Classification of trout stream reaches in the Vermillion River, Minnesota, USA

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Introduction

The purpose of this white paper is to describe the rationale for, and method of, dividing the Vermillion River into different trout stream reaches. These trout stream reaches will provide a geographic location for modeling in-stream daily temperatures in response to storm events and land cover in the Vermillion River Watershed, as part of an EPA Targeted Watershed grant for the Vermillion River. The EPA Targeted Watershed grant is being used to fund the conceptual development of a market-regulatory framework (i.e., non-point trading program) that will balance increasing thermal inputs from new developments with increasing thermal reduction practices in the watershed. The market-regulatory framework will be applied throughout the western Vermillion River watershed where a designated trout stream and other watershed parameters (e.g., flow volume, fecal coliform contamination, sediment, phosphorus) are regulated by several entities, including the Vermillion River Watershed Joint Powers Organization, the Minnesota Department of Natural Resources, the Minnesota Pollution Control Agency, and municipalities. A fundamental assumption of the Vermillion market-regulatory framework is that the in-stream thermal response model will enable the market and regulators to understand the effect of development or land cover change on in-stream thermal conditions at any point in the Vermillion River.

Prior to 1950 the Vermillion River supported a population of brook trout. The population was lost likely due to low oxygen levels caused by poorly treated municipal wastewater. Agricultural practices also may have played a role in the loss of brook trout as farming practices shifted from mixed agriculture (pasture, hay, small grains, row crops) to row crop agriculture. After improved wastewater treatment facilities were built, oxygen levels increased and brown trout were introduced in the early 1990s. Since that time the brown trout population has increased in the number and size of individuals and is self-perpetuating.

Approximately 43 miles of the Vermillion River and its tributaries are designated as trout stream (Figure 1). A 13.4 mile reach of the Vermillion River and 6.5 miles of tributary streams were designated as trout stream in 1988 by the Minnesota Department of Natural Resources (MNDNR). In 2003 MNDNR designated an additional 13.2 mile reach of the Vermillion River as a trout stream, as well as 9.9 additional tributary miles.

Methods

Three sources of data were used to classify trout reaches in the Vermillion River. A review of the literature produced a general idea of brown trout thermal tolerances (Bell 2006). Secondly, data on trout distribution in the Vermillion River were obtained by electrofishing surveys from 1998-2006. Lengths of all captured trout were measured and a subset aged from scale samples to establish age-length relationships that could be applied to all fish sampled (Table 1). Age data allowed the assessment of the catch of young-of-the-year and adult trout from different portions of the Vermillion River.

Table 1. Vermillion River trout length and age.

	1 Year	2 Years	3 Years	4 Years
Mean Length (mm)	131	241	354	445
Std. Dev.	14.6	28.7	18.8	32.0

The third source of data was 33 in-stream temperature monitoring stations in the Vermillion River Watershed (Figure 2). These stations were first installed in 2005. The locations were evaluated and modified in 2006 to better represent tributaries and mainstem reaches in the watershed. Hobo data loggers continuously recorded data in 15-minute increments during the period when thermal stress was most likely to affect brown trout populations (June – September). Data from the loggers were checked for errors and plotted as continuous temperature versus time, and as daily mean and maximum temperatures (Figure 3). Stream temperatures from 2006 were used in classification of stream reaches because not all areas of the trout stream were adequately sampled in 2005.

The distribution of adult and young-of-the-year trout were mapped and different reaches were classified based on presence and abundance of adult and young-of-the year trout. The general thermal tolerances of adult and young-of-the-year trout were considered for each of the resulting reaches and were compared with stream temperature data. Thus each reach was classified in terms of a combined trout-temperature criterion.

The resulting trout stream reach classification was compared with a classification of groundwater reaches (Emmons & Olivier Resources 2007). The groundwater reach classification lends insight into the distribution of groundwater discharge locations relative to reaches that are important to trout. The types of groundwater reaches were: significant gaining reach (>0.1 cfs per 500 feet), gaining reach (0.001-0.1 cfs per 500 feet), and losing reach. All things being equal, the significant gaining reaches where groundwater discharge is high should correspond to reaches where both trout and young-of-the-year trout are present.

Results

Literature review

The optimal temperature for adult and young brown trout is approximately 8-18 C (Ferguson 1958; Coutant 1977; Nettles et al. 1987; Garrett and Bennett 1995, Elliot 1981). The optimum growth rate for trout feeding on invertebrates is 13.9 C., while the optimum growth rate for piscivorous fish is 17.0 C. The latter is a more appropriate temperature threshold in the Vermillion given the fish-dominated diet of brown trout there.

