ENHANCING STORM WATER INFILTRATION TO REDUCE WATER TEMPERATURE DOWNSTREAM

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A substantial storm water management project was recently completed in the city of Sun Prairie, about ten miles east of Madison, Wisconsin. The primary goal of this project was to protect the water quality of Token Creek, one of the last remaining cold-water trout streams in south central Wisconsin.

Reducing the downstream movement of sediment and preventing excessive heating of the runoff were two challenges faced in this project. A team of engineers and scientists from the city of Sun Prairie, the Wisconsin Department of Natural Resources, Dane County's Land Conservation Department, and Vierbicher Associates, Inc., joined forces to meet the goals of this project. This team designed and built a series of stone-filled gabion weirs to filter sediment, and they engineered a stone-lined channel to infiltrate runoff into the ground.

State funding earmarked for the reduction of non-point source pollution supported this project. The outcome being a system which treats storm water runoff from more than 492 acres of new residential development. Enhanced infiltration provided by the stone-lined channel is designed to reduce stream water temperatures by moving the surface runoff under ground. The gabion weirs are designed to remove sediment from the streamflow by trapping large particles and filtering smaller ones. The capability of this storm water treatment system to reduce stream temperature was designed with a site-specific thermal model. The substantial accumulation of sediment upstream from the gabions indicates the systems ability to treat storm water runoff. The system's design and functionality, along with its aesthetic appearance in a densely developed subdivision, demonstrate its success in suburban Sun Prairie. Because infiltration is becoming more important as a storm water management practice, this treatment strategy may have applications wherever development occurs.

Introduction

The Token Creek Watershed is a 27 square-mile sub basin of the Yahara-Lake Mendota Priority Watershed in south central Wisconsin, on the northeast side of Madison, immediately adjacent to the city of Sun Prairie (Figure 1). This watershed supported a native brook trout fishery prior to European settlement (Sorge, 1996). Today, natural springs, which discharge more than 4000 gallons per minute of 50-degree Fahrenheit water to Token Creek, continue to support a cold-water fishery (University of Wisconsin, 1997, Wisconsin Department of Natural Resources Unpublished Data). Development around the city of Madison and especially the outlying areas near Sun Prairie is increasing. The result is increased pressure to build near wildlife habitat areas and watersheds that support such fisheries. The challenge then is to create development that is compatible with the surrounding environment and to develop in ways that minimize degradation of natural resources.

