During the May 2-6 period, no wet pond discharges occurred to the infiltration basin (Figure 29). Three very small rain events, totaling 0.06 inch, were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

During a moderate rain event (0.61 inch) on May 7, the wet detention pond once again began discharging to the infiltration basin at 14:30 CDT (2:30 PM). Wet pond discharge to the infiltration basin, due to the May 7 rain event and a subsequent series of five very small-moderate rain events (totaling 1.17 inches) during the May 8-13 period, continued for 9.0 days, until 15:40 CDT (3:40 PM) on May 16. During the May 17-24 period, no wet pond discharges occurred to the infiltration basin (Figure 29). Two very small rain events, totaling 0.21 inch, were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

The first of six significant summer rainfall events occurred on May 25. The comparative Sterling Ponds and Sumner Creek thermographs for the May 25 rain event (1.72 inches) are presented in Figure 30. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 21:30 CDT (9:30 PM) on May 25, shortly after the onset of heavier rainfall at 20:00 CDT (8:00 PM). Wet pond discharge to the infiltration basin, due to the May 25 rainfall event and a subsequent large rain event (0.80 inch) on May 30, continued through the end of May. No wet pond discharge to Sumner Creek was evident during the May 25 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 30). The magnitude of the May 25 rain event (1.72 inches) slightly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet the entire event was captured in the wet pond and infiltrated. After the May 25 rain event began, two small thermal spikes (2.6° C and 2.2° C) occurred in lower Sumner Creek at Site 4A. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause. The initial thermal spike (2.6° C) occurred shortly after the rain event began, and may be attributed to storm water runoff from WI Highway 35, located immediately upstream from Site 4A. A secondary thermal spike (2.2° C) occurred two hours after the first, and may have been caused by a slow release of warm water from natural wetland areas in the upstream Sumner Creek drainage way.

The entire May rainfall amount of 4.58 inches (Figure 3) was captured in the Sterling Ponds wet pond or infiltrated in the Sterling Ponds infiltration basin.

June

The comparative Sterling Ponds thermographs for June 2010 are presented in Figure 31. The month of June was slightly cooler but much wetter than normal. Rainfall events (ranging from 0.02-2.97 inches) were recorded on sixteen dates, with one of the six significant summer rainfall events occurring on June 25 (Figure 2).

Due to the two large rain events during the last week in May (1.72 inches on May 25 and 0.80 inch on May 30), the Sterling Ponds wet detention pond was already discharging to the Sterling Ponds infiltration basin on June 1. After small rain events on June 1 (0.18 inch) and June 2 (0.03 inch), wet pond discharge to the infiltration basin continued until 20:20 CDT (8:20 PM) on June 2.

During a moderate rain event (0.41 inch) on June 4, the wet detention pond once again began discharging to the infiltration basin at 04:20 CDT (4:20 AM). Wet pond discharge to the infiltration basin continued throughout the entire 21-day period from June 4-24, due to frequent (eleven) rain events ranging from 0.02-1.44 inches and totaling 4.05 inches. The very large rain event on June 23 (1.44 inches) resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin, as indicated by the rapidly increasing temperature at Site 5IB at 06:20 CDT (6:20 AM), shortly after the onset of heavier rainfall at 03:00 CDT (3:00 AM). However, no wet pond discharge to Sumner Creek was evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A (Figure 32). The magnitude of the June 23 rain event (1.44 inches) was slightly less than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; and this event was captured in the wet pond and infiltrated.

The second of six significant summer rainfall events occurred on June 25. The comparative Sterling Ponds and Sumner Creek thermographs for the June 25 rain event (2.97 inches) are presented in Figure 32. With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the very large rain event on June 23, the June 25 rain event resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin, as indicated by the rapidly increasing temperature at Site 5IB at 19:20 CDT (7:20 PM), shortly after the onset of heavier rainfall at 18:30 CDT (6:30 PM). With very intense rainfall continuing at 19:00 CDT (7:00 PM), the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 20:10 CDT (8:10 PM), as indicated by the nearly identical temperatures at Sites 5P and 5MHW (Figure 32). Wet pond discharge to the Sumner Creek drainage way continued for 3.5 hours, until 23:40 CDT (11:40 PM). During this 3.5-hour period, the wet pond discharge temperature averaged 22.6º C and ranged from 21.4-23.4º C. Wet pond discharge to the Sumner Creek drainage way was likely influenced by the great magnitude and short duration of the June 25 rainfall event. With the majority of the rain falling in a 2.5-hour period, and with the wet detention pond continuing to discharge to the infiltration basin after the June 23 rain event, the wet pond was quickly inundated with storm water. Wet pond inflow simply exceeded outflow to the infiltration basin, with the excess water discharged through the outlet structure. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. Field observations during a large rainfall event in July 2008 indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the Sterling Ponds wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. Indeed, the brief wet pond discharge to the Sumner Creek drainage way after the June 25 rain event caused no thermal spike downstream at Site 4 (Figure 32). The very prominent thermal spike (5.5º C) evident near the mouth of Sumner Creek (Site 4A) at 21:20 CDT (9:20 PM) on June 25 (Figure 32) cannot be attributed to the Sterling Ponds storm water discharge, since the spike at Site 4A, located 1.5 miles downstream, occurred shortly after the storm water discharge began. It seems apparent that the thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35. Warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way may have contributed to the extended duration of this thermal spike at Site 4A, until 10:20 CDT (10:20 AM) on June 26. Sterling Ponds wet pond discharge to the infiltration basin, due to the June 25 rain event, a subsequent large rain event (0.80 inch) on June 26, and a very small rain event (0.03 inch) on June 27, continued through the end of June.