Brown trout will tolerate temperatures 18-20 C, although they can experience negative growth from prolonged exposure due to high metabolic costs (Elliot 1994). Some mortality is possible from prolonged exposure to temperatures above 20 C (Coutant 1975); however, significant mortality is not seen until prolonged exposure to temperatures above 23 C (Elliott 1994).

Adult brown trout have different thermal tolerances than young brown trout (Gardner and Leetham 1914; Ferguson 1958; Coutant 1977; Nettles et al. 1987; Elliot 1994; Garrett and Bennett 1995; Elliot and Hurley 2001). Young brown trout thermal tolerances were investigated by Brown (1946), Lee and Rinne (1980), Elliot (1994) and Elliot and Hurley (2000). It is known that young brown trout are more susceptible to higher temperatures than adult trout because they have lower body mass to dissipate heat, and also a smaller energy reserve to draw on during periods of thermal stress (Elliot 1994).

As mean temperatures climb above 23 C for young and above 25 C for adults, significant direct mortality occurs (Frost and Brown 1967; Binns and Eiserman 1979; Elliot 1981; Bowlby and Roff 1986). However, adult brown trout tolerate short exposure (<1 hour) to temperatures up to 29 C (Lee and Rinne 1980; Elliot and Elliot 1995). Experiments that attempt to mimic diel fluctuations in temperature typically seen in nature have found that brown trout tolerate single event exposure of 21-27 C in a 48-hour period (Lee and Rinne 1980; Wehrly et al. 2007). In a field study of trout streams in Wisconsin and Michigan, Wehrly et al. (2007) found that brown trout could tolerate a daily mean of up to 25 C for 24 hours, a 7-day mean up to 23 C, a 14-day mean up to 22.5 C, and 21-day mean up to 22 C. Wehrly et al. differs from most other studies of temperature tolerance in the use of field rather than laboratory data. Field data are likely to be more applicable to developing temperature criteria because they incorporate temperature changes due to both weather and diel fluctuations, rather than hold temperature constant as in most laboratory studies. Field data also incorporate other indirect effects on trout survival, such as food base and in-stream habitat conditions.

Suitable thresholds for temperature in trout streams must provide protection from both acute and chronic heat stress, with some margin of safety below critical temperatures. With that in mind, we developed thermal thresholds for short and long term exposure to high water temperatures (Table 2). Adult trout and young-of-the-year have different temperature tolerances and are listed separately.

Table 2. Effect of stream temperature on brown trout growth and survival. High and low temperatures are given in Celsius and Fahrenheit.

Adult	**Low C**	**High C**	**Low F**	**High F**	**Exposure (Days)**	**Population Change**
Lethal	NA	>25	NA	>77	1	Significant direct mortality
Chronic	20	25	68	77	>10	Indirect mortality and limited reproduction
Stress	18	20	64	68	>60	Minor reductions in fitness and reproduction
Optimal	8	18	46	64	NA	Stable or increasing
Young-of-Year						
Lethal	NA	>23	NA	>73	1	Significant direct mortality
Chronic	20	23	68	73	>10	Low recruitment
Stress	18	20	64	68	>30	Lowered year-class strength
Optimal	8	18	46	64	NA	Stable or increasing

Temperature thresholds in Table 2 are keyed to the number of days that exceed a certain temperature over the entire June-September critical period. This differs from other researchers who utilize moving averages to describe trout temperature tolerances (e.g. Wehrly et. al. 2007). We chose to use total days exceeding a threshold rather than a moving average because we are assessing land cover changes in the watershed and impacts on trout in the stream. Land cover change assessment involves modeling of land cover heat loading and stream flow-temperature behavior during simulated climatic conditions. The introduction of moving averages for temperature would add complexity to the model that the project cannot support. We believe that while our temperature thresholds are not directly comparable to moving average data, the two are highly correlated.

Trout reach classification

We were able to compare 2006 daily mean temperatures of stream reaches with a classification of trout reaches based on the presence of adult trout and young-of-the-year trout. Air temperature in 2006 was above average, with a July mean temperature of 17.6° C compared to a 25-year average of 14.5° C at the Rosemount Agricultural Experiment Station. Precipitation was below average, with a

July total of 6.4 cm compared to a 25-year average of 10.4 cm. In the 25-year period, there were 4 years that exceeded the 2006 July mean air temperature, and 8 years where precipitation was below the 2006 amount. Warmer air temperature and lower precipitation (which influences groundwater flow) likely created warmer water temperatures in 2006 than might be expected in a typical year.

