City of River Falls
North Kinnickinnic River Monitoring Project

2014 Report

Report prepared by SEH Inc., for the

City of River Falls Engineering Department
December 2014

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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 Impact of Untreated Storm Water").

In 2002, the City adopted a new Storm Water 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 Storm Water Management Ordinance requirements, the thermal, water quality, water quantity, and biological impacts of new development will be undetectable or greatly reduced.

River Falls Precipitation:

Due to the major influence of precipitation and ensuing storm water runoff on river flow, temperature, and water quality, an analysis of seasonal precipitation is conducted as a part of this project. Two rain gauges reside within or near the North Kinnickinnic River Monitoring Project Area.

The primary project rain gauge, operated by the City of River Falls, is an electronic tipping-bucket rain gauge that measures 15-minute precipitation amounts in 0.01-inch increments. This rain gauge is part of an Onset HOBO U30 Weather Station that began operating in December 2010. The weather station is located at the River Falls City Hall (222 Lewis Street), in relatively close proximity to all six North Kinnickinnic River monitoring stations. The City of River Falls weather station also serves as a source of 15-minute air temperature and relative humidity data, thereby allowing determination of daily mean, minimum, and maximum air temperatures in River Falls.

The secondary project rain gauge, operated by the United States Geological Survey (USGS), is located at the 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. 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 localized and quite variable rainfall patterns. Nonetheless, the USGS rain gauge generally provides a good estimate of rainfall in the project area.

In addition to measuring daily rainfall amounts, the City of River Falls and USGS rain gauges provide very helpful information on the timing and intensity of rain events.

Throughout the 2014 monitoring season, the City of River Falls rain gauge operated very reliably and generated all of the daily and 15-minute rainfall data used in this report. However, the USGS provided the daily rainfall data generated by the gauge at the Kinnickinnic River monitoring station, and these data are available upon request.

A total of 31.48 inches of precipitation was recorded in River Falls (by the City of River Falls weather station) during the April-September 2014 period, 9.79 inches more than the normal total of 21.69 inches for the April-September time period (Figure 1). For comparative purposes, April-September rainfall amounts for prior North Kinnickinnic River Monitoring Project years (2004-2013) are also presented in Figure 1. “Normal” monthly and seasonal rainfall amounts are based upon measurements made by the National Weather Service at the Twin Cites International Airport during the “climate normal period” of 1981-2010. The April-September 2014 period (31.48 inches of rain) was the third-wettest April-September period since the start of the North Kinnickinnic River Monitoring Project in 2004. Since project monitoring began, seven monitoring years (2004, 2006, 2007, 2008, 2011, 2012, and 2013) have been drier than normal, while four monitoring years (2005, 2009, 2010, and 2014) have been wetter than normal.

Daily rainfall amounts during the April-September 2014 period are presented in Figure 2. Rain fell on 75 days, or 41% of the April-September 2014 period.

Monthly rainfall amounts during the April-September 2014 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. April, May, June, and August were all wetter than normal, with rainfall surpluses of 2.81 inches in April, 2.28 inches in May, 6.80 inches in June, and 0.67 inch in August. June 2014 rainfall was particularly notable. The monthly total of 11.05 inches in River Falls was 2.6 times greater than the normal monthly total of 4.25 inches. As measured by the National Weather Service in Minneapolis-St. Paul, MN, the June 2014 rainfall total of 11.36 inches fell just short of the all-time June record of 11.67 inches, set 140 years ago in 1874. In River Falls, the combined rainfall of 27.13 inches in April, May, June, and August was 12.56 inches above normal, and accounted for 86% of the total April-September 2014 precipitation. In sharp contrast, July and September were much drier than normal, with rainfall deficits of 1.58 inches in July and 1.19 inches in September. The combined rainfall of 4.35 inches in July and September was 2.77 inches below normal, and accounted for only 14% of the total April-September 2014 precipitation. The largest rain events of the monitoring year occurred on June 1 (2.53 inches), and August 29 (2.28 inches) (Figure 2).

With a much drier-than normal September 2013, severe drought conditions (DSI = D2) were apparent in the North Kinnickinnic River Monitoring Project Area by mid-September 2013 (U.S. Drought Monitor, at http://droughtmonitor.unl.edu/). These conditions persisted into late February 2014, when moderate drought conditions (DSI = D1) were evident. Spring snowmelt and above-normal April 2014 rainfall (Figure 3) contributed to further drought abatement, with abnormally dry conditions (DSI = D0) apparent by late April. Above-normal May 2014 rainfall brought drought conditions to an end by mid-May. The near-historic June rainfall and above-normal August rainfall kept drought conditions at bay through late September 2014, in spite of the below-normal September rainfall. At the end of September 2014, the Palmer Drought Severity Index (http://www.ncdc.noaa.gov/temp-and-precip/drought/weekly-palmers.php) indicated that very moist conditions were present in the North Kinnickinnic River Monitoring Project Area.

Besides being much wetter than normal, the April-September 2014 monitoring period was slightly cooler than normal. The mean air temperature in River Falls during the April-September 2014 period was 61.9º Fahrenheit (F), 1.8º F lower than the normal mean of 63.7º F for the April-September period, as measured by the National Weather Service at the Twin Cities International Airport. Monthly mean air temperatures during the April-September 2014 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1981-2010, are presented in Figure 4.

All months during the April-September 2014 period were cooler than normal, with April (-5.2º F) and July (-4.0º F) experiencing the greatest departures.

The distribution of River Falls daily rainfall amounts during the April-September 2014 period is presented in Figure 5. On 44 (58%) of the 75 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 44 days contributed only 11% of the total April-September 2014 precipitation. Twenty-two of these 44 days occurred in the cooler months of April, May, and September (Figure 6). On 6 (8%) of the 75 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 6 days contributed an additional 7% of the total April-September 2014 precipitation. Three of these 6 days occurred in April, May, and September (Figure 6), when air temperatures were cooler. On 9 (12%) of the 75 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 9 days contributed 17% of the total April-September 2014 precipitation. Five of these 9 days occurred in April, May, and September (Figure 6), when air temperatures were cooler. On 5 (7%) of the 75 days with measurable precipitation, rainfall amounts ranged from 0.76-1.00 inch. These 5 days in April, May, and June (Figure 6) contributed 13% of the total April-September 2014 precipitation. On 11 (15%) of the 75 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. However, these 11 days contributed 52% of the total April-September 2014 precipitation. Precipitation amounts in excess of 1 inch occurred on April 28 (1.08 inches), May 8 (1.35 inches), May 19 (1.65 inches), June 1 (2.53 inches), June 7 (1.77 inches), June 14 (1.22 inches), June 15 (1.07 inches), June 19 (1.05 inches), July 7 (1.09 inches), August 18 (1.28 inches), and August 29 (2.28 inches) (Figures 2 and 6).

The 4 largest summer precipitation events, with rainfall amounts in excess of 1.50 inches, occurred on May 19 (1.65 inches), June 1 (2.53 inches), June 7 (1.77 inches), and August 29 (2.28 inches). These 4 rain events were generally characterized by convective thunderstorm activity. On May 19, June 1, and June 7, air temperatures were relatively mild (high temperatures of 60° F, 75° F and 65° F, respectively); whereas the air temperature on August 29 was very warm (high temperature of 86° F). Rainfall on May 19 (1.65 inches) occurred during a 5-hour period (11:00-16:00 CDT), with a peak rainfall rate of 0.53 inch per hour (12:15-13:15 CDT). According to NOAA Atlas 14, Volume 8 for Wisconsin (2013), a 5-hour rain event of 1.65 inches in River Falls has a 1.4-year recurrence interval. Rainfall on June 1 (2.53 inches) primarily occurred during an 8-hour period (00:00-07:45 CDT), with a peak rainfall rate of 1.32 inches per hour (02:45-03:45 CDT). According to NOAA Atlas 14, Volume 8, an 8-hour rain event of 2.53 inches in River Falls has a 5.5-year recurrence interval. Rainfall on June 7 (1.77 inches) primarily occurred during a 7-hour period (06:00-13:00 CDT), with a peak rainfall rate of 0.73 inch per hour (06:00-07:00 CDT). According to NOAA Atlas 14, Volume 8, a 7-hour rain event of 1.77 inches in River Falls has a 1.3-year recurrence interval. Rainfall on August 29 (2.28 inches) occurred in three separate waves, from 01:00-04:00 CDT (0.65 inch), from 12:30-14:30 CDT (0.10 inch), and from 18:00-24:00 CDT (1.53 inches), with a peak rainfall rate of 0.96 inch per hour (19:30-20:30 CDT). These four largest summer precipitation events in May, June, and August contributed substantially to the above-normal precipitation amounts for these three months (Figure 3). The May 19 rain event accounted for 29% of the total May rainfall, the June 1 and June 7 rain events accounted for 39% of the total June rainfall, and the August 29 rain event accounted for 46% of the total August rainfall. The four largest summer rain events contributed 26% of the total April-September 2014 precipitation.

Rainfall events in excess of 0.50 inch occurred on 25 days throughout the April-September 2014 period, with 5 events in April, 5 events in May, 8 events in June, 2 events in July, 3 events in August, and 2 events in September (Figures 2 and 6). These 25 rainfall events in excess of 0.50 inch (33% of the April-September 2014 rain events) contributed 82% of the total April-September 2014 precipitation. Conversely, 50 rainfall events of 0.50 inch or less (67% of the April-September 2014 rain events) contributed only 18% of the total April-September 2014 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 75 days with measurable precipitation during the April-September 2014 period, 71 days (95%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Infiltration of these 71 rain events (23.25 inches) would account for 74% of the total April-September precipitation (31.48 inches). Only the rainfall amounts on May 19 (1.65 inches), June 1 (2.53 inches), June 7 (1.77 inches), and August 29 (2.28 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 four rainfall events, thereby accounting for infiltration of 93% (29.25 inches) of the total rainfall (31.48 inches) that occurred during the April-September 2014 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 2014 period is presented as a hydrograph in Figure 8. Daily rainfall, as measured at the USGS monitoring station, is also presented in Figure 8.

Precipitation patterns help explain the changes that occur in the Kinnickinnic River hydrograph, due to runoff events in the watershed. Daily rainfall amounts in excess of 1 inch and combined rainfall amounts in excess of 1 inch on consecutive (back-to-back) days generally had the greatest influence on the April-September 2014 Kinnickinnic River hydrograph (Figure 8).

The Kinnickinnic River hydrograph suggests that 17 significant runoff events occurred during the April-September 2014 period (Figure 8). Peak daily mean flows for all of these runoff events were ≥ 200 cubic feet per second (cfs).

Three of the 17 significant runoff events occurred in April, with peak daily mean flows ranging from 316-1,120 cfs. Some of the early April precipitation (0.57 inch) fell as snow, with 4.0 inches of snow recorded on April 3 and April 4 in nearby Hudson, WI. With additional antecedent winter snowfall on the ground (40 inches of snow were recorded in Hudson during January, February, and March 2014), the two significant early April runoff events, with peak daily mean flows of 1,120 cfs on April 1 and 421 cfs on April 7, were caused by snowmelt. The significant runoff event in late April, with a peak daily mean flow of 316 cfs on April 29, was caused by a combined 2.75 inches of rain during the April 27-29 period. With very cool air and water temperatures in April, thermal impacts of storm water runoff are generally not a concern, but water quality impacts can be problematic, due to frozen soils and a lack of vegetative cover in the watershed.

Three of the 17 significant runoff events occurred in May, when thermal impacts of storm water runoff become a concern due to warmer air and water temperatures. Rainfall on May 8 (1.35 inches) resulted in a peak daily mean flow of 224 cfs on May 9. The combined rainfall on May 11-12 (1.30 inches) resulted in a peak daily mean flow of 361 cfs on May 12. The fourth-largest rain event of the summer on May 19 (1.65 inches) resulted in a peak daily mean flow of 507 cfs on May 20.

Six of the 17 significant runoff events occurred in June, due to nearly unprecedented rainfall (11.05 inches). The combined rainfall on May 31 and June 1 (3.12 inches), including the largest rain event of the summer on June 1 (2.53 inches), resulted in a peak daily mean flow of 943 cfs on June 1, the largest rain-generated runoff event of the summer. The third-largest rain event of the summer on June 7 (1.77 inches) resulted in a peak daily mean flow of 293 cfs on June 7. The combined rainfall on June 14-15 (2.29 inches) resulted in a peak daily mean flow of 723 cfs on June 15. Similarly, the combined rainfall on June 18-19 (1.76 inches) resulted in a peak daily mean flow of 637 cfs on June 20. With excessive antecedent precipitation and extremely moist soil conditions, a smaller rain event on June 24 (0.29 inch) resulted in a peak daily mean flow of 357 cfs on June 26. Finally, the rainfall on June 28 (0.80 inch) resulted in a peak daily mean flow of 539 cfs on June 29.