All rainfall during the June 1-23 and June 26-27 periods (15 events ranging from 0.02-1.44 inches and totaling 5.09 inches) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the June 25 rain event (2.97 inches) was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on June 25, the duration of this discharge was quite short (3.5 hours), compared to the duration of discharge to the infiltration basin, which continued through the end of June.

July

The comparative Sterling Ponds thermographs for July 2010 are presented in Figure 33. The month of July was warmer than normal, with above-normal precipitation. Rainfall events (ranging from 0.01-1.67 inches) were recorded on ten dates, with one of the six significant summer rainfall events occurring on July 22 (Figure 2).

Due to the two large rain events during the last week in June (2.97 inches on June 25 and 0.80 inch on June 26), the Sterling Ponds wet detention pond was already discharging to the Sterling Ponds infiltration basin on July 1. Infiltration of these two large rain events continued until 21:30 CDT (9:30 PM) on July 1 (Figure 33).

A small rain event (0.25 inch) on July 4 was captured in the Sterling Ponds wet detention pond. During a large rain event (0.97 inch) on July 5, the wet detention pond once again began discharging to the infiltration basin at 22:40 CDT (10:40 PM), shortly after the onset of heavier rainfall at 21:45 CDT (9:45 PM). Due to the July 5 rain event and subsequent very small rain events on July 6 (0.06 inch) and July 7 (0.01 inch), wet pond discharge to the infiltration basin continued until 08:20 CDT (8:20 AM) on July 10 (Figure 33). A small rain event (0.07 inch) on July 11 caused a relatively brief discharge from the Sterling Ponds wet detention pond to the infiltration basin, beginning at 17:00 CDT (5:00 PM) on July 11 and ending at 06:00 CDT (6:00 AM) on July 13.

During a large rain event (0.81 inch) on July 14, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 11:30 CDT (11:30 AM), shortly after the onset of rainfall at 10:00 CDT (10:00 AM). Due to the July 14 rain event and a subsequent moderate rain event (0.42 inch) on July 17, wet pond discharge to the infiltration basin continued through July 21 (Figure 33).

The third of six significant summer rainfall events occurred on July 22. The comparative Sterling Ponds and Sumner Creek thermographs for the July 22 rain event (1.67 inches) are presented in Figure 34. With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the rain events on July 14 and July 17, the July 22 rain event resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin. The increased discharge is indicated by the nearly identical temperatures at Site 5P and Site 5IB at 07:50 CDT (7:50 AM), after 0.49 inch of rain had fallen from 03:00 CDT (3:00 AM) to 07:45 CDT (7:45 AM). Wet pond discharge to the infiltration basin, due to the July 22 rainfall event, a large rain event (1.16 inches) on July 24, and a moderate rain event (0.51 inch) on July 27, continued through the end of July. No wet pond discharge to Sumner Creek was evident during the July 22 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 34). The magnitude of the July 22 rain event (1.67 inches) slightly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet the entire event was captured in the wet pond and infiltrated. Shortly after the July 22 rain event ended, a very prominent thermal spike (4.7º C) was evident in lower Sumner Creek (Site 4A) at 12:50 CDT (12:50 PM) (Figure 34). Smaller thermal spikes of 3.3º C and 2.9º C were also apparent at Site 4A after the July 24 and July 27 rain events, respectively. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause.

The entire July rainfall amount of 5.93 inches (Figure 3) was captured in the Sterling Ponds wet pond or infiltrated in the Sterling Ponds infiltration basin.

August

The comparative Sterling Ponds thermographs for August 2010 are presented in Figure 35. The month of August was much warmer than normal, with above-normal precipitation. Rainfall events (ranging from 0.01-2.19 inches) were recorded on ten dates, with one of the six significant summer rainfall events occurring on August 10 (Figure 2).

Due to the two rain events during the last week in July (1.16 inches on July 24 and 0.51 inch on July 27), the Sterling Ponds wet detention pond was already discharging to the

Sterling Ponds infiltration basin on August 1. With subsequent small rain events occurring on August 2 (0.05 inch), August 3 (0.02 inch), and August 4 (0.21 inch), wet pond discharge to the infiltration basin continued through August 7.

