Summary of the City of Waukesha's Return Flow Compliance with Root River Thermal Requirements

PREPARED FOR:	City of Waukesha
PREPARED BY:	CH2M HILL
DATE:	April 2, 2015
ATTACHMENTS:	Preliminary Thermal Analysis of a City of Waukesha Lake Michigan Return Flow to the Root River (Attachment A-5 in Appendix A of Volume 4 of the Application)

The Wisconsin Department of Natural Resources had requested a brief summary of the City of Waukesha's plan for compliance with thermal limits proposed for the Root River. This memorandum provides that summary and for ease of reference, attached also is the analysis included in The City of Waukesha's Application for Lake Michigan Water Supply with Return Flow (Application). The attached thermal analysis was included as Attachment A-5 in Appendix A of Volume 4 of the Application and outlines the site conditions at the proposed Root River discharge location and several options for meeting thermal requirements proposed by the department.

Like many wastewater treatment plant (WWTP) discharges, the early winter months of October through December are the most restrictive months for meeting thermal limits. This situation results largely because the instream water quality criteria are low and the ambient air temperatures are not much lower than the wastewater temperatures, making heat exchange from the wastewater to the ambient air more difficult compared to months when ambient air temperatures are much lower (such as January or February months).

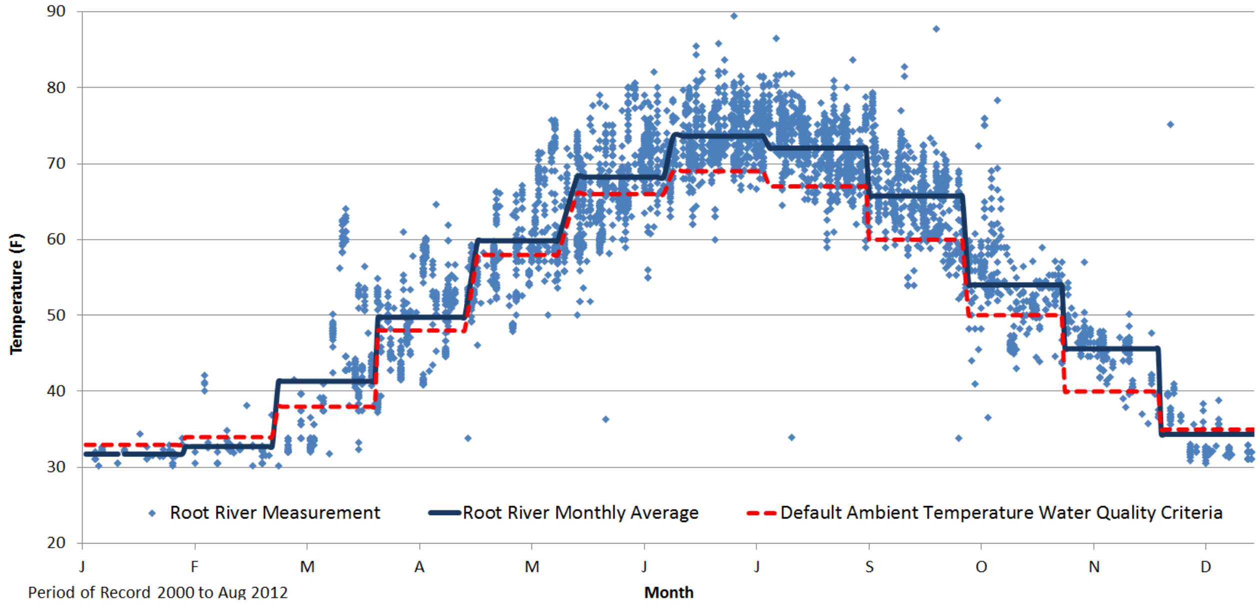
The thermal limits previously calculated by the department and presented in a memorandum dated December 13, 2011, assumed a constant return flow rate (20.1 cfs or 13 mgd) and river flow rate (1.8 cfs or 1.2 mgd) throughout the year. The current return flow management plan calls for a maximum return flow rate of 15.6 cfs (10.1 mgd), but WWTP flows during the critical months of October through December will be lower because historically WWTP flow rates decrease in winter months. Monthly 7Q10 calculations for the proposed return flow location ranged between 3.2 cfs and 5.7 cfs for the same months, which are two to three times greater than the constant flow rate of 1.8 cfs assumed in the limits calculation. Because the Root River flows are greater and the return flow is less than those used in the thermal limit calculations dated December 13, 2011, the thermal limits will be less strict than those currently proposed for the Root River return flow.

The existing Fox River discharge was demonstrated to comply with thermal requirements through a mixing zone study. The proposed Root River return flow location has several geomorphic features that are *more* supportive of thermal dissipation and prevention of a thermal barrier, such as the long river meander and the outfall being located on the outside of the meander. In the absence of a Root River discharge to complete a mixing zone study now, the Fox River mixing zone study can be correlated to the Root River location and is supportive of return flow having minimal or no thermal impacts. Consequently, like the Fox River discharge, the Root River discharge may comply with thermal standards in a mixing zone and without having numeric limits on the return flow prior to discharge to the Root River.

The calculated thermal limits were understood to use default ambient temperature water quality criteria. However, the temperature data in the Root River shows that in-stream temperature is greater than the default criteria during the critical months of October and November; December in-stream temperature is very similar to the default criteria. A graph was included in the analysis (Exhibit 10) and a revised version is included below that shows default ambient criteria included in NR102. The Root River watershed at the point of return flow discharge is not considered an urbanized watershed, it does not have significant point source discharges, and the stream is well shaded in the upstream watershed. Consequently, the elevated in-stream temperature above the default criteria suggest that developing site specific criteria is appropriate and should be considered during detailed permitting.

EXHIBIT 10 (REVISED WITH DEFAULT CRITERIA FROM NR102)

Lower Root River Temperature Measurements



While relying upon lower return flow rates, higher river flow rates, less strict effluent limits, site specific criteria, and utilization of a mixing zone appears reasonable for complying with thermal standards, alternatives exist for addressing thermal impacts of a return flow if needed. For example, thermal dissipation through the 20-mile return flow pipeline and an outfall design comprised of multiple discharge locations would contribute towards reducing thermal impacts. The cost of these alternatives range from no cost (thermal dissipation in the return flow pipeline) to an estimated construction cost of $300,000 (three outfalls along the 900 feet shoreline at the Root River discharge location). These additional costs, if needed, are considered marginal and included within the $15 million dollar contingency for the return flow pipeline. More expensive and energy intensive options exist, but based on the thermal analysis completed for the Application, they are not anticipated.

