Deer Creek Watershed

Total Maximum Daily Load Report: Turbidity Impairments

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Deer Creek Watershed Total Maximum Daily Load Report: Turbidity Impairments

Prepared for
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List of Acronyms/Abbreviations

AUID	assessment unit identification number
BMP(s)	best management practice(s)
CSAH	County State Aide Highway
EPA	U.S. Environmental Protection Agency
FMGs	Forest Management Guidelines
FNU	formazin nephelometric units
LA	load allocation
mg/L	milligrams per liter
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Dataset
NRBP	Nemadji River Basin Project
NPDES	National Pollutant Discharge Elimination System
NTU	nephelometric turbidity units
TMDL	total maximum daily load
TSS	total suspended solids
USGS	United States Geological Survey
WLA	wasteload allocation

TMDL SUMMARY

EPA/MPCA Required Elements	Summary	TMDL Page #
Location	- Deer Creek watershed - Nemadji River Basin - Carlton County, Minnesota	5
303(d) Listing Information	- Listed Reach: Deer Creek (Headwaters to Nemadji River) - Assessment Unit ID (AUID): 04010301-531 - Impaired Affected Use: Aquatic Life - Impairment: Turbidity - Year Listed: 2004	2
Applicable Water Quality Standards/ Numeric Targets	The turbidity standard for Class 2A waters is 10 NTU. This is Equivalent to 4 mg/L TSS based on NTU to TSS relationship developed for the water body.	2
Loading Capacity (expressed as daily load)	The loading capacity (lbs/day) is defined based on five flow zones: High Flows: 429; Moist Conditions: 73; Mid-Range Flows: 40; Dry Conditions: 40; Low Flows: 27 *See Table 3.1*	15
Wasteload Allocation	Wasteload allocations are only applied to construction and industrial stormwater sites representing 0.1% of the total daily loading capacity. *See Table 3.1*	15
Load Allocation	Load Allocation represents 89.9% of the total daily loading capacity for each flow zone. *See Table 3.1*	15
Margin of Safety	Explicit MOS of 10% of the total daily loading capacity is used; *See Table 3.1*	15
Seasonal Variation	Load duration curve methodology accounts for seasonal variation; *see Section 3.6*	21
Reasonable Assurance	The continued monitoring of the stream to track progress and the future development of a detailed implementation plan with specific action items provides reasonable assurance towards the implementation of this TMDL. *See Section 6.0.*	29
Monitoring	A general overview of follow-up monitoring is provided in this report including recommendation to continue existing monitoring (*See Section 4.0)*.	24

Loading capacity by flow zone (lbs/day):

High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
429	73	40	40	27

TMDL SUMMARY

EPA/MPCA Required Elements	Summary	TMDL Page #
Implementation	A discussion of factors to consider for implementation is provided (*See Section 5.0)*. A separate more detailed implementation plan will be developed at a later date. Implementation activities include: - Limiting livestock access to riparian areas - Promoting silviculture BMPs - Assessment, prioritization and remediation of mass wasting and erosion sites within the watershed - Assess and repair failing dam structures - Evaluate sediment volcanoes impact and possible BMP actions	26
Public Participation	*See Section 7.0.* Meetings, websites and newsletters have been used to enhance public participation. A public meeting was held April 17, 2013 for TMDL review.	30

The Clean Water Act, Section 303(d), requires that every two years states publish a list of waters that do not meet water quality standards and do not support their designated uses. These waters are then considered to be "impaired". Once a waterbody is placed on the impaired waters list, a Total Maximum Daily Load (TMDL) must be developed. The TMDL provides a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards. It is the sum of the individual wasteload allocations (WLAs) for point or permitted sources, load allocations (LAs) for nonpoint or nonpermitted sources and natural background, plus a margin of safety (MOS). In 2004 Deer Creek was listed by the Minnesota Pollution Control Agency (MPCA) as an impaired stream for turbidity (a measure of cloudiness of water that affects aquatic life). Deer Creek has been identified as a significant sediment loading tributary within the Nemadji River basin and ultimately to Lake Superior (NRCS, 1996).

