City of River Falls
North Kinnickinnic River Monitoring Project

2008 Technical Review

Report prepared by SEH Inc., for the

City of River Falls Engineering Department
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Project Introduction:

The Kinnickinnic River is one of the premier, naturally sustaining trout fisheries in the Upper Midwest, primarily producing brown trout. There has been a lot of concern about how new development in River Falls may affect the river, especially due to storm water runoff from impervious surfaces in these urbanizing areas. Not only can storm water runoff contribute chemicals from lawns, cars, etc., but the thermal impacts of untreated storm water are also a concern, as described on the North Kinnickinnic River Monitoring Project website (see "The Thermal Impacts of Storm Water"). In 2002, the City adopted a new Storm Water Management Ordinance, which is designed to protect the Kinnickinnic River from the negative impacts of storm water runoff associated with new development. For new development and re-development projects, the City of River Falls Storm Water Management Ordinance requires that, for a 1.5-inch, 24-hour rainfall event, the post-development runoff volume and peak flow rate must not exceed the pre-development runoff volume and peak flow rate. To achieve this requirement, developers must provide on-site infiltration of storm water.

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

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

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

River Falls Precipitation:

Due to the major influence of precipitation on river flow, temperature, and water quality, an analysis of seasonal precipitation is conducted as a part of this project. During the April-September 2008 monitoring period, hourly precipitation was measured in 0.01-inch increments with an electronic tipping-bucket rain gauge. The rain gauge, provided by the Wisconsin Department of Natural Resources (WDNR), is located in the Sterling Ponds subdivision at the northwest corner of the City of River Falls. This location places the rain gauge in very close proximity to all six North Kinnickinnic River monitoring stations. A weather station at Rocky Branch Elementary School, on the south side of River Falls, serves as an alternate source of daily rainfall data. This station is part of an extensive network of local weather stations supported by KSTP-TV in Minneapolis, MN, via the Automated Weather Source. The Rocky Branch Weather Station also serves as a source of daily mean, minimum, and maximum air temperatures in River Falls. In addition, daily precipitation data are available from the United States Geological Survey (USGS) Kinnickinnic River monitoring station at County Highway F, near Kinnickinnic State Park, approximately five miles west of River Falls.

A total of 20.01 inches of precipitation was recorded in River Falls (at Sterling Ponds) during the April-September 2008 period, only 0.66 inch less than the normal total of 20.67 inches for the April-September time period. Rain fell on 64 days, or 35% of the April-September 2008 period. In comparison, a near-normal total of 19.82 inches of precipitation was recorded in River Falls during the April-September 2004 monitoring period, an above-normal total of 36.45 inches was measured during the April-September 2005 period, a below-normal total of 17.16 inches was measured during the April-September 2006 period, and a below-normal total of 18.36 inches was measured during the April-September 2007 period (Figure 1). “Normal” monthly and seasonal rainfall amounts are based upon measurements made by the National Weather Service at the Twin Cites International Airport during the “climate normal period” of 1971-2000.

Daily rainfall amounts during the April-September 2008 period are presented in Figure 2. Monthly rainfall amounts during the April-September 2008 period, with a comparison to normal monthly rainfall amounts, are presented in Figure 3. April 2008 was the wettest month (5.94 inches), exceeding the normal monthly rainfall amount by 3.63 inches. After April, the summer of 2008 (May-September) was drier than normal, with a total summer rainfall deficit of 4.29 inches. All months during the May-September 2008 period were drier than normal, with monthly rainfall deficits ranging from 0.40 inch to 1.55 inches. The greatest rainfall deficits occurred in June and August, and the lowest monthly rainfall amounts were recorded in August (2.50 inches) and September (2.08 inches). Until mid-September 2007, the North Kinnickinnic River Monitoring Project Area was affected by a region-wide drought that began in early 2006 (see Figure 1). In April 2008, no drought conditions were apparent in the project area, but lower than normal summer rainfall resulted in abnormally dry conditions (Drought Severity Index = D0) by late August 2008 and moderate drought conditions (DSI = D1) by mid-September 2008 (U.S. Drought Monitor, at http://www.drought.unl.edu/dm/index.html).

Besides being slightly drier than normal, the April-September 2008 monitoring period was slightly cooler than normal. The mean air temperature in River Falls during the April-September 2008 period was 62.5º Fahrenheit (F), 0.7º F lower than the normal mean of 63.2º F for the April-September period, as measured at the Twin Cities International Airport. Monthly mean air temperatures during the April-September 2008 period, with a comparison to normal monthly mean temperatures during the "climate normal period" of 1971-2000, are presented in Figure 4. The first half of the 2008 monitoring period was colder than normal, while the second half was warmer than normal. The months of April and May were nearly 4º F colder than normal, and the month of June was slightly colder than normal. The months of July, August, and September were all slightly warmer than normal, with September experiencing the greatest departure (2.1º F).

The distribution of River Falls daily rainfall amounts during the April-September 2008 period is presented in Figure 5. Although the 2008 monitoring season was slightly drier than normal, it was characterized by numerous (52) days with rainfall amounts of 0.50 inch or less. On 34 (53%) of the 64 days with measurable precipitation, rainfall amounts were 0.25 inch or less. These 34 days contributed only 14% of the total April-September 2008 precipitation. Seventeen of these 34 days occurred in the cooler months of April, May, and September (Figure 6). On 18 (28%) of the 64 days with measurable precipitation, rainfall amounts ranged from 0.26-0.50 inch. These 18 days contributed an additional 34% of the total April-September 2008 precipitation. Eleven of these 18 days occurred in April, May, and September (Figure 6), when air temperatures were cooler. On 5 (8%) of the 64 days with measurable precipitation, rainfall amounts ranged from 0.51-0.75 inch. These 5 days contributed 16% of the total April-September 2008 precipitation, and occurred in April (3 days), June, and August (Figure 6). Only 3 (5%) of the 64 days with measurable precipitation had rainfall amounts in the 0.76-1.00 inch range (Figure 6), contributing 12% of the total April-September 2008 precipitation. These three rainfall events occurred in April, July, and August. On 4 (6%) of the 64 days with measurable precipitation, rainfall amounts exceeded 1.00 inch. These 4 days with the largest rainfall events contributed 24% of the total April-September 2008 precipitation. Rainfall amounts in excess of 1 inch occurred on April 10, May 2, June 5, and July 25 (Figures 2 and 6). On 3 of the 4 days, rainfall amounts ranged from 1.01-1.25 inches. On 1 of the 4 days (April 10), the rainfall amount exceeded 1.50 inches. All of these 4 largest rainfall events occurred during the April-July period, and all were produced by convective thunderstorm activity. No large rain events occurred in August or September, as drought conditions were emerging.

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 64 days with measurable precipitation during the April-September 2008 period, 63 days (98%) had rainfall amounts less than 1.5 inches in 24 hours (a midnight-to-midnight total). Infiltration of these 63 rain events (18.49 inches) would account for 92% of the total April-September precipitation (20.01 inches). Only the rainfall amount on April 10 (1.52 inches) exceeded the 1.5-inch infiltration criterion. Even so, substantial infiltration of the April 10 rainfall event would have occurred under the requirements of the storm water ordinance, thereby accounting for infiltration of nearly 100% (19.99 inches) of the total rainfall (20.01 inches) that occurred during the April-September 2008 period. Figure 7 depicts the annual effectiveness of the River Falls Storm Water Ordinance for infiltrating storm water runoff generated by rainfall during the April-September period. This figure was prepared for illustrative purposes only, and was created with the assumption that the entire 1.5-inch event is infiltrated. This scenario essentially assumes zero pre-development runoff, which may not necessarily be the case.