Attachment A-5

Preliminary Thermal Analysis of a City of Waukesha Lake Michigan Return Flow to the Root River

Preliminary Thermal Analysis of a City of Waukesha Lake Michigan Return Flow to the Root River

PREPARED FOR: City of Waukesha

PREPARED BY: CH2M HILL

DATE: June 24, 2013

Summary

This memorandum is a preliminary thermal analysis of a City of Waukesha return flow discharge to the Root River. The purpose of this analysis is to identify one or more methods to comply with the Wisconsin Department of Natural Resources (WDNR) thermal regulations in NR 102 and NR 106. The Waukesha return flow is not "hot" and does not pose any acute thermal threat to aquatic life. Rather, like many wastewater treatment plants in Wisconsin, the return flow temperature is warmer than the ambient Root River temperature in late fall and winter months, with the highest measured temperatures ranging from 51 to 70 degrees Fahrenheit (October through January, see Exhibit 1). The WDNR thermal sub-lethal standards during these months can be triggered by typical municipal wastewater effluent.

The analysis compares the physical riverine characteristics of the current City of Waukesha Fox River discharge to that of the Root River. Preliminary indications are that mixing of the discharge within the Fox River will meet the thermal requirements, and presumably, if similar conditions exist on the Root River, mixing will also satisfactorily meet the thermal discharge requirements to the Root River.

The analysis concludes that several options exist to meet the thermal requirements. These include:

- Thermal mixing analysis of the Root River
- Using site specific ambient temperatures to establish thermal limits
- Management techniques to lower the return flow temperature before discharge
- Combinations of the above techniques

This analysis demonstrates that multiple options exist for the Root River return flow to achieve WDNR thermal rule compliance. Consequently, return flow as it relates to thermal discharge, can reasonably protect the chemical, physical, and biological integrity of the Root River. With a successful Lake Michigan application, more detailed data gathering and analysis for thermal and other water quality requirements will occur to apply for a Root River discharge permit.

Introduction

As part of the City of Waukesha Application for Lake Michigan Diversion with Return Flow (Application), return flow to the Root River is being evaluated. The City's wastewater treatment plant (WWTP) currently discharges to the Fox River, which is in the Mississippi River watershed. The proposed project will include a new return flow pump station, pipeline, and outfall for return flow to the Root River, a tributary to Lake Michigan. The potential discharge location is near river mile 25.5, downstream of the confluence of the Root River Canal with the Root River. The purpose of this memorandum is to summarize a preliminary analysis of thermal limits and compliance alternatives.

Methods applicable to the Root River return flow which could be used to reasonably achievable compliance with the thermal discharge requirements include:

- Comparison of the watershed hydrology, geomorphology, and river flow rates of the Root River with those from the Fox River where the existing WWTP discharge does not require thermal limits
- Mixing zone and dissipative cooling study
- Consideration of site specific ambient temperatures on the Root River
- The following management techniques
    - Heat Exchange in Return Flow Pipeline
    - Treatment Wetlands
    - Surface Aerators
    - Cooling Towers
    - Chillers
    - Multiple Discharge Locations
    - Subsurface Flow
- Combinations of the above techniques

This memorandum summarizes background information applicable to a Root River discharge and each of the methods which could be used to meet the thermal discharge requirements.

Background

The Wisconsin Department of Natural Resources has adopted new thermal rules (NR 102 and 106) for the protection and propagation of aquatic life that applies to WPDES permit holders discharging to surface waters. In preparation for this new rule, the City has been collecting effluent temperature data since December 2010. The WDNR had provided the City with weekly average effluent limitations for the Fox River on January 17, 2012. More recently in the permit for the WWTP (August 1, 2013), effluent temperature limits were not proposed based on results of a mixing zone study and only effluent monitoring is required. In contrast to the Fox River, the WDNR has proposed effluent thermal limits for a Root River discharge. On February 5, 2013 the WDNR provided the City with draft effluent thermal limits (WDNR, 2011) for a Root River return flow that were based in-part on a return flow rate used during an Underwood Creek evaluation (SEH, 2009). A summary of the potential thermal limits for a Root River return flow is shown in Exhibit 1.

EXHIBIT 1
Water Quality-Based Effluent Temperature Limitation

			Root River		
Month	Sub-Lethal Water Quality Criteria (F)	WWTP Highest Monthly Effluent Temperature; [Weekly Average] [1] (F)	Receiving Water Flow Rate (cfs)	Highest 7-day Rolling Average Effluent Flow Rate (mgd)	Weekly Average Effluent Limitation (F)
Jan	49	51	1.8	13.0	49
Feb	50	52	1.8	13.0	50
Mar	52	52	1.8	13.0	52
Apr	55	55	1.8	13.0	55
May	65	61	1.8	13.0	65

EXHIBIT 1
Water Quality-Based Effluent Temperature Limitation

			Root River		
Month	**Sub-Lethal Water Quality Criteria (F)**	**WWTP Highest Monthly Effluent Temperature; [Weekly Average] [1] (F)**	**Receiving Water Flow Rate (cfs)**	**Highest 7-day Rolling Average Effluent Flow Rate (mgd)**	**Weekly Average Effluent Limitation (F)**
Jun	76	65	1.8	13.0	76
Jul	81	72	1.8	13.0	81
Aug	81	73	1.8	13.0	81
Sep	73	70	1.8	13.0	73
Oct	61	68	1.8	13.0	61
Nov	49	60	1.8	13.0	49
Dec	49	57	1.8	13.0	49

1. WDNR analysis of WWTP effluent from January 17, 2012.

Some of the information used in the analysis is not representative of the return flow management plan. For example, a constant return flow rate of 13 mgd was used for each month and did not consider a maximum return flow rate of 16.7 mgd or seasonal flow variations at the WWTP, such as October through December when WWTP flow rates are less. Seasonal variations were also not accounted for in the receiving water flow rate where they are typically greater than the constant 1.8 cfs used in the analysis. The location of the return flow discharge was also in a much smaller portion of the watershed - approximately 15 square miles compared to the 126.2 square miles of the proposed return flow discharge location (see below of additional watershed size documentation). While these changes would result in higher effluent limits, they are expected to only have a minor affect (raising the effluent limit less than 3 degrees). This is supported by effluent limits calculated by the WDNR for the Fox River discharge in Exhibit 2 which had greater receiving water flow rates and lower WWTP flow rates. (These effluent limits were calculated prior to the mixing zone study being completed, when WDNR evaluated reasonable potential for thermal effluent limits. As summarized in the permit, the mixing zone study has demonstrated that thermal limits are not needed for the Fox River.)