Deer Creek is a small perennial tributary to the Nemadji River located entirely in Carlton County, Minnesota with a drainage area of 5,063 acres. A majority of the watershed (> 90%) is privately owned with the remainder in a state owned wildlife management area. Most of the watershed is undeveloped with 52.9% of the watershed classified as forested, 22.3% as wetlands, 13.4% as agricultural, 10.0% as grassland or scrubland and only 1.1% of the watershed as low intensity development.

A sampling station located directly downstream of Highway 23 and 0.84 miles upstream from the North Fork of the Nemadji River was used for the TMDL analysis. At the Hwy 23 sampling location a total suspended solids (TSS) concentration of 4 mg/L corresponds to the 10 NTU turbidity standard. Continuous flow measurements were combined with periodic sampling throughout the ice free months between 2008 and 2010. Median TSS concentrations for the three year period were recorded as 78.5 mg/L for high flow events (0-10% flow duration), 31.0 mg/L for moist conditions (10-40% flow duration), 9.0 mg/L for mid-range flows (40-60% flow duration), 20.0 mg/L for dry conditions (60-90% flow durations) and 23.5 mg/L for low flows (90-100% flow durations). The 4 mg/L TSS concentration has been applied to determine TMDL loading capacities, since it is the most conservative surrogate concentration for the turbidity standard and the Hwy 23 sampling station is most representative of the overall watershed.

The five flow rate categories were used to calculate the total suspended solid loading capacities and allocations for Deer Creek (Table EX.1), based on the mid-point flow rate for each of the flow zones and the 4 mg/L TSS concentration that corresponds to the 10 NTU standard. To meet the TMDL, total daily loads at the Highway 23 station would have to be equal to or lower than 429 lbs/day for high flows, 73 lbs/day for moist conditions, 40 lbs/day for mid-range flows, 40 lbs/day for dry conditions, and 27 lbs/day for low flows.

Duration curves are a helpful visual tool to envision where the current data is plotting relative to the target limit (4 mg/L) and how that relates to streamflow. The duration curve plots each flow observation based on its percentile rank. A flow duration interval of 10% represents a value where only 10% of the flow rates are higher represented on the graphic as "high flows". A 90% interval represents a low flow rate where 90% of measurements are higher, represented on the graphic as "low flows".

A load duration curve was created for three years of combined data (2008-2010) at the Lower Deer Creek station located near Hwy 23 (Figure EX.1), which shows that all recorded measurements were above the turbidity standard and the higher loads in the moist and high flow zones are the result of both increased flows and elevated TSS concentrations.

Table EX.1 Total suspended solids loading capacities and allocations (AUID: 04010301-531)

	Flow Zone				
	High	Moist	Mid	Dry	Low
	lbs/day				
TOTAL DAILY LOADING CAPACITY	429	73	40	40	27
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0	0	0	0	0
Communities Subject to MS4 NPDES Requirements	0	0	0	0	0
Construction and Industrial Stormwater	0.43	0.07	0.04	0.04	0.03
Load Allocation	385.8	65.8	35.8	35.8	24.4
Margin of Safety	42.9	7.3	4.0	4.0	2.7