A moderate rainfall event on August 8 (0.55 inch) occurred in two “waves” during the early morning and evening, with 0.52 inch recorded from 01:45-03:15 CDT (1:45-3:15 AM) and 0.03 inch recorded from 19:45-20:30 CDT (7:45-8:30 PM). With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the rain events in late July and early August, the first wave of rainfall (0.52 inch) on August 8 resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin (Figure 36). The increased discharge is indicated by the rapidly increasing temperature at Site 5IB at 02:20 CDT (2:20 AM), shortly after the onset of heavier rainfall at 01:45 CDT (1:45 AM). In spite of the apparently moderate amount of rainfall (0.52 inch) and relatively low intensity (0.42 inch per hour) during the first wave, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 03:00 CDT (3:00 AM) on August 8, as indicated by the nearly identical temperatures at Sites 5P and 5MHW (Figure 36). Wet pond discharge to the Sumner Creek drainage way continued for 12.5 hours, until 15:30 CDT (3:30 PM). During this 12.5-hour period, the wet pond discharge temperature averaged 24.7º C and ranged from 24.2-25.3º C. The second wave of rainfall (0.03 inch) on August 8 also resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin (Figure 36). The increased discharge is indicated by the rapidly increasing temperature at Site 5IB at 19:50 CDT (7:50 PM), shortly after the onset of rainfall at 19:45 CDT (7:45 PM). In spite of the apparently very small amount of rainfall during the second wave, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 20:10 CDT (8:10 PM) on August 8, as indicated by the nearly identical temperatures at Sites 5P and 5MHW (Figure 36). Wet pond discharge to the Sumner Creek drainage way continued for 2.7 hours, until 22:50 CDT (10:50 PM). During this 2.7-hour period, the wet pond discharge temperature averaged 25.4º C and ranged from 24.1-25.8º C. The wet pond discharges to the Sumner Creek drainage way after the two waves of rainfall on August 8 caused no thermal spikes downstream at Site 4 (Figure 36). However, very prominent thermal spikes (7.2º C and 5.5º C) were evident near the mouth of Sumner Creek (Site 4A) at 04:20 CDT (4:20 AM) and 21:30 CDT (9:30 PM) on August 8 (Figure 36). These thermal spikes at Site 4A cannot be attributed to the storm water discharges at Sterling Ponds, since they occurred shortly after the storm water discharges began, and no thermal spikes were apparent at Site 4, located 1.5 miles upstream. The thermal spikes at Site 4A had a more “local” cause, perhaps including storm water runoff from WI Highway 35. With the Sterling Ponds wet detention pond discharging to the Sumner Creek drainage way during both waves of rainfall on August 8, it is highly likely that the rainfall amounts measured at the USGS monitoring station did not accurately represent the rainfall amounts that occurred in River Falls, five miles to the east. Several lines of evidence suggest that this was the case. At 20:19 CDT (8:19 PM) on August 8, a trained National Weather Service (NWS) observer in River Falls reported that 0.94 inch of rain fell in 37-minutes. This amount is substantially greater than the amount (0.03 inch) recorded at the USGS monitoring station during the same time period. The magnitude of rainfall in River Falls (0.94 inch) and the high intensity rate (1.52 inches per hour) provide a better explanation for the Sterling Ponds wet detention pond discharge to the Sumner Creek drainage way during the second wave of rainfall. The presence and great magnitudes of the thermal spikes at Site 4A during both waves of rainfall also suggest that more rain fell in River Falls during both waves, compared to the amounts recorded at the USGS monitoring station.

The fourth (and largest) of the six significant summer rainfall events occurred on August 10-11. A combined total of 2.43 inches of rain fell at the USGS monitoring station in a 24-hour period, including 2.19 inches of rain on August 10 and 0.24 inch of rain on August 11. However, trained National Weather Service (NWS) observers recorded much higher 24-hour rainfall amounts (3.46-5.07 inches) within a 3-mile radius of River Falls. The comparative Sterling Ponds and Sumner Creek thermographs for the August 10-11 rain event are presented in Figure 37. With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the large rain event on August 8, the August 10-11 rain event resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin (Figure 37). The increased discharge is indicated by the nearly identical temperatures at Site 5P and Site 5IB at 21:30 CDT (9:30 PM), shortly after the onset of heavier rainfall at 21:15 CDT (9:15 AM). The Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 23:30 CDT (11:30 PM) on August 10, as indicated by the nearly identical temperatures at Sites 5P and 5MHW (Figure 37). Wet pond discharge to the Sumner Creek drainage way continued for 20 hours, until 19:30 CDT (7:30 PM) on August 11. During this 20-hour period, the wet pond discharge temperature averaged 25.0º C and ranged from 24.2-26.7º C. Wet pond discharge to the Sumner Creek drainage way was likely influenced by the great magnitude and short duration of the August 10-11 rainfall event. With the majority of the rain falling in a 4-hour period, and with the wet detention pond already near maximum capacity due to the August 8 rain event, the wet pond was quickly inundated with storm water. Wet pond inflow simply exceeded outflow to the infiltration basin, with the excess water discharged through the outlet structure. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. Field observations during a large rainfall event in July 2008 indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the Sterling Ponds wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. However, a small thermal spike (1.6º C) was apparent downstream at Site 4 in Sumner Creek after the August 10-11 rain event (Figure 37). Warmer water began flowing at Site 4 at 02:20 CDT (2:20 AM) on August 11 and continued flowing for 6 hours, until 08:20 CDT (8:20 AM). During this 6-hour period, the temperature of Sumner Creek at Site 4 averaged 23.2º C and ranged from 22.7-23.6º C. The Sterling Ponds wet pond discharge to the Sumner Creek drainage way likely contributed to the warm water flow at Site 4 on August 11. However, given the magnitude and intensity of the August 10-11 rain event, the release of warm water from natural wetland areas in the upstream Sumner Creek drainage way may also have contributed to the warm water flow at Site 4. The very prominent thermal spike (8.8º C) evident near the mouth of Sumner Creek (Site 4A) at 00:40 CDT (0:40 AM) on August 11 (Figure 37) cannot be attributed to the Sterling Ponds storm water discharge, since the spike at Site 4A, located 1.5 miles downstream, occurred shortly after the storm water discharge began, and two hours before the thermal spike was evident at Site 4. It seems apparent that the thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35 and/or warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way. However, the "plug" of warm water passing through Site 4 on August 11, including the warm water discharged from the Sterling Ponds wet pond, may have contributed to the secondary thermal spike (2.3º C) at Site 4A at 12:50 CDT (12:50 PM) on August 11. Sterling Ponds wet pond discharge to the infiltration basin, due to the August 10-11 rainfall event, a large rain event (1.39 inches) on August 13, and a very small rain event (0.01 inch) on August 14, continued until 09:00 CDT (9:00 AM) on August 20 (Figure 35). No wet pond discharge to Sumner Creek was evident during the large rain event on August 13, as documented by the temperature data at Site 5MHW, and no thermal spike was apparent in Sumner Creek at Site 4 (Figure 37). During the August 13 rain event, a very prominent thermal spike (4.8° C) was apparent at Site 4A (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.