EXHIBIT 2
Calculated Effluent Limits for a Fox River Discharge - Prior to Mixing Zone Study

Receiving Water Flow Rate (cfs)	**Highest 7-day Rolling Average Effluent Flow Rate (mgd)**	**Weekly Average Effluent Limitation (F)**
10.00	13.043	51
13.00	11.374	53
23.00	17.302	55
58.00	22.276	58
28.00	15.952	67
21.00	37.566	77
12.00	26.029	82
12.00	15.527	83
9.90	11.443	75

EXHIBIT 2
Calculated Effluent Limits for a Fox River Discharge - Prior to Mixing Zone Study

Receiving Water Flow Rate (cfs)	Highest 7-day Rolling Average Effluent Flow Rate (mgd)	Weekly Average Effluent Limitation (F)
11.0	10.434	63
15.00	9.800	51
12.00	12.094	51

These effluent limits were calculated prior to the mixing zone study being completed, when WDNR was evaluating reasonable potential for thermal effluent limits. As summarized in the permit documentation, the mixing zone study has demonstrated that numeric thermal limits are not needed for the Fox River.

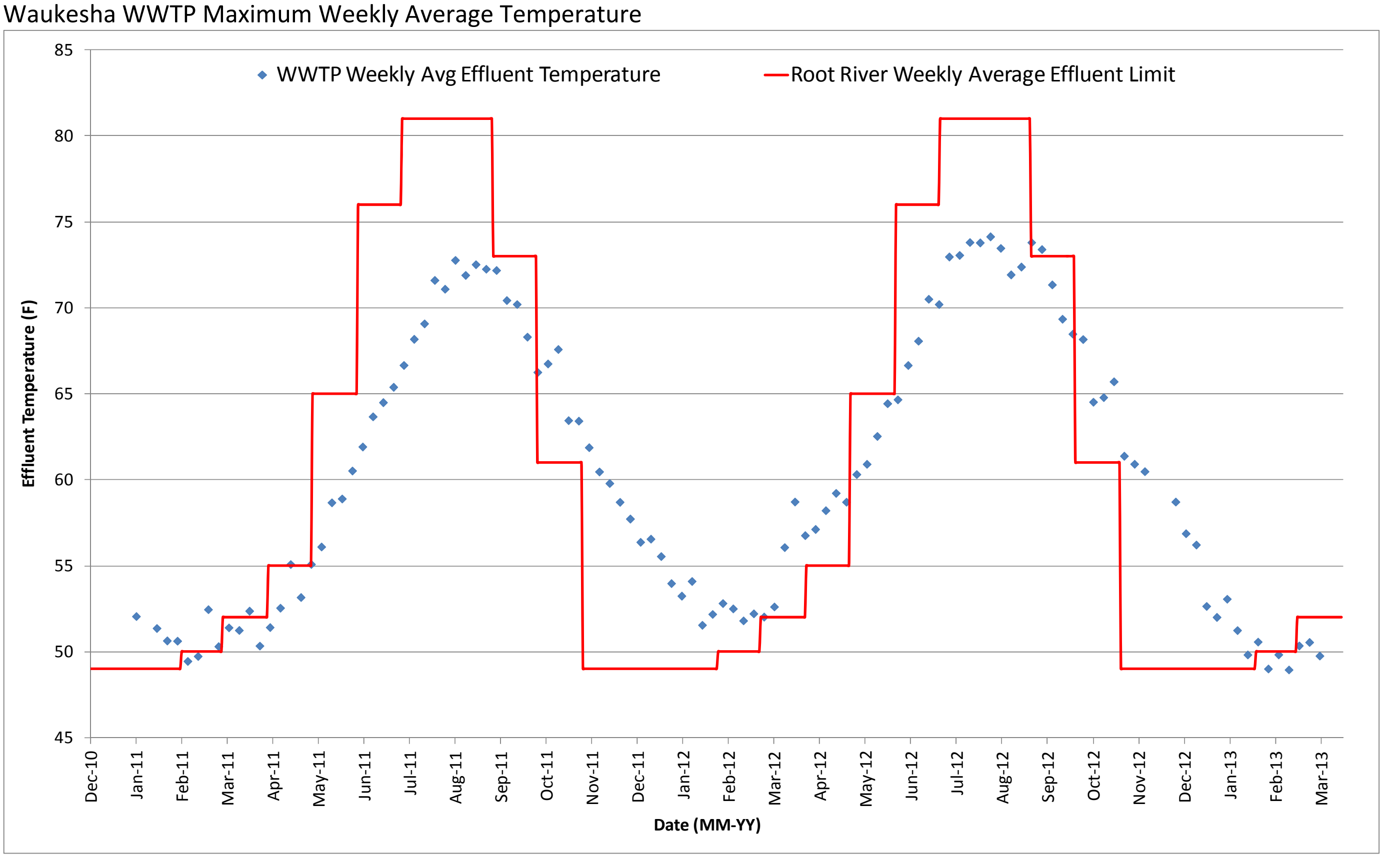
The WDNR also provided daily maximum effluent limitations for the Root River but based on the WWTP's effluent temperature data, the daily maximum effluent limits will be met.

Evaluation

Initial Compliance assessment

Root River effluent limits and effluent temperature data from the WWTP was evaluated for the period of record, from December 2010 to March 2013 (Exhibit 3). The WWTP effluent generally meets the temperature limits except for fall and winter months October through March. This is common among many municipal wastewater treatment plants and of the City's Fox River discharge, however as noted above a mixing zone study was completed and demonstrated that the WWTP effluent temperature does not impact the Fox River.

EXHIBIT 3
Waukesha WWTP Maximum Weekly Average Temperature



Based upon these data, an evaluation of probable alternatives to demonstrate compliance with the thermal rules was conducted. These include comparing to mixing zone results in the Fox River and other methods to demonstrate thermal rule compliance. These alternatives are described below.

Watershed Size and Receiving Water Flow Rate Adjustments

Thermal limits are influenced by the receiving water flow rates, which are affected by factors such as the watershed's size, climate, slope, and land use. These factors are essentially the same for the Fox River at the WWTP and the Root River at the return flow location. The Root and Fox River watershed's are adjacent to each other and have similar development patterns, and therefore their climate and land use are essentially the same. The WWTP existing outfall is within 0.6 miles of the USGS stream gage 05543830 where the Fox River watershed area is 126 square miles. This is essentially the same as the 126.2 square mile watershed area for the Root River return flow, based on the HSPF model from the Southeastern Wisconsin Planning Commission's (SEWRPC) Regional Water Quality Management Plan Update (Exhibits 4 and 5). In addition, the watershed slope is also essentially the same size as calculated by the Flood Insurance Studies for the Fox River and Root River locations – 0.08 percent slope for the Fox River upstream of the WWTP Fox River outfall and 0.09 percent slope for the Root River upstream of the return flow location. The Fox River upstream of the WWTP has greater point source discharges (e.g. Brookfield and Sussex WWTP) than does the Root River and Root River Canal, but the Root River low flows used for determining effluent thermal limits are expected to be more similar to the Fox River flows and greater than the 1.8 cfs used in the draft effluent limit calculations (Exhibit 1).