Kinnickinnic River Flow:

The flow of the Kinnickinnic River is a reflection of strong ground water (spring) contributions, as well as precipitation-induced storm water runoff from predominantly agricultural and urban land uses throughout the 165-square mile Kinnickinnic River Watershed. The United States Geological Survey (USGS) operates a Kinnickinnic River monitoring station (number 05342000) at County Highway F, near Kinnickinnic State Park, approximately five miles west of River Falls. The station measures river stage (water height) and flow at 15-minute intervals, and precipitation in 0.01-inch increments. Because accurate monitoring of river stage and flow entails a significant investment in equipment and labor, no continuous measurement of river flow is currently being conducted within the North Kinnickinnic River Monitoring Project Area. For this reason, the Kinnickinnic River flow information provided by the USGS monitoring station is particularly valuable, as it clearly documents when runoff events are occurring and storm water impacts may be apparent. The City of River Falls, Kinnickinnic River Land Trust, and Trout Unlimited provide annual cost-share funding 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 2008 period is presented as a hydrograph in Figure 8. Daily rainfall, as measured in River Falls at Sterling Ponds, is also presented in Figure 8.

Precipitation patterns help explain the changes that occur in the Kinnickinnic River hydrograph, due to runoff events in the watershed. Numerous (14) rain events in April 2008 produced an active hydrograph with a regular series of runoff events (Figure 8). Small rain events on April 1 (0.36 inch) and April 4 (0.06 inch) and a larger rain event on April 6 (0.66 inch) produced moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 128 cfs (April 4) and 135 cfs (April 7), respectively. Back-to-back rain events (a combined 2.18 inches) on April 10 (1.52 inches) and April 11 (0.66 inch) produced the second-largest runoff event of the April-September 2008 monitoring period, with a peak daily mean flow of 188 cfs (April 11). The April 10 rain event (1.52 inches) was the largest recorded during the April-September 2008 period. Smaller back-to-back rain events on April 18-19 (a combined 0.78 inch) and April 21-22 (a combined 0.88 inch), followed by a larger rain event on April 24 (0.77 inch), produced a series of successively higher increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 115 cfs (April 19), 141 cfs (April 22), and 172 cfs (April 25), respectively. With above-normal rainfall (Figure 3), saturated soils, and minimal canopy closure in the agricultural and forested areas of the watershed, substantial runoff occurred in April 2008.

With drier conditions prevailing and below-normal precipitation evident during the May-September 2008 period (Figure 3), runoff events were relatively infrequent (Figure 8). Numerous (39) small rain events (less than 0.50 inch) throughout this period had little influence on the Kinnickinnic River hydrograph, producing peak daily mean flows of 100 cfs or less. Rainfall amounts in excess of 1 inch generally had the greatest influence on the hydrograph. A large rain event on May 2 (1.02 inches) produced the third-largest runoff event of the April-September 2008 monitoring period, with a peak daily mean flow of 188 cfs (May 3). The magnitude of this event was likely aided by the very wet antecedent conditions in April.

Two large runoff events occurred during the first half of June 2008 (Figure 8). A large rain event on June 5 (1.09 inch) produced the largest runoff event of the April-September 2008 monitoring period, with a peak daily mean flow of 192 cfs (June 6). Back-to-back rain events (a combined 1.15 inches) on June 11 (0.40 inch) and June 12 (0.75 inch) produced the fourth-largest runoff event of the April-September 2008 monitoring period, with a peak daily mean flow of 174 cfs (June 12). The magnitudes of these two June runoff events were likely aided by wet antecedent conditions and a lack of vegetative growth and canopy cover in the agricultural and forested areas of the watershed, due to a cooler than normal spring (Figure 4).

A moderate rain event on July 19 (0.76 inch) and a large rain event on July 25 (1.16 inches) resulted in only moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 118 cfs (July 20) and 111 cfs (July 25), respectively (Figure 8). These moderate runoff events, in spite of rainfall amounts in excess of 0.75 inch, can be attributed to increasingly drier conditions during the May-mid July period, as well as full canopy closure in the agricultural and forested areas of the watershed. In late August, back-to-back rain events (a combined 1.14 inches) on August 27 (0.43 inch) and August 28 (0.71 inch) also produced a moderate increase in the Kinnickinnic River hydrograph, with a peak daily mean flow of 112 cfs (August 28). The magnitude of the August runoff event was also tempered by drier soil conditions, full canopy closure, and extensive evapotranspiration in the agricultural and forested areas of the watershed.

The Kinnickinnic River hydrograph suggests that twelve significant runoff events occurred during the April-September 2008 period (Figure 8). Peak daily mean flows for all of these runoff events exceeded 110 cfs. Six of these twelve significant runoff events occurred in April, due to frequent rain events and above-normal precipitation. With cool air and water temperatures in April, thermal impacts of storm water runoff are generally not a concern, but water quality impacts can be problematic, due to frozen soils and a lack of vegetative cover in the watershed. Three of the twelve significant runoff events occurred in early May and early-mid June, when thermal impacts of storm water runoff become a concern due to warmer air and water temperatures. On May 2, a 1.02 inch rain event resulted in a 3-day runoff event (May 2-4), with a peak daily mean flow of 188 cfs. On June 5, a 1.09 inch rain event produced a 3-day runoff event (June 5-7), with a peak daily mean flow of 192 cfs. On June 11 and 12, back-to-back rain events totaling 1.15 inches resulted in a 3-day runoff event (June 12-14), with a peak daily mean flow of 174 cfs. Three of the twelve significant runoff events occurred in July and August, during the two warmest months of the year (Figure 4), when thermal impacts of storm water runoff can be a considerable concern. On July 19, a 0.76 inch rain event resulted in a 2-day runoff event (July 19-20), with a peak daily mean flow of 118 cfs. On July 25, a 1.16 inch rain event resulted in a 3-day runoff event (July 25-27), with a peak daily mean flow of 111 cfs. On August 27 and 28, back-to-back rainfall events totaling 1.14 inches resulted in a 2-day runoff event (August 28-29), with a peak daily mean flow of 112 cfs. The six runoff events in May, June, July, and August should be the focus for evaluating possible storm water impacts in the North Kinnickinnic River Monitoring Project Area in 2008, and are further analyzed in this report.

With above-normal precipitation in April and below-normal precipitation during the May -September period (Figure 3), Kinnickinnic River base flows steadily decreased from approximately 95 cfs in April to approximately 85 cfs in early July, as measured at County Highway F. Base flows then remained in the 83-86 cfs range during August and September.

Temperature Monitoring:

In 2008, temperature monitoring was conducted at six City of River Falls monitoring stations (Sites 1-6) in the North Kinnickinnic River Monitoring Project Area. To evaluate the thermal performance of the storm water management practices at Site 5 in the Sterling Ponds subdivision, temperature monitoring was conducted at three locations: the wet detention pond (Site 5P), the wet detention pond outlet to the infiltration basin (Site 5IB), and the wet detention pond outfall to Sumner Creek (Site 5MHW).

The local Kiap-TU-Wish Chapter of Trout Unlimited (TU) also conducted temperature monitoring at one Kinnickinnic River station (Site 1A) within the project area, between Sites 1 and 2. The TU monitoring station is located along Quarry Road on the northeast edge of River Falls, just east of the WI Highway 35 bypass, and just upstream of the Sumner Creek confluence. The TU station has been in service during all summer periods (May-September) since 1992. In 2005, as an additional contribution to the North Kinnickinnic River Monitoring Project, TU established a temperature monitoring station in Sumner Creek (Site 4A), approximately 100 feet upstream of the creek confluence with the Kinnickinnic River. This station was in service during the summer periods (May -September) of 2005-2008. The thermal impacts of Sumner Creek on the Kinnickinnic River, including any storm water contributions from Sterling Ponds, can be evaluated at this location.