Two of the 17 significant runoff events occurred in July. Rainfall on July 7 (1.09 inches) resulted in a peak daily mean flow of 278 cfs on July 8. The combined rainfall on July 11-12 (0.93 inch) resulted in a peak daily mean flow of 284 cfs on July 13.

Two of the 17 significant runoff events occurred in August. Rainfall on August 18 (1.28 inches) resulted in a peak daily mean flow of 264 cfs on August 18. The second-largest rain event of the summer on August 29 (2.28 inches) resulted in a peak daily mean flow of 304 cfs on August 30.

One of the 17 significant runoff events occurred in September. A moderate rain event on September 3 (0.62 inch) resulted in a peak daily mean flow of 225 cfs on September 4.

The thermal impacts of storm water runoff are generally a concern throughout the May-September period, due to warmer air and water temperatures. As such, the fourteen runoff events during the May-September period should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2014, and are further analyzed in this report.

With above-normal rainfall (+9.79 inches) during the April-September 2014 period, Kinnickinnic River base flows generally ranged from 115-150 cfs, as measured at County Highway F (Figure 8). Base flows increased substantially (from 115 cfs to 150 cfs) during the wetter-than-normal (+11.89 inches) April-June period, but gradually decreased (from 150 cfs to 130 cfs) during the drier-than-normal (-2.10 inches) July-September period. With above-normal rainfall and considerable groundwater recharge during the April-September 2014 period, the Kinnickinnic River base flow in late September (130 cfs) was notably higher than the base flow in early April (115 cfs).

Temperature Monitoring:

The thermal impacts of untreated storm water discharges on segments of the Kinnickinnic River within the City of River Falls, especially in the downtown and Glen Park areas, have been clearly documented by temperature monitoring research conducted by the local Kiap-TU-Wish Chapter of Trout Unlimited (TU). These thermal impacts are also evident in the South Fork of the Kinnickinnic River. The TU temperature monitoring research can be viewed at:

http://www.kiaptuwish.org/storm-water

A direct storm sewer discharge to the Kinnickinnic River at Division Street

The intent of the City of River Falls Storm Water Management Ordinance is to prevent storm water impacts on the Kinnickinnic River, including thermal pollution, in areas of the city with new development, such as the Sterling Ponds subdivision.

In 2014, temperature monitoring was conducted at five sites within the North Kinnickinnic River Monitoring Project Area:

Site:	Deployment Period:	Location:
Site 1:	No 2014 data available	Kinnickinnic River at North Main St.
Site 1A:	No 2014 data available	Kinnickinnic River at Quarry Road
Site 4:	No Deployment	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2014	Sumner Creek: Mouth
Site 5IN:	May 9-September 30, 2014	Sterling Ponds: Wet Pond Inlet
Site 5P:	May 9-September 30, 2014	Sterling Ponds: Wet Pond
Site 5IB:	May 9-September 30, 2014	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 9-September 30, 2014	Sterling Ponds: Wet Pond Outlet

The Kinnickinnic River monitoring locations at Site 1 (downstream from Sumner Creek) and Site 1A (upstream from Sumner Creek) were established to evaluate any storm water-related impacts of Sumner Creek and the Sterling Ponds subdivision on the Kinnickinnic River. Unfortunately, this comparative evaluation was not possible in 2014. The temperature monitoring equipment was deployed at Sites 1 and 1A in April 2014. However, the cable anchoring the temperature logger shelter at Site 1 was sheared by debris during a summer flood, and the logger was lost. The temperature logger at Site 1A experienced a dead battery.

The Sumner Creek monitoring locations at Site 4 (culvert under Huppert Street) and Site 4A (near the mouth of the creek) were established to evaluate any storm water-related impacts of the Sterling Ponds subdivision on Sumner Creek. The temperature logger at Site 4 was not deployed in 2014.

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).

A more detailed description of the 2014 temperature monitoring sites and the temperature monitoring equipment typically deployed at these eight locations can be found in the 2012 Technical Report.

Kinnickinnic River Temperature Monitoring Results:

Due to temperature monitoring equipment failure and loss (as noted above), May-September (summer) 2014 temperature monitoring data could not be obtained for the Kinnickinnic River at Sites 1 and 1A.

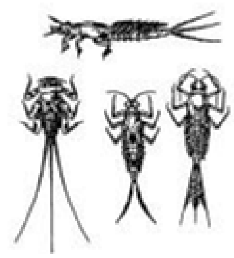
The most direct way to determine if any thermal impacts occurred in the Kinnickinnic River as a result of the Sterling Ponds subdivision is to compare the temperature monitoring data at Site 1, located immediately downstream from Sumner Creek, to the temperature monitoring data at Site 1A, located immediately upstream from Sumner Creek. Site 1A serves as control or reference site, since it is not impacted by Sterling Ponds storm water discharges. With no temperature monitoring data available for Sites 1 and 1A, this comparison was not possible in 2014.

Sumner Creek and Sterling Ponds Temperature Monitoring Results:

Sumner Creek

Sumner Creek is a low-gradient tributary of the Kinnickinnic River that exhibits only intermittent flow for the majority of its length. Permanent flow begins in the vicinity of the WI Highway 35 bypass, near the creek confluence with the Kinnickinnic River (Site 4A). From this location, the creek drainage way extends upstream to Radio Road on the far northwest corner of River Falls. The upper portion of the Sumner Creek drainage way, including Sites 4 and 6, conveys no flow for the majority of the year. The headwaters area near (former) 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 at Huppert Street. 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.

May-September (summer) 2014 temperature monitoring data were obtained for Sumner Creek at Site 4A, which is located near the mouth of the creek, 1.5 miles downstream from the Sterling Ponds subdivision (Figure 9). Site 4A is the only Sumner Creek monitoring location with permanent flow throughout the summer. At Site 4A, Sumner Creek temperatures averaged 13.7° C and ranged from 5.9-21.5° C during the May-September 2014 period. The summer mean temperature of Sumner Creek (13.7º C) reflects strong spring activity. Approximately 94% of all temperatures recorded at Site 4A during the May-September 2014 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). Approximately 99% of all temperatures recorded at Site 4A during the May-September 2014 period were ≤ 20° C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). As such, Sumner Creek potentially provides a good thermal environment for a brown (or brook) trout fishery, and is an important contributor of cold water to the Kinnickinnic River.



Rainfall-related Sumner Creek temperatures excursions beyond 17° C were recorded during and after seven rain events in 2014:

- During and after the largest rain event of the summer (2.53 inches) on June 1, the Sumner Creek temperature at Site 4A exceeded 17º C for a 42.3-hour period. The June 1 rain event also produced temperature excursions beyond 20º C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). During and after the June 1 rain event, the Sumner Creek temperature at Site 4A exceeded 20º C for a 14.8-hour period and reached a maximum of 21.5º C.
- During and after the June 15 rain event (1.07 inches), the Sumner Creek temperature at Site 4A exceeded 17º C for a 12.5-hour period, reaching a maximum of 18.8º C.
- During and after the June 19 rain event (1.05 inches), the Sumner Creek temperature at Site 4A exceeded 17º C for a 32.7-hour period and slightly exceeded 20º C for a 1.8-hour period, reaching a maximum of 20.1º C.
- During and after the June 28 rain event (0.80 inch), the Sumner Creek temperature at Site 4A exceeded 17º C for an 11.2-hour period, reaching a maximum of 18.6º C.
- During and after the July 7 rain event (1.09 inches), the Sumner Creek temperature at Site 4A exceeded 17º C for a 5.8-hour period, reaching a maximum of 18.6º C.

- During and after the August 18 rain event (1.28 inches), the Sumner Creek temperature at Site 4A slightly exceeded 17º C for a 1.3-hour period, reaching a maximum of 17.1º C.
- Finally, during and after the second-largest rain event of the summer (2.28 inches) on August 29, the Sumner Creek temperature at Site 4A exceeded 17º C for a 24.8-hour period, reaching a maximum of 18.5º C.

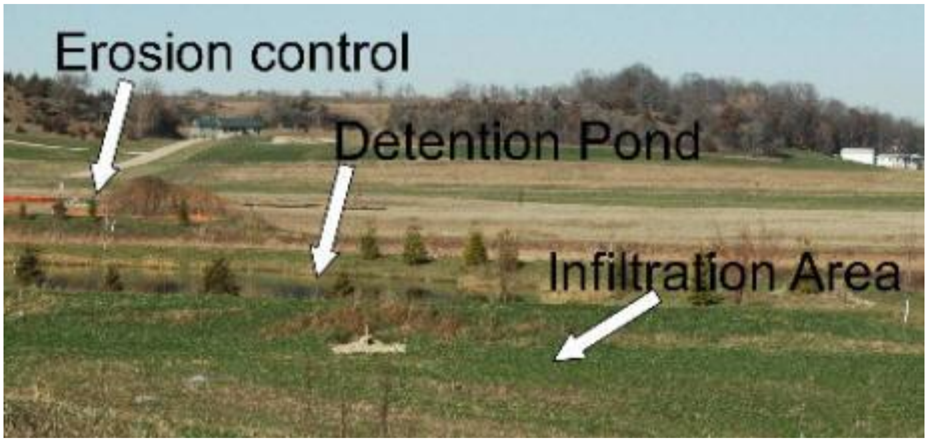
During significant precipitation and runoff events, the thermograph at Site 4A (Figure 9) can be evaluated to determine if rapid temperature increases (thermal spikes), which are characteristic of warm storm water discharges, were apparent at Site 4A, downstream from the Sterling Ponds subdivision. Of concern are the 13 thermal spikes that occurred at Site 4A during 12 rain events throughout the May-September period (Figure 9). These thermal spikes ranged from 0.6-6.1° C in magnitude and were caused by rain events ranging from 0.59-2.53 inches. The most prominent Sumner Creek thermal spike (6.1º C) occurred on June 1, after the largest summer rain event (2.53 inches) on a warm day (75º F) (Figure 9). As noted above, the June 1 thermal spike peaked at 21.5º C and exceeded optimum temperature thresholds for both macroinvertebrates (17º C) and brown trout (20º C). Rain events on June 15, June 19, June 28, July 7, August 18, and August 29 also caused thermal spikes (4.7º C, 1.9º C, 1.3º C, 2.1º C, 2.6º C, and 2.0º C, respectively) that exceeded the optimum temperature threshold for macroinvertebrates (17º C), as noted above. As such, thermal spikes of this magnitude and duration could have a detrimental impact on aquatic life (especially macroinvertebrates) in lower Sumner Creek. The six additional Sumner Creek thermal spikes were characterized by small magnitudes (0.6-1.4° C). In spite of their relative frequency during the May-September period, none of these six thermal spikes exceeded the optimum temperature thresholds for macroinvertebrates and brown trout.

Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2013. Possible sources contributing to thermal spikes in lower Sumner Creek may include: storm water runoff from WI Highway 35, located immediately upstream from Site 4A; warm water from natural wetland areas in the upper Sumner Creek drainage way; and storm water discharges from the Sterling Ponds subdivision.

Sterling Ponds

Temperature monitoring data for the Sterling Ponds storm water management practices were obtained in the wet detention pond (Site 5P), at the wet pond inlet (Site 5IN), at the wet pond discharge to the infiltration basin (Site 5IB) (see photo below), and at the wet pond discharge to Sumner Creek (Site 5MHW).

The May-September (summer) 2014 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 10. At Site 5P, Sterling Ponds wet detention pond temperatures averaged 21.6° C and ranged from 11.4-29.5° C during the summer period. Approximately 71% of all summer temperatures exceeded 20° C, with wet pond temperatures consistently remaining above 20° C from May 25 to June 7, and from June 17 until September 6. 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 (21.6° C) was substantially warmer than the summer mean temperature of Sumner Creek at Site 4A (13.7º C), clearly demonstrating the potential for thermal impact when the pond discharges to the creek, and emphasizing the importance of the River Falls Storm Water Management Ordinance, which requires storm water infiltration.



Storm water best management practices at Sterling Ponds

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

Temperature data from three of the Sterling Ponds monitoring stations (Sites 5P, 5IB, and 5MHW) and the downstream Sumner Creek monitoring station (Site 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 10) 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 Site 4A.

During the summer of 2014, the thermal performance of Sterling Ponds stormwater management practices can be evaluated monthly by comparing the Sterling Ponds and Sumner Creek thermographs. Performance of these storm water management practices during the nine significant precipitation and runoff events in May and June is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). Six of these nine significant events (May 8, May 11-12, June 14-15, June 18-19, June 24, and June 27-28) were characterized by 24-hour rainfall amounts less than 1.5 inches, and hence would be expected to meet the infiltration requirement of the River Falls Storm Water Management Ordinance.