Proposed thermal thresholds for adults and young-of-the-year were checked against measured stream temperatures at sites and adjusted so that criteria generally matched on the ground conditions, although some sites did exceed the thresholds during the warm summer of 2006 (Table 3). The resulting trout-temperature classification characterized three types of reaches (Figure 4).

Natural Reproduction-Coldwater Refuge Reach ("Refuge Reach")
Adult brown trout have been documented in this reach. Numerous individuals or groupings of individual young-of-the-year brown trout have been documented also. The daily mean stream temperature in this reach typically exceeds 20 C fewer than 10 days per year and does not exceed 23 C, the lethal limit for young-of-the-year brown trout.

Adult Trout Reach
Adult brown trout have been documented in this reach, but young-of-the-year trout either have not been documented or are restricted to a few individuals. The daily mean stream temperature of this reach typically exceeds 20 C for more than 10 days per year, and at times exceeds 23 C.

Non-trout Reach
Brown trout have not been documented in this reach on a regular basis. The daily mean stream temperature in this reach typically exceeds 20 C for more than 30 days per year, or the daily mean temperature exceeds 25 C for more than one day per year.

Table 3. Number of days in June-September 2006 where daily mean water temperature exceeded a given temperature at sampling stations on the mainstem and major tributaries of the Vermillion River.

SOUTH BRANCH VERMILLION RIVER					
Temp C	**CH79**	**MN50**	**CH81**	**Klaus**	**SB802**
18	23	52	57	18	33
19	8	36	35	10	18
20	4	16	20	4	9
21	2	11	12	3	4
22	0	6	6	0	2
23	0	3	4	0	0
24	0	2	2	0	0
25	0	0	0	0	0
26	0	0	0	0	0

MAINSTEM VERMILLION RIVER							
	Hamburg	**225th St.**	**Denmark**	**CHP1**	**Biscayne**	**Blaine**	**US52**
18	12	78	34	46	64	86	81
19	5	61	15	26	41	66	59
20	2	41	7	13	21	50	38
21	2	20	5	6	14	26	20

22	0	14	2	4	8	14	9
23	0	7	0	0	4	8	4
24	0	4	0	0	0	4	2
25	0	3	0	0	0	2	0
26	0	0	0	0	0	0	0

	SOUTH CREEK			**NORTH & MIDDLE CREEKS**	
	SC Cedar	**Flagstaff**	**SC 5**	**North & Middle**	**North Creek**
18	2	7	3	57	69
19	2	2	2	34	47
20	2	2	2	18	29
21	2	2	2	9	14
22	1	2	1	4	7
23	1	1	0	1	4
24	0	0	0	0	0
25	0	0	0	0	0
26	0	0	0	0	0
27	0	0	0	0	0

There are four refuge reaches and four trout reaches on the Vermillion River. These reaches together comprise the designated trout stream and also include a portion of the South Branch being considered for designation.

South Branch Refuge Reach. South Branch from its juncture with the Vermillion River upstream to County Road 81.

Farmington Refuge Reach. Mainstem of the Vermillion River from above the Empire Wastewater Treatment Plant east of Biscayne Avenue upstream to the mouth of South Creek.

Flagstaff Refuge Reach. Mainstem reach that begins south of Flagstaff Avenue and ends upstream at Highview Avenue.

South Creek Refuge Reach. South Creek from its mouth at the Vermillion River to upstream to Hamburg Avenue in Lakeville.

South Branch Trout Reach. South Branch above the refuge reach and between County Road 81 and Blaine Avenue.

Empire-Vermillion Trout Reach. Mainstem of the Vermillion River in Empire and Vermillion Townships from the refuge reach at the Empire WWTP downstream to the end of the designated trout stream just east of TH52.

225th Trout Reach. Mainstem from the mouth of South Creek extending upstream to south of Flagstaff Avenue.

Middle-North Creeks Trout Reach. This reach is a small stream segment that begins at the mainstem refuge reach and runs upstream a short distance into Middle and North Creeks. This reach is centered on TH3.

There was no strong association of significant groundwater gaining reaches (>0.1 cfs per 500 feet) defined by EOR (2007) with trout refuge reaches. Rather the significant gaining reaches occurred in both trout refuge reaches and adult-only trout reaches. Refuge reaches either included only a gaining reach (0.001 – 0.1 cfs per 500 feet) or primarily a gaining reach with a small area of significant gaining reach.