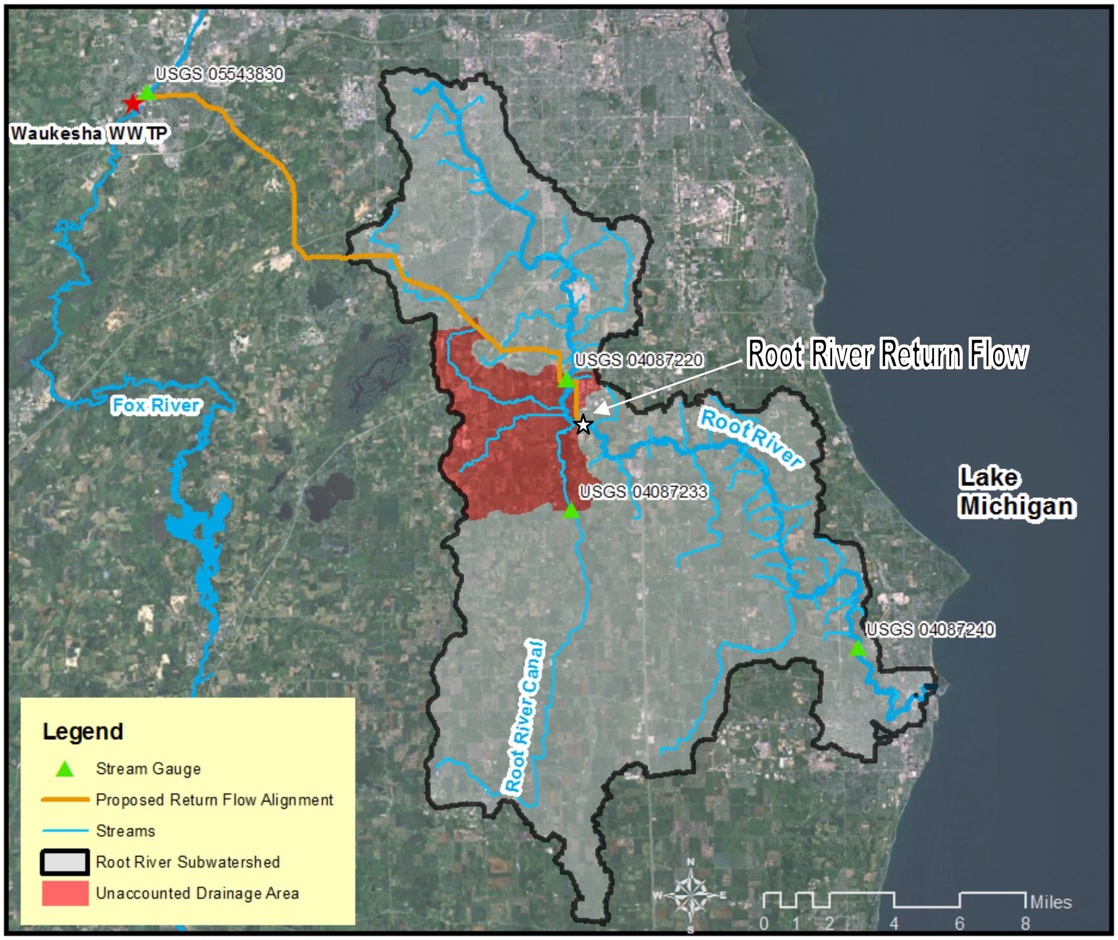
EXHIBIT 4
Drainage Area at River Gage Locations

Location	Drainage Area (sq miles)
USGS 04087220—Root River near Franklin	49.2
USGS 04087233—Root River Canal near Franklin	57.0
Unaccounted Subbasins (from SEWRPC HSPF model)	20.0
Root River at the Potential Discharge	126.2
USGS 05543830—Fox River at Waukesha	126.0

Source: USGS, 2013

EXHIBIT 5

Waukesha WWTP, Root River Watershed, and Root River Return Flow Location Map



The daily average and 7-day rolling average flow rates over a 49 year period of record at each stream gauge were acquired from USGS. Review of USGS flow gage information shows that that flow rates are similar between the Fox River at the WWTP outfall and the Root River return flow location (Exhibits 6 and 7). The flow rate at the Root River return flow location was estimated as the sum of the flow rate at the USGS gage at Franklin (gage # 04087220) and the gage on the Root River Canal near Franklin (gage # 04087233), and prorated for the unaccounted drainage area (Exhibit 4 and 5). Because the flow rates are similar, and for some periods the Root River is significantly greater than the Fox River, the effluent thermal limits for the Root River discharge are expected to be greater than currently calculated by WDNR, and closer to the limits calculated for the Fox River (Exhibit 2). Consequently, the temperature difference between the calculated limit and the return flow is expected to be less (Exhibit 1), especially for months when thermal standards are more stringent (October-March).

EXHIBIT 6

Average Daily Flow Rates of Fox River near the WWTP and Root River at the Return Flow Location