However, the May 19, June 1, and June 7 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 2014 are presented in Figure 11. The month of May was slightly cooler (-0.4° F) and much wetter (+2.28 inches) than normal. Precipitation events ranging from 0.01-1.65 inches were recorded on ten dates (Figure 2), with three of the fourteen significant summer rainfall events occurring on May 8, May 11-12, and May 19.

Due to cool and inclement weather during the first week of May, the temperature loggers at Sites 5IN, 5P, 5IB, and 5MHW were not installed until May 9. When the loggers were installed, the Sterling Ponds wet detention pond was discharging to the Sterling Ponds infiltration basin (Figure 11), likely due to the first significant precipitation and runoff event on May 8. Although a combined 2.75 inches of rain fell during the April 27-29 period, it is likely that small antecedent rain events on May 1 (0.11 inch) and May 2 (0.01 inch) were infiltrated in advance of the May 8 rain event (1.35 inches). Wet pond discharge to the infiltration basin, due to the May 8 rain event (with a very small rain event (0.01 inch) on May 10 also contributing), was still in progress when the May 11 rain event began (Figures 11-12).

The second of fourteen significant summer rainfall and runoff events occurred on May 11-12. The comparative Sterling Ponds and Sumner Creek thermographs for the May 11-12 rain events, with a combined 1.30 inches of rain, are presented in Figure 12. The back-to-back rain events on May 11 (0.51 inch) and May 12 (0.79 inch) were characterized by extended rainfall durations and low rainfall intensities. With 0.51 inch of rain falling in a 2.75-hour period from 21:15-24:00 CDT (9:15 PM-12:00 AM) on May 11, a reinforced discharge from the wet pond to the infiltration basin began at 23:50 CDT (11:50 PM), as indicated by the increasing temperature at Site 5IB (Figure 12). However, the Sterling Ponds wet detention pond also began discharging to the Sumner Creek drainage way at 23:50 CDT (11:50 PM) on May 11, as indicated by the increasing temperature at Site 5MHW (Figure 12). With an additional 0.79 inch of rainfall on May 12, the wet detention pond discharge to the Sumner Creek drainage way continued for 9.0 hours, until 08:50 CDT (8:50 AM) on May 12. During this 9.0-hour period, the wet pond discharge temperature averaged 14.6º C and ranged from 13.9-15.1º C. Field observations during a large rainfall event in July 2008 indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the Sterling Ponds wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. The extended discharge (9.0 hours) of warmer storm water from the Sterling Ponds wet pond to Sumner Creek may have contributed to the small thermal spike (1.4º C) evident at Site 4A at 05:30 CDT (5:30 AM) on May 12 (Figure 12). However, since the temperature increase at Site 4A, located 1.5 miles downstream, began 20 minutes after the Sterling Ponds storm water discharge commenced, it is also likely that local causes contributed to the thermal spike at Site 4A. These local causes may have included storm water runoff from the nearby WI Highway 35 interchange and/or warmer water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way.

Although the Sterling Ponds wet detention pond likely captured the majority of the May 11 rain event (0.51 inch) before discharge to the Sumner Creek drainage way occurred, the entirety of the combined 24-hour May 11-12 rain event (1.30 inches) was not captured and infiltrated, as required by the River Falls Storm Water Management Ordinance. The very large antecedent rain event on May 8 (1.35 inches) likely contributed to the inability of the Sterling Ponds wet detention pond to capture the entire May 11-12 rain event, due to insufficient pond capacity. Indeed, wet pond discharge to the infiltration basin, due to the May 8 rain event, was still in progress when the May 11-12 rain event began. Wet pond discharge to the infiltration basin, due to the May 11-12 rain event, continued for 3.9 days, until 22:30 CDT (10:30 PM) on May 15 (Figures 11 and 12).

The third of fourteen significant summer rainfall and runoff events occurred on May 19. The comparative Sterling Ponds and Sumner Creek thermographs for the May 19 rain event (the fourth-largest rain event of the summer) are presented in Figure 13. Rainfall on May 19 (1.65 inches) occurred during a 5-hour period (11:00-16:00 CDT), with a peak rainfall rate of 0.53 inch per hour (12:15-13:15 CDT). The high temperature on May 19 was a moderate 60° F. The Sterling Ponds wet detention pond began discharging to the Sterling Ponds infiltration basin at 13:00 CDT (1:00 PM) (Figure 13), after 0.69 inch of rain had fallen. At 15:40 CDT (3:40 PM), the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way, as indicated by the rapidly-increasing temperature at Site 5MHW (Figure 13). By this time, 1.62 inches of rainfall had occurred on May 19, indicating that the Sterling Ponds wet pond had sufficient capacity to capture the majority of the May 19 rain event (1.65 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via wet pond drawdown (to the infiltration basin) after the combined May 11-12 rain event, which was complete on May 15 (above). The Sterling Ponds wet detention pond discharge to the Sumner Creek drainage way continued for 10.8 hours, until 02:30 CDT (2:30 AM) on May 20. During this 10.8-hour period, the wet pond discharge temperature averaged 11.0º C and ranged from 10.5-11.3º C. The extended discharge (10.8 hours) of relatively cool storm water from the Sterling Ponds wet pond to Sumner Creek may have contributed to the very small thermal spike (0.6º C) evident at Site 4A at 02:10 CDT (2:10 AM) on May 20 (Figure 13). Wet pond discharge to the infiltration basin, due to the May 19 rain event, continued for 4.2 days, until 18:50 CDT (6:50 PM) on May 23 (Figures 11 and 13).

A moderate rain event on May 26 (0.42 inch) and a small rain event on May 27 (0.20 inch) were both captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond. The wet pond did not discharge to the infiltration basin during these two rain events (Figure 11).

Due to a moderate rain event on May 31 (0.59 inch), which began at 17:15 CDT (5:15 PM), the Sterling Ponds wet detention pond began discharging to the Sterling Ponds infiltration basin at 18:10 CDT (6:10 PM) (Figure 11), after 0.48 inch of rain had fallen. Wet pond discharge to the infiltration basin, due to the May 31 rain event, was still in progress when the very large rain event (2.53 inches) began on June 1 (see *June* below).

In summary for May, temperature monitoring at Site 5 (which began on May 9) indicated that the Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the May 9-15 period, due to a large rain event on May 8 (1.35 inches) and a large combined rain event on May 11-12 (1.30 inches). Although unconfirmed by monitoring, it is likely that the small rain events on May 1 (0.11 inch) and May 2 (0.01 inch) were infiltrated. Although wet pond discharge to the infiltration basin due to the May 8 rain event (1.35 inches) was still in progress when the May 11 rain event began, it is also likely that the majority of the May 8 rain event was infiltrated. The 3.1-day period between the end of rainfall on May 8 and the onset of rainfall on May 11 provided considerable infiltration time. The very small rain event on May 10 (0.01 inch) was also likely infiltrated. In total, 1.48 inches of rain during the May 1-10 period was likely infiltrated. The combined rainfall on May 11-12 (1.30 inches) caused a wet pond discharge to Sumner Creek, with a discharge duration of 9.0 hours. However, it seems likely that the majority of the combined May 11-12 rain event (1.30 inches) was infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on May 11-12, the duration of the wet pond discharge to Sumner Creek (9.0 hours) was much shorter than the duration of the discharge to the infiltration basin (3.9 days). Due to the May 19 rain event (1.65 inches), the Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the May 19-23 period. However, the May 19 rain event also caused a wet pond discharge to Sumner Creek, with a discharge duration of 10.8 hours. Similarly, it seems likely that the majority of the May 19 rain event was also infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on May 19-20, the duration of the wet pond discharge to Sumner Creek (10.8 hours) was much shorter than the duration of the discharge to the infiltration basin (4.2 days). A moderate rain event on May 26 (0.42 inch) and a small rain event on May 27 (0.20 inch) were both captured in the Sterling Ponds wet pond. It is likely that the majority of a moderate rain event on May 31 (0.59 inch) was infiltrated. Although wet pond discharge to the infiltration basin due to the May 31 rain event (0.59 inch) was still in progress when the June 1 rain event began, the 5.5-hour period between the end of rainfall on May 31 and the onset of rainfall on June 1 provided a fair amount of infiltration time for a rain event of this size.

June

The comparative Sterling Ponds thermographs for June 2014 are presented in Figure 14. The month of June was slightly cooler (-0.3° F) and much wetter (+6.80 inches) than normal. Rainfall events (ranging from 0.01-2.53 inches) were recorded on eighteen dates (Figure 2), with six of the fourteen significant summer rainfall events occurring on June 1, June 7, June 14-15, June 18-19, June 24, and June 28.

As noted above (*May*), the Sterling Ponds wet detention pond was discharging to the Sterling Ponds infiltration basin when the month of June began, due to the moderate rain event (0.59 inch) on May 31.

The fourth of fourteen significant summer rainfall and runoff events occurred on June 1. The comparative Sterling Ponds and Sumner Creek thermographs for the June 1 rain event (the largest rain event of the summer) are presented in Figure 15. Rainfall on June 1 (2.53 inches) occurred in two "waves", from 00:00-03:45 CDT and 05:45-08:15 CDT. The first rainfall wave delivered more rain (1.68 inches), with a higher peak rainfall intensity rate (1.32 inches per hour from 02:45-03:45 CDT). The second rainfall wave delivered less rain (0.76 inch), with a much lower peak rainfall intensity rate (0.40 inch per hour from 05:45-06:45 CDT). The first wave of rainfall produced a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin at 02:00 CDT. Just after the onset of the most intense rainfall at 02:45 CDT, the wet detention pond began discharging to the Sumner Creek drainage way at 03:20 CDT (3:20 AM), as indicated by the rapidly-increasing temperature at Site 5MHW (Figure 15). By 03:20 CDT, 1.49 inches of rain had fallen, indicating that the Sterling Ponds wet pond had sufficient capacity to capture the majority of the first rainfall wave (1.68 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via sufficient wet pond drawdown (to the infiltration basin) after the moderate May 31 rain event, in spite of a relatively short time period (5.5 hours) between the May 31 and June 1 rain events. The second wave of rainfall (0.76 inch) simply reinforced the Sterling Ponds wet pond discharge to the Sumner Creek drainage way. This discharge continued for 28.7 hours, until 08:00 CDT (8:00 AM) on June 2. During this 28.7-hour period, the wet pond discharge temperature averaged 19.5º C and ranged from 17.6-21.7º C. An initial thermal spike (3.1º C) evident near the mouth of Sumner Creek (Site 4A) at 05:00 CDT (5:00 AM) on June 1 (Figure 15) cannot be attributed to the Sterling Ponds storm water discharge, since the temperature increase at Site 4A, located 1.5 miles downstream, occurred shortly after the Sterling Ponds storm water discharge began at 03:20 CDT. It seems apparent that the initial thermal spike at Site 4A had a more "local" cause, perhaps including storm water runoff from WI Highway 35. However, the extended discharge (28.7 hours) of warm storm water from the Sterling Ponds wet pond to Sumner Creek may have contributed to a secondary thermal spike (2.1º C) evident at Site 4A at 12:50 CDT (12:50 PM) on June 1, as well as to the extended duration (20.0 hours) of warmer-than-normal water at Site 4A, until 20:10 CDT (8:10 PM) on June 1, when a peak temperature of 21.5º C occurred. Given the magnitude of the June 1 rain event, it is very likely that warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way also contributed to the extended presence of warmer water at Site 4A, including the largest thermal spike of the summer (6.1º C). Wet pond discharge to the Sterling Ponds infiltration basin, primarily due to the June 1 rain event, continued for 6.3 days, until the June 7 rain event began. Very small rain events on June 2 (0.07 inch), June 5 (0.07 inch) and June 6 (0.01 inch) were also captured and infiltrated before June 7.