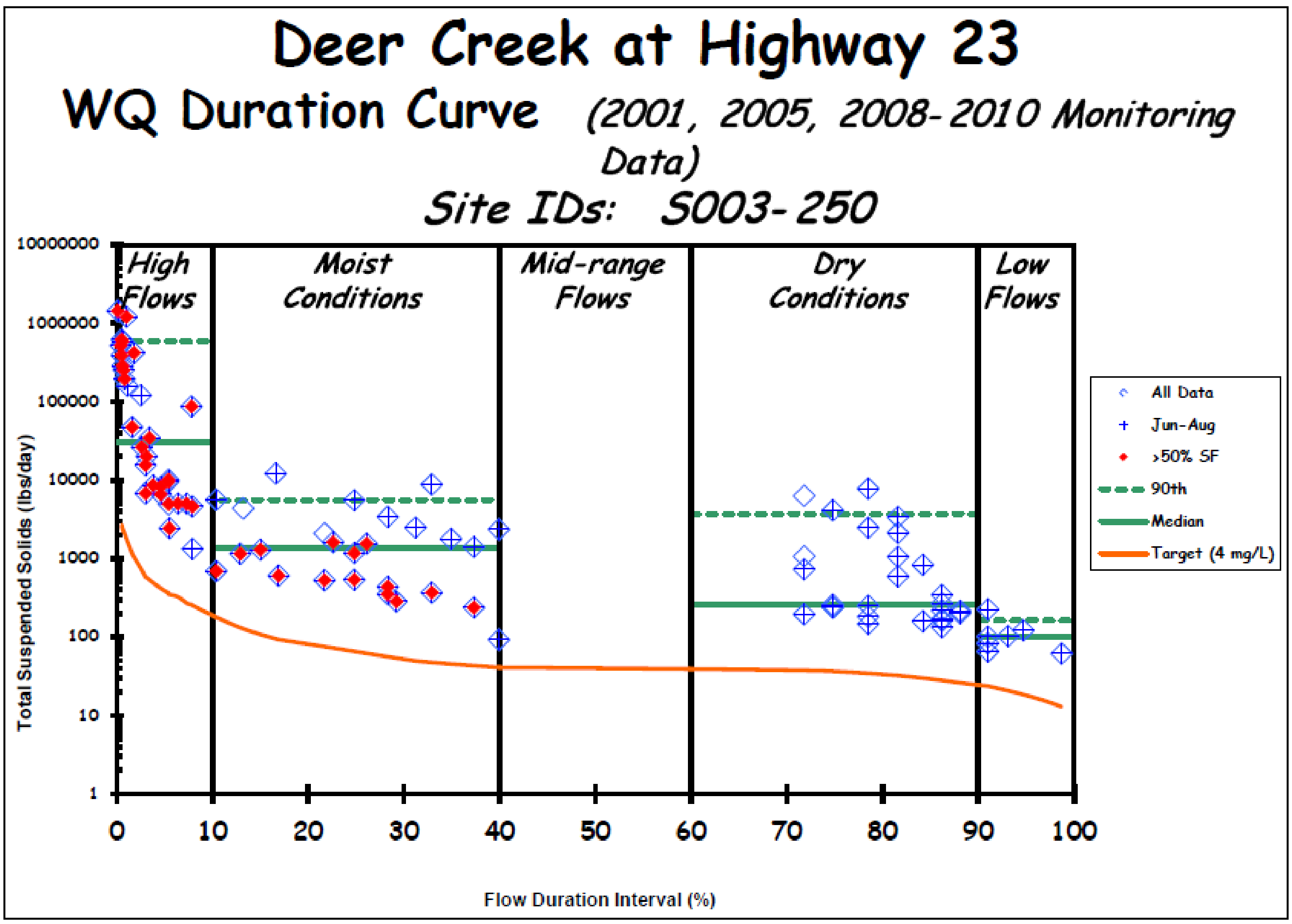


Figure EX.1 TSS load duration curve for Lower Deer Creek (2008-2010)

Major sources of turbidity in Deer Creek include nickpoint migration of stream channels and streambank slumping induced by adjustments in hydrology caused by past watershed wide land use changes and possibly climate change; destabilization of stream banks from livestock grazing in riparian zones; and the presence of sediment volcanoes in the middle of the Deer Creek main stem providing a steady influx of sediment from groundwater discharge points. Silviculture activities are also expected to contribute to some of the watershed land cover changes that affect hydrology and sediment loading in the Deer Creek watershed.

1.0 Introduction

A Total Maximum Daily Load (TMDL) is a calculation resulting in the maximum amount of a single pollutant that a waterbody can receive from all contributing point and nonpoint sources and still meet state water quality standards and/or designated uses. The term "TMDL" represents the reporting format required by the EPA as defined by, "A written plan and analysis of an impaired waterbody established to ensure that the water quality standards will be attained and maintained throughout the waterbody in the event of reasonably foreseeable increases in pollutant loads" (EPA definition of TMDL from Clean Water Act). TMDLs are approved by the U.S. Environmental Protection Agency (EPA) based on the following elements:

1. They are designed to implement applicable water quality criteria;
2. Include a total allowable load as well as individual waste load allocations and load allocations;
3. Consider the impacts of background pollutant contributions;
4. Consider critical environmental conditions;
5. Consider seasonal environmental variations;
6. Include a margin of safety;
7. Provide opportunity for public participation; and
8. Have a reasonable assurance that the TMDL can be met.