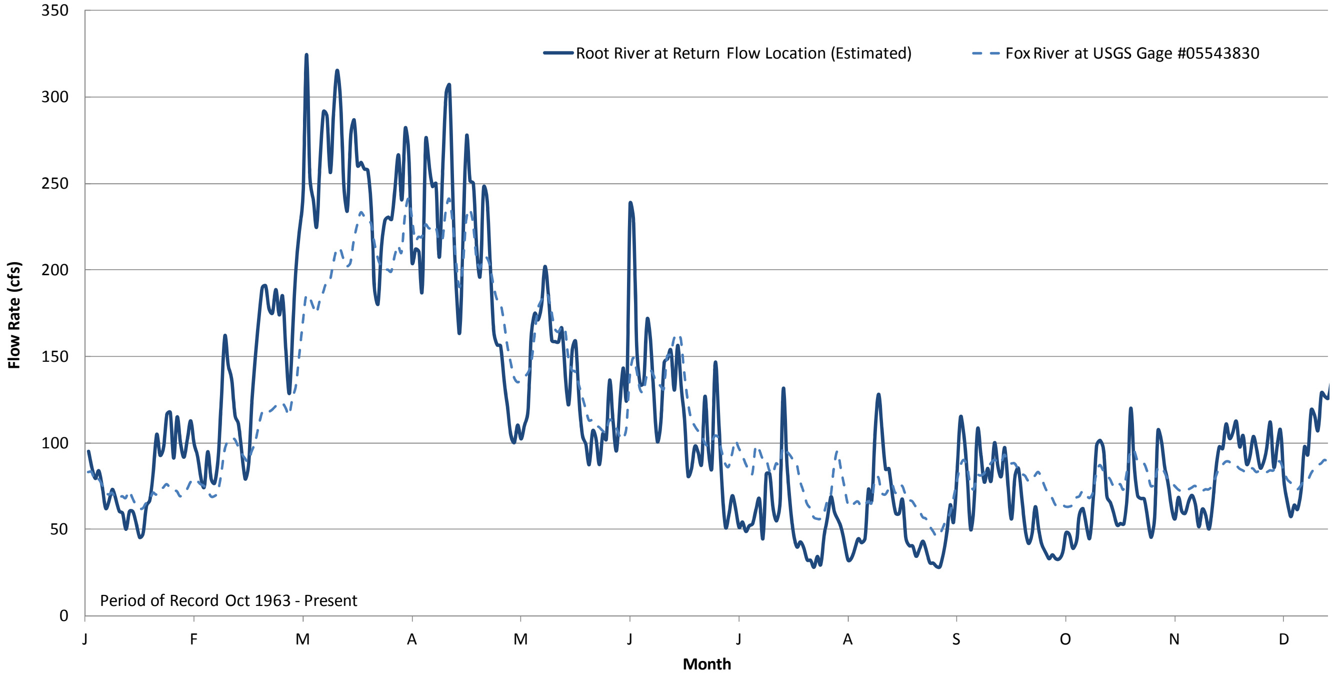
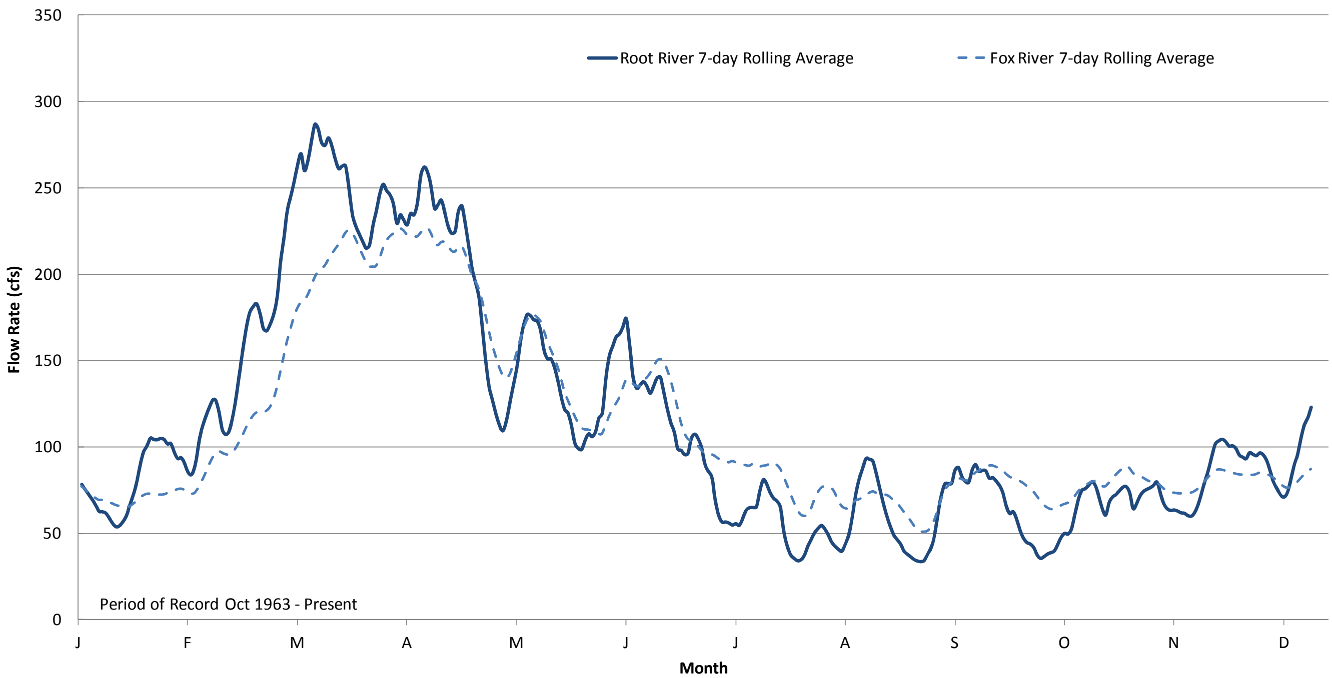


EXHIBIT 7

7-day Rolling Average Daily Flow Rates of Fox River near the WWTP and Root River at the Return Flow Location



Methods to Comply with Thermal Requirements

Mixing Zone Study

The Fox River Mixing Zone Study was completed in September 2012 in support of the WWTP's permit renewal application and to demonstrate the rivers ability to dissipate heat from the effluent. The mixing zone analysis concluded that the existing discharge location meets the provisions specified in NR 102.05 (Strand Associates, 2012) and the discharge is progressively diluted from the source of the receiving system. As noted above, the WDNR has reviewed this study as part of the permit issuance and concluded that sufficient dissipative cooling occurs, a thermal barrier is not present, and that thermal limits are not needed for the Fox River.

While it is not possible to complete a mixing zone study the same as what was done on the Fox River, there are several similarities to the Root River and Fox River at the discharge locations where correlations could be made on expected findings. In fact, initial observations show promise that the Root River location is more conducive to thermal dissipation and preventing a thermal barrier than the Fox River location.

- The Fox River has four meanders that start 250 feet downstream of the WWTP outfall (Exhibit 8). These meanders would encourage shifting of the thermal plume across the channel at each meander creating a possible thermal barrier, but this shifting was not observed during the mixing zone study. In contrast, the Root River return flow location is along the outside bend of one long gradual bend that is about 1,500 feet before its first meander (Exhibit 9). Return flow discharge along this long meander would encourage the return flow to remain along the river's edge (the same as that observed in the Fox River for a similar river setting) and not create a thermal barrier. The Fox River meanders would be more likely to create a thermal barrier with effluent exceeding 50 percent of the width, however this was not observed during the mixing study. Because the Root River is less likely to have these conditions, similar (or better) conditions are expected at the Root River location than the Fox River discharge to maintain a zone of free passage within the mixing zone.
- The outfall location at the Fox and Root River is on the outside bend of the river where flow patterns are more turbulent than inside bends or straight sections, and consequently mixing is more prevalent. This is evidenced by scour that commonly occurs along the outside of river bends, in contrast to inner bends where scour is less or possibly non-existent. The Root River has very little scour along the outside bend because it is protected with dense vegetation, but because of these flow patterns, there is a greater potential for thermal dissipation and mixing when compared to an inside bend or straight portion of river. Consequently, the Root and Fox Rivers have similar geomorphic features near these outfall locations and could be expected to have similar thermal dissipation qualities. The Root River could have better mixing qualities because the meander bend is much longer than at the Fox River location.
- The Fox and Root Rivers are similarly sized – the Fox River is about 70 feet wide at the outfall and downstream, and the Root River is about 65 feet. Because they also have similar flow rates and slopes as discussed above, their hydraulic characteristics are similar and could be expected to have similar thermal dissipation and mixing.
- The Root River has significantly more shading with mature trees along the river banks than does the Fox River. This could cool the effluent more quickly than that in the Fox River.
- The Fox River outfall is oriented at a sharp angle to the river to encourage the effluent to hug the shoreline. A similar design detail could be incorporated into the Root River outfall, however an outfall with greater turbulence could be considered to enhance mixing while encouraging the return flow to "hug the shoreline" to maintain a zone of free passage.