The fifth of fourteen significant summer rainfall and runoff events occurred on June 7. The comparative Sterling Ponds and Sumner Creek thermographs for the June 7 rain event (the third-largest rain event of the summer) are presented in Figure 15. Rainfall on June 7 (1.77 inches) occurred during a 7-hour period (06:00-13:00 CDT). However, with convective thunderstorm activity at the start of this rain event, the majority of rainfall (1.29 inches) occurred from 06:00-07:45 CDT, with a peak rainfall rate of 0.73 inch per hour (06:00-07:00 CDT). The high temperature on June 7 was a moderate 65° F. With very intense rainfall starting at 06:15 CDT (6:15 AM) and 0.70 inch of rain falling in a 45-minute period from 06:15-07:00 CDT, a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin began at 06:50 CDT (6:50 AM). Wet pond discharge to the infiltration basin, due to the June 7 rain event, continued for 4.2 days, until 11:00 CDT (11:00 AM) on June 11 (Figure 14). Although the magnitude of the June 7 rain event (1.77 inches) exceeded the magnitude (1.5 inches) that requires infiltration (via the City of River Falls Storm Water Management Ordinance), the entirety of the June 7 rain event was infiltrated, and no wet pond discharge to Sumner Creek occurred. With a 6.3-day drawdown period after the June 1 rain event, the Sterling Ponds wet pond gained sufficient capacity to capture the June 7 rain event, especially the initial 1.29 inches that occurred within the first 1.75 hours. It was also helpful that the remainder of the rainfall (0.48 inch) on June 7 occurred over an extended time period (5.25 hours), at very low rainfall intensity rates.

Although the rain event on June 12 was small (0.14 inch), the Sterling Ponds wet pond discharged to the infiltration basin for a 15.5-hour period (Figure 14), from 02:10 CDT (2:10 AM) until 17:40 CDT (5:50 PM). The entirety of this small rain event was infiltrated.

The sixth of fourteen significant summer rainfall and runoff events occurred on June 14-15. The comparative Sterling Ponds and Sumner Creek thermographs for the June 14-15 rain events, with a combined 2.29 inches of rain, are presented in Figure 14. The back-to-back rain events on June 14 (1.22 inches) and June 15 (1.07 inches) were characterized by extended rainfall durations and relatively low rainfall intensities. With 0.20 inch of rain falling in a 1.75-hour period from 13:15-15:00 CDT (1:15-3:00 PM) on June 14, the Sterling Ponds wet pond began discharging to the infiltration basin at 15:30 CDT (3:30 PM), as indicated by the increasing temperature at Site 5IB (Figure 14). Wet pond discharge to the infiltration basin, due to the June 14-15 rain events and a moderate rain event on June 16 (0.48 inch), continued for 3.5 days, until the June 18 rain event began.

The seventh of fourteen significant summer rainfall and runoff events occurred on June 18-19. The comparative Sterling Ponds and Sumner Creek thermographs for the June 18-19 rain events, with a combined 1.76 inches of rain, are presented in Figure 14. The back-to-back rain events on June 18 (0.71 inch) and June 19 (1.05 inches) were characterized by extended rainfall durations and relatively low rainfall intensities. With 0.22 inch of rain falling in a 1.25-hour period from 02:15-03:30 CDT (2:15-3:30 AM) on June 18, a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin began at 03:30 CDT (3:30 AM). Wet pond discharge to the infiltration basin, due to the June 18-19 rain events, a moderate rain event on June 22 (0.52 inch), and a very small rain event on June 23 (0.02 inch), continued for 6.7 days, until the June 24 rain event began.

The eighth of fourteen significant summer rainfall and runoff events occurred on June 24. The high temperature on June 24 was a very warm 88° F, which generated convective thunderstorm activity in the early evening. The magnitude of the June 24 rain event was relatively small in River Falls (0.29 inch) and at the USGS gauging station near County Road F (0.34 inch). However, additional rain fell in the upper Kinnickinnic River Watershed, thereby resulting in the peak daily mean flow of 357 cfs at County Road F on June 26. The comparative Sterling Ponds and Sumner Creek thermographs for the June 24 rain event are presented in Figure 14. With 0.28 inch of rain falling in a 1.25-hour period from 18:15-19:30 CDT (6:15-7:30 PM) on June 24, a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin began at 19:30 CDT (7:30 PM). Wet pond discharge to the infiltration basin, due to the June 24 rain event, a very small rain event on June 25 (0.01 inch), and a small rain event on June 27 (0.18 inch), continued for 4.0 days, until the June 28 rain event began.

The ninth of fourteen significant summer rainfall and runoff events occurred on June 28. The high temperature on June 28 was a very warm 86° F, which generated convective thunderstorm activity in the late afternoon. Rain (0.80 inch) fell during a 1.75-hour period from 17:45-19:30 CDT (5:45-7:30 PM), with a peak rainfall rate of 0.73 inch per hour (17:45-18:45 CDT). The comparative Sterling Ponds and Sumner Creek thermographs for the June 28 rain event are presented in Figure 14. With 0.73 inch of rain falling in a 1.0-hour period from 17:45-18:45 CDT (5:45-6:45 PM) on June 28, a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin began at 18:40 CDT (6:40 PM). Wet pond discharge to the infiltration basin, due to the June 28 rain event, a small rain event on June 30 (0.11 inch), a very small rain event on July 1 (0.05 inch), and a very small rain event on July 2 (0.01 inch), continued for 4.0 days, until 19:30 CDT (7:30 PM) on July 2.

With the exception of brief time periods on June 11-12 (0.6 day) and June 12-14 (1.9 days), the Sterling Ponds wet detention pond continuously discharged to the infiltration basin during the month of June. The total infiltration time in June was 27.5 days, in response to 11.05 inches of rain. The largest rain event of the year on June 1 (2.53 inches) caused a wet pond discharge to Sumner Creek, with a discharge duration of 28.7 hours. Although a wet pond discharge to the Sumner Creek drainage way occurred on June 1-2, it seems likely that the majority of the June 1 rain event was infiltrated, since the duration of the wet pond discharge to Sumner Creek (28.7 hours) was much shorter than the duration of the discharge to the infiltration basin (6.3 days). After the June 1 rain event, all subsequent rain events in June (8.52 inches of rain on 17 days) were fully infiltrated.

July

The comparative Sterling Ponds thermographs for July 2014 are presented in Figure 16. The month of July was much cooler (-4.0° F) and drier (-1.58 inches) than normal. Rainfall events (ranging from 0.01-1.09 inch) were recorded on nine dates (Figure 2), with two of the fourteen significant summer rainfall events occurring on July 7 and July 11-12.

As noted above (*June*), the Sterling Ponds wet detention pond was discharging to the Sterling Ponds infiltration basin when the month of July began. Due to multiple rain events (a combined total of 0.97 inch) during the June 28-July 2 period, the Sterling Ponds wet pond discharged to the infiltration basin until 19:30 CDT (7:30 PM) on July 2 (Figure 16). A very small rain event on July 6 (0.03 inch) was captured in the Sterling Ponds wet pond.

The tenth of fourteen significant summer rainfall and runoff events occurred on July 7. The high temperature on July 7 was a very warm 88° F, which generated convective thunderstorm activity in the early evening. Rain (1.09 inches) primarily fell during a 1.0-hour period from 18:00-19:00 CDT (6:00-7:00 PM), with a peak rainfall rate of 1.04 inches per hour. The comparative Sterling Ponds and Sumner Creek thermographs for the July 7 rain event are presented in Figure 16. With 1.04 inches of rain falling in a 1.0-hour period from 18:00-19:00 CDT on July 7, the Sterling Ponds wet pond began discharging to the infiltration basin at 19:00 CDT (7:00 PM). Wet pond discharge to the infiltration basin, due to the July 7 rain event, continued for 3.6 days, until the July 11 rain event began.

The eleventh of fourteen significant summer rainfall and runoff events occurred on July 11-12. The comparative Sterling Ponds and Sumner Creek thermographs for the July 11-12 rain events, with a combined 0.93 inch of rain, are presented in Figure 16. With convective thunderstorm on both days, the back-to-back rain events on July 11 (0.58 inch) and July 12 (0.35 inch) were characterized by relatively short rainfall durations and moderate rainfall intensities. A time period of 27.25 hours separated these two rain events. With 0.49 inch of rain falling in a 1.25-hour period from 08:30-09:45 CDT (8:30-9:45 AM) on July 11, a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin began at 09:40 CDT (9:40 AM). Wet pond discharge to the infiltration basin, due to the July 11-12 rain events and a very small rain event on July 14 (0.06 inch), continued for 5.1 days, until 12:00 CDT on July 16.

A small rain event on July 25 (0.24 inch) and a very small rain event on July 27 (0.05 inch) were both captured in the Sterling Ponds wet pond, with no discharge to the infiltration basin (Figure 16).

In summary for July, six rain events (a combined 2.14 inches) were infiltrated in the Sterling Ponds infiltration basin, with a total infiltration time of 10.5 days. Three rain events (a combined 0.32 inch) were captured in the Sterling Ponds wet pond, with no discharge to the infiltration basin.

August

The comparative Sterling Ponds thermographs for August 2014 are presented in Figure 17. The month of August was very slightly cooler (-0.1° F) and slightly wetter (+0.67 inch) than normal. Rainfall events (ranging from 0.01-2.28 inches) were recorded on eleven dates (Figure 2), with two of the fourteen significant summer rainfall events occurring on August 18 and August 29.

A moderate rain event on August 2 (0.53 inch) and very small rain events on August 11 (0.08 inch) and August 17 (0.08 inch) were captured in the Sterling Ponds wet pond, with no discharge to the Sterling Ponds infiltration basin (Figure 17).

The twelfth of fourteen significant summer rainfall and runoff events occurred on August 18. A warm day on August 17 (78° F) generated convective thunderstorm activity shortly after midnight. Rain on August 18 (1.28 inches) fell during a 1.5-hour period from 00:15-01:45 CDT (0:15-1:45 AM), with a peak rainfall rate of 1.09 inches per hour (00:30-01:30 CDT). The comparative Sterling Ponds and Sumner Creek thermographs for the August 18 rain event are presented in Figure 17. With 1.24 inches of rain falling in a 1.25-hour period from 00:15-01:30 CDT (0:15-1:30 AM) on August 18, the Sterling Ponds wet pond began discharging to the infiltration basin at 01:30 CDT (1:30 AM). Wet pond discharge to the infiltration basin, due to the August 18 rain event, a small rain event on August 21 (0.19 inch), a very small rain event on August 23 (0.01 inch), and a small rain event on August 24 (0.11 inch), continued for 7.1 days, until 04:00 CDT (4:00 AM) on August 25. A very small rain event on August 28 (0.01 inch) was captured in the Sterling Ponds wet pond.

The thirteenth of fourteen significant summer rainfall and runoff events occurred on August 29. The comparative Sterling Ponds and Sumner Creek thermographs for the August 29 rain event (the second-largest rain event of the summer) are presented in Figure 18. Rainfall on August 29 (2.28 inches) primarily occurred in two “waves”, from 03:00-04:00 CDT and 18:00-24:00 CDT. The first rainfall wave delivered less rain (0.63 inch), with a lower peak rainfall intensity rate (0.63 inch per hour from 03:00-04:00 CDT). The second rainfall wave delivered more rain (1.53 inches), with a higher peak rainfall intensity rate (0.96 inch per hour from 19:30-20:30 CDT). With 0.63 inch of rain falling in a 1.0-hour period from 03:00-04:00 CDT (3:00-4:00 AM) during the first wave of rainfall on August 29, the Sterling Ponds wet pond began discharging to the infiltration basin at 04:00 CDT (4:00 AM). Shortly after the 1.0-hour period of most intense rainfall (0.96 inch from 19:30-20:30 CDT), the wet detention pond began discharging to the Sumner Creek drainage way at 20:50 CDT (8:50 PM), as indicated by the rapidly-increasing temperature at Site 5MHW (Figure 18). By 20:50 CDT, 1.96 inches of rain had fallen on August 29, indicating that the Sterling Ponds wet pond had sufficient capacity to capture the majority of this rain event (2.28 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via complete wet pond drawdown (to the infiltration basin) after the August 18, 21, 23, and 24 rain events. With wet pond discharge to the infiltration basin ending at 04:00 CDT (4:00 AM) on August 25, the intervening time (4.0 days) between August 25 and the August 29 rain event provided additional opportunity for wet pond water volume reduction, via infiltration through the bottom of the pond and evaporative water loss. The remaining rainfall on August 29 (0.32 inch) simply reinforced the Sterling Ponds wet pond discharge to the Sumner Creek drainage way. This discharge continued for 11.0 hours, until 07:50 CDT (7:50 AM) on August 30. During this 11.0-hour period, the wet pond discharge temperature averaged 21.4º C and ranged from 20.7-21.8º C. An initial thermal spike (1.7º C) evident near the mouth of Sumner Creek (Site 4A) at 21:40 CDT (9:40 PM) on August 29 (Figure 18) cannot be attributed to the Sterling Ponds storm water discharge, since the temperature increase at Site 4A, located 1.5 miles downstream, occurred shortly after the Sterling Ponds storm water discharge began at 20:50 CDT. It seems apparent that the initial thermal spike at Site 4A had a more “local” cause, perhaps including storm water runoff from WI Highway 35. However, the extended discharge (11.0 hours) of warm storm water from the Sterling Ponds wet pond to Sumner Creek may have contributed to a small secondary thermal spike (0.8º C) evident at Site 4A at 00:10 CDT (0:10 AM) on August 30. Given the magnitude of the August 29 rain event, it is very likely that warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way also contributed to the thermal spike (2.0º C) present at Site 4A. Wet pond discharge to the Sterling Ponds infiltration basin, primarily due to the August 29 rain event, continued for 2.8 days, until the September 1 rain event began. Small rain events on August 30 (0.24 inch) and August 31 (0.16 inch) were also infiltrated during this time period.