In general, the TMDL is developed according to the following relationship:

$$\mathbf{TMDL} = \sum \mathbf{WLA} + \sum \mathbf{LA} + \mathbf{MOS} + \mathbf{RC}$$

Where:

∑WLA = sum of all wasteload allocations; portion of the TMDL allocated to existing or future point sources of the relevant pollutant;

∑LA = sum of all load allocation; portion of the TMDL allocated to existing or future nonpoint sources of the relevant pollutant. The load allocation may also encompass "natural background" contributions;

MOS = margin of safety; an accounting of uncertainty about the relationship between pollutant loads and the quality of the receiving water body. The margin of safety can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity (USEPA, 1999); and

RC = reserve capacity, an allocation for future growth which accounts for reasonably foreseeable increases in pollutant loads. This is an MPCA-required element, if applicable, for TMDLs.

This report details the TMDL analysis conducted for Deer Creek. The background information relevant to the turbidity impairment is provided in Section 2.0, followed by the TMDL technical elements provided in Section 3.0. Monitoring, implementation, reasonable assurance and public participation are addressed together in Sections 4.0, 5.0, 6.0 and 7.0.

2.0 Background Information

2.1 Turbidity Water Quality Standard

Section 303(d) of the Clean Water Act provides authority for completing TMDLs to achieve state water quality standards and/or designated uses. In 2004, Deer Creek was placed on the 303(d) list of impaired waters for elevated turbidity levels (Table 2.1).

Table 2.1 Deer Creek watershed 303(d) impairments addressed in this report

Reach	Description	Year listed	Assessment Unit ID	Affected Use	Pollutant or Stressor
Deer Creek	Headwaters to Nemadji River	2004	04010301-531	Aquatic life	Turbidity

Turbidity in water is caused by suspended sediment, organic material, dissolved salts, and stains that scatter light in the water column making the water appear cloudy. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking or food processing uses, and can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected, and spawning beds may be covered. In addition, greater thermal impacts may result from increased sediment deposition in the stream.

Turbidity standards in the state of Minnesota are defined based on an assigned water class. All waters of Minnesota are allocated classes based on their suitability for the following beneficial uses:

1. Domestic consumption
2. Aquatic life and recreation
3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resource value

Deer Creek is listed in the Minn. Rules Ch. 7050.0470 classification as a 1B, 2A, 3B water body. A turbidity standard is associated with each of the three classifications. Assessments of water quality are usually based on Class 2 beneficial uses (aquatic life and recreation) given that other uses will largely be protected if Class 2 standards are met. Class 2A waters are defined as:

> **Class 2A waters**. The quality of Class 2A surface waters shall be such as to permit the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface waters is also protected as a source of drinking water.

The turbidity standard for Class 2A waters is defined as:

> **Minn. Rules Ch. 7050.0222, turbidity water quality standard for Class 2A waters** is 10 nephelometric turbidity units (NTUs). The designated use that this standard protects is

aquatic life. Impairment assessment procedures for turbidity are provided in the guidance manual for determination of impairment (MPCA, 2007a). Essentially, impairment listings occur when greater than ten percent of data points collected within the previous ten-year period exceed the 10 NTU standard (or equivalent values for total suspended solids or transparency tube data).

2.2 General Watershed Characteristic

Deer Creek is a small perennial tributary to the Nemadji River located entirely in Carlton County Minnesota with a drainage area of 5,063 acres (Figure 2.1). A majority of the land, (> 90%) is privately owned land with the remainder in a state owned wildlife management area. No tribal lands are located in the watershed. Deer Creek has been identified as a significant sediment loading tributary within the Nemadji River basin and ultimately to Lake Superior (NRCS, 1996).

Sediment carried into the Nemadji River from its tributaries is carried downstream to Superior Harbor and eventually out into Lake Superior. From previous studies, the average annual sediment load of the Nemadji River is well over 100,000 tons. Of that, 14 percent of all the silt and clay is trapped in Superior Bay. About 74 percent is carried out into Lake Superior (NRCS, 1998b). It has been estimated that 89 percent of the fines (silt- and clay- sized particles) eroded come from stream bank and bluff erosion along tributary streams. The remaining 11 percent of fines originated from watershed sources like roadside erosion and sheet and rill erosion. The majority (about 92 percent) of all stream bank and bluff erosion occurs in the red-clay portion of the basin which included Deer Creek (NRCS, 1998b).