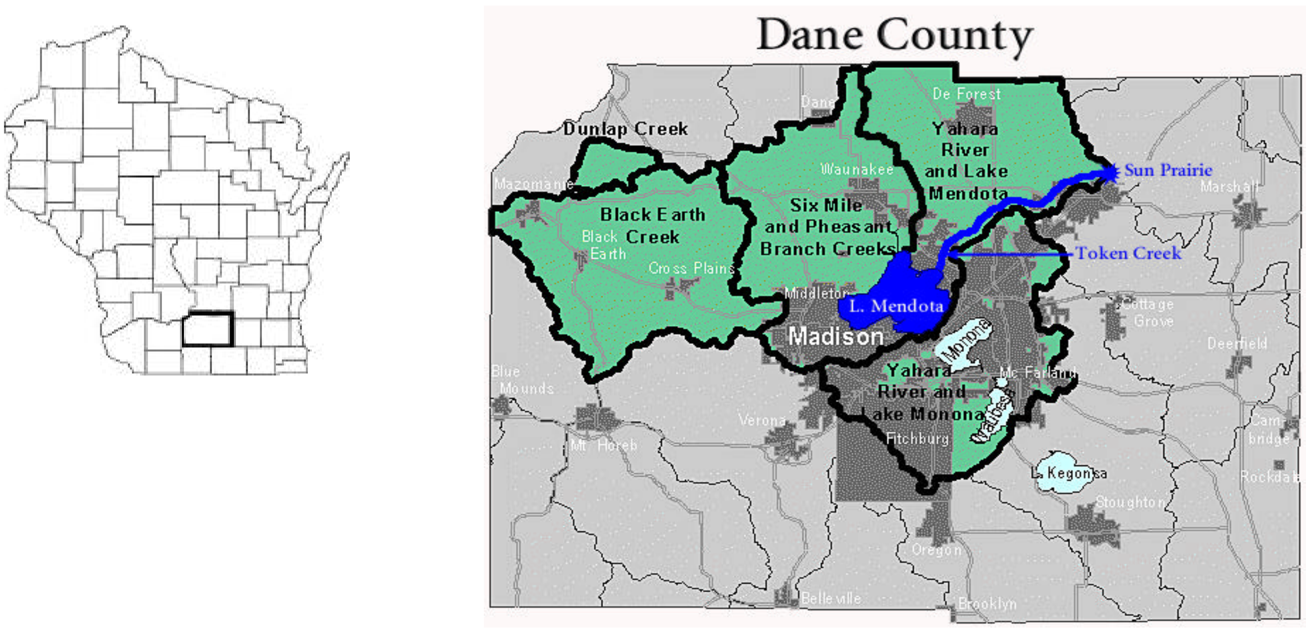

Figure 1. Location of Dane County, Wisconsin, and Token Creek in the Yahara River and Lake Mendota Priority Watershed. The proximity of Token Creek to the growing cities of Madison and Sun Prairie increases the demand for development in the watershed. The importance of the cold-water fishery in Token Creek and the priority designation of downstream lakes create a regulatory agency emphasis on protecting water quality. Map modified from Dane County, http://www.co.dane.wi.us/landcopnservation/pwshed.htm.

Background

Regulatory agencies realize the importance of the natural resources and they understand the value of limiting sediment inflow and water temperature increases to an urbanizing stream that also supports a cold-water fishery. As a result, proposed developments in the Token Creek Watershed are closely scrutinized for their contributions of non-point source pollution. In addition, there is a regulatory emphasis placed on managing water temperature increases and there are no concise compliance standards, documented best management practices (BMPs), or design manuals to rely upon or use as targets. Therefore, biologists and engineers commonly use professional judgement, personal experience, and modeling to predict the outcome of various management practices.

In the case of Token Creek, where there were benefits to protecting the creek for, the participants were quite cooperative. For example, the developer for the residential subdivision generously donated land along Token Creek tributary drainageways to the city of Sun Prairie so it could be managed in the public interest. The developer realized benefits from protecting Token Creek if home site and property values are higher as a result of the attractive storm water management features in the dedicated public lands and a viable cold-water fishery downstream. Furthermore, the city of Sun Prairie will benefit from an increased tax base of the higher home values. Regulatory agencies also benefit because enhanced protection of the natural resources is one of their primary directives.

Purpose and Scope

Token Creek is part of the Yahara-Mendota designated Priority Watershed Project, which aims to reduce sediment and nutrient flows into Lake Mendota. This designation and the creek's high value as a cold-water fishery, prompted the State of Wisconsin's Department of Natural Resources, (WiDNR) to award a Non-Point Source Pollution Abatement Program cost-share grant to the city of Sun Prairie to design and install BMPs in the Token Creek Watershed. In support of the Priority Watershed Program, Dane County's Land Conservation Department is working with the agricultural industry to ensure that agricultural BMPs are installed throughout the watershed to reduce sediment inflows to the lake. The Land Conservation Department is also developing a model to predict the effects of land-use change on water temperature and to predict the change in water temperature derived from various land-management practices. The resources at Dane County and the WiDNR assisted the city of Sun Prairie and their engineering consultant, Vierbicher Associates Inc., with the design of BMPs to reduce the movement of sediment and heated runoff to Token Creek.

The cost-share grant from WiDNR supported design and construction of BMPs in a proposed 492-acre residential subdivision along a tributary to Token Creek. Dane County provided design recommendations based on their experience with agricultural practices in the area and results of detailed temperature modeling. Vierbicher Associates provided engineering design and construction plans. The city of Sun Prairie supervised design and construction of the project and the WiDNR and Dane County provided regulatory agency oversight. The two primary goals of the project:

- To protect the water quality of Token Creek (primarily by controlling sediment inflow and water-temperature increases)
- To provide BMPs that are attractive and improve property values

The purpose of this paper is to describe the Token Creek Water Quality Control Project and the design process used to select BMPs for this project. Primarily because the project provides an introduction to relatively new storm water management techniques (rock-filled gabion dams and rock-lined channel storm water infiltration), and a new engineering tool (water temperature modeling). These new techniques and tools provide protection against non-point source pollution, in addition to mitigating thermal impacts from storm water runoff. Both the project's design process, including the new engineering techniques and tools and the project's unique BMPs, should have broad applications in urban storm water management. The project also provides valuable examples of cooperation between adjacent city governments, regulatory and funding agencies, and design professionals.