In summary for August, the first half of the month was relatively dry. A moderate rain event on August 2 (0.53 inch) and very small rain events on August 11 (0.08 inch) and August 17 (0.08 inch) were captured in the Sterling Ponds wet pond, with no discharge to the Sterling Ponds infiltration basin. Four rain events (a combined 1.59 inches) during the August 18-24 period were fully infiltrated, with a total infiltration time of 7.1 days. A very small rain event on August 28 (0.01 inch) was captured in the Sterling Ponds wet pond. The second-largest rain event of the year on August 29 (2.28 inches) caused a wet pond discharge to Sumner Creek, with a discharge duration of 11.0 hours. Although a wet pond discharge to the Sumner Creek drainage way occurred on August 29-30, it seems like much of the August 29 rain event was infiltrated, since the duration of the wet pond discharge to Sumner Creek (11.0 hours) was notably shorter than the duration of the discharge to the infiltration basin (a minimum of 2.8 days). Small rain events on August 30 (0.24 inch) and August 31 (0.16 inch) were fully infiltrated. Four rain events in August (a combined 0.70 inch) were captured in the Sterling Ponds wet pond, with no discharge to the Sterling Ponds infiltration basin. Six rain events in August (a combined 1.99 inches) were fully infiltrated. Since the August 29 rain event was partially infiltrated, the combined wet pond discharge time to the infiltration basin in August was 9.9 days.

September

The comparative Sterling Ponds thermographs for September 2014 are presented in Figure 19. The month of September was cooler (-1.3° F) and drier (-1.19 inches) than normal. Rainfall events (ranging from 0.01-0.62 inch) were recorded on ten dates (Figure 2), with one of the fourteen significant summer rainfall events occurring on September 3.

As noted above (*August*), the Sterling Ponds wet detention pond was discharging to the Sterling Ponds infiltration basin when the month of September began. A small rain event on September 1 (0.33 inch) was fully infiltrated, but the Sterling Ponds wet pond was still discharging to the infiltration basin when the September 3 rain event began, likely due in part to the extensive antecedent rainfall (a combined 2.68 inches) on August 29-31.

The fourteenth (final) of fourteen significant summer rainfall and runoff events occurred on September 3. The high temperature on September 3 was a warm 79° F, which generated convective thunderstorm activity in the late evening. Rain (0.62 inch) primarily fell during a 1.5-hour period from 20:45-22:15 CDT (8:45-10:15 PM), with a relatively low peak rainfall rate of 0.29 inch per hour (20:45-21:45 CDT). The comparative Sterling Ponds and Sumner Creek thermographs for the September 3 rain event are presented in Figure 19. Rainfall (0.52 inch) during the 1.5-hour period from 20:45-22:15 CDT (8:45-10:15 PM) on September 3 resulted in a reinforced discharge from the Sterling Ponds wet pond to the infiltration basin by 22:20 CDT (10:20 PM). Wet pond discharge to the infiltration basin, due to the September 3 rain event and a very small rain event on September 4 (0.01 inch), continued for 4.3 days, until 04:40 CDT (4:40 AM) on September 8.

A very small rain event on September 9 (0.04 inch) was captured in the Sterling Ponds wet pond, and a moderate rain event on September 10 (0.51 inch) was fully infiltrated. Sterling Ponds wet pond discharge to the infiltration basin, due to the September 10 rain event, began at 02:30 CDT (2:30 AM) and continued for 3.6 days, until 17:40 CDT (5:40 PM) on September 13 (Figure 19).

The second half of September was quite dry. Very small rain events on September 15 (0.02 inch), September 19 (0.01 inch), and September 21 (0.02 inch) and small rain events on September 20 (0.19 inch) and September 29 (0.14 inch) were captured in the Sterling Ponds wet pond, with no discharge to the infiltration basin (Figure 19).

In summary for September, four rain events (a combined 1.47 inches) were infiltrated in the Sterling Ponds infiltration basin, with a total infiltration time of 10.8 days. Six rain events (a combined 0.42 inch) were captured in the Sterling Ponds wet pond, with no discharge to the infiltration basin.

Effectiveness of Sterling Ponds Storm Water Management Practices:

2014 Performance Assessment

During the May-September (summer) 2014 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 (Site 4A).

The performance of Sterling Ponds storm water management practices during the summer of 2014 is presented in Figures 20 and 21. With the exception of a large combined rain event (1.30 inches) on May 11-12 and three very large summer rain events on May 19 (1.65 inches), June 1 (2.53 inches), and August 29 (2.28 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River Falls Storm Water Management Ordinance. These 53 rain events, ranging in magnitude from

0.01-1.77 inches, represent a total of 18.25 inches of precipitation, or 70% of the total summer rainfall amount (26.01 inches). Of these 53 rain events, 15 events, ranging in magnitude from 0.01-0.53 inch and totaling 2.06 inches of precipitation (8% 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 38 remaining summer rain events, ranging in magnitude from 0.01-1.77 inches and totaling 16.19 inches of precipitation (62% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin. Due to above-normal rainfall (+6.98 inches) and an increased frequency of rainfall during the May-September (summer) 2014 period, the Sterling Ponds wet detention pond discharged to the infiltration basin for 78.2 days, or 51% of the summer period.

Seven rainfall events in May were stored in the Sterling Ponds wet detention pond or diverted to the Sterling Ponds infiltration basin (Figure 21). These events ranged from 0.01-1.35 inches in magnitude and represented a monthly total of 2.69 inches, or 10% of the total summer rainfall amount. Seventeen rain events in June, ranging from 0.01-1.77 inches and totaling 8.52 inches, were all infiltrated (Figure 21). These June rain events represented 33% of the total summer rainfall. Nine rain events in July, ranging from 0.01-1.09 inches and totaling 2.46 inches, were stored in the wet detention pond or infiltrated (Figure 21). These July rain events represented 10% of the total summer rainfall. Ten rain events in August, ranging from 0.01-1.28 inches and totaling 2.69 inches, were stored in the wet detention pond or infiltrated (Figure 21). These August rain events represented 10% of the total summer rainfall. Ten rain events in September, ranging from 0.01-0.62 inch and totaling 1.89 inches, were stored in the wet detention pond or infiltrated (Figure 21). These September rain events represented 7% of the total summer rainfall.

The Sterling Ponds wet detention pond only discharged to Sumner Creek during a large combined rain event (1.30 inches) on May 11-12 and during three very large summer rain events on May 19 (1.65 inches), June 1 (2.53 inches), and August 29 (2.28 inches). These discharges of storm water to Sumner Creek were directly measured at Site 5MHW. The combined rainfall on these five dates totaled 7.76 inches (30% of the total summer rainfall).

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on May 11-12 was a bit unusual, as the combined rainfall amount on May 11-12 (1.30 inches) was less than the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. Furthermore, the back-to-back rain events on May 11 (0.51 inch) and May 12 (0.79 inch) were characterized by moderate rainfall amounts, extended rainfall durations, and low rainfall intensities. Although the Sterling Ponds wet detention pond likely captured the majority of the May 11 rain event (0.51 inch) before discharge to the Sumner Creek drainage way occurred, the entirety of the combined 24-hour May 11-12 rain event (1.30 inches) was not captured and infiltrated, as required by the River Falls Storm Water Management Ordinance. The very large antecedent rain event on May 8 (1.35 inches) probably utilized most of the Sterling Ponds wet pond capacity, thereby contributing to the inability of the Sterling Ponds wet detention pond to capture and infiltrate the entire May 11-12 rain event, due to insufficient pond capacity. Indeed, wet pond discharge to the infiltration basin, due to the May 8 rain event, was still in progress when the May 11-12 rain event began. Although the 3.1-day period between the end of rainfall on May 8 and the onset of rainfall on May 11 provided considerable infiltration time, it was apparently an insufficient amount of time for the wet pond to drain to the infiltration basin and regain enough capacity to store the combined May 11-12 rain event. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. The length of the wet pond discharge to the Sumner Creek drainage way (9.0 hours) was likely minimized by the extended duration of the combined rain events (6 hours) and some available capacity in the wet pond when the May 11 rain event began. 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. However, it seems likely that the majority of the combined May 11-12 rain event (1.30 inches) was infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on May 11-12, the duration of this wet pond discharge to Sumner Creek (9.0 hours) was much shorter than the duration of the discharge to the infiltration basin (3.9 days).

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on May 19-20 was primarily triggered by the large magnitude of the May 19 rain event (1.65 inches). With an extended rainfall duration (5 hours) and a moderate rainfall intensity (a peak rainfall rate of 0.53 inch per hour) on May 19, the Sterling Ponds wet pond had sufficient capacity to capture the majority of the May 19 rain event (1.65 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via wet pond drawdown (to the infiltration basin) after the combined May 11-12 rain event, which was complete on May 15. Nonetheless, the wet pond inflow rate simply exceeded the outflow rate to the infiltration basin on May 19, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. The length of the wet pond discharge to the Sumner Creek drainage way (10.8 hours) on May 19-20 was likely minimized by the extended duration of the rain event (5 hours) and considerable available capacity in the wet pond when the May 19 rain event began. 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. However, it seems likely that the majority of the combined May 19 rain event (1.65 inches) was infiltrated. Although a wet pond discharge to the Sumner Creek drainage way occurred on May 19-20, the duration of this wet pond discharge to Sumner Creek (10.8 hours) was much shorter than the duration of the discharge to the infiltration basin (4.2 days). The wet pond discharge to Sumner Creek on May 19-20 was not entirely unexpected, as the magnitude of the May 19 rainfall event (1.65 inches) clearly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance.

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on June 1-2 was primarily triggered by the great magnitude of the June 1 rain event (2.53 inches) and a very high rainfall intensity (a peak rainfall intensity rate of 1.32 inches per hour) during the initial wave of rainfall. The Sterling Ponds wet pond had sufficient capacity to capture the majority of the first rainfall wave (1.68 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via limited wet pond drawdown (to the infiltration basin) during the relatively short time period (5.5 hours) between the May 31 rain event (0.59 inch) and the June 1 rain event. The second wave of rainfall (0.76 inch) on June 1 reinforced the Sterling Ponds wet pond discharge to the Sumner Creek drainage way. With the wet detention pond still discharging to the infiltration basin after the May 31 rain event, the wet pond was quickly inundated with storm water on June 1. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. The very lengthy wet pond discharge to the Sumner Creek drainage way (28.7 hours) on June 1-2 was primarily influenced by the great magnitude of the June 1 rain event (2.53 inches). However, moderate antecedent rainfall (0.59 inch) on May 31 was also a likely influence. The short time duration (5.5 hours) between the May 31 and June 1 rain events provided only a limited opportunity for the May 31 rainfall to be infiltrated before the June 1 rain event began. As such, the antecedent rain event on May 31 utilized wet pond storage capacity that could have been used to capture a greater proportion of the June 1 rain event, resulting in a reduced wet pond discharge to the Sumner Creek drainage way. Additional wet pond storage capacity would also have been helpful for abatement of any "first-flush" temperature and water quality impacts. Although an extended wet pond discharge to the Sumner Creek drainage way occurred on June 1-2, the duration of this discharge was relatively short (28.7 hours), compared to the duration of discharge to the infiltration basin (a minimum of 6.3 days). Since the storm water volumes discharged to the infiltration basin and Sumner Creek were not measured, it is not possible to precisely determine the amounts of storm water infiltrated versus discharged. The wet pond discharge to Sumner Creek on June 1-2 was not entirely unexpected, as the magnitude of the June 1 rainfall event (2.53 inches) significantly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance.

Although the magnitude of the June 7 rain event (1.77 inches) exceeded the magnitude (1.5 inches) that requires infiltration (via the City of River Falls Storm Water Management Ordinance), the entirety of the June 7 rain event was infiltrated, and no wet pond discharge to Sumner Creek occurred. With a 6.3-day drawdown period after the June 1 rain event, the Sterling Ponds wet pond gained sufficient capacity to capture the June 7 rain event, especially the initial 1.29 inches that occurred within the first 1.75 hours. It was also helpful that the remainder of the rainfall (0.48 inch) on June 7 occurred over an extended time period (5.25 hours), at very low rainfall intensity rates.