Discussion

The purpose of this stream reach classification was to identify locations serving as refuges for trout during adverse temperature periods caused by drought, high daily temperatures, and influxes of warm surface runoff caused by certain storms. One conclusion of the classification is that refuge reaches have great value for trout in the Vermillion River because they are the places where trout most likely will persist should the rest of the river become unsuitable for trout during adverse periods.

At the same time, adult trout reaches lacking young-of-the-year have value as additional territory for adult trout. The adult trout reaches may enable the Vermillion to support a larger population of brown trout than would exist if trout were restricted to refuge reaches, and to increase the likelihood that the trout population will persist despite periods of adverse stream temperature. Persistence of brown trout in the Vermillion may depend on movement of individuals between types of reaches in response to habitat becoming available in those reaches. Individuals inhabiting the adult trout reaches are available to colonize the refuge reaches when individuals living in refuge reaches die, and conversely excess fish produced in the refuge reaches, where young-of-the-year live, can find and occupy space in the adult trout reaches if trout in those reaches die. It is expected that refuge reaches would provide the young fish for recolonization of adult-only trout reaches after adverse temperature periods causes mortality there.

This view of the trout population in the Vermillion River is consistent with a mainland-island model of extinction-colonization dynamics described by island biogeography theory (MacArthur and Wilson 2001). Field observations of in-stream habitat lead us to conclude that the habitat quality of refuge and adult trout reaches varies largely during adverse temperature periods. If this is so, then the dynamics of the trout population in the Vermillion River over many years would be governed by extinction and colonization events. During extremely adverse periods, the adult trout reaches would act as "islands" in which extinction occurs more frequently than in the "mainland" refuge reaches. Following extinction in an adult-trout reach, individuals from refuge reaches would recolonize that adult-only trout reach. Young-of-the-year also would come from refuge reaches. However, due to the effect of current on young-of-the-year, they would more likely colonize downstream reaches than headwater reaches. This suggests that upstream refuge reaches may be more important sources of young-of-the-year for the entire trout stream than downstream refuge reaches. The island-mainland extinction-colonization dynamic was observed in a stream in Oklahoma (Gotelli and Taylor 1999). Metapopulation theory did not satisfactorily explain the distribution pattern of fish species in that Oklahoma stream.

The temperature tolerances of brown trout can vary depending on local stream conditions (Wehrly et al. 2007) and so stream temperature should be considered with other factors when assessing the status of the trout population in the Vermillion River. Variability in and between reaches does not mean that it is acceptable to raise temperatures at locations that already exceed temperature thresholds or lack young-of-the-year. Rather, variability suggests that several factors likely interact and determine the condition of reaches. Important groundwater discharge areas and high quality trout habitat are unevenly distributed in the Vermillion River system. Tree and tall shrub cover is unevenly distributed along channels. Where it is present, woody cover reduces stream warming caused by direct solar radiation and also creates fish habitat. Surface watersheds are different sizes and support different land uses. Rather it is more accurate to treat the Vermillion River as a fine-scale mosaic of reaches of varying suitability for trout, but which in total are capable of supporting a trout population.

Within the fine-scale mosaic of varying suitability, groundwater discharge areas likely serve as refuges where trout avoid higher stream temperatures elsewhere (Ebersole et al. 2001). The lack of correspondence between significantly gaining groundwater reaches (where young-of-the year would be expected) and refuge reaches raises two possibilities. Either the EOR groundwater reach classification is not fine scale enough to represent the important groundwater discharge locations in the Vermillion River, or trout are responding to additional factors unrelated to temperature, such as habitat quality. Fine-scale mapping of groundwater discharge areas may reveal localized areas of higher discharge than previously reported in adult trout reaches, providing mini-refuges for small numbers of young-of-the-year (Olsen 2007). Indeed, young-of-the-year occasionally are seen in adult trout reaches. Conversely, within a refuge or adult trout reach there are likely to be areas that receive little if any groundwater discharge (Olsen 2007) or experience greater warming due to poor riparian shading. As a result, some sites (e.g., Blaine Avenue) exceed the criteria for stream temperature despite being located in an adult trout reach.

The genetic heterozygosity of the founding population of brown trout established in the early 1990s can affect the amount of adaptation by the trout population to stream temperature over time. A brown trout strain with a diverse genotype could potentially adapt to rising stream temperatures because some individuals in the population have the capacity to live and reproduce at the elevated temperature without experiencing stress (Lobon-Cervia and Rincon 1998). Trout that experience physiological stress at the higher temperatures are less capable of reproducing. Consequently, over time the offspring of the adapted trout would make up an increasing proportion of the stream's trout population, if stream temperatures remain elevated.