BMP Selection

The proposed 492-acre single-family development was planned to include about 15 acres of green space along the tributary drainageways to Token Creek and the remaining land converted to approximately 0.25-acre residential lots (Figure 2). Each lot was planned to contain a 3-bedroom home (2,500 square feet) and a 2-car garage (480 square feet). This lot configuration results in about 4,400 square feet of total impervious surface if an allowance of 900 square feet is made for roads and 520 square feet is allowed for driveways, and sidewalks. The result of this development is an alteration of land use from 100 percent open-pastureland and forest to about 34 percent impervious area.

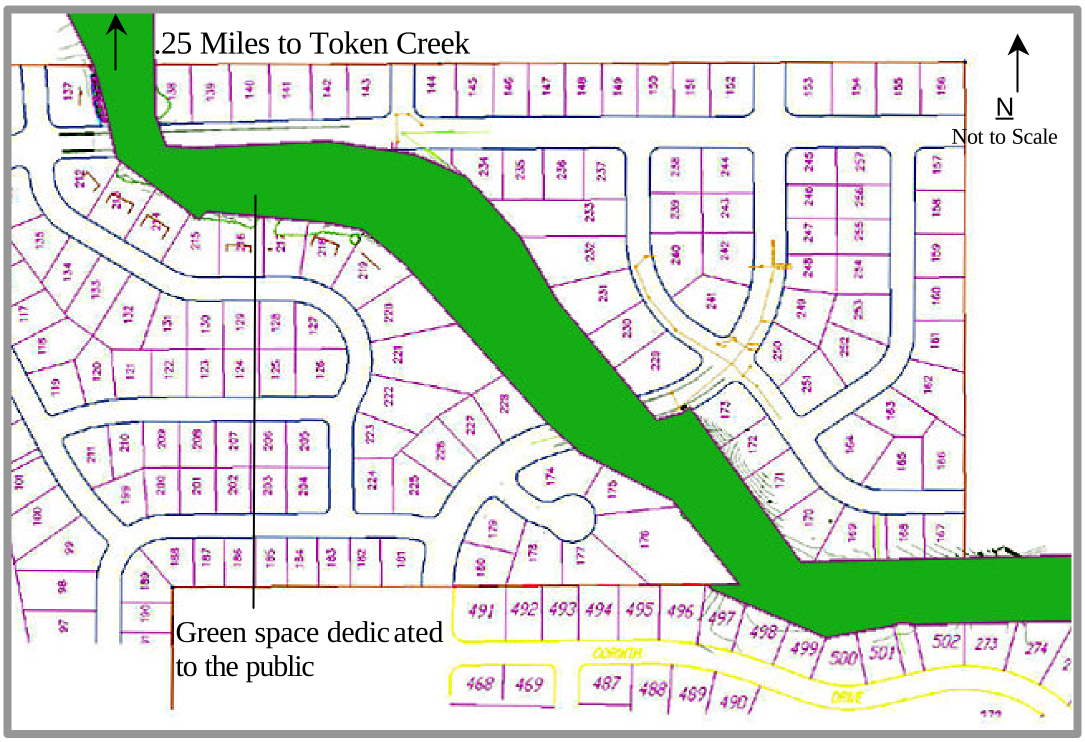

Figure 2. Proposed single-family residential development in the watershed of a tributary to Token Creek. Of the approximately 492-acres proposed for development, 15-acres will be dedicated to the public as green space and the remaining land will be subdivided into approximate 0.25-acre lots.

The result of this type of land-use conversion typically is an increase in runoff and a substantial increase in peak discharge, severe streambank erosion, and degradation of water quality including elevated water temperatures. Common BMPs available to address these concerns would include storm water detention ponds, streambank reinforcement, and created wetlands. Principal concerns with these common BMPs as a result of a cold-water fishery less than 0.25 miles downstream include storing and ponding water that would potentially increase the water temperature and unsightly wetland areas that might attract mosquitoes. The city of Sun Prairie as the supervisor of design and construction and the regulatory agencies within their review capacity both understood the need to closely coordinate this project. Early in the design process consultations with regulatory agency staff resulted in considerable efficiencies in the design. For example, in headwater areas where wetlands prevail along the drainageway, consideration of the need to infiltrate runoff and preserve wetlands resulted in agreement on selection of an erosion control mat for stream bank stabilization instead of rock lining. In addition, the agreement between engineers and regulators to place rock dams near planned or existing roadway and bike path embankments minimized the disturbance to the site by concentrating fill materials and provided for easy maintenance of the storm water management system. The common acceptance of the need to mitigate water temperature increases in Token Creek among designers and reviewers brought together a team of engineers and scientists that otherwise would be working independently. The design process, techniques, and tools this team used to complete this one project are now complementary items in new countywide storm water management and erosion control ordinances, Statewide model ordinances, and the daily practice of the individual engineers and scientists involved in the project. One of the most important new engineering tools is the application of a temperature model developed during the project.