A very small rain event (0.02 inch) on August 24 was captured in the Sterling Ponds wet pond, with no wet pond discharge to the infiltration basin (Figure 35). During a large rain event (0.82 inch) on August 31, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 05:00 CDT (5:00 AM), shortly after the onset of heavy rainfall at 04:15 CDT (4:15 AM). Due to the August 31 rain event, wet pond discharge to the infiltration basin continued through September 1 (Figure 38).

All rainfall during the August 1-4 and August 13-31 periods (7 events ranging from 0.01-1.39 inches and totaling 2.52 inches) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the August 8 and August 10-11 rainfall events (a combined 2.98 inches) was also infiltrated. Although three wet pond discharges to the Sumner Creek drainage way occurred on August 8 and August 10-11, the combined duration of these discharges was relatively short (35 hours), compared to the duration of discharge to the infiltration basin (a minimum of 63 hours).

September

The comparative Sterling Ponds thermographs for September 2010 are presented in Figure 38. The month of September was slightly cooler and much wetter than normal. Rainfall events (ranging from 0.02-2.58 inches) were recorded on nine dates, with two of the six significant summer rainfall events occurring on August 31-September 2 and September 23 (Figure 2).

Due to the large rain event (0.82 inch) on August 31, the Sterling Ponds wet detention pond was already discharging to the Sterling Ponds infiltration basin when the second large rain event (0.88 inch) occurred on September 2. Wet pond discharge to the infiltration basin, due to the September 2 rain event and a very small rain event (0.08 inch) on September 6, continued until 19:20 CDT (7:20 PM) on September 8 (Figure 38).

No wet pond discharges to Sumner Creek were evident during the large, nearly back-to-back rain events on August 31 and September 2, as documented by the temperature data at Site 5MHW (Figures 35 and 38), and no thermal spikes were apparent in Sumner Creek at Site 4. During the August 31 and September 2 rain events, prominent thermal spikes (4.3° C and 3.0° C, respectively) were apparent at Site 4A (Figure 25). However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause.

Very small rain events on September 10 (0.09 inch) and September 11 (0.02 inch) were captured in the Sterling Ponds wet pond, with no wet pond discharge to the infiltration basin (Figure 38). During a moderate rain event (0.75 inch) on September 15, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 13:50 CDT (1:50 PM), shortly after the onset of rainfall at 12:15 CDT (12:15 PM). Due to the September 15 rain event and a very small rain event (0.03 inch) on September 16, wet pond discharge to the infiltration basin continued through September 20 (Figure 38).

A consecutive series of large (1.25 inch), moderate (0.79 inch), and very large (2.58 inch) rain events on September 21, 22, and 23, respectively, produced the second-largest runoff event of the 2010 monitoring season, with a peak daily mean flow of 656 cfs measured at the USGS monitoring station on September 24 (Figure 8).

With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the moderate rain event on September 15, the September 21 rain event (1.25 inches) resulted in a continuing but reinforced (increased) discharge from the wet pond to the infiltration basin (Figure 39). The increased discharge is indicated by the nearly identical temperatures at Site 5P and Site 5IB at 03:10 CDT (3:10 AM), shortly after the onset of heavier rainfall at 02:15 CDT (2:15 AM). No wet pond discharge to Sumner Creek was evident during the September 21 rain event, as documented by the temperature data at Site 5MHW (Figure 39), and no thermal spike was apparent in Sumner Creek at Site 4. A small thermal spike (2.0° C) was apparent at Site 4A at 05:10 CDT (5:10 AM) (Figure 39). However, this thermal spike cannot be attributed to a storm water discharge at Sterling Ponds, and seemed to have a more local cause. Sterling Ponds wet detention pond discharge to the infiltration basin continued during the moderate rain event (0.79 inch) on September 22.