From various investigations to date, the high sediment yield of the Nemadji River Basin appears to be a result of changes in the hydrologic system and, possibly, climate change. Hydrologic changes caused by human activities have resulted in increased volumes and rates of runoff and stream-flow. These changes have resulted in higher stream-flow regimes that, in turn, have increased stream bank and bluff erosion and slumping. The major human activities that have had a significant impact on the hydrology of the basin are the early logging practices dating back to the mid 1800's.

In the Mid 1800s, the Nemadji Basin was dominated by vast stands of White Pine and Red Pine. Following logging, deciduous forests dominated by quaking aspen replaced the pine forests, a change that would be expected to increase water yield (Koch et al., 1977). In the early 1900s forested areas were replaced by agricultural lands peaking in the 1950s after which some agricultural lands were converted to deciduous forest. Currently the three main land uses in the Deer Creek watershed are deciduous forest, woody wetlands and pasture/hay (Table 2.2) representing 74% of the total area according to land use data from the United States Geological Survey (USGS) 2006 National Land Cover Database (2006NLCD; Fry et al., 2011). Overall 52.9% of the watershed is forested, 22.3% is covered in wetlands, 13.4% is agricultural, 10.0% is grassland or scrubland and only 1.1% of the watershed has low intensity development.

The evolution of rivers and streams in the Nemadji Basin creates a certain amount of natural erosion and sedimentation. Additionally, confined aquifer discharge through the lacustrine sediments along the streams adds suspended sediment to the system. This has been documented in the Deer Creek and Mud Creek subwatersheds.

Monitoring conducted by Nemadji River Basin Project (NRBP) staff in 2004 showed that total suspended solids in Nemadji streams typically have total suspended solids (TSS) concentration less than 40 mg/L, whereas Deer Creek was above 600 mg/L, a fifteen-fold difference (CCSWCD, 2005).

Table 2.2 2006 NLCD land use classification found in the Deer Creek watershed

Land Use	Percent of watershed
Deciduous Forest	41.6%
Woody Wetlands	20.6%
Pasture/Hay	11.4%
Evergreen Forest	9.2%
Shrub/Scrub	7.1%
Mixed Forest	2.1%
Cultivated Crops	2.0%
Grassland/Herbaceous	1.7%
Emergent Herbaceous Wetlands	1.7%
Developed, Open Space	1.2%
Developed, Low Intensity	1.1%
Open Water	0.3%

The root cause of turbidity in the upper Nemadji River is driven by erosion of inorganic cohesive-sediment banks consisting of lacustrine clays and mixed clay till (clay-silt-very fine sands). Soils mass movement, bluff and streambank erosion contribute the largest load of sediment to the Nemadji River and Lake Superior harbor (Andrews et al., 1980; Banks and Brooks, 1996).