The temperature ranges associated with different effects on brown trout should not be taken as an absolute measure of brown trout response. Rather the temperature ranges are intended to be used as indicators of the likely response of brown trout and are useful for dividing the Vermillion River into different management reaches. For example, although 25 C is a proposed lethal limit for adult brown trout, in fact trout have been observed in stream reaches where water temperature exceeded the 25 C threshold at some monitoring stations during the hot, dry summer of 2006. However, other stations in that reach did not exceed the threshold. The presence of trout throughout the reach strongly suggests that a lethal temperature at a monitoring station within a larger reach does not eliminate that area around the monitoring station as a trout reach.

One conspicuous disagreement between stream temperatures, thermal thresholds, and the observed trout population was in the lower portion of the Farmington Refuge Reach at sites CHP1 and Biscayne. These sites have consistently had significant numbers of young-of-the-year trout present during fish sampling, and yet they exceeded the recommended number of days over 18 C by 16 and 34 days, respectively. These data suggest that a small number of days with temperatures in excess of 20 degrees are more significant to young-of-year-survival than a large number of 18-20 C days. This is consistent with Wehrly et al.'s findings that 7-day and longer exposures to temperatures over 20 C (22-23 C specifically) have a significant effect on trout. However, the higher temperatures at CHP1 and Biscayne may nevertheless result in poor growth that leads to higher over-winter mortality.

We suggest that stream temperature monitoring continue in the Vermillion for three additional years, with the entire period of record thus being 2005-2010. In 2010 it would be appropriate to refine the days of exposure in Table 1. The longer period of measurement also will enable the development of a probability measure of the chance that 25 C or other threshold temperature will occur at a monitoring station in any given year. The year 2006 was extreme in the historical climate record and therefore lethal days in 2006 have a lower probability of occurring in the future. In other words, the criteria presented in this paper represent a first approximation of temperature effects in the Vermillion River, to be modified as new data are obtained.

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List of Figures

Figure 1. Vermillion River designated trout stream.
Figure 2. Locations of paired surface water and groundwater thermal sampling stations.
Figure 3. Continuous plot of temperature versus data at three surface water sampling stations on the South Creek of the Vermillion River.
Figure 4. Trout-temperature stream reach classification of the Vermillion River.
Figure 5. Groundwater reach classification of the Vermillion River.

Figure 1. Vermillion River designated trout stream. (Prepared by Dakota County GIS Department.