Temperature Modeling

A Temperature Urban Runoff Model (TURM) was developed and tested in Dane County, Wisconsin, to predict the thermal impact of proposed development projects (Arrington et al., 2002, Roa-Espinosa, 2003). A number of sample model runs are presented here to help understand how several variables interact to result in the stream temperatures predicted by the model. Three of the important variables that determine stream temperature as a result of a storm are:

- the percentage of impervious area of the parcel,
- the parcel area and
- the baseflow of the stream that the parcel drains into.

Percentage of Impervious Area and Water Temperature

Impervious surfaces, such as pavement or asphalt, increase stream temperature for two reasons. First, impervious surfaces absorb solar radiation, which raises their surface temperature. When it storms, some of this heat is transferred to the water that falls on these surfaces as precipitation. Second, impervious surfaces reduce infiltration, which increases the runoff volume from these surfaces. (Pervious surfaces, like grass or other vegetation, allow some of the precipitation that falls on them to infiltrate into the soil.) As the percentage of impervious area of a parcel increases, more of the total runoff from the parcel comes from the heated runoff contributed by the impervious surfaces. Therefore, as percentage impervious area increases, the temperature of the water runoff from the parcel increases and the temperature of the stream that the runoff enters increases as well.

Because there are some significant seasonal variations in storms and their effect on water temperature the model uses a typical summer rainstorm event in Dane County to predict water temperature changes. The assumed storm and local environmental conditions accompanying the storm event are described in Table 1.

Table 1. Typical storm and environmental conditions assumed for mid-summer storms in Dane County, Wisconsin from TURM predictions.

rainfall depth	0.5	inches
rainfall duration	4	hours
hour of day rain start (between 1 and 24 hours)	14	
Time of concentration (Tc)	0.100	hours
wind speed	10.2	ft/s
rain temperature (during storm)	73.7	°F
Initial temp. of impervious surface	93.6	°F
Air temperature	80.0	°F
Relative humidity	80.0%	

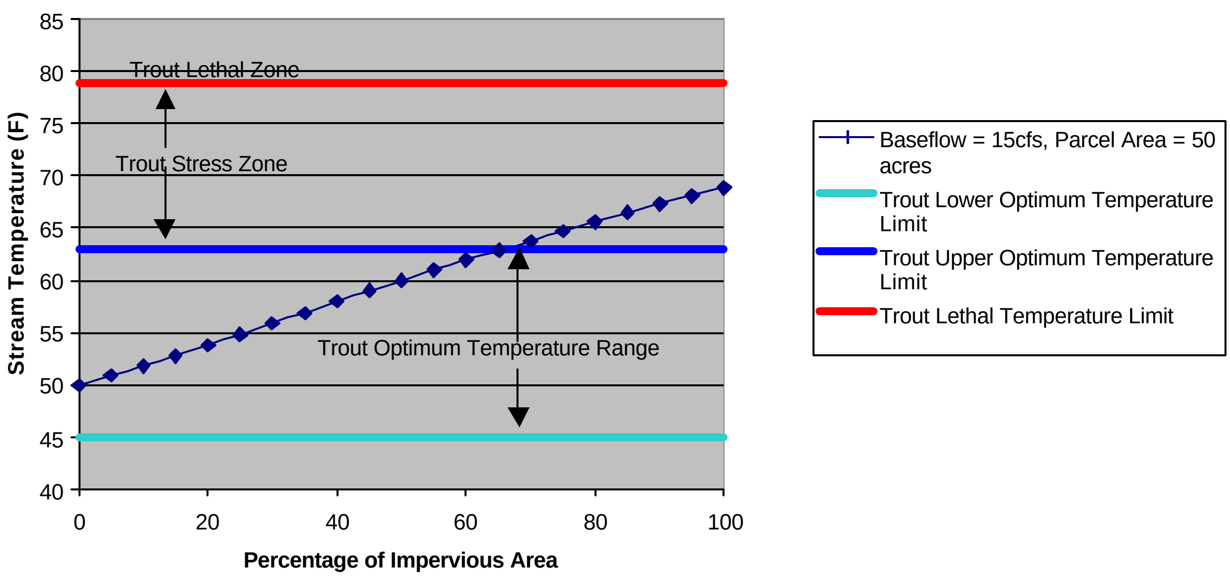

Figure 3. There is an increasing trend in stream temperature with increasing percentage impervious area for a given parcel area and baseflow. Baseflow is given in cubic feet per second (cfs).