EXHIBIT 8

WWTP Outfall to Fox River

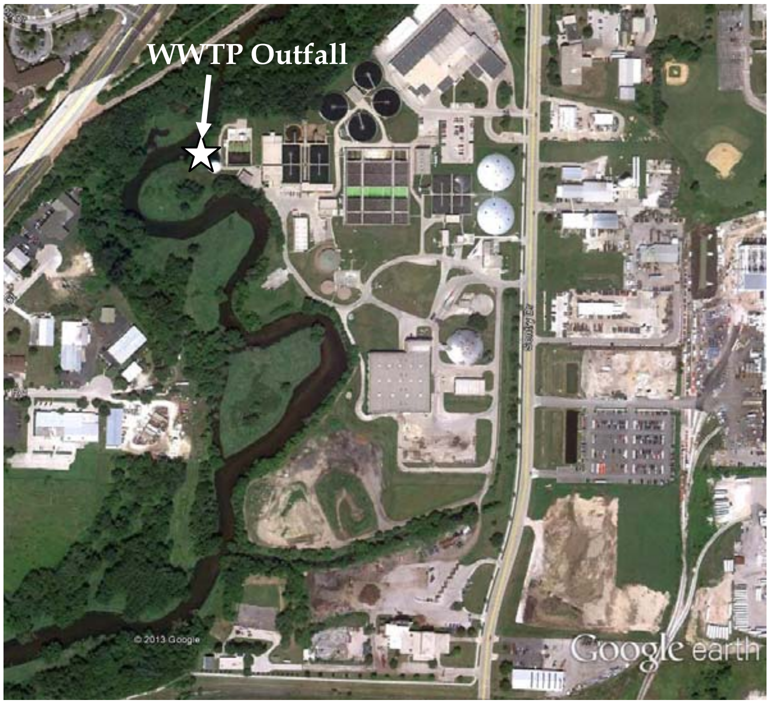
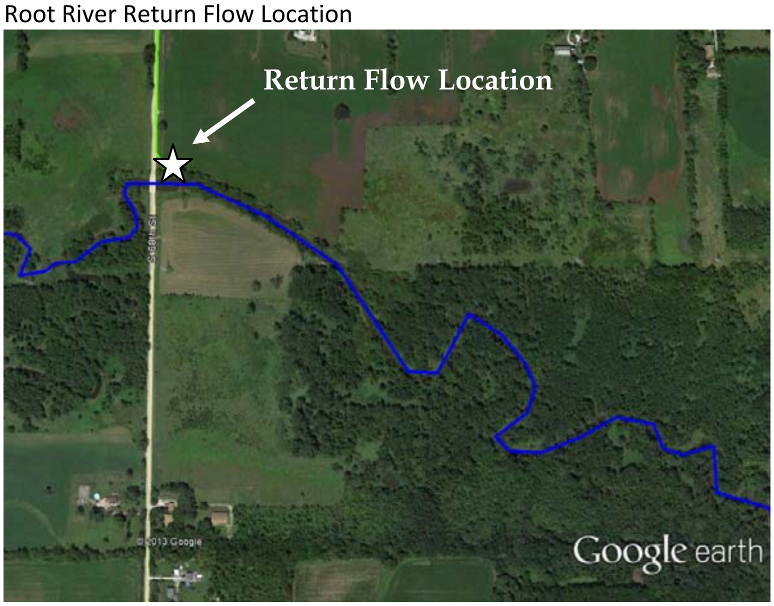


EXHIBIT 9

Root River Return Flow Location



Because of the significant similarities between the Fox and Root River at the outfall locations, the Fox River mixing zone study, and similarities of environmental and geomorphic conditions, thermal characteristics are expected to be similar or possible better for the Root River location.

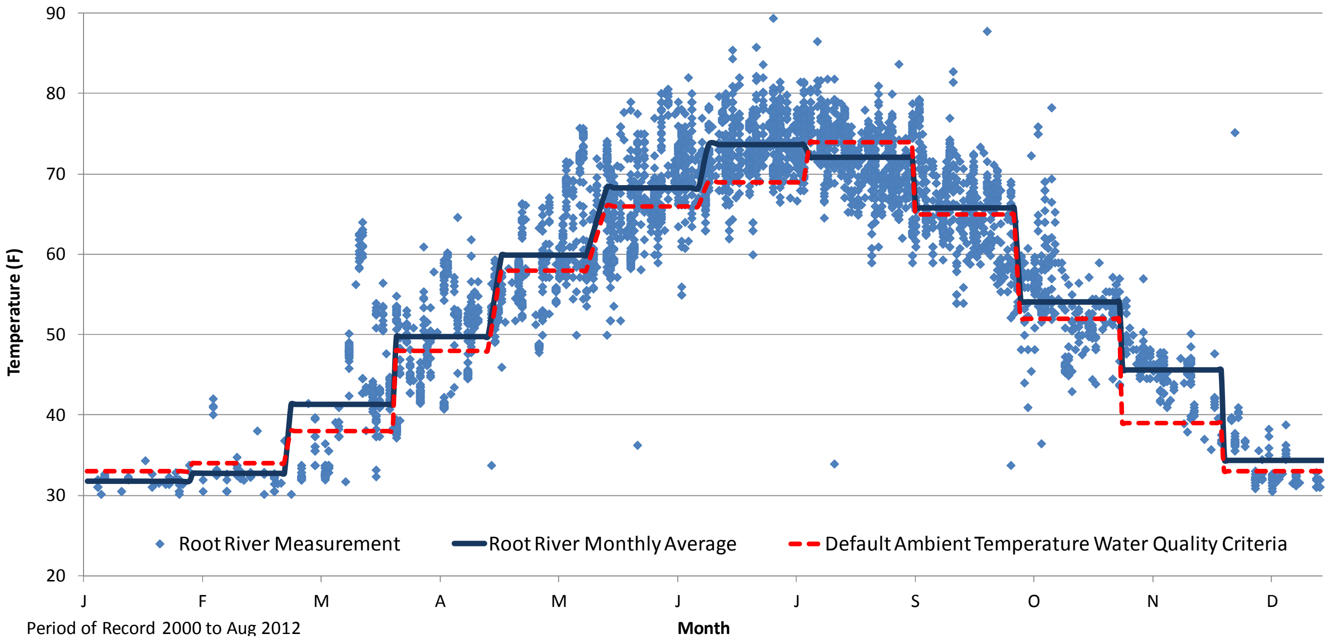
In-Stream Temperature Analysis

As part of the Southeastern Wisconsin Regional Planning Commission's (SEWRPC) Root River Restoration Plan, Root River temperature measurements were compiled from multiple sources from early 1964 through August

2012.[1] The data was provided to the City and included more than 5,700 temperature measurements between 2000 and August 2012 in the Lower Root River subwatershed that extends from Lake Michigan to the river's confluence with the Root River Canal (Exhibit 10).