The last of the six significant summer rainfall events occurred on September 23, when 2.58 inches of rain fell in a 24-hour period. The comparative Sterling Ponds and Sumner Creek thermographs for the September 23 rain event are presented in Figure 39. With the Sterling Ponds wet detention pond already discharging to the infiltration basin after the rain events on September 21 and September 22, the September 23 rain event resulted in a continuing discharge from the wet pond to the infiltration basin (Figure 39). In addition, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 00:00 CDT (0:00 AM) on September 23, as indicated by the identical temperatures at Sites 5P and 5MHW (Figure 39). Wet pond discharge to the Sumner Creek drainage way continued for 34.5 hours, until 10:30 CDT (10:30 AM) on September 24. During this 34.5-hour period, the wet pond discharge temperature averaged 17.2º C and ranged from 16.4-18.2º C. The onset of wet pond discharge to the Sumner Creek drainage way on September 23 was clearly caused by the magnitude of rainfall during the preceding 48-hour period (a combined 2.04 inches on September 21 and September 22). With the wet detention pond already at maximum capacity and rainfall continuing after midnight on September 22, wet pond inflow simply exceeded outflow to the infiltration basin, and the excess water was discharged through the outlet structure. The extended duration of the wet pond discharge to the Sumner Creek drainage way (34.5 hours) can be attributed to the great magnitude of rainfall (2.58 inches) on September 23, as well as the very extended (all-day) duration. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. Field observations during a large rainfall event in July 2008 indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the Sterling Ponds wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. However, a moderate thermal spike (4.4º C) was apparent downstream at Site 4 in Sumner Creek during the September 23 rain event (Figure 39). Due to the September 22 rain event, warmer water began flowing at Site 4 at 21:10 CDT (9:10 PM) on September 22. Due to heavy rainfall on September 23, warmer water continued flowing at Site 4 for 41 hours, until 14:10 CDT (2:10 PM) on September 24. During this 41-hour period, the temperature of Sumner Creek at Site 4 averaged 16.2º C and ranged from 13.4-18.9º C. The Sterling Ponds wet pond discharge to the Sumner Creek drainage way likely contributed to the warm water flow at Site 4 on September 22-24. However, given the magnitude of the September 23 rain event and considerable antecedent rainfall on September 21-22, the release of warm water from natural wetland areas in the upstream Sumner Creek drainage way also contributed to the warm water flow at Site 4. The small thermal spike (3.1º C) evident near the mouth of Sumner Creek (Site 4A) at 03:10 CDT (3:10 AM) on September 23 (Figure 39) cannot be attributed to the Sterling Ponds storm water discharge, since the spike at Site 4A, located 1.5 miles downstream, occurred shortly after the storm water discharge began. It seems apparent that the thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35 and/or warm water flowing from natural wetland or storage areas immediately upstream in the Sumner Creek drainage way. How ever, the "plug" of warm water passing through Site 4 on September 22-24, including the warm water discharged from the Sterling Ponds wet pond on September 23-24, may have contributed to the secondary thermal spike (3.5º C) at Site 4A at 21:20 CDT (9:20 PM) on September 23. Sterling Ponds wet pond discharge to the infiltration basin, due to the September 21-23 rain events, continued through the end of September (Figure 38).

All rainfall during the September 1-22 period (8 events ranging from 0.02-1.25 inches and totaling 3.89 inches) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the September 23 rainfall event (2.58 inches) was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on September 23-24, the duration of this discharge was relatively short (1.4 days), compared to the duration of discharge to the infiltration basin (a minimum of 8.0 days).

Effectiveness of Sterling Ponds Storm Water Management Practices:

2010 Performance Assessment

During the May-September (summer) 2010 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 very large rain event on June 25 (2.97 inches), a moderate rain event on August 8 (0.55 inch), a very large rain event on August 10-11 (a combined 2.43 inches), and a very large rain event on September 23 (2.58 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River Falls Storm Water Management Ordinance. These 54 rain events, ranging in magnitude from 0.01-1.72 inch, represent a total of 22.01 inches of precipitation, or 72% of the total summer rainfall amount (30.54 inches). Of these 54 rain events, 9 events, ranging in magnitude from 0.01-0.25 inches and totaling 0.65 inch of precipitation (2% 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 45 remaining summer rain events, ranging in magnitude from 0.01-1.72 inches and totaling 21.36 inches of precipitation (70% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin. Due to much greater than normal rainfall and the frequency of rainfall during the May-September (summer) 2010 period, the Sterling Ponds wet detention pond discharged to the infiltration basin for 112 days, or 73% of the summer period.

All 24 rainfall events in May and July were stored in the wet detention pond or diverted to the infiltration basin. These events ranged from 0.01-1.72 inches in magnitude and represented monthly totals of 4.58 and 5.93 inches, respectively, or 34% of the total summer rainfall amount. Fifteen small-to-large rain events in June, ranging from 0.02-1.44 inches and totaling 5.09 inches, were either infiltrated or stored in the wet detention pond. These June rain events represented 17% of the total summer rainfall. Seven small-to-large rain events in August, ranging from 0.01-1.39 inches and totaling 2.52 inches, were either infiltrated or stored in the wet detention pond. These August rain events represented 8% of the total summer rainfall. Eight small-to-large rain events in September, ranging from 0.02-1.25 inches and totaling 3.89 inches, were either infiltrated or stored in the wet detention pond. These September rain events represented 13% of the total summer rainfall.