Parcel Area and Water Temperature

In general, at a given percentage of imperviousness, the larger the parcel area, the more runoff it contributes to the stream. More heated runoff means greater stream temperature increases resulting from a storm.

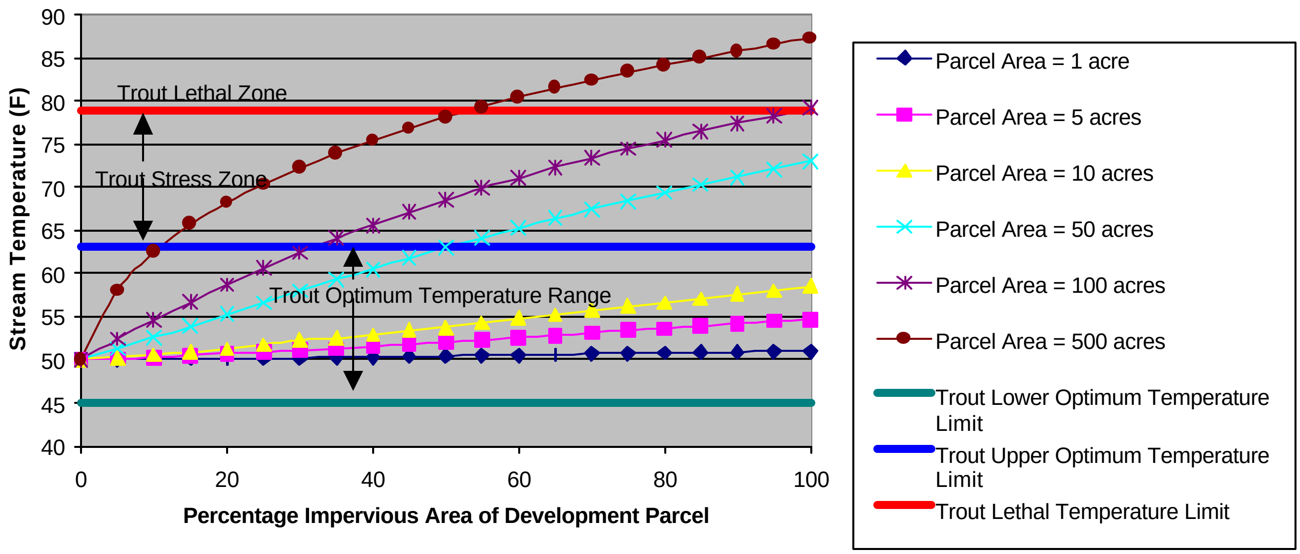

Figure 4. For a given percentage of impervious area and a given baseflow, the greater the parcel area, the greater the stream temperature.

Baseflow and Water Temperature

Baseflow is the flow rate (volume of water per unit time) of a stream before a storm. Typically small baseflow is found on small streams and tributaries, whereas large baseflow is found on larger streams. Stream temperature resulting from a storm is a mixture of the initial stream temperature and the runoff temperature. At a given volume of heated runoff (determined from the parcel area and the percentage imperviousness) there is a greater stream temperature increase in a stream with a small baseflow than a stream with a large baseflow. This is because the runoff volume is a greater proportion of the stream volume in a small baseflow stream than a large baseflow stream.