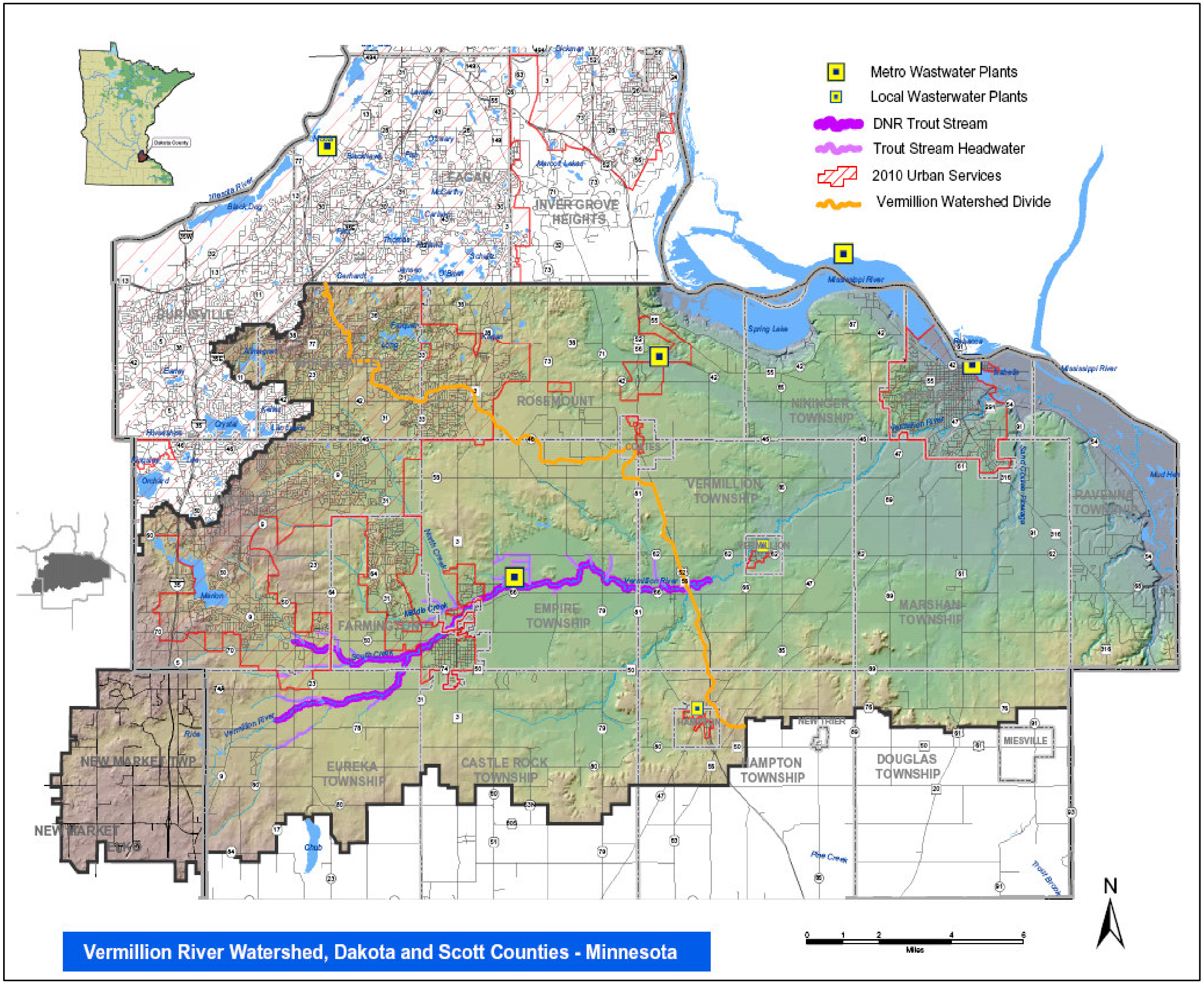

Figure 2. Locations of paired surface water and groundwater thermal sampling stations.