Onset Computer Corporation's® HOBO Water Temp Pro Loggers are used to measure water temperature at all City of River Falls monitoring stations (Sites 1-6). A Ryan Instruments® RTM 2000 Temperature Logger was used to measure water temperature at the TU monitoring station at Quarry Road (Site 1A) through 2007. In 2008, an Onset® StowAway TidbiT Logger was used to measure water temperature at Site 1A. Onset

Computer Corporation’s® Optic StowAway Templogger is used at the TU monitoring station in Sumner Creek (Site 4A). All Onset and Ryan temperature loggers are programmed to record temperatures at 10-minute intervals. Date and time stamps and the 10-minute temperature data are electronically recorded by each logger; and all recorded information is downloaded as necessary. The brief 10-minute time interval was selected so that any rapid temperature increases associated with warm storm water runoff could be readily documented. All temperature loggers were deployed throughout the May-September (summer) period. The thermal impacts of storm water runoff are most likely to occur during this summer period, when air temperatures are highest. The summer 2008 deployment periods (and locations) for the temperature loggers at the ten monitoring stations were as follows:

Site:	Deployment Period:	Location:
Site 1:	May 1-September 30, 2008	Kinnickinnic River
Site 1A:	May 1-September 30, 2008	Kinnickinnic River
Site 2:	May 1-September 30, 2008	Kinnickinnic River
Site 3:	May 1-September 30, 2008	Kinnickinnic River
Site 4:	May 1-September 30, 2008	Sumner Creek: Wet Pool in Culvert
Site 4A:	May 1-September 30, 2008	Sumner Creek: Mouth
Site 5P:	May 1-September 30, 2008	Sterling Ponds: Wet Pond
Site 5IB:	May 1-September 30, 2008	Sterling Ponds: Infiltration Basin
Site 5MHW:	May 1-September 30, 2008	Sterling Ponds: Wet Pond Outlet
Site 6:	May 1-September 30, 2008	Sumner Creek: Dry Box Culvert

Kinnickinnic River Temperature Monitoring Results:

The May-September (summer) 2008 temperature monitoring data obtained for the Kinnickinnic River at Sites 1, 1A, 2, and 3 are presented as thermographs in Figures 9-12, respectively. Of immediate note in these thermographs is the strong diurnal (daily) temperature pattern in the river. Although cold ground water continually feeds the river via springs along the entire riverway, the temperature of the Kinnickinnic River is greatly influenced by ambient air temperature. During the daylight hours, the river gradually warms and generally reaches a daily maximum temperature in the late afternoon or early evening (4:30-6:30 PM). At night, the river gradually cools and typically reaches a daily minimum temperature just after sunrise (7:30-9:30 AM). These diurnal temperature fluct uations in the river are natural, and the river’s residents, including macroinvertebrates and trout, have become accustomed to a constantly but slowly changing temperature regime.

Also of note in the 2008 Kinnickinnic River thermographs are the relatively frequent changes in the daily minimum and maximum river temperatures and daily temperature ranges that are influenced by local weather patterns (cold fronts and warm fronts) and seasonal climate changes. During the summer 2008 period, for example, the monthly mean river temperature in the North Kinnickinnic River Project Area (Sites 1, 1A, 2, and 3) was coolest in May (11.8 degrees Celsius (°C)) and warmest in July (16.0° C).

At Sites 1, 1A, 2, and 3, river temperatures averaged 14.0° C and ranged from 6.9-19.7° C over the course of the summer. Monthly and summer mean temperatures at each of these four monitoring sites are presented in Figure 13. These monthly and summer mean temperatures were nearly identical at Sites 1, 1A, and 2, but slightly cooler at Site 3, especially during the June-August period.

Lower-than-normal river temperatures probably prevailed in the North Kinnickinnic River Project Area during the summer of 2008, since the 2008 summer average air temperature of 19.1º C (66.4º F) was slightly lower than the normal summer average air temperature of 19.2° C (66.5° F). A comparison of 2004-2008 summer average air temperatures and river temperatures (at Sites 1, 1A, and 2) can be found in the North Kinnickinnic River Monitoring Project Indicators. Note that the 2008 summer average air temperature of 19.1º C and summer average river temperature of 14.1º C were the lowest summer average temperatures recorded in the North Kinnickinnic River Monitoring Project Area since the summer of 2004.

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

A comparison of all upstream summer temperature data at Sites 1A and 2 to all downstream summer temperature data at Site 1 is presented in Figure 14. This comparison indicates that summer temperatures were nearly identical at these three locations. The temperature similarities at Sites 1, 1A, and 2 are even more evident in the monthly thermographs for May, June, July, August, and September 2008 (Figures 15-19, respectively). Figures 14-19 indicate that daily maximum temperatures tended to be slightly warmer at Site 1, while the daily minimum temperatures tended to be slightly cooler at Site 1A. Figure 13 shows that the monthly and summer mean temperatures at Sites 1, 1A, and 2 were also nearly identical. The following should be noted concerning aquatic life in the Kinnickinnic River:

1. Approximately 90% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2008 period were less than or equal to (≤) 17° C, which is considered to be the top of the optimum temperature range for a healthy coldwater macroinvertebrate community (Galli, 1990). A temperature of 17° C is considered to be the physiological optimum for brown trout survival (Armour, 1994).

2. Approximately 99% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2008 period were ≤ 19° C, which is considered to be the top of the optimum temperature range for brown trout growth (Armour, 1994).

3. 100% of all temperatures recorded at Sites 1, 1A, and 2 during the May-September 2008 period were ≤ 20° C, which is considered to be the top of the optimum temperature range for brown trout survival (Armour, 1994). With a cooler-than-normal summer (average air temperature of 19.1º C), river temperatures exceeding 20º C were not recorded during the May-September 2008 period, a situation which has not occurred since the summer of 2004 (average air temperature of 18.7º C).

During six significant rainfall events in May, June, July, and August 2008, thermographs at Sites 1 and 2 can be compared to determine if rapid temperature increases (thermal spikes), which are characteristic of warm storm water discharges, were apparent at Site 1.

No thermal spikes were evident at Site 1 in May (Figure 15), in spite of a significant rainfall event on May 2 (1.02 inches). A closer examination of the thermographs for Sites 1 and 2 during the 1.02-inch rainfall event on May 2 (Figure 20) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. Thermal spikes commonly occur at the Trout Unlimited temperature monitoring site at Division Street, due to the thermal impacts of direct storm water discharges from the downtown area of River Falls. However, no thermal spike was apparent at Division Street during the May 2 rain event. Lack of a thermal spike is likely due to the extended duration of the rain event (13 hours), in conjunction with very cool air temperatures (3.3-12.8º C), which provided little heating of impervious surfaces.

No thermal spikes were evident at Site 1 in June (Figure 16), in spite of two significant rainfall events on June 5 (1.09 inches) and June 11-12 (a combined 1.15 inches). A closer examination of the thermographs for Sites 1 and 2 during the 1.09-inch rainfall event on June 5 (Figure 21) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. During the same rain event, however, the thermograph for the Trout Unlimited temperature monitoring site at Division Street (Figure 21) shows a very prominent thermal spike (of 2.3º C), due to the thermal impacts of direct storm water discharges from the downtown area of River Falls. Similarly, when the thermographs for Sites 1, 2, and Division Street are compared during the 1.15-inch rainfall event on June 11-12 (Figure 22), no thermal spike is evident at Site 1, while three small thermal spikes (of 0.4-1.1º C) are evident at Division Street.