EXHIBIT 10

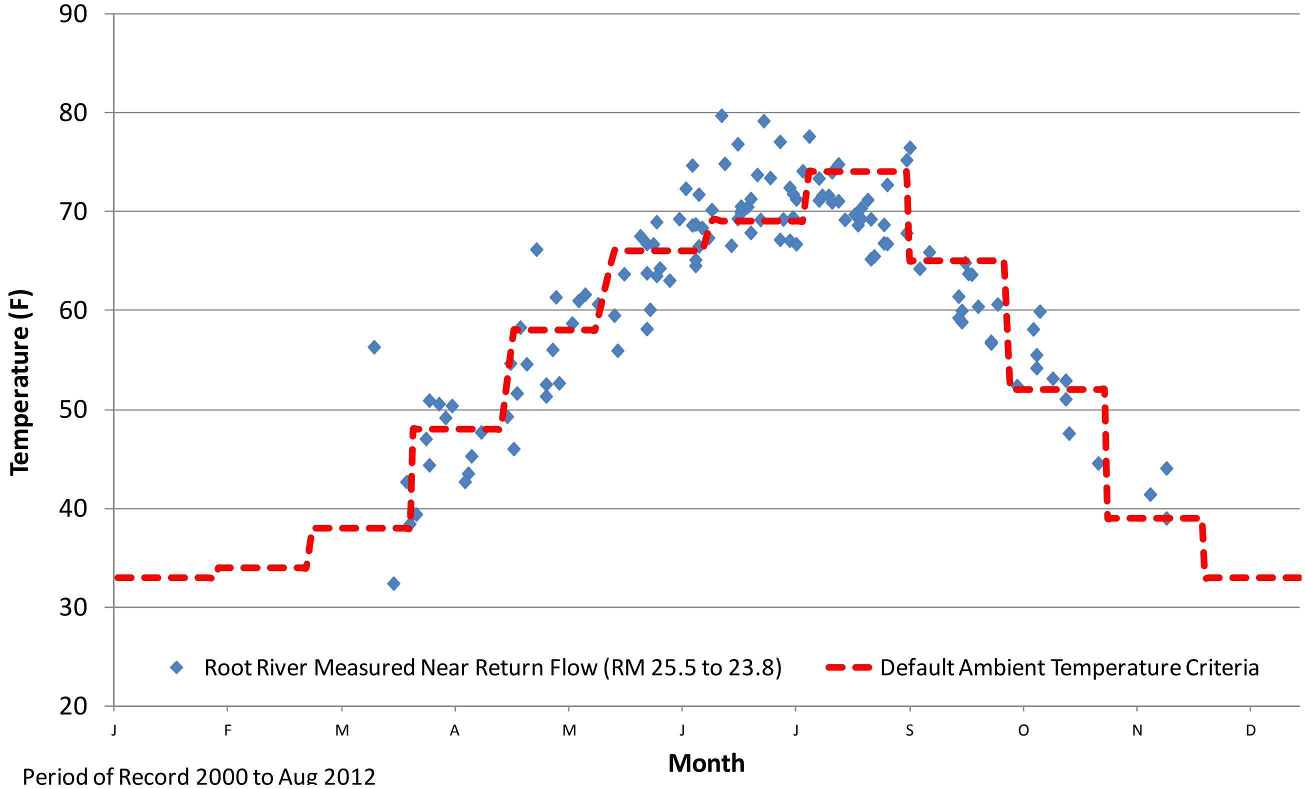
Lower Root River Temperature Measurements



The monthly average temperature based on the sampling data since 2000 is very different for some months than the default (not site specific) ambient temperature for a small warm stream provided in NR 102.25. The sampling data is most often greater than the default values and in some months, such as November, the sampling data shows that the river is about six degrees warmer than the default ambient temperatures. Because the default ambient temperature values are lower than the site specific values, and the default values are used to determine effluent temperature limitations in the absence of site-specific ambient temperature data, if the site specific data were to be used, it would result in a higher effluent temperature limits for months like November. This similar trend is observed at measurement locations nearest the return flow location that is between river miles 25.5 and 23.8 (Exhibit 11). Consequently if the City is successful is receiving Lake Michigan water, the City may choose to gather additional site specific temperature data to evaluate site specific temperature requirements. This initial data evaluation indicates a higher temperature limit is likely using site specific data.

[1] Root River temperature data from the following sources: the Milwaukee Metropolitan Sewerage District, the City of Racine Health Department, US Geologic Survey, Wisconsin Department of Natural Resources, the University of Wisconsin-Extension's Water Action Volunteers Program, and SEWRPC.

EXHIBIT 11
Lower Root River Temperature Measurements Near Return Flow Location (River Mile 25.5 to 23.8)



HSPF Model

As part of the Root River water quality modeling (CH2M HILL 2013) the temperature data within the HSPF model supplied by SEWRPC and used in the Regional Water Quality Management Plan Update was reviewed. The model simulated existing conditions temperature at an assessment point near the potential discharge location using 11 years (1987-1997) of continuous simulation. The temperature data within the model was not consistent with the measured data more recently supplied by SEWRPC, therefore it was not considered further in this evaluation.

Data Evaluation Conclusions

As discussed above, the calculated effluent temperature limits are expected to be greater than currently calculated due to updates in receiving water and return flow rates, and using site specific temperature data instead of default values. In addition, the mixing zone study completed for the Fox River and its support of removing temperature limits for the Fox River discharge is promising for the Root River because the rivers are similar in size, environmental factors, and geomorphology, and the Root River return flow has some features that are more beneficial for mitigating the return flow temperature. Based upon these observations, achieving a reasonable expectation of thermal standards compliance is shown by the mixing zone findings on the Fox River and the similar characteristics of flow on the Root River.

Other Thermal Discharge Management Alternatives

Should additional measures need to be taken to reduce temperature effects on the Root River, there are several alternatives that could be evaluated during detailed design and site-specific permitting. These are discussed below.