The Sterling Ponds wet detention pond only discharged 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). 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 June 25 was triggered by the great magnitude (2.97 inches) and short duration of the June 25 rainfall event. With the majority of the rain falling in a 2.5-hour period, and with the wet detention pond already discharging to the infiltration basin after a large antecedent rain event (1.44 inches) on June 23, 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. Although a wet pond discharge to the Sumner Creek drainage way occurred on June 25, the duration of this discharge was quite short (3.5 hours), compared to the duration of discharge to the infiltration basin, which continued through the end of June. 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.

Two Sterling Ponds wet pond discharges to the Sumner Creek drainage way during two waves of rainfall on August 8 were likely triggered by the magnitude and intensity of rainfall. It is highly likely that the rainfall amount (0.55 inch) measured at the USGS monitoring station on August 8 did not accurately represent the rainfall amount that occurred in River Falls, five miles to the east. A trained National Weather Service (NWS) observer in River Falls reported that 0.94 inch of rain fell in 37 minutes during the second wave of rainfall in the evening. Although two wet pond discharges to the Sumner Creek drainage way occurred on August 8, the combined duration of these discharges was quite short (15 hours), compared to the duration of discharge to the infiltration basin (67 hours) prior to the very large rain event on August 10-11. 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 Sterling Ponds wet pond discharge to the Sumner Creek drainage way on August 10-11 was triggered by the great magnitude (a combined 2.43 inches) and short duration of the August 10-11 rainfall event. With the majority of the rain falling in a 4-hour period, and with the wet detention pond already near maximum capacity and discharging to the infiltration basin after the large antecedent rain event on August 8, 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. Although a wet pond discharge to the Sumner Creek drainage way occurred on August 10-11, the duration of this discharge was quite short (20 hours), compared to the duration of discharge to the infiltration basin (56 hours) prior to the next large rain event (1.39 inches) on August 13. 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 Sterling Ponds wet pond discharge to the Sumner Creek drainage way on September 23-24 was clearly caused by the magnitude of antecedent rainfall during the preceding 48 -hour period (a combined 2.04 inches on September 21 and September 22), along with very heavy rainfall (2.58 inches) on September 23. With the wet detention pond already at maximum capacity on September 23, wet pond inflow simply exceeded outflow to the infiltration basin, and the excess water was discharged through the outlet structure. The extended duration of the wet pond discharge to the Sumner Creek drainage way (34.5 hours) can be attributed to the great magnitude and very extended (all-day) duration of rainfall on September 23. Although a wet pond discharge to the Sumner Creek drainage way occurred on September 23-24, the duration of this discharge was quite short (34.5 hours), compared to the duration of discharge to the infiltration basin, which continued through the end of September. Since the storm water volumes discharged to the infiltration basin and Sumner Creek were not measured, it is not possible to precisely determine the amounts of storm water infiltrated versus discharged.

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 54 summer rain events, ranging in magnitude from 0.01-1.72 inches. All runoff from these events was stored or infiltrated. Of these 54 summer rain events, two rain events on May 25 (1.72 inches) and July 22 (1.67 inches) clearly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance; yet these two events were entirely infiltrated. Excessive rainfall on June 25 (2.97 inches), August 10-11 (2.43 inches), and September 23 (2.58 inches) caused storm water discharges to the Sumner Creek drainage way; but the 24-hour rainfall amounts for these three storms greatly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance. Rainfall on August 8 also caused a storm water discharge to the Sumner Creek drainage way. However, due to the lack of accurate rainfall data for River Falls, it is not possible to determine if the August 8 rainfall amount exceeded the 1.5-inch infiltration standard.

Temperature monitoring of all 2005-2010 summer rain events has revealed some performance issues and possible opportunities for improvement of the current Sterling Ponds storm water management practices and/or revision of the storm water management ordinance. Those performance issues are summarized below.

2005-2006 Performance Issues

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

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

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

2007 Performance Modeling and Wet Pond Outlet Modification

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

2007 Performance Issues

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

The largest rain event of the summer on August 27 (1.72 inches) exceeded the 1.5-inch ordinance requirement for infiltration, as did six rain events in 2005 and 2006 that also delivered storm water to Sumner Creek. During the 2005 and 2006 rain events, the Sterling Ponds wet pond released storm water to Sumner Creek shortly after the onset of discharge to the infiltration basin, with lag times as short as 10 minutes. Storm water discharges to the creek also occurred for extended time periods ranging from 4-14 hours.

In contrast, the August 27, 2007 rain event produced a longer lag time (1 hour) and a relatively short discharge time (4 hours). Based upon this single 2007 rain event, it seems that the modification of the wet pond outlet structure may have provided more storm water storage and infiltration, including early in the rain event, when first-flush temperature and water quality impacts are more significant.