In July, no thermal spikes were evident at Site 1 (Figure 17), in spite of two significant rainfall events on July 19 (0.76 inch) and July 25 (1.16 inches). A closer examination of the thermographs for Sites 1 and 2 during the 0.76-inch rainfall event on July 19 (Figure 23) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision. During the same rain event, however, the thermograph at Division Street (Figure 23) shows a very prominent thermal spike (of 1.7º C). Similarly, when the thermographs for Sites 1, 2, and Division Street are compared during the 1.16-inch rainfall event on July 25 (Figure 24), no thermal spike is evident at Site 1, while a very prominent thermal spike (of 2.6º C) is evident at Division Street.

In August, no thermal spikes were evident at Site 1 (Figure 18), in spite of a significant rainfall event on August 27-28 (a combined 1.14 inches). A closer examination of the thermographs for Sites 1, 2, and Division Street during this rainfall event (Figure 25) indicates that no thermal spike occurred at Site 1, downstream from Sumner Creek and the Sterling Ponds subdivision, while a very prominent thermal spike (of 1.8º C) is evident at Division Street.

Finally, no thermal spikes were evident at Site 1 in September (Figure 19), although no significant rainfall events occurred during the month. While rain fell on eight dates in September, none of these events exceeded 0.50 inch in magnitude.

While the presence of thermal spikes at Division Street is attributed to the thermal impacts of untreated storm water discharges to the Kinnickinnic River, the lack of thermal spikes at Site 1 could be attributed to several factors, including effective storm water management at the Sterling Ponds subdivision, or simply a lack of Sterling Ponds storm water discharges and/or storm water conveyance down Sumner Creek, even during the largest runoff events in 2008.

Sumner Creek and Sterling Ponds Temperature Monitoring Results:

<u>Sumner Creek</u>

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

The May-September (summer) 2008 temperature monitoring data obtained for Sumner Creek at Site 4A are presented as a thermograph in Figure 26. Site 4A near the creek mouth was the only Sumner Creek monitoring location with permanent flow throughout the summer. At Site 4A, Sumner Creek temperatures averaged 11.6° C and ranged from 7.0-17.8° C during the May-September 2008 period. The summer mean temperature of Sumner Creek (11.6º C) was notably colder than the summer mean temperature of the Kinnickinnic River (14.0º C) at Sites 1, 1A, 2, and 3, reflecting strong spring activity. Nearly 100% of all temperatures recorded at Site 4A during the May-September 2008 period were ≤ 17° C. Temperatures exceeding 17° C were only recorded for a brief period during the largest rainfall event of the summer on July 25 (1.16 inches).

Based upon the summer 2008 temperature data, lower Sumner Creek may have potential as a brook trout stream, and is regardless an important contributor of cold water to the Kinnickinnic River. Of concern, however, are several thermal spikes that occurred at Site 4A during the large rain events in June and July (Figure 26). Prominent thermal spikes in lower Sumner Creek, ranging from 1.9-3.5° C, occurred during the June 5, June 11-12, and July 25 rain events. These Sumner Creek thermal spikes were of comparable or even greater magnitude than those observed at the Division Street monitoring site on the same dates (Figures 21, 22, and 24). In spite of their magnitude, none of these thermal spikes had a discernible impact on Kinnickinnic River temperatures at Site 1, downstream from Sumner Creek (Figures 21, 22, and 24). However, thermal spikes of this magnitude and frequency may have detrimental impacts on aquatic life in lower Sumner Creek, especially macroinvertebrates. Numerous thermal spikes were also apparent in lower Sumner Creek (Site 4A) during the summers of 2005-2007. Possible sources contributing to thermal spikes in lower Sumner Creek may include: storm water runoff from WI Highway 35, located immediately upstream from Site 4A; warm water from natural wetland areas in the upper Sumner Creek drainage way; and storm water discharges from the Sterling Ponds subdivision.

Sterling Ponds

The May-September (summer) 2008 temperature monitoring data obtained for the Sterling Ponds wet detention pond at Site 5P are presented as a thermograph in Figure 27. At Site 5P, wet detention pond temperatures averaged 19.8° C and ranged from 9.1-27.4° C during the summer period. Approximately 55% of all summer temperatures exceeded 20° C, and wet pond temperatures continuously remained above 20° C from June 19 until August 29. 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 (19.8° C) was substantially higher than the summer mean temperature of Sumner Creek at Site 4A (11.6º C), clearly demonstrating the potential for thermal impact when the pond discharges to the creek, and emphasizing the importance of the River Falls Storm Water Management Ordinance, which requires storm water infiltration.

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

Temperature data from the three Sterling Ponds monitoring stations (Sites 5P, 5IB, and 5MHW) and the two downstream Sumner Creek monitoring stations (Sites 4 and 4A) can be used to evaluate the effectiveness of the Sterling Ponds storm water management practices for infiltrating storm water and minimizing warm storm water discharges to Sumner Creek. Given the warm and relatively stable thermal regime (Figure 27) in the Sterling Ponds wet detention pond (measured at Site 5P), pond discharges to the infiltration basin can be readily identified when the temperature at Site 5IB closely matches that at Site 5P. Similarly, pond discharges to Sumner Creek can be readily identified when the temperature at Site 5MHW closely matches that at Site 5P. Warm storm water discharges to Sumner Creek may be detectable as thermal spikes at Sites 4 and 4A.

During the summer of 2008, the thermal performance of Sterling Ponds stormwater management practices can be evaluated monthly by comparing the Sterling Ponds and Sumner Creek thermographs. Performance of these stormwater management practices during the six significant rainfall events in May, June, July, and August is of particular interest, and may help explain the possible causes of the thermal impacts (spikes) observed in lower Sumner Creek (Site 4A). However, none of these six significant events were characterized by rainfall amounts in excess of 1.5 inches, and hence would be expected to meet the infiltration requirement of the River Falls Storm Water Management Ordinance.

May

The comparative Sterling Ponds thermographs for May 2008 are presented in Figure 28. The month of May was cooler and drier than normal, with small rainfall events (ranging from 0.01-0.39 inch) recorded on eleven dates.

One of the six significant summer rainfall events occurred on May 2. The comparative Sterling Ponds and Sumner Creek thermographs for the May 2 rain event (1.02 inches) are presented in Figure 29. As indicated by the identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 12:30 CDT (12:30 PM) on May 2, shortly after the onset of heavier rainfall at 12:00 CDT (12:00 PM). Wet pond discharge to the infiltration basin, due to the May 2 rainfall event and a smaller rain event on May 3 (0.23 inch), continued for 3.7 days, until 04:40 CDT (4:40 AM) on May 6. After a small rain event (0.17 inch) on the afternoon of May 6, the wet detention pond once again began discharging to the infiltration basin at 19:10 CDT (7:10 PM) on May 6, and continued discharging until 19:00 CDT (7:00 PM) on May 7. During the May 2-7 time period, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A.

During the remainder of the month (May 8-31), no wet pond discharges occurred to either the infiltration basin or Sumner Creek. Nine small rain events, ranging from 0.01-0.39 inch and totaling 1.42 inches, were captured in the wet pond, where the water infiltrated or evaporated from the pond. The entire May rainfall amount of 2.84 inches (12 events ranging from 0.01-1.02 inches) (Figure 6) was captured in the Sterling Ponds wet pond or infiltrated.