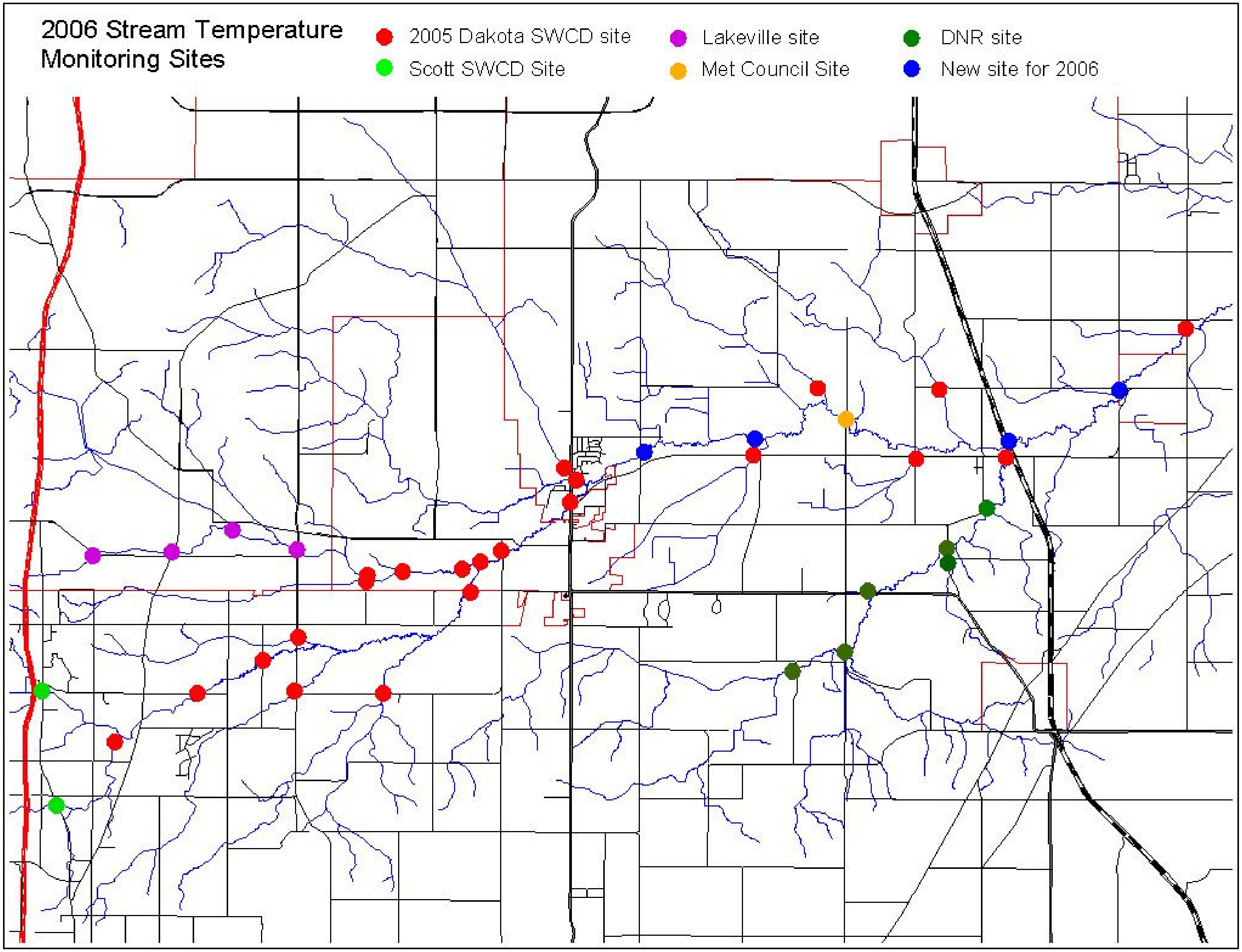

Figure 3. Continuous plot of temperature versus data at three surface water sampling stations on the South Creek of the Vermillion River.

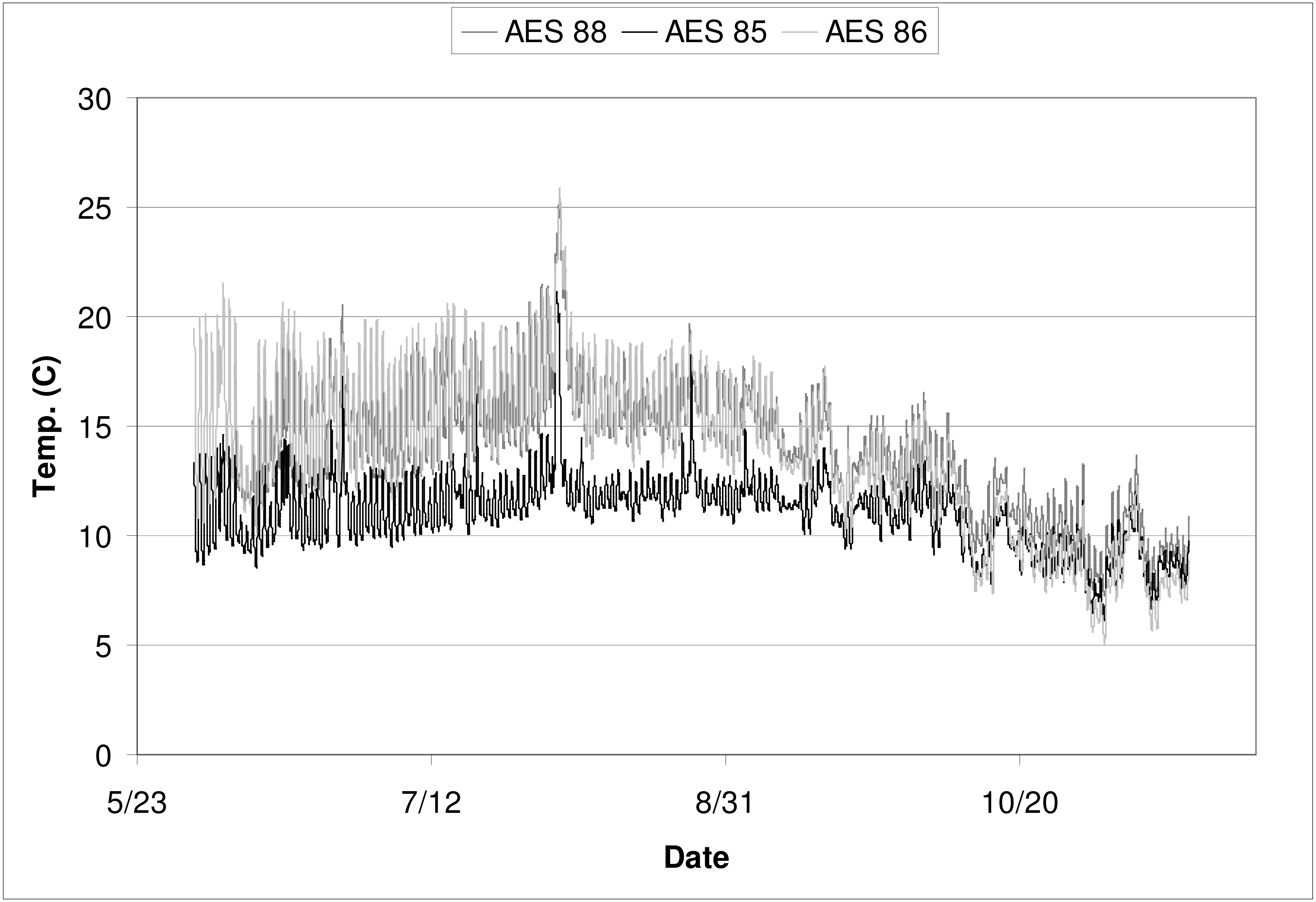

Figure 4. Trout-temperature stream reach classification in the Vermillion River.