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

2008 Performance Issues

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

2009 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2009 indicated that warm storm water was discharged from the wet pond to Sumner Creek during large back-to-back rain events on August 7-8 (a combined 4.74 inches within 24 hours). Wet pond discharge to Sumner Creek during the very large rain event on August 8 (3.76 inches) was likely due to several factors. A large, antecedent rain event on August 7 (0.98 inch) significantly reduced the storage capacity in the wet detention pond, which had only been discharging to the infiltration basin for 13.5 hours when heavy rain began on August 8. Other factors triggering wet pond discharge to Sumner Creek include the extreme magnitude (3.76 inches), high intensity, and short (4-hour) duration of the August 8 rain event. Due to these factors, no time lag occurred between the onset of additional wet pond discharge to the infiltration basin and the onset of discharge to Sumner Creek; hence no first-flush abatement of temperature and water quality impacts was possible for the August 8 event. The excessive rainfall (4.74 inches) within a 24-hour period on August 7-8 (a once in 15-year rain event) contributed to the very lengthy (15-hour) wet pond discharge to Sumner Creek. Given that the rainfall amount on August 8 (3.76 inches) and the 24-hour rainfall total on August 7-8 (4.74 inches) greatly exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, given the back-to-back nature of the August 7-8 rain events, and given the intensity of the August 8 rain event, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances. In spite of the great magnitude of the August 7-8 rain events (4.74 inches), wet pond delivery to the infiltration basin (infiltration time) was relatively short (5.0 days), allowing the wet pond to quickly regain the capacity to capture and fully infiltrate the next large rain events on August 19 (0.88 inch) and August 20 (0.97 inch). Also of positive note in 2009 is that the very large rain events on July 21 (2.25 inches) and August 25 (2.45 inches), which clearly exceeded the 1.5-inch ordinance requirement, were both fully infiltrated. The ability to capture and infiltrate these two large events can probably be attributed to modification (elevation) of the wet pond outlet structure in 2007, which created more storage capacity in the wet pond.

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 circumstances contributing to these wet pond discharges to Sumner Creek are detailed in the *2010 Performance Assessment* above.

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. 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 National Weather Service (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 hours 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 2005-2010 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.

Summary

Temperature monitoring of the Sterling Ponds storm water management practices during the 2005-2010 period indicates that storm water discharges to Sumner Creek are occurring:

- During rain events larger than 1.5 inches (2005-2007 and 2009-2010);
- During back-to-back rain events, when rainfall amounts range from 1.0-1.5 inches and time periods between rain events are less than 48 hours (2006-2007);
- During very intense rain events, when rainfall amounts range from 1.0-1.5 inches (2008).

A summary of the 2005-2010 Sterling Ponds storm water discharges to Sumner Creek, including discharge dates, rainfall amounts, discharge lags, and discharge times, is provided in Appendix A.

Modifications made to the control structure for the Sterling Ponds wet pond outlet to Sumner Creek seemed to improve storage and infiltration capacity for these types of events in 2007-2010. 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.

While this project is primarily focused on evaluating long-term trends, annual performance information is important as well. With the exception of the large rain 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 storm water management practices at Sterling Ponds prevented thermal impacts on Sumner Creek and the Kinnickinnic River during the May-September (summer) 2010 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 54 rain events, ranging in magnitude from 0.01-1.72 inch and totaling 22.01 inches of precipitation (72% of the total summer precipitation). All storm water runoff from these events was

infiltrated, as required by the River Falls Storm Water Management Ordinance. Monitoring and analysis of storm water conveyance from the Sterling Ponds wet pond to the infiltration basin will continue in the future, to determine if the intent of the ordinance is being met.

- Smaller rainfall events (less than one inch) caused no thermal impacts on Sumner Creek (see Appendix B). During large rain events on June 25, August 8, August 10-11, and September 23, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, for extended time periods (2.5-34.5 hours). The warm storm water discharges during the August 10-11 and September 23 rain events caused thermal spikes in Sumner Creek at Site 4, and probably contributed to the extended thermal spikes 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 15 rain events throughout the May-September period. These thermal spikes ranged from 2.8° C -8.8° C in magnitude and were caused by rain events ranging from 0.42-2.97 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 2005-2010 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 2005-2010 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 2006-2010 period. Beyond 2010, 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.

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 was re-located to Sites 5IN (Sterling Ponds wet detention pond inlet) and 5MHW (Sterling Ponds wet detention pond outlet) in 2010. 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 2011.

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 this station, the river is assumed to be in a base flow condition. During dry periods between runoff events, the Kinnickinnic River maintained a summer 2010 base flow of 75-85 cfs at County Highway F (Figure 8). Base flows tended to be a bit lower (75-80 cfs) during the April-July period, and a bit higher (80-85 cfs) during the August-September period, after the two largest runoff events in mid-August and late 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 2010, 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 2010 base flow surveys were conducted using a handheld SonTek® FlowTracker Acoustic Doppler Velocimeter (ADV).

The spring 2010 base flow survey was conducted on May 20. These spring 2010 survey results are presented in Figure 41, with a comparison to the spring 2006-2009 survey results. In spring 2010, Kinnickinnic River base flows in the project area increased gradually from upstream to downstream, with flows of 40 cfs, 41 cfs, and 47 cfs measured at Sites 3, 2, and 1, respectively. Sumner Creek provided a very small contribution (0.4 cfs) to the Kinnickinnic River, just upstream of Site 1. An additional 64% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (77 cfs), including contributions from the South Fork of the Kinnickinnic

River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (3.8 cfs). The spring 2010 Kinnickinnic River base flows in the project area (Sites 1-3) were nearly identical to the spring 2009 base flows, due to abnormally dry conditions in May and continuation of a region-wide drought that developed in 2006. In Sumner Creek, the spring 2010 base flow was also nearly identical to the spring 2009 base flow. The spring 2010 base flow in Rocky Branch Creek increased by 54%, while the spring 2010 base flow in the Kinnickinnic River at County Highway F decreased by 4%, compared to the spring 2009 base flows at these locations. 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). Within the project area, the spring 2010 base flows were amongst the lowest recorded since monitoring began in 2006. 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.