June

The comparative Sterling Ponds thermographs for June 2008 are presented in Figure 30. The month of June was drier than normal, with near-normal temperatures. Small rainfall events (ranging from 0.01-0.29 inch) were recorded on nine dates, and two of the six significant summer rainfall events occurred on June 5 and June 11-12.

The comparative Sterling Ponds and Sumner Creek thermographs for the June 5 rain event (1.09 inches) and the June 11-12 rain event (1.15 inches) are presented in Figure 31 . As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 19:00 CDT (7:00 PM) on June 5, shortly after the onset of heavier rainfall at 18:00 CDT (6:00 PM). Due to the June 5 rainfall event, several smaller rain events during the June 6-10 period (a combined 0.54 inch), the June 11-12 rainfall event, and a small rain event on June 14 (0.13 inch), wet pond discharge to the infiltration basin continued for 11.4 days, until 04:20 CDT (4:20 AM) on June 17. Rainfall amounts during the June 5-14 period totaled 2.91 inches. During the two significant rainfall events on June 5 and June 11-12, no wet pond discharges to Sumner Creek were evident, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Site 4 (Figure 31). Shortly after the June 5 rain event began, a moderate thermal spike (3.3° C) occurred in lower Sumner Creek at Site 4A. A smaller thermal spike (1.9° C) was also apparent at Site 4A during the June 11-12 rain event. However, these thermal spikes cannot be attributed to storm water discharges at Sterling Ponds, and seemed to have a more local cause.

The June 17-30 period was quite dry, with small rainfall events recorded on only four dates. During this time period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek (Figure 30). The four small rain events, ranging from 0.01-0.07 inch and totaling 0.18 inch, were captured in the wet pond, where the water infiltrated or evaporated from the pond. The entire June rainfall amount of 3.17 inches (12 events ranging from 0.01-1.09 inches) (Figure 6) was captured in the Sterling Ponds wet pond or infiltrated.

July

The comparative Sterling Ponds thermographs for July 2008 are presented in Figure 32. The month of July was slightly drier and warmer than normal. Small rainfall events (ranging from 0.01-0.50 inch) were recorded on seven dates, and two of the six significant summer rainfall events occurred on July 19 and July 25.

During the July 1-18 period, no wet pond discharges occurred to either the infiltration basin or Sumner Creek. Six small rain events, ranging from 0.01-0.50 inch and totaling 1.49 inches, were captured in the Sterling Ponds wet pond, where the water infiltrated or evaporated from the pond.

The comparative Sterling Ponds and Sumner Creek thermographs for the July 19 rain event (0.76 inch) are presented in Figure 33. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 18:10 CDT (6:10 PM) on July 19, shortly after the onset of heavier rainfall at 17:00 CDT (5:00 PM). Wet pond discharge to the infiltration basin, due to the July 19 rainfall event, continued for 2.6 days, until 09:00 CDT (9:00 AM) on July 22. No wet pond discharge to Sumner Creek was evident during the July 19 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A (Figure 33).

The comparative Sterling Ponds and Sumner Creek thermographs for the July 25 rain event (1.16 inches) are presented in Figure 34. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 16:20 CDT (4:20 PM) on July 25, shortly after the onset of heavier rainfall at 16:00 CDT (4:00 PM). As indicated by the nearly identical temperatures at Sites 5P and 5MHW, the Sterling Ponds wet detention pond began discharging to the Sumner Creek drainage way at 16:40 CDT (4:40 PM) on July 25 and continued discharging until 20:00 CDT (8:00 PM). During this 3.3-hour period, the wet pond discharge temperature averaged 23.6º C and ranged from 23.4-23.9º C. Some storage of this storm water discharge likely occurred in the wetland that comprises the creek drainage way upstream from Site 4. A site visit by a Trout Unlimited member (Kent Johnson) confirmed that the wet detention pond was discharging to the Sumner Creek drainage way at 17:55 CDT (5:55 PM). The discharged water was creating a shallow pool near the outlet structure, with no connection to the Sumner Creek drainage way. Field observations indicated that some opportunity exists for infiltration, evaporation, and wetland storage (in the Sumner Creek drainage way) of storm water discharged from the wet pond outlet. Furthermore, the presence of dense wetland vegetation severely restricts storm water flow through the drainage way. Indeed, no thermal spike was apparent downstream at Site 4 in Sumner Creek after the July 25 rain event. Wet pond discharge to the Sumner Creek drainage way was likely influenced by the magnitude and short duration of the July 25 event. With 1.06 inches of rain falling in 30 minutes (16:00-16:30 CDT), the wet pond was quickly inundated with storm water. Wet pond inflow simply exceeded outflow to the infiltration basin, with the excess water discharged through the outlet structure. At 18:50 CDT (6:50 PM) on July 25, a moderate thermal spike (3.5° C) occurred in lower Sumner Creek at Site 4A. However, this thermal spike cannot be attributed to the storm water discharge at Sterling Ponds, and seemed to have a more local cause, perhaps including storm water runoff from WI Highway 35 and/or warm water flowing from natural wetland or storage areas in the upstream Sumner Creek drainage way. Wet pond discharge to the infiltration basin, due to the July 25 rainfall event, continued for 4.1 days, until 19:00 CDT (7:00 PM) on July 29.

All rainfall during the July 1-19 period (7 events ranging from 0.01-0.76 inch and totaling 2.25 inches) and during a small rain event on July 31 (0.07 inch) was captured in the Sterling Ponds wet pond or infiltrated. It seems likely that the majority of the July 25 rainfall (1.16 inches) was also infiltrated. Although a brief wet pond discharge to the Sumner Creek drainage way occurred on July 25, the duration of this discharge was relatively short (3.3 hours), compared to the duration of discharge to the infiltration basin (98 hours).

August

The comparative Sterling Ponds thermographs for August 2008 are presented in Figure 35. The month of August was much drier and slightly warmer than normal. Small to moderate rainfall events (ranging from 0.01-0.79 inch) were recorded on seven dates, and one of the six significant summer rainfall events occurred on August 27-28.

Small rainfall events on August 3-4 (a combined 0.36 inch) resulted in a relatively brief wet pond discharge to the infiltration basin, starting at 01:40 CDT (1:40 AM) on August 4 and continuing until 17:00 CDT (5:00 PM) on August 4 (Figure 36). A small rain event on August 6 (0.15 inch) was captured in the Sterling Ponds wet pond. The moderate rainfall event on August 12 (0.79 inch) resulted in a wet pond discharge to the infiltration basin, starting at 09:50 CDT (9:50 AM) on August 12 and continuing for 3.4 days, until 20:20 CDT (8:20 PM) on August 15 (Figure 36). Very small rain events on August 15, 21, and 22 (a combined 0.06 inch) were captured in the Sterling Ponds wet pond.

The last of the six significant summer rainfall events occurred on August 27-28. The comparative Sterling Ponds and Sumner Creek thermographs for the August 27-28 rain event (1.14 inches) are presented in Figure 37. As indicated by the nearly identical temperatures at Sites 5P and 5IB, the Sterling Ponds wet detention pond began discharging to the infiltration basin at 01:30 CDT (1:30 AM) on August 28, shortly after the onset of heavier rainfall at 23:00 CDT (11:00 PM) on August 27. Wet pond discharge to the infiltration basin, due to the August 27-28 rainfall event, continued for 3.7 days, until 18:50 CDT (6:50 PM) on August 31. No wet pond discharge to Sumner Creek was evident during the August 27-28 event, as documented by the temperature data at Site 5MHW, and no thermal spikes were apparent in Sumner Creek at Sites 4 and 4A (Figure 37).