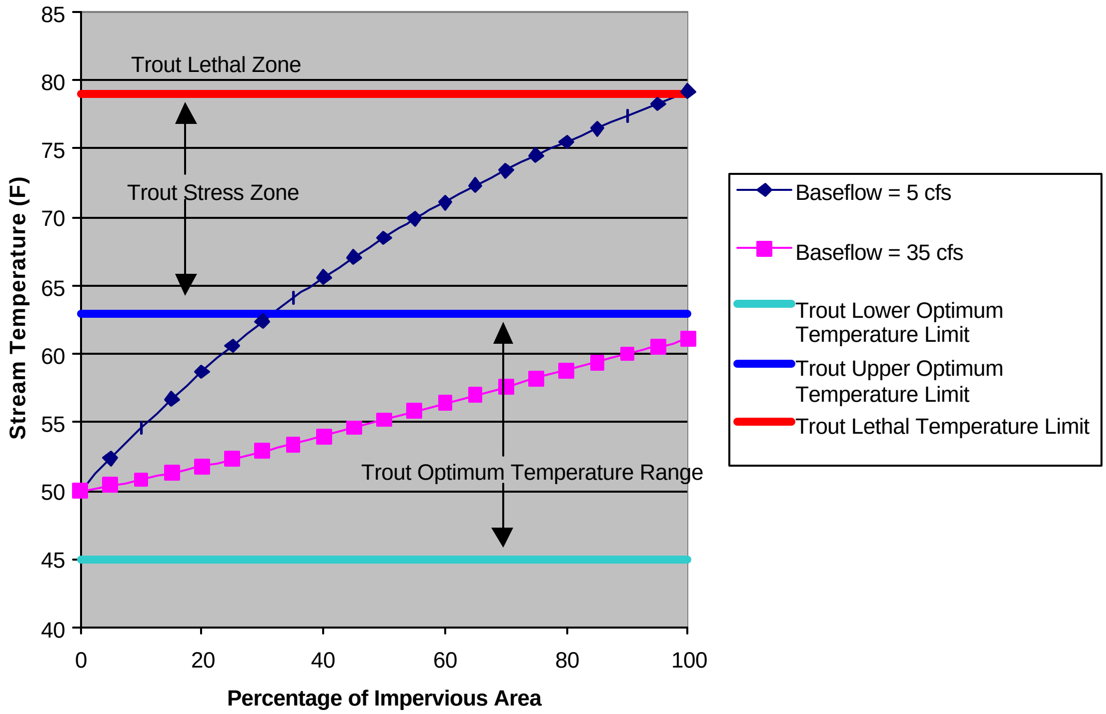

Figure 5. For a given parcel area and a given percentage of imperviousness, higher stream temperatures are found in streams with smaller baseflow and lower stream temperatures are found in streams with larger baseflow. Baseflow is given in cubic feet per second (cfs).

Watershed Characteristics and Water Temperature

Understanding the inter-relation between watershed characteristics and water temperature elucidates opportunities to manage development or mitigate the effects of development in a watershed (Figure 6). For this developing tributary watershed to Token Creek, which generally has a larger parcel area (492-acres) and a lower base flow about (9 cubic feet per second), mitigating increases in stream temperature and reducing the movement of sediment to the creek were common goals of the developer, the city, and the regulatory and funding agencies. Because additional single-family housing is in high demand in this area mitigating the potential harmful effects of development was more desirable than reducing the size or number of housing units developed.