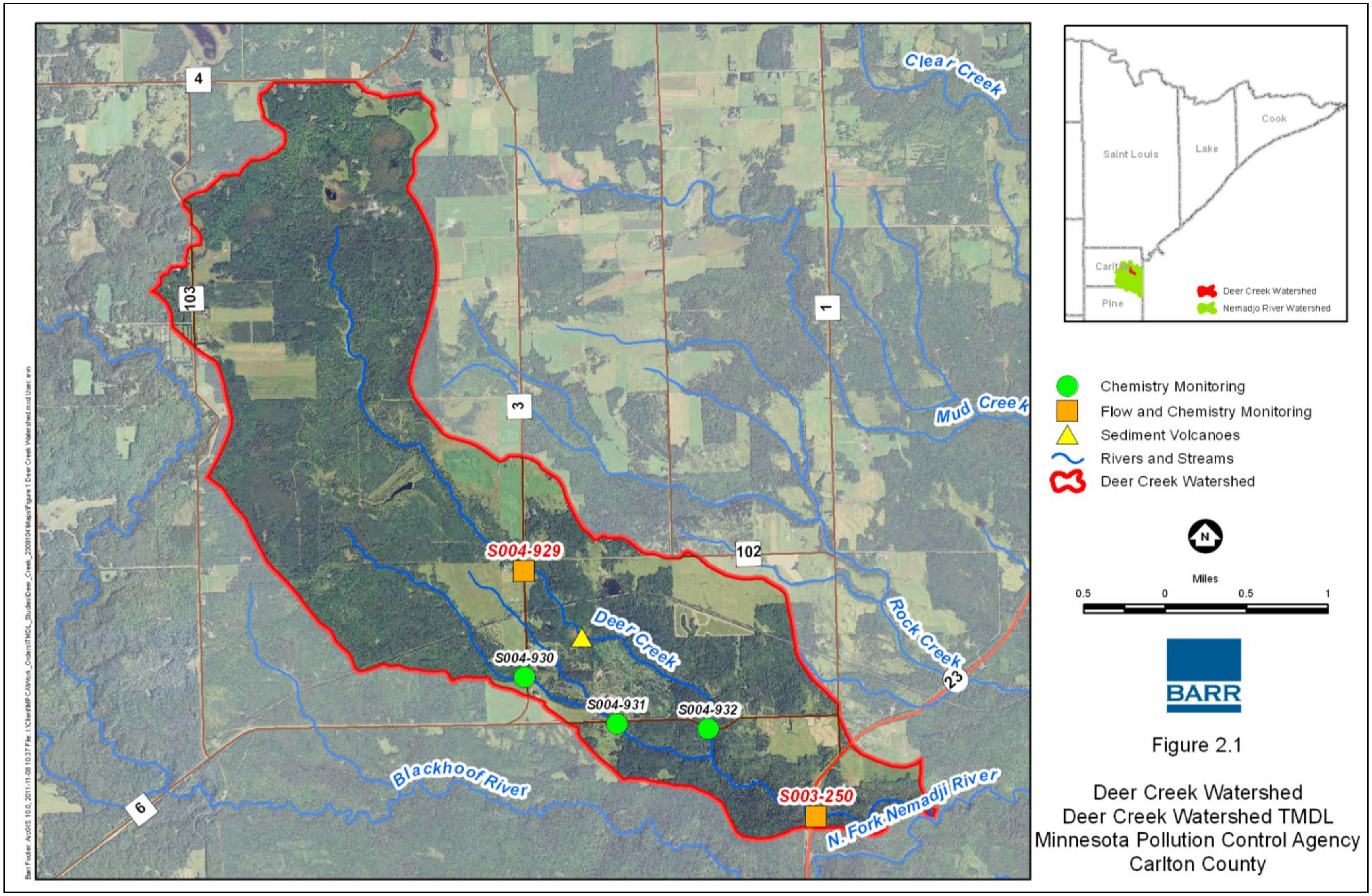


Figure 2.1 Deer Creek Watershed and Sampling Locations

3.0 Turbidity TMDL Discussion and Components

3.1 Turbidity Sources

Conclusions regarding turbidity sources and current loading are based largely on previous research conducted on both Deer Creek and also the entire Nemadji River watershed. Some of the research conducted will be highlighted in this section. For a complete list of references pertaining to turbidity sources please see Appendix A for an annotated bibliography. This analysis will focus primarily on the suspended sediment and organic material components to TSS, as they are the primary sources of turbidity in this watershed. A simplified turbidity conceptual model is presented in Figure 3.1 that shows several possible candidate sources in the Deer Creek watershed. This figure illustrates both "external" and "internal" sources. Most nonpoint sources are typically considered external in that they are located in the watershed outside of the stream or river channel yet contribute TSS. Internal sources of TSS typically encompass processes that occur within the channel (including the bed, banks and bluffs) or the floodplain of a waterway or stream. Such processes include channel and floodplain erosion or scour, bank slumping, and the presence of sediment volcanoes. The components of this conceptual model, as they pertain to this watershed, are evaluated below in a general way. The relative amounts of sediment loading from each of the primary sources will be evaluated in more detail as a part of future watershed modeling developed for the implementation planning phase of the TMDL project.

Livestock in Riparian Zone

Livestock grazing in riparian areas can contribute to excess turbidity via soil runoff directly from devegetated areas, resuspending of sediments by walking in the stream, and by destabilizing the banks leading to increased bank erosion or slumping. Based on 2006 land use data, pasture or hay covered areas encompass 11.4% of the Deer Creek watershed (Table 2.1). A recent study concluded that grazing in the riparian areas of Deer Creek significantly reduced stream bank stability (Riedel et al., 2006). Stream bank materials in the analyzed sections of Deer Creek were generally stable. Instabilities were found in areas with reduced riparian vegetation and subsequent bank erosion caused by cattle traffic. The introduction of hoof shear from cattle traffic resulted in the largest decrease in stream bank stability even when compared to the loss of riparian vegetation (Riedel et al., 2006). No confined animal feeding operations (CAFOs) that would require a permit are located in the watershed.