The autumn 2010 base flow survey was conducted on November 8. These autumn 2010 survey results are presented in Figure 42, with a comparison to the autumn 2005-2009 survey results. In autumn 2010, Kinnickinnic River base flows increased notably (30%) from upstream (43 cfs at Site 3) to downstream (56 cfs at Site 1) in the project area. Sumner Creek provided a small contribution (0.9 cfs) upstream of Site 1. An additional 86% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (104 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (5.0 cfs). The autumn 2010 Kinnickinnic River base flows in the project area (Sites 1-3) increased notably (by 8-51%), compared to autumn 2009, due to above-normal precipitation throughout the April-September 2010 period, but especially in September (Figure 3). In Sumner Creek, the autumn base flows were nearly identical in 2009 and 2010. The autumn 2010 base flows in Rocky Branch Creek and in the Kinnickinnic River at County Highway F increased by 31% and 35%, respectively, compared to the autumn 2009 base flows at these locations. The autumn 2006-2010 base flows at all monitoring sites in the North Kinnickinnic River Monitoring Project Area were less than the autumn 2005 base flows, which were probably influenced by much wetter than normal conditions in 2005 (Figure 1). Within the project area, autumn base flows rebounded in 2010, 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.

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

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. Conversely, performance monitoring at Sterling Ponds has demonstrated that the storm water management practices have provided excellent infiltration capacity since 2004, thereby helping to sustain groundwater recharge during an extended dry period. With above-normal precipitation during the summer of 2010, base flows are rebounding at all sites in the project area.

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

Macroinvertebrate Monitoring:

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

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

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

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

Where:

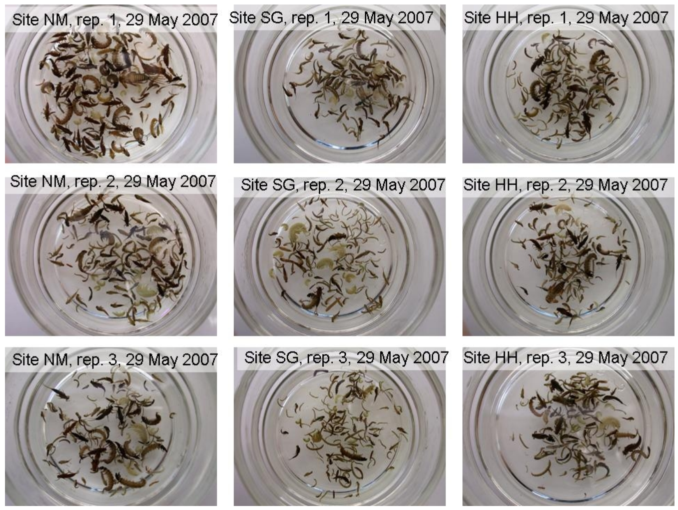
T = number of individuals in the taxon
TV = tolerance value of the taxon
n = number of taxa
N = total number of individuals in the sample

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



Site 1 Site 2 Site 3

Triplicate macroinvertebrate samples collected at Sites 1-3 in 2007

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

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

Hagen	Lat. 44°53'22.2", Long. 92°36'19.5"	3.60	3.13	3.89	3.74
	Mean of 3 reps:	3.67	3.44	3.83	3.75

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

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

Macroinvertebrate monitoring was also conducted in May 2008, May 2009, and May 2010, 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 2004-2010 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 2005-2010

2005:

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

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

2006:

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

Date	Rainfall Amount	Discharge Lag	Discharge Time
July 24	1.80 inches	10 minutes	4 hours
August 2*	2.26 inches	No Data	No Data
August 24*	1.63 inches	No Data	No Data

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

2007:

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

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

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

2008:

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

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

2009:

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

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

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

2010:

The Sterling Ponds wet detention pond discharged to Sumner Creek during three 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)

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 2010

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 2010. 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 2010, due to several factors:

1. Building progress remained very limited in the Sterling Ponds subdivision in 2010, and has only occurred in the southeast and northeast quadrants of the subdivision during the 2004-2010 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, leaving the year-end total at 58 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.

A build-out total of 600 units is projected for Sterling Ponds. By year-end 2010, a combined 154 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, and 2010 are available on the project website ("Annual Reports"). With 58 of approximately 150 single family units (39%) complete in the southeast quadrant, 96 of approximately 150 family units (64%) complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2010, 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 2010 build-out map) was only 12% (7.8 acres of 66.8 acres) in 2010, reflecting a build-out rate of 35% (52 of 148 lots).

2. Four wet storm water detention ponds were already in place in 2010, 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 2010. 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 2010 period (see 2010 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 2010, as required by the ordinance. Indeed, monitoring of the southeast storm water management practices in 2010 demonstrated excellent infiltration for 54 summer rain events, ranging in magnitude from 0.01-1.72 inches and totaling 22.01 inches (72% 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 2010 capably evaluated ordinance effectiveness and identified the storm water impacts related to four 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.