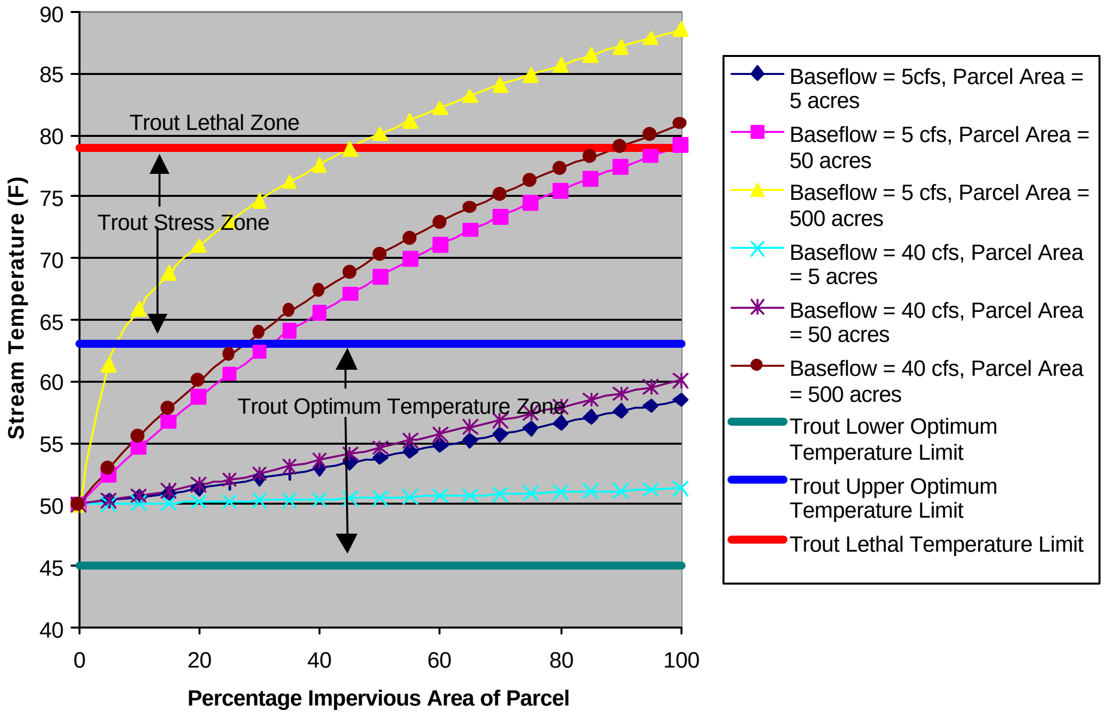

Figure 6. The relative trends of how stream temperature varies with percentage impervious area for different combinations of parcel areas and baseflow. For small parcels and large baseflow, there is little thermal impact to the stream, regardless of the percentage of impervious area. On the other hand, large parcels that drain into a stream with a small baseflow cause a substantial stream temperature increase, even at relatively low percentages of imperviousness. Baseflow is given in cubic feet per second (cfs).

A 21.6-degree F increase in stream temperature is predicted to result from the proposed development in this Token Creek Tributary watershed by the TURM (Table 2). The resulting water temperature of 71.6 degrees F is above the stress zone for trout and, thus, is undesirable. Therefore some temperature mitigating management practices are necessary.

Table 2. For a given rainfall event a temperature increase of 21.6 degree F is predicted to result from the proposed development in this tributary to Token Creek.

Temperature Urban Runoff Model

POST-DEVELOPMENT

Units: english

Required Inputs:

% Connected imperviousness in watershed	34%	
Watershed area	492.00	acres
Base flow in stream	9.0	cfs
Existing stream temp.	50.0	°F

Outputs:

Temp. of runoff from development	93.8	°F
Difference between runoff and stream temp	43.8	°F
Temp. of stream after development	71.6	°F
Increase in stream temp.	21.6	F

The model runs described here represent the relative thermal impact of various development scenarios if heated runoff has little opportunity to cool before entering a stream. The combinations of percentage of impervious area, parcel area, and baseflow do not necessarily have the impact shown above if temperature reduction practices are used to mitigate the thermal impacts of development. The two basic principles behind thermal reduction practices are to slow down heated runoff on its way to the stream (to give it time to cool) and to increase infiltration of heated runoff (to reduce the volume of heated water that reaches the stream). Some useful temperature reduction practices include rock cribs, thermal swales, and retention/infiltration area.

In this development a treatment train was proposed where storm water runoff was collected in the streets and developed lots and directed to the existing drainageway. In the most headwater areas where the drainageway was poorly defined, an erosion mat was used to stabilize the channel and rock-check dams slowed the water and enhanced infiltration (Figure 7).

Figure 7. Erosion control matting and a rock check dam combine to reduce stream channel erosion and enhance storm water infiltration in developed headwater areas.

In areas where runoff is concentrated into a defined channel, a rock lining was used in the channel to protect the streambank from erosion, to dissipate heat by contact, and to more rapidly infiltrate the runoff below the surface (Figure 8). Rock-filled gabion dams were installed along the drainageway where flow was restricted by a roadway or bike path embankment. These rock dam sites were also used for maintenance access as considerable debris and sediment accumulated upstream from these structures (Figure 8).

Figure 8. A rock lined channel provided rapid infiltration of runoff, substantial heat dissipation, and near complete control of channel erosion. Rock-filled gabion dams located near channel restrictions provided easily accessible maintenance sites. Sediment and debris that accumulated upstream from the dams could be readily removed in these areas. The rock dams filtered large sediment and debris, slowed the flow of water, and dissipated heat.

The treatment train strategy implemented in the Token Creek Water Quality Project included a total of 3,055 feet of channel reinforcement and five gabion-dam structures (Figure 9). TURM predicted an increase in water temperature of only 10.7 degrees F as a result of the planned development following installation of the storm water BMPs (Table 3).