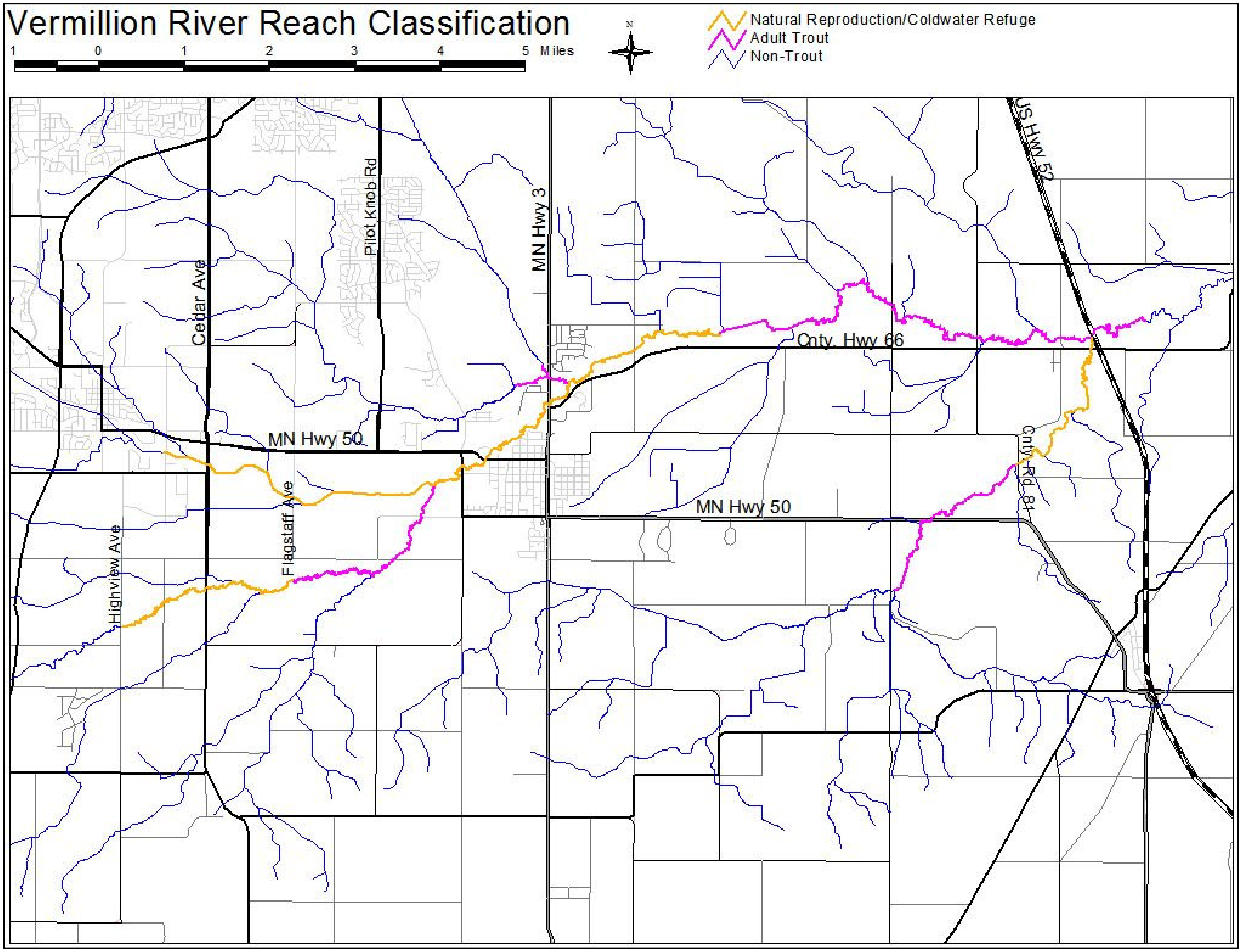

Figure 5. Groundwater reach classification of the Vermillion River and tributaries. (Prepared by Emmons and Olivier Resources.)