The entire August rainfall amount of 2.50 inches (9 events ranging from 0.01-0.79 inch) (Figure 6) was captured in the Sterling Ponds wet pond or infiltrated.

September

The comparative Sterling Ponds thermographs for September 2008 are presented in Figure 38. The month of September was warmer than normal, and the driest month during the summer of 2008. Small rainfall events (ranging from 0.01-0.50 inch) were recorded on eight dates. No significant summer rainfall events occurred in September.

A small rainfall event on September 2 (0.33 inch) resulted in a wet pond discharge to the infiltration basin, starting at 13:10 CDT (1:10 PM) on September 2 and continuing for 2.1 days, until 14:30 CDT (2:30 PM) on September 4 (Figure 38). A small rain event on September 6 (0.18 inch) resulted in a relatively brief wet pond discharge to the infiltration basin, starting at 21:00 CDT (9:00 PM) on September 6 and continuing until 04:30 CDT (4:30 AM) on September 7 (Figure 38). A very small rain event on September 7 (0.02 inch) was captured in the Sterling Ponds wet pond. The September 11 rainfall event (0.50 inch) resulted in a wet pond discharge to the infiltration basin, starting at 05:30 CDT (5:30 AM) on September 11, shortly after the onset of heavier rainfall at 05:00 CDT (5:00 AM). Due to the September 11 rainfall event and smaller rain events on September 13 and 14 (a combined 0.56 inch), wet pond discharge to the infiltration basin continued for 7.2 days, until 09:20 CDT (9:20 AM) on September 18 (Figure 38). The September 23 rainfall event (0.44 inch) resulted in a wet pond discharge to the infiltration basin, starting at 20:20 CDT (8:20 PM) on September 23 and continuing for 3.7 days, until 14:00 CDT (2:00 PM) on September 27 (Figure 38). A very small rain event on September 29 (0.05 inch) was captured in the Sterling Ponds wet pond.

The entire September rainfall amount of 2.08 inches (8 events ranging from 0.02-0.50 inch) (Figure 6) was captured in the Sterling Ponds wet pond or infiltrated.

Effectiveness of Sterling Ponds Storm Water Management Practices:

2008 Performance Assessment

During the May-September (summer) 2008 period, the extent of storm water discharge to the Sterling Ponds infiltration basin could be readily determined, as temperature monitoring of the basin (Site 5IB) was conducted throughout the summer. The extent of storm water discharge to Sumner Creek could be directly determined via temperature monitoring at the wet pond outlet (Site 5MHW) and/or indirectly determined by the presence of thermal spikes in Sumner Creek (Sites 4 and 4A).

With the exception of the large rain event on July 25 (1.16 inches), all summer (May-September) rainfall events were fully infiltrated, as required by the River Falls Storm Water Management Ordinance. These 49 rain events, ranging in magnitude from 0.01-1.09 inches, represent a total of 12.91 inches of precipitation, or 92% of the total summer rainfall amount (14.07 inches). Of these 49 rain events, 27 events, ranging in magnitude from 0.01-0.50 inch and totaling 3.52 inches of precipitation (25% of the total summer rainfall amount) were entirely stored in the Sterling Ponds wet detention pond. With relatively dry conditions and some lengthy periods (5-8 days) between rain events throughout the summer, the Sterling Ponds wet pond readily stored smaller rain events, with the storm water infiltrating in the pond or evaporating. The 22 remaining rain events, ranging in magnitude from 0.01-1.09 inches and totaling 9.39 inches of precipitation (67% of the total summer rainfall amount), were diverted into the Sterling Ponds infiltration basin.

All 41 rainfall events in May, June, August, and September were stored in the wet detention pond or diverted to the infiltration basin. These events ranged from 0.01-1.09 inches in magnitude and represented monthly totals of 2.84, 3.17, 2.50, and 2.08 inches, respectively, or 75% of the total summer rainfall amount. Eight small-to-large rain events in July, ranging from 0.01-0.76 inches and totaling 2.32 inches, were either infiltrated or stored in the wet detention pond. These July rain events represented 17% of the total summer rainfall.

The Sterling Ponds wet detention pond only discharged to Sumner Creek during the largest rain event of the summer season, on July 25 (1.16 inches). This discharge of storm water to Sumner Creek was directly measured at Site 5MHW and verified with a site visit. Wet pond discharge to the Sumner Creek drainage way was likely influenced by the intensity of the July 25 rain event. With 1.06 inches of rain falling in 30 minutes (16:00-16:30 CDT), the wet pond was probably inundated with storm water and quickly reached capacity. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way.

Although the July 25 rain event resulted in a brief discharge of storm water to the Sumner Creek drainage way, it seems likely that the majority of storm water from this rain event was infiltrated rather than discharged. The duration of the discharge to the Sumner Creek drainage way was relatively short (3.3 hours), compared to the duration of discharge to the infiltration basin (98 hours). Since the storm water volumes discharged to the infiltration basin and Sumner Creek were not measured, it is not possible to precisely determine the amounts of storm water infiltrated versus discharged.

The temperature data for Site 5P, Site 5IB, and Site 5MHW suggest that the performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 49 summer rain events, ranging in magnitude from 0.01-1.09 inches. All runoff from these events was infiltrated, as required by the River Falls Storm Water Management Ordinance. However, there are possible opportunities for improvement of the current Sterling Ponds storm water management system and/or revision of the storm water management ordinance.

2005-2006 Performance Issues

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

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

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

2007 Performance Modeling and Wet Pond Outlet Modification

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

2007 Performance Issues

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

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

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

2008 Performance Issues

The largest rain event of the summer on July 25 (1.16 inches) was less than the 1.5-inch infiltration requirement in the River Falls Storm Water Management Ordinance. However, this event was not fully infiltrated, as the Sterling Ponds wet pond released warm storm water to Sumner Creek for a 3.3-hour period. The performance issue on July 25 was not antecedent rain events as we had seen it the past, in this case the performance is likely related to the intensity of this event. With 1.06 inches of rain falling in 30 minutes (16:00-16:30 CDT), the wet pond was probably inundated with storm water and quickly reached capacity. The wet pond inflow rate simply exceeded the outflow rate to the infiltration basin, with the excess water discharged through the outlet structure to the Sumner Creek drainage way. Evidence of rapid inundation of the wet pond due to the intensity of the event is provided by the very short time lag (20 minutes) between the onset of wet pond discharge to the infiltration basin and the onset of discharge to Sumner Creek. The River Falls Storm Water Management Ordinance requires infiltration for a 1.50-inch, 24-hour storm; the intensity of this event exceeds that requirement.

The intensity of the July 25, 2008 rain event (1.06 inches in 30 minutes) was even greater than the intensity of the September 20, 2007 rain event (nearly an inch in an hour). The duration of storm water discharge to Sumner Creek on July 25, 2008 (3.3 hours) was comparable to the discharge times observed during the large rain events in August and September 2007 (3-5 hours). These shorter discharge times, compared to those observed during large rain events in 2005, can probably be attributed to modification (elevation) of the wet pond outlet structure in 2007. More capacity in the wet pond resulted in reduced discharge to Sumner Creek and more post-event discharge to the infiltration basin.