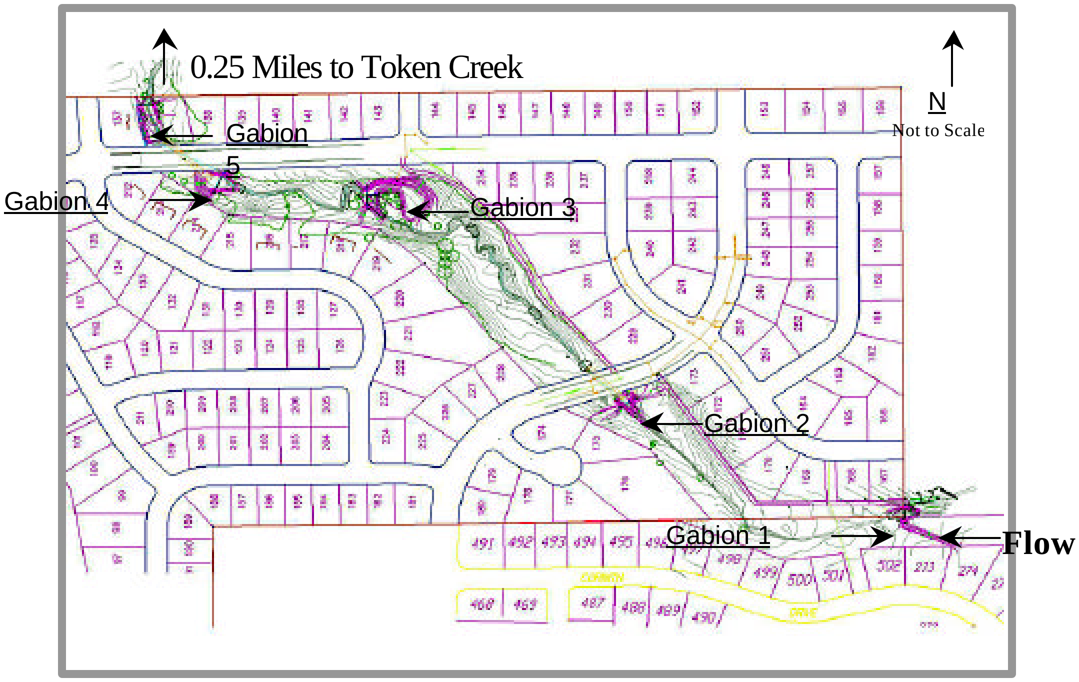

Figure 9. A storm water treatment train that included five gabion dams and 3,055 feet of channel reinforcement was installed along this tributary to Token Creek to mitigate water temperature increases and reduce stream bank erosion.

Table 3. TURM predicted the water temperature in Token Creek would be 60.7 degrees F following the development of a 492-acre single-family residential area once BMP's designed to mitigate for water temperature increases were in place. The increase in water temperature of 10.7 degrees F relates back to the 9-cfs baseflow from the springs that had a temperature of 50 degrees F.

Temperature Urban Runoff Model

POST-DEVELOPMENT

Temperature Reduction Practices:

☑ stone bed/basin	40000 cubic feet, 6 inch stone	
Temperature outletting practices:	66.5	°F
Temperature of stream after practices	60.7	°F
Increase in stream temp. after practices	10.7	°F

Conclusions

The Token Creek Water Quality Control Project positively affected the water quality of the creek. The project also demonstrated the success of close working relationships among designers, regulatory and funding agencies, and contractors. Everyone, including the developer, supported the project's emphasis on mitigating thermal impacts and controlling the downstream movement of sediment. The rapid and profitable sales of homes in the subdivision demonstrate the project's acceptance by the public. The lack of streambank erosion and the accumulation of debris and sediment upstream from the rock-filled gabion dams indicate adequate performance of the project's erosion control features. Although not supported by a post-construction monitoring program at this site, a healthy cold-water fishery downstream in Token Creek indicates the relatively new TURM may be providing useful guidance to designers. Although specifically developed for Dane County Wisconsin, this temperature model, the temperature mitigating BMP's, and the design process used on this project may have applications much wider than the local area. More details of the TURM are also presented in these proceedings (Roa-Espinosa, 2003). Additional documentation of the TURM and guidance for its use can be found on the Dane County WWW page at "http://www.co.dane.wi.us/landconservation/thmodelpg.htm". Additional examples of similar BMP's and projects are also available by contacting any of the authors.

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