Watershed wide land use changes

The Nemadji River basin as a whole has seen significant land use changes over the past two centuries including timber harvesting in the 1800s, forest fires and the conversion of wooded coniferous forest land to hay and pasture during the early 1900s. Land use changes between 2008 and 2010 in an area of Deer Creek indicate that silviculture activities occur in the area, and depending on BMP implementation, would be expected to change surface runoff and the resulting sediment contributions to the streams during a period of time.

Broad land use changes have altered stream flows causing the channel base elevations to down cut which in turn induced an array of knickpoint migrations throughout the basin resulting in mass wasting and associated channel incision (Riedel et al., 2005; Magner, 2004). A full assessment of the influence of incision in terms of turbidity is difficult. There is no specific monitoring data that provides a breakdown of contributions for upland erosion versus these near-channel sources. Headwater ditches are shorter than the natural channel and, thus, steeper in gradient. As such they generally exhibit higher velocities and higher peak flows. Also, their geometry is such that there is limited access to the floodplain. Therefore, the energy is confined to the channel. The net result is increased potential for bank erosion. The land use changes have resulted in estimated increased sedimentation rates into Lake Superior from 0.89 mm/year during pre-historic post glacial period to 2.00 mm/year from 1890 to 1955 (Kemp et al., 1978).

Sediment Volcanoes

The sediment volcanoes in Deer Creek occur at the toe of 10 meter high slumps. Groundwater flow discharged at the surface expression of the slump faults transport coarse sediments which are deposited near the discharge point, forming a volcano-shape structure, and finer sediment into suspension causing excess turbidity in the creek (Mooers and Wattrus, 2005). Approximately 10 volcanoes have been observed between 2006 and 2008 discharging approximately 100 gallons per minute of groundwater to the creek (Mooers and Wattrus, 2005). It is hypothesized that the sediment volcanoes formed in the Deer Creek watershed in the early 1990s after the formation of a large beaver dam which ponded water up to 3 meters. The beaver dam was built and washed out a number of times between the early 1990's to 2001 when it was removed by the Minnesota Department of Natural Resources. The elevated pore water pressure could have increased the shear stress and/or decreased the shear strength along the lower boundary of the clay. In a positive feedback process the dewatering of the aquifer caused subsidence which leads to more slumping and more sediment being transported through the volcano. The pond drainage could have also led to fracturing of a glacio-lacustrine clay confining layer over a locally extensive aquifer (Mossberger 2010).

Failing "Red Clay Dam" Structures

The Red Clay Project was a 1970's era project that encompassed watersheds in Northeast Minnesota and Northern Wisconsin draining to Lake Superior. In Minnesota, efforts focused on sediment retention structures in two subwatersheds of the Nemadji River Basin in Carlton County. Four structures were constructed in the Deer Creek Watershed. The design life of these structures was 10-25 years depending on the specific project and the design life has now been exceeded. Three of the four structure sites in the Deer Creek watershed were assessed by a multi-agency team which found failed metal pipes and, in one case, a breached structure. Soil loss from this breached structure site is approximately 8775 tons, and will continue to increase as the channel seeks to stabilize itself. Potential soil loss from 2 other sites where the metal pipes are rusted out is 3,900 tons.

Cultivated Cropland

Cultivated cropland can contribute to excess turbidity via sheet/rill erosion of soil; destabilization of banks (if inadequate buffers) leading to increased bank erosion; and also drainage alterations on cropped land leading to increased flows causing bank/bed erosion. Based on the land use data from 2006, areas covered with cultivated crops represent only 2% of the watershed (Table 2.2). While land use coverage indicates the presence of cultivated croplands the dominant agricultural classification is pasture/hay management representing 11.4% of the watershed resulting in minimal turbidity contributions from row cropland.