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on August 29-30 was primarily triggered by the great magnitude of the August 29 rain event (2.28 inches) and a high rainfall intensity (a peak rainfall intensity rate of 0.96 inch per hour) during the second wave of rainfall. The Sterling Ponds wet pond had sufficient capacity to capture the majority of this rain event (1.96 inches) before discharge to the Sumner Creek drainage way began. This capacity was gained via complete wet pond drawdown (to the infiltration basin) after the August 18, 21, 23, and 24 rain events. With wet pond discharge to the infiltration basin ending on August 25, the intervening time (4.0 days) between August 25 and the August 29 rain event provided additional opportunity for wet pond water volume reduction, via infiltration through the bottom of the pond and evaporative water loss. The remaining rainfall on August 29 (0.32 inch) reinforced the Sterling Ponds wet pond discharge to the Sumner Creek drainage way. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin on August 29, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. The length of the wet pond discharge to the Sumner Creek drainage way (11.0 hours) on August 29-30 was likely minimized by the considerable available capacity in the wet pond when the August 29 rain event began. In contrast, the length of the wet pond discharge to the Sumner Creek drainage way (28.7 hours) on June 1-2 was markedly longer, in spite of a comparable rainfall amount (2.53 inches) on June 1. This difference in discharge length is likely due to front-loading of the June 1 rain event (majority of rainfall during the initial wave) and reduced wet pond capacity due to antecedent rainfall on May 31. Although an extended wet pond discharge to the Sumner Creek drainage way occurred on August 29-30, the duration of this discharge was relatively short (11.0 hours), compared to the duration of discharge to the infiltration basin (a minimum of 2.8 days). Since the storm water volumes discharged to the infiltration basin and Sumner Creek were not measured, it is not possible to precisely determine the amounts of storm water infiltrated versus discharged. The wet pond discharge to Sumner Creek on August 29-30 was not entirely unexpected, as the magnitude of the August 29 rainfall event (2.28 inches) significantly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance.

The temperature data for Site 5P, Site 5IB, and Site 5MHW suggest that the performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 53 summer (May-September) rain events, ranging in magnitude from 0.01-1.77 inches. All runoff from these events was stored or infiltrated (Figures 20 and 21). The large combined rain event (1.30 inches) on May 11-12 and three very large rain events on May 19 (1.65 inches), June 1 (2.53 inches), and August 29 (2.28 inches) caused storm water discharges to the Sumner Creek drainage way; but the 24-hour rainfall amounts for three of these storms (May 19, June 1, and August 29) were greater than the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance.

A summary of the performance of Sterling Ponds storm water management practices during the entire 2005-2014 project period is presented in Figure 22.

Temperature monitoring of all 2005-2014 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. The 2005-2013 performance issues are detailed in the 2012 and 2013 Technical Reports, while the 2014 performance issues are summarized below.

2014 Performance Issues

Temperature monitoring of the Sterling Ponds storm water management practices in 2014 indicated that warm storm water was discharged from the Sterling Ponds wet pond to Sumner Creek during a large combined rain event (1.30 inches) on May 11-12 and three very large rain events on May 19 (1.65 inches), June 1 (2.53 inches), and August 29 (2.28 inches). The circumstances contributing to these wet pond discharges to Sumner Creek are detailed in the *2014 Performance Assessment* above.

The Sterling Ponds wet pond discharge to the Sumner Creek drainage way on May 11-12 was a bit unusual and problematic, as the combined rainfall amount on May 11-12 (1.30 inches) was not captured and fully infiltrated, as required by the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. A large antecedent rain event on May 8 (1.35 inches) likely utilized much of the Sterling Ponds wet pond capacity, thereby contributing to the inability of the Sterling Ponds wet detention pond to capture and infiltrate the May 11-12 rain events, due to insufficient pond capacity. Although the 3.1-day period between the end of rainfall on May 8 and the onset of rainfall on May 11 provided considerable infiltration time, it was apparently an insufficient amount of time for the wet pond to drain to the infiltration basin and regain enough capacity to store the combined May 11-12 rain event. The inability to infiltrate the May 8 rain event (1.35 inches) within a 3.1-day period may suggest that the wet pond outlet to the infiltration basin was partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin, or perhaps by organic material in the pipe itself. The lack of a discharge lag (the time lag between the onset of Sterling Ponds wet pond discharge to the infiltration basin and the onset of wet pond discharge to Sumner Creek) on May 11 (Appendix A) also suggests that the wet pond outlet to the infiltration basin may have been partially plugged.

The great magnitude of rainfall on May 19 (1.65 inches), June 1 (2.53 inches), and August 29 (2.28 inches) was a major factor contributing to the Sterling Ponds wet pond discharges to Sumner Creek during these rain events. Given that the 24-hour rainfall amounts on these dates exceeded the 1.5-inch infiltration standard set by the River Falls Storm Water Management Ordinance, it is understandable that Sterling Ponds storm water management practices were inadequate to ensure complete infiltration of storm water under these circumstances. Past monitoring has documented that wet pond discharges to Sumner Creek commonly occur when 24-hour rainfall amounts exceed 1.5 inches (Appendix A). During the 2005-2014 monitoring period, wet pond discharges occurred during 21 rain events ranging from 1.59-4.00 inches. On average, two such rain events occur each summer.

In addition to great rainfall magnitudes, high rainfall intensity rates and short rainfall durations also contributed to the Sterling Ponds wet pond discharges to Sumner Creek during the June 1 and August 29 rain events. Both rain events were characterized by convective thunderstorm activity that produced periods of very intense rainfall, with peak rainfall rates of 1.32 inches per hour during the June 1 storm and 0.96 inch per hour during the August 29 storm. Rainfall durations during these two rain events were relatively short. The majority (1.72 inches) of the June 1 rainfall (2.53 inches) occurred in one-hour periods during two waves of rain. The majority (1.59 inches) of the August 29 rainfall (2.28 inches) also occurred in one-hour periods during two waves of rain. These high-intensity, short-duration storm pulses rapidly delivered storm water to the Sterling Ponds wet pond, quickly overwhelming the capacity of the pond. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged to Sumner Creek.

Wet pond discharges to Sumner Creek during the May 11-12 and June 1 rain events were also significantly affected by antecedent rainfall, with 1.35 inches of rain (May 8) preceding the May 11-12 rain event and 0.59 inch of rain (May 31) preceding the June 1 rain event. These antecedent rain events reduced the storage capacity in the Sterling Ponds wet detention pond and provided limited intervening periods of time for storm water discharge to the infiltration basin before the onset of additional rainfall. As such, the Sterling Ponds wet detention pond was still discharging to the infiltration basin when the May 11-12 and June 1 rain events began. As noted above, the 3.1-day period between the May 8 and May 11-12 rain events should have provided sufficient time to fully infiltrate the May 8 rain event. In contrast, the short time duration (5.5 hours) between the May 31 and June 1 rain events provided only a very limited opportunity for the May 31 rainfall to be infiltrated before the June 1 rain event began.

No discharge lag was apparent during the May 11-12 rain event, while discharge lags of 2.7 hours, 1.3 hours, and 16.8 hours were evident during the May 19, June 1, and August 29 rain events, respectively (Appendix A). Discharge lags, defined as the time lag between the onset of Sterling Ponds wet pond discharge to the infiltration basin and the onset of wet pond discharge to Sumner Creek, provide a limited opportunity for first-flush abatement of temperature and water quality impacts. For this reason, longer discharge lags are desirable when rain events ≥1.5 inches result in Sterling Ponds wet pond discharges to Sumner Creek. During the 2005-2014 monitoring period, wet pond discharge lags ranging from none (instantaneous) to 17.5 hours were associated with the 22 rain events ranging from 1.30-4.00 inches (Appendix A).

As noted above, the lack of a discharge lag during the May 11-12 rain event suggests that the Sterling Ponds wet pond outlet to the infiltration basin may have been partially plugged. The short discharge lag (2.7 hours) during the May 19 rain event reinforces the possibility that the wet pond outlet to the infiltration basin may have been partially plugged. The extended rainfall duration (5 hours) and moderate rainfall intensity on May 19 should have gradually filled the Sterling Ponds wet pond to capacity, thereby creating a longer discharge lag.

The short discharge lag (1.3 hours) during the June 1 rain event can be attributed to the great magnitude of the rain event (2.53 inches), a high rainfall intensity rate (1.32 inches per hour), the short duration (2 hours) of heavy rainfall, the timing of heavy rainfall at the front end of the storm, and moderate antecedent rainfall on May 31 (0.59 inch), which reduced the capacity of the Sterling Ponds wet pond before the June 1 rain event began.

The short discharge lags during the May 11-12 and June 1 rain events provided very little opportunity for first-flush abatement of temperature and water quality impacts.

The 16.8-hour discharge lag during the August 29 rain event was the second-longest recorded during the 2005-2014 monitoring period. This much-extended discharge lag can be attributed to two rainfall waves on August 29, with an intervening 14.0-hour period between these two waves. The first (early morning) rainfall wave on August 29 (0.63 inch of rain) used some of the available capacity of the Sterling Ponds wet pond and resulted in a discharge to the infiltration basin at 04:00 CDT (4:00 AM). The second (evening) rainfall wave on August 29 delivered much more rain (1.53 inches) at a higher rainfall intensity rate. With the second rainfall wave rapidly consuming the remaining capacity of the Sterling Ponds wet pond, the discharge to Sumner Creek commenced at 20:50 CDT (8:50 PM). The extended discharge lag on August 29 provided a significant opportunity for first-flush abatement of the temperature and water quality impacts associated with the first rainfall wave on August 29.

Sterling Ponds wet pond discharge times to Sumner Creek during the May 11-12, May 19, June 1, and August 29 rain events were 9.0 hours, 10.8 hours, 28.7 hours, and 11.0 hours, respectively (Appendix A). Discharge time is simply defined as the length of time that the Sterling Ponds wet pond discharges to Sumner Creek. During the 2005-2014 monitoring period, wet pond discharge times ranging from 2.5-34.5 hours were associated with the 22 rain events ranging from 1.30-4.00 inches (Appendix A and Figure 23). For these rain events ≥1.5 inches, reduced wet pond discharge times are clearly more desirable than extended discharge times.

Given that the combined rainfall amount on May 11-12 (1.30 inches) was less than the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance, the discharge time associated with this rain event (9.0 hours) was much too lengthy. Although antecedent rainfall on May 8 (1.35 inches) may have influenced this extended discharge time, the inability to fully infiltrate the May 8 rain event within a 3.1-day period, the lack of a discharge lag, and the extended discharge time during the May 11-12 rain event all suggest that the wet pond outlet to the infiltration basin may have been partially plugged.

The comparatively short wet pond discharge time associated with the May 19 rain event (10.8 hours) can be attributed to a rainfall magnitude (1.65 inches) that was slightly greater than the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. The Sterling Ponds wet pond also had sufficient capacity to capture the majority of the May 19 rain event, as the antecedent rainfall on May 11-12 (1.30 inches) was infiltrated by May 15. Considering all rain events ≥ 1.5 inches during the 2005-2014 monitoring period, the wet pond discharge time (10.8 hours) associated with the May 19 rain event (1.65 inches) was the fifth-shortest recorded. A comparison of the May 19, 2014 rain event to five similarly-sized rain events in the 1.50-2.00 inch rainfall range indicates that a slightly smaller rain event in 2013 (1.59 inches) and four slightly larger rain events in 2005 (1.76 inches), 2006 (1.80 inches), 2007 (1.72 inches), and 2011 (1.78 inches) produced wet pond discharge times ranging from 4.0-16.0 hours (Appendix A and Figure 23).

Although the dynamics and magnitudes of the rain events on June 1 (2.53 inches) and August 29 (2.28 inches) were very similar, the wet pond discharge times associated with these two rain events were markedly different.

The extended wet pond discharge time associated with the June 1 rain event (28.7 hours) can be primarily attributed to the great magnitude of rainfall that inundated the wet pond. Rainfall magnitude on June 1 (2.53 inches) significantly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. However, moderate antecedent rainfall on May 31 (0.59 inch) also played a key role by reducing the capacity of the Sterling Ponds wet pond before the June 1 rain event occurred. In addition, the May 31 rainfall amount was not entirely infiltrated by June 1. The timing of the heaviest rainfall (1.68 inches) at the front end of the June 1 rain event also contributed to the extended discharge time. Considering all rain events ≥ 1.5 inches during the 2005-2014 monitoring period, the wet pond discharge time (28.7 hours) associated with the June 1 rain event (2.53 inches) was the second-longest recorded. A comparison of the June 1 rain event to similarly-sized rain events in the 2.00-2.60 inch rainfall range indicates that only a slightly larger rain event on September 23, 2010 (2.58 inches) had a longer discharge time (34.5 hours). Three slightly smaller rain events in 2005 (2.49 inches), 2010 (2.43 inches), and 2011 (2.46 inches) produced wet pond discharge times ranging from 14.0-20.0 hours (Appendix A and Figure 23).