Summary

Temperature monitoring of the Sterling Ponds storm water practices during the 2005-2008 period indicates that storm water discharges to Sumner Creek are occurring:

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

Modifications made to the control structure for the Sterling Ponds wet pond outlet to Sumner Creek seemed to improve storage and infiltration capacity for these types of events in 2007 and 2008. Each of these situations exceed the intent of the River Falls Storm Water Management Ordinance, so storm water discharges to Sumner Creek might be expected. However ordinance revisions could be considered for the back-to-back events and the very intense events. 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). In addition, perhaps some provision should be made in the River Falls Storm Water Management Ordinance to ensure adequate infiltration of back-to-back 1.5-inch, 24-hour rain events. More capacity in the wet pond may be helpful for capturing more storm water volume during very intense rain events, but the increased volume in the pond could require more infiltration time, which may prove problematic when large, back-to-back rain events occur.

While this project is primarily focused on evaluating long-term trends, annual information is important as well. The storm water management practices at Sterling Ponds prevented thermal impacts on Sumner Creek and the Kinnickinnic River during the May-September (summer) 2008 period. The following should be noted:

- The summer temperature regime in the Kinnickinnic River at Sites 1, 1A, and 2 (above and below the Sumner Creek confluence) was generally excellent for coldwater macroinvertebrate and brown trout communities.
- The performance of the Sterling Ponds storm water management practices (wet detention pond and infiltration basin) was excellent during 49 summer rain events, ranging in magnitude from 0.01-1.09 inches and totaling 12.91 inches (92% of the total summer precipitation). All storm water runoff from these events was infiltrated, as required by the River Falls Storm Water Management Ordinance. Monitoring and analysis of storm water conveyance from the Sterling Ponds wet pond to the infiltration basin will continue in the future, to determine if the intent of the ordinance is being met.
- Smaller rainfall events (less than one inch) caused no thermal impacts on Sumner Creek (see Appendix A). During a large rain event on July 25, the Sterling Ponds wet detention pond discharged warm water to the Sumner Creek drainage way, for an extended time period (3.3 hours). However, this warm storm water discharge did not cause a thermal spike in Sumner Creek at Site 4, and was not responsible for the thermal spike observed in lower Sumner Creek, at Site 4A.

The presence, intensity, and frequency of thermal spikes will continue to be monitored in the years to come.

- The "first-flush" thermal spikes (1.9-3.5° C) observed in lower Sumner Creek (Site 4A) during the three largest summer rain events appear unrelated to the storm water discharges at Sterling Ponds, and seem to have a more local cause that needs further investigation.

Based upon the 2005-2008 temperature monitoring results, it appears that the Sterling Ponds storm water management practices are producing long-term positive results that protect the Kinnickinnic River. Beyond 2008, these same trends will be monitored from year to year, to determine if favorable results are apparent in the future.

Water Quality Monitoring:

No runoff event-based water quality monitoring was conducted in 2008. Although April was a very wet month, the summer (May-September) monitoring season was characterized by below-normal precipitation (Figure 3) and relatively dry conditions in July, August, and September. Three large rain events on May 2 (1.02 inches), June 5 (1.09 inches), and June 11-12 (1.15 inches) produced significant increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 188 cfs, 192 cfs, and 174 cfs (Figure 8), respectively, at the USGS monitoring station (County Highway F). However, no water quality samples were obtained during these three runoff events. After mid-June, very few significant runoff events occurred in the North Kinnickinnic River Monitoring Project Area. Numerous small rain events (less than 0.50 inch) in June, July, August, and September had little influence on the Kinnickinnic River hydrograph (Figure 8). Due to relatively dry antecedent conditions and full canopy closure in the agricultural and forested areas of the watershed, the large rain events on July 19 (0.76 inch), July 25 (1.16 inches), and August 27-28 (1.14 inches) also produced very moderate increases in the Kinnickinnic River hydrograph, with peak daily mean flows of 118 cfs, 111 cfs, and 112 cfs, respectively (Figure 8). Given more normal precipitation and runoff conditions, the water quality monitoring component of the North Kinnickinnic River Monitoring Project will be initiated in 2009.

Base Flow Surveys:

The USGS stream flow gauge located at County Highway F, as described earlier in this report, was used to determine when a base flow condition existed in the North Kinnickinnic River Monitoring Project Area. When 3-4 days of "flat-line" flow was observed at this station, the river was assumed to be in a base flow condition. During dry periods between runoff events, the Kinnickinnic River maintained a base flow of approximately 83-95 cfs at County Highway F. Real-time and recent (31-day) stage, flow, and precipitation data for this monitoring station are web-accessible at:

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

In the spring and autumn of 2008, instantaneous measurements of base flow were obtained at Sites 1-3 in the Kinnickinnic River and at the mouth of Sumner Creek (Site 4A) within the North Kinnickinnic River Monitoring Project Area. The 2008 base flow surveys were conducted using a SonTek® FlowTracker handheld Acoustic Doppler Velocimeter (ADV).

The spring 2008 base flow survey was conducted on June 24-25. These spring 2008 survey results are presented in Figure 39, with a comparison to the spring 2006-2007 survey results. In spring 2008, Kinnickinnic River base flows were identical at Sites 2 (50 cfs) and 3 (50 cfs) and slightly higher at Site 1 (58 cfs). Sumner Creek provided a very small contribution (0.2 cfs) to the Kinnickinnic River, just upstream of Site 1. An additional 48% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (86 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (5 cfs). The spring 2008 Kinnickinnic River base flows in the project area (Sites 1 -3) increased very slightly (by 4-7%), compared to spring 2007, likely due to above-normal precipitation in April 2008. In Sumner Creek, the spring 2008 base flow was 67% less than the spring 2007 base flow. The spring 2008 base flows in Rocky Branch Creek and in the Kinnickinnic River at County Highway F increased by 17% and 19%, respectively, compared to the spring 2007 base flows at these locations. The spring 2007 and spring 2008 base flows at all monitoring sites were less than the spring 2006 base flows, which were probably influenced by much wetter than normal conditions in 2005 (Figure 1).

The autumn 2008 base flow survey was conducted on October 30. These autumn 2008 survey results are presented in Figure 40, with a comparison to the autumn 2005-2007 survey results. In autumn 2008, Kinnickinnic River base flows increased slightly from upstream to downstream, with flows of 46 cfs, 48 cfs, and 51 cfs measured at Sites 3, 2, and 1, respectively. Sumner Creek provided a small contribution (0.8 cfs) upstream of Site 1. An additional 63% increase in Kinnickinnic River base flow occurred between Site 1 and County Highway F (83 cfs), including contributions from the South Fork of the Kinnickinnic River (unmeasured), Mann Valley Creek (unmeasured), and Rocky Branch Creek (3 cfs). The autumn 2008 Kinnickinnic River base flows in the project area (Sites 1-3) decreased very slightly (by 8-10%), compared to autumn 2007, likely due to below-normal precipitation during the May-September 2008 period. In Sumner Creek, however, the autumn 2008 base flow was 60% greater than the autumn 2007 base flow. The autumn 2008 base flows in Rocky Branch Creek and in the Kinnickinnic River at County Highway F decreased by 9% and 14%, respectively, compared to the autumn 2007 base flows at these locations.

Based upon several years of base flow survey data, it seems apparent that climatic variability can cause significant annual changes in spring and autumn base flows within the North Kinnickinnic River Monitoring Project Area. Below-normal rainfall during the summers of 2006-2008 resulted in markedly reduced base flows during the autumns of 2006-2008, compared to the autumn of 2005, which was preceded by a summer with above-normal rainfall.

One goal of the River Falls Storm Water Management Ordinance is to maintain strong base flow conditions in the Kinnickinnic River by requiring storm water management practices that promote infiltration of rainfall, thereby maintaining shallow aquifer levels, as well as the springs that provide cold water for the river. Annual spring and autumn base flow surveys will provide a baseline for determining if base flow conditions will be sustained in the future as development progresses in the North Kinnickinnic River Monitoring Project Area.