Heat Exchange in Return Flow Pipeline

Preliminary heat loss calculations were performed for the return flow pipeline using Applied Flow Technology (AFT) Fathom software. The software requires that the user provide the air film convective heat transfer coefficient (1993 ASHRAE Handbook-Fundamentals, American Society of Heating, Refrigeration and Air-

Conditioning Engineers, Inc.). A 20-mile 30-inch ductile iron pipe conveying 16.7 mgd was assumed for the return flow. The months of November and October were evaluated because they have the highest difference between historical discharge temperature and temperature limits. These months also have the least temperature differential between the return flow temperature and ambient air. For these months, the preliminary calculations have a temperature drop of approximately one to two degrees F. While there is a temperature drop, it would have to be combined with mixing or other measures to meet the proposed effluent limits.

Treatment Wetlands

The return flow location is a large flat area adjacent to the Root River that is currently farmed. The city has an agreement with the land owner for purchase of the land. The land could be converted to a treatment wetland to reduce temperature before discharge. Wetlands are a proven sustainable solution to temperature compliance (among other benefits such as nutrient uptake and habitat creation). For example, three cities in Oregon are using treatment wetlands as part of their compliance for temperature (Cities of Salem, Woodburn, and Roseburg).

Wetlands directly reduce effluent temperature through evaporative and radiant cooling. The degree of temperature reduction is determined by several factors, including topographic and riparian shading, vegetative coverage and density, climatic conditions and the effluent flow and temperature. Preliminary calculations to estimate the wetland surface area and hydraulic retention time needed to meet effluent limitations currently calculated by WDNR (a change of 11 degrees F in November) resulted in a wetland system of approximately 150 acres. This exceeds the practical space available for return flow but it demonstrates that a wetland system could serve as part of the thermal compliance and that with higher limit calculations based upon site specific conditions, a wetland system would be sufficient. If needed, detailed heat source modeling could be conducted during detailed design and site specific permitting.

Surface Aerators

Similar to the treatment wetland area, surface aerators could be used. Surface aerators are often used at industrial treatment plants where effluent temperatures can be significantly greater than the discharge from a municipal WWTP. Surface aerators would require an impoundment several feet deep, which is possible at the return flow location, and would have high energy demands.

Cooling Towers

Cooling towers remove latent heat through evaporative cooling using a fan that blows air across the cooling fluid. Cooling towers are significantly influence by ambient air temperatures and for months when the ambient air temperature is similar to the temperature limit (e.g. October and parts of November), cooling towers have less effectiveness. Cooling towers have moderate energy demands and could be located at the WWTP or at the return flow location.

Chillers

Chillers use a refrigeration cycle to remove heat from circulating fluid. They are effective at reducing temperatures to 35 to 45 degrees F but they have very high energy demands for compressor operation and have high capital costs.

Multiple Discharge Locations

In lieu of having a single discharge point, which is common for nearly all dischargers, multiple pipe outfalls could be located along the Root River to gradually disperse the return flow in the river. A lower effluent flow rate enables the receiving river's flow rate to more quickly dissipate heat and minimizes the potential for a thermal barrier. The return flow location includes over 900 feet of river shoreline that could be used for multiple (e.g. two or three) outfall locations. Using multiple discharge locations has the potential to fully mitigate the thermal impact from return flow because the Root River has a much greater length before its first bend, and because the Root and Fox Rivers have similar geomorphic features at the outfall locations.

Subsurface Flow

A subsurface flow system consisting of granular media could be used to cool the return flow effluent prior to discharge to the Root River. A system could be similar to that used in the City of Milwaukee's Menomonee Valley and Canal Street stormwater management units. As part of that system, stormwater in each of the stormwater treatment units (i.e. bioretention facilities) infiltrates into a gravel bed consisting of recycled concreted several feet thick and three-to-four feet below the ground surface. The infiltrated water flows through the gravel/recycled concrete to feed a treatment wetland and ultimately the Menomonee River. This system was designed as part of the Canal Street redevelopment to provide a cool water discharge to one of the stormwater management units (swamp forest that required a cool water discharge) and to the Menomonee River. A similar system could be developed for the Root River return flow.

Combinations of Management Techniques

Combinations of the various techniques described above, including mixing zone analysis, site specific temperature data considerations, and any number of management techniques to reduce the return flow temperature can be used to satisfactorily achieve the WDNR thermal requirements.

Conclusion

There are significant similarities between the Fox River at the WWTP and the Root River return flow location that allow a reasonable comparison between the thermal limits between both locations. Based on analyses completed for the WWTP discharge to the Fox River, thermal limits are not needed. Similarly, limits also may not be needed for a Root River discharge or they could be several degrees less stringent than currently proposed by the WDNR.

The watershed size, land use, slope, river width/depth, and other environmental factors such as climate are very similar, and for some parameters like watershed size, slope, and climate, the locations are essentially the same. When reviewing USGS flow gage information for the Fox and Root Rivers, the historic flow rates are very similar yet the flow rates in the thermal calculations performed by WDNR for the Fox and Root Rivers are very different. The flow rates are not expected to be the same, but the Root River flow rates used for the thermal calculation are expected to be similar to the Fox River and are expected to provide slightly higher limits. Similarly, the return flow rates used in the WDNR Root River limit calculation will be less in fall/winter months (October through February) and will result in slightly higher limits because the current return flow management plan has a maximum daily return flow rate of 16.7 mgd.

The Fox River mixing zone study has supported the WDNR's decision that the WWTP's discharge complies with thermal requirements. There are significant similarities between the Root River discharge location and the Fox River, and there are several geomorphic features at the Root River that are *more* supportive of thermal dissipation and preventing a thermal barrier. A more detailed analysis of the Root River could be completed during detailed design and permitting, but the Fox River mixing zone study can be correlated to the Root River location and is supportive of return flow having minimal or no thermal impacts. Consequently, the same as the Fox River, the Root River may comply with thermal standards without having numeric limits.

While relying upon mixing appears reasonable for complying with thermal standards, several alternatives exist for addressing thermal impacts of a return flow if it is needed. Treatment wetlands, dissipation through the pipeline, and having multiple discharge locations all contribute towards reducing thermal impacts. More expensive and energy intensive options exist if they are needed to meet limits. However, based on the Fox River mixing zone study and this preliminary analysis for the Root River, thermal limits may not be needed or could be less strict than those calculated. Consequently complying with thermal requirements will be achieved and any additional costs are expected to be marginal and included within the contingency of the cost estimates for return flow.

This analysis demonstrates that multiple options exist for the Root River return flow to achieve WDNR thermal rule compliance. Consequently, return flow as it relates to thermal discharge, can reasonably protect the chemical, physical, and biological integrity of the Root River. With a successful Lake Michigan application, more detailed data gathering and analysis for thermal and other water quality requirements will occur to apply for a Root River discharge permit.

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