In contrast, the wet pond discharge time associated with the August 29 rain event (11.0 hours) was notably shorter than the discharge time associated with the June 1 rain event (28.7 hours). Certainly the wet pond discharge time on August 29-30 (11.0 hours) was substantially influenced by the great magnitude of rainfall (2.28 inches), which significantly exceeded the 1.5-inch, 24-hour infiltration standard set by the River Falls Storm Water Management Ordinance. However, complete wet pond drawdown to the infiltration basin after the August 18, 21, 23, and 24 rain events and an intervening 4.0-day dry period between August 25 and the August 29 rain event created considerable wet pond capacity to capture much of this event, thereby reducing the discharge time. The timing of the heaviest rainfall (1.53 inches) during the second (evening) rainfall wave on August 29 also helped to reduce the discharge time by enabling some infiltration of the first (early morning) rainfall wave (0.63 inch). Considering all rain events ≥ 1.5 inches during the 2005-2014 monitoring period, the wet pond discharge time (11.0 hours) associated with the August 29 rain event (2.28 inches) was the sixth-shortest recorded. A comparison of the August 29 rain event to six similarly-sized rain events in the 2.00-2.50 inch rainfall range indicates that two slightly smaller rain events in 2012 (2.05 inches and 2.27 inches) produced longer wet pond discharges (19.3 hours and 14.8 hours, respectively). Four slightly larger rain events in 2005 (2.49 inches), 2010 (2.43 inches), 2011 (2.46 inches), and 2013 (2.31 inches) also produced longer wet pond discharge times, ranging from 14.0-20.0 hours (Appendix A and Figure 23).

As observed throughout the 2005-2014 monitoring period, the seasonal timing of Sterling Ponds wet pond discharges to Sumner Creek can greatly influence the potential for downstream thermal impacts. The June 1 and August 29 rain events were both characterized by strong convective thunderstorm activity on warm days. On June 1, air temperatures were relatively warm, ranging from 18-24° C (64-75° F). As such, the temperature of the wet pond discharge to Sumner Creek on June 1-2 averaged 19.5º C and ranged from 17.6-21.7º C during the 28.7-hour discharge period. In comparison, air temperatures on August 29 were notably warmer, ranging from 18-30° C (65-86° F). As a result, the temperature of the wet pond discharge to Sumner Creek on August 29-30 was also warmer, averaging 21.4º C and ranging from 20.7-21.8º C during the 11.0-hour discharge period. The average Sterling Ponds wet pond discharge temperatures on June 1-2 (19.5º C) and August 29-30 (21.4º C) were substantially higher than pre-rainfall temperatures in Sumner Creek (Site 4A) on June 1 (15.4° C) and August 29 (16.5° C), indicating the strong potential for downstream thermal impacts during both rain events. In fact, the June 1-2 wet pond discharge may have contributed to a secondary thermal spike (2.1º C) evident at Site 4A, as well as to the extended duration (20.0 hours) of warmer-than-normal water at Site 4A, until 20:10 CDT (8:10 PM) on June 1, when a peak temperature of 21.5º C occurred. The August 29-30 wet pond discharge may have contributed to a small secondary thermal spike (0.8º C) evident at Site 4A, as well as to the extended duration (4.3 hours) of warmer-than-normal water at Site 4A, until 23:50 CDT (11:50 PM) on August 29, when a peak temperature of 18.5º C occurred.

The extended time (8.7 days) needed to infiltrate the combined precipitation during the July 7-14 period (2.08 inches) seems excessive, especially since 52% of this precipitation (1.09 inches) occurred on July 7. The extended time (7.1 days) needed to infiltrate the combined precipitation during the August 18-24 period (1.59 inches) seems quite excessive, especially since 81% of this precipitation (1.28 inches) occurred on August 18. Finally, the extended time (3.6 days) needed to infiltrate the moderate rain event (0.51 inch) on September 10 also seems quite excessive. These three instances of overly-extended Sterling Ponds wet pond discharges to the infiltration basin in 2014 suggest that the wet pond outlet to the infiltration basin may have been partially plugged, perhaps by pond vegetation at the wet pond end (entrance) of the pipe leading to the infiltration basin, or perhaps by organic material in the pipe itself. As noted previously, the inability to fully infiltrate the May 8 rain event (1.35 inches) within a 3.1-day period, the lack of a discharge lag during the May 11 rain event, and the short discharge lag (2.7 hours) during the May 19 rain event all reinforce the possibility that the wet pond outlet to the infiltration basin may have been partially plugged in 2014.

2005-2014 Performance Summary

Temperature monitoring of the Sterling Ponds storm water management practices during the 2005-2014 period indicates that storm water discharges to Sumner Creek are occurring:

- During rain events larger than 1.5 inches (2005-2007 and 2009-2014);

- During back-to-back rain events, when rainfall amounts range from 0.44-1.5 inches and time periods between rain events are less than 48 hours (2006, 2007, 2011, 2013, and 2014);
- During very intense rain events, when rainfall amounts range from 1.0-1.5 inches (2008).

A summary of the 2005-2014 Sterling Ponds storm water discharges to Sumner Creek, including discharge dates, rainfall amounts, discharge lags, and discharge times, is provided in Appendix A. Figure 23 compares rainfall amounts to Sterling Ponds wet pond discharge times during the 2005-2014 period.

In June 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 provided more storm water storage in the wet pond and allowed 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 total suspended solids (TSS) and total phosphorus (TP). As such, the modification should be beneficial for the back-to-back rain events and very intense rain events ≤1.5 inches that are occasionally causing wet pond discharges to Sumner Creek. More storm water storage capacity in the wet pond should also increase discharge lags and reduce the discharge times associated with rain events larger than 1.5 inches.

The modification made to the control structure for the Sterling Ponds wet pond outlet to Sumner Creek seemed to improve storage and infiltration capacity for these types of events in 2007, 2008, and 2009, but was not particularly helpful for the very large rain events (12 events ≥1.5 inches) that occurred in 2010, 2011, 2012, 2013, and 2014. 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. In addition, perhaps some provision should be made in the River Falls Storm Water Management Ordinance to ensure adequate infiltration of back-to-back 1.5-inch, 24-hour rain events. More capacity in the wet pond may be helpful for capturing more storm water volume during very intense rain events, but the increased volume in the pond could require more infiltration time, which may prove problematic when large, back-to-back rain events occur.

Given the frequent number of rain events ≥1.5 inches during the 2004-2014 monitoring period (28), including 21 that resulted in wet pond discharges to Sumner Creek during the 2005-2014 period, perhaps an ordinance amendment should be considered to require infiltration of all 24-hour rain events ≤2.0 inches. Such an ordinance modification would have covered 11 (42%) of the 28 rain events ≥1.5 inches during the 2004-2014 monitoring period, and potentially would have resulted in 7 fewer rain events with wet pond discharges to Sumner Creek.

The extended Sterling Ponds wet pond discharge times to the infiltration basin after rain events during the July 7-14 and August 18-24 periods and after the September 10 rain event suggest possible partial plugging of the pipe conveying wet pond storm water to the infiltration basin. The inability to fully infiltrate the May 8 rain event (1.35 inches) within a 3.1-day period, the lack of a discharge lag during the May 11 rain event, and the short discharge lag (2.7 hours) during the May 19 rain event all reinforce the possibility that the wet pond outlet to the infiltration basin may have been partially plugged in 2014. Figure 24 compares rainfall amounts to Sterling Ponds wet pond infiltration times during the 2011-2014 period. Rainfall amounts during three time periods in 2013 (May 1-11, May 18-June 1, and June 12-15) were also characterized by extended infiltration times. In addition, six rain events in 2011-2012 (ranging from 0.48-2.13 inches) were characterized by extended Sterling Ponds wet pond discharge times to the infiltration basin (ranging from 4.7-11.1 days). Given these circumstances in 2011-2014, maintenance work may be needed to clear the pipe between the Sterling Ponds wet pond and the infiltration basin. The wet pond end (entrance) of the pipe should be checked to ensure that it is not partially plugged by pond vegetation or other organic material. In addition, it may be beneficial to flush the entire length of the pipe.

While this project is primarily focused on evaluating long-term trends, annual performance information is important as well. With the exception of the combined rain events on May 11-12 (1.30 inches) and three very large rain events on May 19 (1.65 inches), June 1 (2.53 inches) and August 29 (2.28 inches), the storm water management practices at Sterling Ponds prevented thermal impacts on Sumner Creek during the May-September (summer) 2014 period. The following should be noted:

- The performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 53 rain events, ranging in magnitude from 0.01-1.77 inches and totaling 18.25 inches of precipitation (70% of the total summer precipitation). All storm water runoff from 52 rain events ≤1.5 inches 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.

- With the exception of the combined rain events on May 11-12, smaller rainfall events (less than one inch) caused no thermal impacts on Sumner Creek due to Sterling Ponds wet pond discharges (see Appendix B). However, during very large rain events on June 1 and August 29, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, for extended time periods (28.7 and 11.0 hours, respectively). The warm storm water discharges during these two rain events may have contributed to secondary thermal spikes (2.1º C and 0.8º C, respectively) in Sumner Creek at Site 4A, as well as to extended durations (20.0 hours and 4.3 hours, respectively) of warmer-than-normal water at Site 4A. The presence, intensity, and frequency of thermal spikes will continue to be monitored in the years to come.
- "First-flush" thermal spikes were also observed in lower Sumner Creek (Site 4A) during the June 1 and August 29 rain events. These "first-flush" thermal spikes (3.1º C on June 1 and 1.7º C on August 29) 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 2005-2014 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 2005-2014 period is presented in Figure 22. 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 2006-2014 period. Beyond 2014, these same trends will be monitored from year to year, to determine if favorable results are apparent in the future.

Water Quality Monitoring:

A re-evaluation of the North Kinnickinnic River Monitoring Project was conducted at the end of the 2012 monitoring season. Given budget considerations and time constraints, as well as the challenge of operating automated monitoring equipment and/or collecting grab samples during rainfall and runoff events, the water quality monitoring component of the project was discontinued.

As future resources allow, it would be good to obtain water quality information on the performance of the Sterling Ponds storm water management practices. Automated monitoring equipment could be located at Sites 5IN (Sterling Ponds wet detention pond inlet) and 5MHW (Sterling Ponds wet detention pond outlet). Along with automated sampling at these two locations, grab sampling could be conducted at Site 5IB (Sterling Ponds infiltration basin). Water samples could 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: 2005-2014 Performance Summary"***, above). Large rain events (>1.0 inch) of various magnitudes could be targeted for this Sterling Ponds water quality monitoring work.

Base Flow Surveys:

The USGS stream flow gauge located at County Highway F, as described earlier in this report, is used to determine when a base flow condition exists in the North Kinnickinnic River Monitoring Project Area. When 3-4 days of "flat-line" flow are observed at the USGS station, the river is assumed to be in a base flow condition. With above-normal rainfall (+9.79 inches) during the April-September 2014 period, Kinnickinnic River base flows generally ranged from 115-150 cfs, as measured at County Highway F (Figure 8). Base flows increased substantially (from 115 cfs to 150 cfs) during the wetter-than-normal (+11.89 inches) April-June period, but gradually decreased (from 150 cfs to 130 cfs) during the drier-than-normal (-2.10 inches) July-September period. With above-normal rainfall and considerable groundwater recharge during the April-September 2014 period, the Kinnickinnic River base flow in late September (130 cfs) was notably higher than the base flow in early April (115 cfs).

Real-time and recent (120-day) stage, flow, and precipitation data for the USGS monitoring station are web-accessible at:

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

In past monitoring years (2005-2012), instantaneous measurements of base flow have been 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. Base flow surveys have been conducted in the spring and autumn, using a handheld SonTek® FlowTracker Acoustic Doppler Velocimeter (ADV).