Macroinvertebrate Monitoring:

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

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

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

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

Where:

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

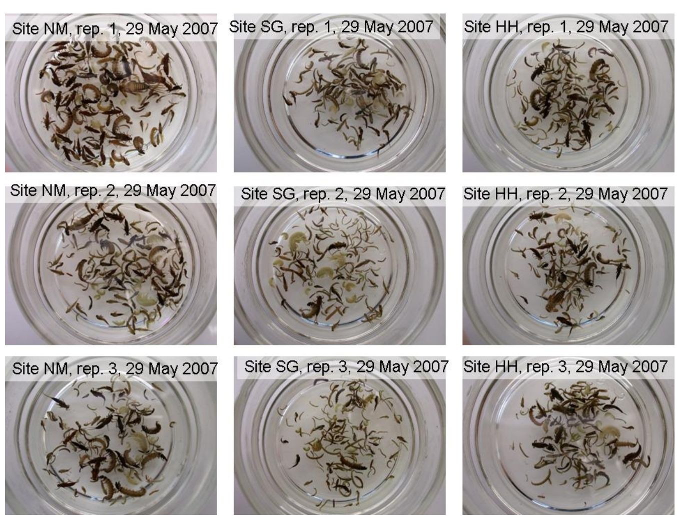
N = total number of individuals in the sample

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

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

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

The 2004-2007 macroinvertebrate HBI values for triplicate samples collected at Sites 1-3 in the North Kinnickinnic River Monitoring Project Area are presented in Table 1 (below). The mean 2004-2007 macroinvertebrate HBI values at Sites 1-3 are also presented in Figure 41. The 2004-2007 data establish a baseline for assessing the long-term health of the macroinvertebrate community within the project area.



Site 1 Site 2 Site 3

Triplicate macroinvertebrate samples collected at Sites 1-3 in 2007

During the 2004-2007 period, mean HBI values at Site 1 were indicative of very good-excellent water quality, mean HBI values at Site 2 were indicative of very good water quality, and mean HBI values at Site 3 were indicative of very good-excellent water quality. Mean annual HBI values at Site 1 have been increasing slightly (Figure 41), indicating a slight degradation of water quality. However, the 2006-2007 values were still indicative of very good water quality. In spite of some apparent degradation during the 2004-2007 period, the mean annual HBI values at Site 1 are all less than or comparable to the mean annual HBI values at Sites 2 and 3, indicating slightly better water quality at Site 1. Mean annual HBI values at Site 2 decreased in 2006 and 2007, indicating improving water quality. However, all annual values during the 2004-2007 period were indicative of very good water quality. Mean annual HBI values at Site 3 were relatively consistent during the 2004-2007 period, and generally indicative of very good water quality.

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

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

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

Samp **g Site**	**Sampling Location**	**2004 HBI Values**	**2005 HBI Values**	**2006 HBI Values**	**2007 HBI Values**
Site 1: North Main	50 yards upstream from North Main Street Bridge, River Falls, WI Lat. 44°52'32.1", Long. 92°37'15.6"	2.77 2.86 2.99	3.17 3.04 2.79	3.57 3.57 3.62	3.64 3.85 4.07
	Mean of 3 reps:	2.87	3.00	3.59	3.85
Site 2: Swinging	Approx. 1.1 miles upstream from North Main Street Bridge, River Falls, WI	4.20 3.99	4.30 4.67	4.01 3.91	3.85 3.84

Gate (STH 65)	Lat. 44°53'12.9", Long. 92°36'40.9"	3.85	4.45	4.13	3.62
	Mean of 3 reps:	4.01	4.47	4.02	3.77
Site 3: Hebert-Hagen	Approx. 0.4 mile downstream from Quarry Rd., River Falls, WI Lat. 44°53'22.2", Long. 92°36'19.5"	3.37 4.04 3.60	3.65 3.55 3.13	3.88 3.72 3.89	3.65 3.86 3.74
	Mean of 3 reps:	3.67	3.44	3.83	3.75

North Kinnickinnic River Monitoring Project Indicators:

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

- Total rainfall in River Falls during the April-September period
- % April-September rainfall infiltrated, per the River Falls Storm Water Management Ordinance
- Summer (May-September) average air temperature in River Falls
- Summer (May-September) average temperatures in the Kinnickinnic River and Sumner Creek
- % of the summer Kinnickinnic River temperatures favorable for biota
- % of the summer Sumner Creek temperatures favorable for biota
- Spring base flow conditions in the Kinnickinnic River and Sumner Creek
- Autumn base flow conditions in the Kinnickinnic River and Sumner Creek
- Kinnickinnic River macroinvertebrate HBI values

The North Kinnickinnic River Monitoring Project Indicators for the 2004-2008 period can be found on the project website. As monitoring continues in the future, these indicators can evaluate the annual effectiveness of the River Falls Storm Water Management Ordinance and track long-term trends that document protection of the Kinnickinnic River.

Appendix A

Reasons why small rainfall events (less than one inch) caused no storm water impacts at Sterling Ponds in 2008

Smaller rainfall and runoff events can have significant storm water impacts on the Kinnickinnic River, as was evident by the numerous thermal spikes (Figures 21-25) caused by direct (untreated) storm water discharges upstream from the Division Street monitoring site in 2008. 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 2008, due to several factors:

1. Building progress remained somewhat limited in the Sterling Ponds subdivision in 2008, and has largely occurred in the southeast and northeast quadrants of the subdivision.

   In the southeast quadrant, only 3 single-family housing units were built by year-end 2003, 19 single-family housing units were built by year-end 2004, 33 single-family housing units were built by year-end 2005, 37 single-family housing units were built by year-end 2006, 53 single-family housing units were built by year-end 2007, and 56 single-family housing units were built by year-end 2008.

   In the northeast quadrant, 2 duplex units were complete by year-end 2005, and 2 multi-family (8-plex) units were under construction. By year-end 2006, 1 single-family unit, 2 duplex units, 3 multi-family 8-plex units, and 2 multi-family 10-plex units were complete, for a total of 49 units. By year-end 2007, 6 single-family units, 5 duplex units, 3 multi-family 8-plex units, and 4 multi-family 10-plex units were complete, for a total of 80 units. By year-end 2008, 12 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 92 units.

   A build-out total of 600 units is projected for Sterling Ponds. By year-end 2008, a total of 148 units (25% of build-out) were complete in the southeast and northeast quadrants of Sterling Ponds.

   Maps of Sterling Ponds build-out progress in 2003, 2004, 2005, 2006, 2007, and 2008 are available on the project website ("What We Monitored"). With 56 of approximately 150 single family units (37%) complete in the southeast quadrant, 92 of approximately 150 family units (61%) complete in the northeast quadrant, and no development occurring in the southwest and northwest quadrants by year-end 2008, impervious surfaces (rooftops, sidewalks, driveways, and streets) still account for a relatively small proportion (??%) of the overall Sterling Ponds subdivision area.

2. Five wet storm water detention ponds were already in place in 2008, 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 2008. 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 2008 period (see 2008 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 2008, as required by the ordinance. Indeed, monitoring of the southeast storm water management practices in 2008 demonstrated excellent infiltration for 49 summer rain events, ranging in magnitude from 0.01-1.09 inches and totaling 12.91 inches (92% 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 2008 capably evaluated ordinance effectiveness and identified the storm water impacts related to one rainfall event in excess of 1 inch (see ***Effectiveness of Sterling Ponds Storm Water Management Practices***). Ongoing annual monitoring and evaluation will be especially important as the Sterling Ponds subdivision continues to develop and impervious area increases.