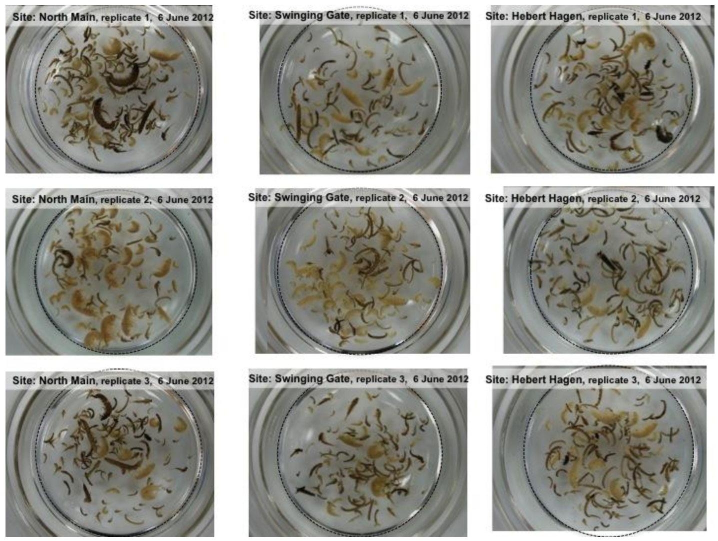
A re-evaluation of the North Kinnickinnic River Monitoring Project was conducted at the end of the 2012 monitoring season. Given budget considerations and time constraints, it was determined that only autumn base flow surveys will be conducted in future monitoring years. However, given time constraints, no autumn base flow surveys were conducted in 2013 and 2014. The results of previous spring and autumn base flow surveys can be found in the 2005-2012 Technical Reports, and in the North Kinnickinnic River Monitoring Project Indicators.

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) (Figure 1) and a continuation of moderate-severe drought conditions are the likely causes of the observed base flow reductions through 2009. With above-normal precipitation during the summer of 2010 and only slightly below-normal precipitation during the summer of 2011 (Figure 1), base flows rebounded at all sites in the project area. The decreased autumn 2012 base flows in the North Kinnickinnic River Monitoring Project Area were caused by much-reduced rainfall in August and September 2012 and the severe drought conditions that developed by early October 2012. Performance monitoring at Sterling Ponds has demonstrated that the storm water management practices have provided excellent infiltration capacity since 2004, thereby helping to sustain groundwater recharge during any extended dry periods.

Annual 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. During the 2004-2012 period, macroinvertebrate samples were collected annually at Sites 1-3 within the North Kinnickinnic River Monitoring Project Area. Triplicate samples were collected each year at each of the three monitoring sites. Sampling was generally conducted in late May or early June. After collection, the organisms in each sample are identified and counted at the University of Wisconsin-Stevens Point Aquatic Biomonitoring Laboratory (Wisconsin Cooperative Fishery Research Unit). Various biological indices can then be calculated for each monitoring site. The index values are indicative of water quality, depending upon the pollution tolerances of the macroinvertebrates collected at the monitoring sites.



Site 1 Site 2 Site 3

Triplicate macroinvertebrate samples collected at Sites 1-3 in 2012

The use of benthic (bottom-dwelling) macroinvertebrates to evaluate stream water quality was initiated in Wisconsin with the work of W. L. Hilsenhoff at the University of Wisconsin-Madison. The Hilsenhoff Biotic Index (HBI), which has been modified and refined over a number of years (Hilsenhoff 1977, 1982, 1987), is particularly useful for determining the influence of organic pollution on macroinvertebrates. The Wisconsin Department of Natural Resources has used this index for many years in long-term stream monitoring programs.

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

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

Where:

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

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

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

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

The 2004-2012 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 2004-2012 macroinvertebrate HBI values at Sites 1-3 are also presented in Figure 25. The 2004-2012 data establish an ongoing baseline for assessing the long-term health of the macroinvertebrate community within the project area.

Table 1. Macroinvertebrate HBI Values in the Kinnickinnic River: 2004-2012

Monitoring Site	2004 HBI Values	2005 HBI Values	2006 HBI Values	2007 HBI Values	2008 HBI Values	2009 HBI Values	2010 HBI Values	2011 HBI Values	2012 HBI Values
Site 1: North Main	2.77 2.86 2.99	3.17 3.04 2.79	3.57 3.57 3.62	3.64 3.85 4.07	2.89 3.95 3.78	4.04 3.85 3.89	3.90 4.03 3.45	3.40 3.46 3.35	2.87 3.45 3.08
Mean of 3 reps:	2.87	3.00	3.59	3.85	3.54	3.93	3.79	3.40	3.13
Site 2: Swinging Gate (STH 65)	4.20 3.99 3.85	4.30 4.67 4.45	4.01 3.91 4.13	3.85 3.84 3.62	5.41 4.18 4.52	4.14 4.08 3.66	4.17 4.21 3.89	3.73 3.93 3.78	3.21 3.07 3.47
Mean of 3 reps:	4.01	4.47	4.02	3.77	4.70	3.96	4.09	3.81	3.25

Site 3: Hebert-Hagen	3.37 4.04 3.60	3.65 3.55 3.13	3.88 3.72 3.89	3.65 3.86 3.74	4.44 3.89 3.78	3.66 3.74 3.26	3.87 4.13 4.10	3.55 3.49 3.71	3.46 3.17 3.39
Mean of 3 reps:	3.67	3.44	3.83	3.75	4.04	3.55	4.03	3.58	3.34

During the 2004-2012 period, mean annual HBI values at Site 1, ranging from 2.87-3.93, were indicative of very good-excellent water quality. Mean annual HBI values at Site 2, ranging from 3.25-4.70, were indicative of good-excellent water quality. Mean annual HBI values at Site 3, ranging from 3.34-4.04, were indicative of very good-excellent water quality.

Mean annual HBI values at Site 1 increased slightly during the 2004-2009 period (Figure 25), indicating a slight degradation of water quality. However, the 2006-2009 values were still indicative of very good water quality. Mean annual HBI values at Site 1 decreased slightly during the 2010-2012 period, indicating improving water quality. In spite of some apparent degradation during the 2004-2009 period, the mean annual HBI values at Site 1 are generally less than or comparable to the mean annual HBI values at Sites 2 and 3, indicating slightly better water quality at Site 1.

Mean annual HBI values at Site 2 have been relatively consistent; but values increased in 2005 and 2008, indicating a slight degradation of water quality. Most recently (2011-2012), mean annual HBI values at Site 2 decreased slightly, indicating improving water quality. With the exception of 2008, all mean annual HBI values during the 2004-2012 period were indicative of very good-excellent water quality.

Mean annual HBI values at Site 3 were relatively consistent during the 2004-2012 period. Most recently (2011-2012), mean annual HBI values at Site 3 decreased slightly, indicating improving water quality. Throughout the 2004-2012 period, all mean annual HBI values at Site 3 were indicative of very good-excellent water quality.

The comparability of mean annual macroinvertebrate HBI values at Sites 1-3 during the 2004-2012 period indicates that no storm water impacts were apparent at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. In fact, the mean 2004-2012 macroinvertebrate HBI values at Sites 1-3 indicate that the best water quality was evident at Site 1. The mean 2004-2012 macroinvertebrate HBI value at Site 1 (3.46) was indicative of excellent water quality, while the mean 2004-2012 macroinvertebrate HBI values at Site 2 (4.01), and Site 3 (3.69) were indicative of very good water quality. The 2004-2012 macroinvertebrate monitoring results nicely corroborate the 2004-2012 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.

A re-evaluation of the North Kinnickinnic River Monitoring Project was conducted at the end of the 2012 monitoring season. Given budget considerations and time constraints, it was determined that future macroinvertebrate monitoring will only be conducted at Sites 1 and 2 on a biennial basis (in even years). As such, no macroinvertebrate monitoring was conducted in 2013. Unfortunately, with consistently high river flows and turbid water in the North Kinnickinnic River Monitoring Project Area throughout the months of May and June 2014, no macroinvertebrate samples could be obtained. An attempt will be made to collect macroinvertebrate samples again in 2015. 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 2004-2014 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
2005-2014

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2012:
The Sterling Ponds wet detention pond discharged to Sumner Creek during two large summer rain events in excess of 1.5 inches.

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

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

2013:
The Sterling Ponds wet detention pond discharged to Sumner Creek during two large summer rain events in excess of 1.5 inches, and during a small-moderate rain event (0.44 inch) on June 22.

Date	Rainfall Amount	Discharge Lag	Discharge Time
June 21	1.59 inches	16.2 hours	7.2 hours
June 22*	0.44 inch	10 minutes	1.3 hours
June 26*	2.31 inches	40 minutes	14.7 hours

*Antecedent rain events occurred on June 21 (1.59 inches) and June 21-23 (a combined 2.32 inches)

2014:
The Sterling Ponds wet detention pond discharged to Sumner Creek during a large combined rain event (1.30 inches) on May 11-12, and during three large summer rain events in excess of 1.5 inches.

Date	Rainfall Amount	Discharge Lag	Discharge Time
May 11-12*	1.30 inches	None	9.0 hours
May 19	1.65 inches	2.7 hours	10.8 hours
June 1*	2.53 inches	1.3 hours	28.7 hours
August 29	2.28 inches	16.8 hours	11.0 hours

*Antecedent rain events occurred on May 8 (1.35 inches) and May 31 (0.59 inch)

Discharge Lag is defined as the time lag between the onset of wet pond discharge to the infiltration basin and the onset of wet pond discharge to Sumner Creek.
Discharge Time is the length of time that wet pond 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 2014

Smaller rainfall and runoff events can have significant storm water impacts on the Kinnickinnic River, as was evident by the numerous thermal spikes caused by direct (untreated) storm water discharges upstream from the Division Street monitoring site during the 2007-2013 period (2007-2013 Technical Reports). 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 2014, due to several factors:

1. Building progress remained very limited in the Sterling Ponds subdivision in 2014, and has only occurred in the southeast and northeast quadrants of the subdivision during the 2004-2014 period.

   In the southeast quadrant, 3 single-family housing units were built by year-end 2003, 19 single-family housing units were built by year-end 2004, 33 single-family housing units were built by year-end 2005, 36 single-family housing units were built by year-end 2006, 48 single-family housing units were built by year-end 2007, 56 single-family housing units were built by year-end 2008, and 58 single-family housing units were built by year-end 2009. No additional single family units were built in 2010 and 2011, leaving the year-end totals at 58 units. In 2012, 1 additional single family unit was built, leaving the year-end total at 59 units. In 2013, 5 additional single family units were built, leaving the year-end total at 64 units. In 2014, 2 additional single family units were built, leaving the year-end total at 66 units.

   In the northeast quadrant, 2 duplex units were complete by year-end 2005, and 2 multi-family (8-plex) units were under construction. By year-end 2006, 1 single-family unit, 2 duplex units, 3 multi-family 8-plex units, and 2 multi-family 10-plex units were complete, for a total of 49 units. By year-end 2007, 3 single-family units, 5 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 77 units. By year-end 2008, 11 single-family units, 8 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 91 units. By year-end 2009, 12 single-family units, 9 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 94 units. In 2010, only two single-family units were built, leaving the year-end total at 96 units, as follows: 14 single-family units, 9 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units. No additional housing units were built in 2011, 2012, 2013, and 2014, leaving the year-end totals at 96 units.

   A build-out total of 600 units is projected for Sterling Ponds. By year-end 2014, a combined 162 units (27% of projected build-out) were complete in the southeast and northeast quadrants of Sterling Ponds.

Maps of Sterling Ponds build-out progress in 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, and 2014 are available on the project website ("Annual Reports"). With 66 (44%) of approximately 150 single family units complete in the southeast quadrant, 96 (64%) of approximately 150 family units complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2014, 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 2014 build-out map) was only 12.7% (8.5 acres of 66.8 acres) in 2014, reflecting a build-out rate of 40.5% (60 of 148 lots). The percent impervious area and percent build-out rate for each of the eleven project years are as follows:

2004:	7.9% Impervious	10.8% Build-out
2005:	9.1% Impervious	18.2% Build-out
2006:	9.5% Impervious	20.9% Build-out
2007:	11.1% Impervious	31.8% Build-out
2008:	11.5% Impervious	33.8% Build-out
2009:	11.7% Impervious	35.1% Build-out
2010:	11.7% Impervious	35.1% Build-out
2011:	11.7% Impervious	35.1% Build-out
2012:	11.8% Impervious	35.8% Build-out
2013:	12.3% Impervious	39.2% Build-out
2014:	12.7% Impervious	40.5% Build-out

2. Four wet storm water detention ponds were already in place in 2014, 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 2014. 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 2014 period (see 2014 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 2014, as required by the ordinance. Indeed, monitoring of the southeast storm water management practices in 2014 demonstrated excellent infiltration for 53 summer rain events, ranging in magnitude from 0.01-1.77 inches and totaling 18.25 inches (70% 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 2014 capably evaluated ordinance effectiveness and identified the storm water impacts related to a combined (two-day) rain event and three 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.