Roadways/Culvert Crossings

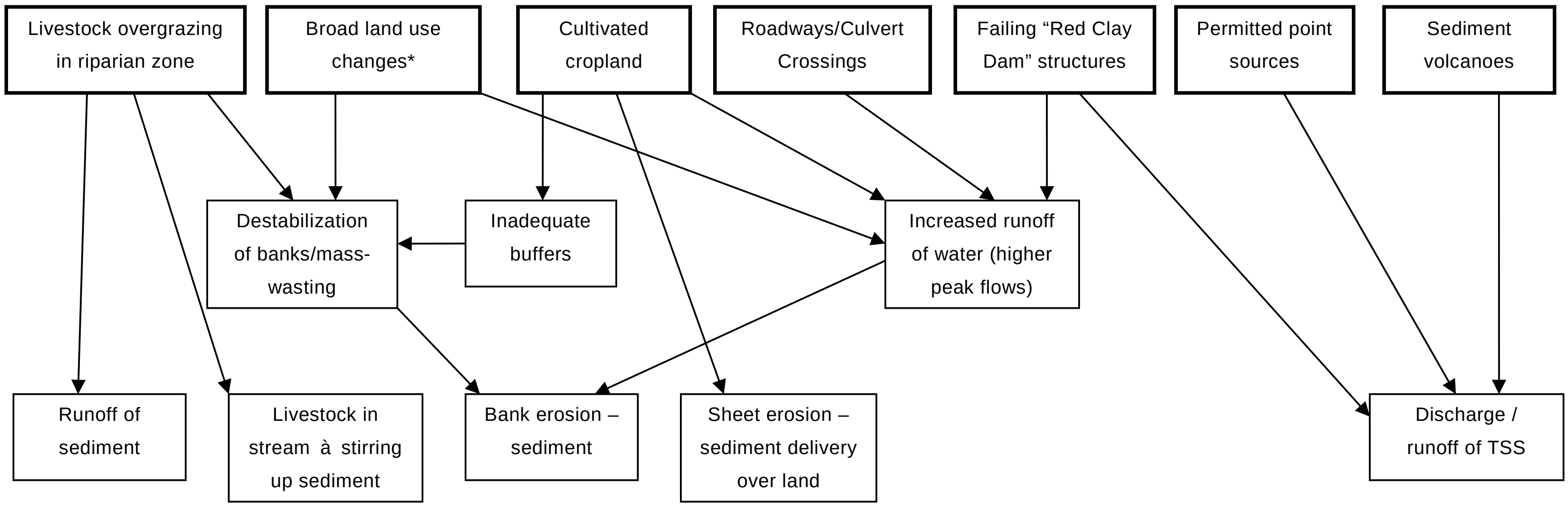
Using the 30 m NLCD impervious surface dataset a total impervious area of 7.25 acres was calculated representing only 0.1% of the total Deer Creek watershed. Impervious surfaces are mostly identified as the county and state roads that cross within the watershed boundaries. Roadways can contribute to excess turbidity directly via sediment delivery and indirectly via adaptations in watershed boundaries leading to changes in runoff volumes that could cause increased bank/bed erosion. Culvert crossings can increase erosion through slope changes and increased water velocities.

Permitted Point Sources

Point sources, for the purpose of this TMDL, are those facilities/entities that discharge or potentially discharge solids to surface water or otherwise contribute to excess turbidity and require a National Pollutant Discharge Elimination System (NPDES) permit from the MPCA. Typical point source categories are: wastewater treatment facilities, construction activities, municipal and industrial stormwater sources.

The only point sources that may apply to this watershed are construction and industrial stormwater sources. No industrial or wastewater treatment plants discharge into Deer Creek and no municipalities are subject to Municipal Separate Storm Sewer Systems (MS4) permit requirements.

Regarding construction, the MPCA issues construction permits for any construction activities disturbing: one acre or more of soil; less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre; or less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. Although stormwater runoff at construction sites that do not have adequate runoff controls can be significant on a per acre basis (MPCA Stormwater web page, 2006), the source appears to be a minor turbidity source in the Deer Creek watershed. Industrial stormwater sources are not currently present in the watershed but, for the purpose of the TMDL, are treated similarly to construction sources.



* Broad land use changes can also cause sediment delivery via:

- bank erosion/mass-wasting or slumping as meandering watercourses attempt to attain new equilibrium
- incision and higher stream power can cause headward erosion and downcutting (nickpoints may form; channel erodes nickpoint resulting in upstream scour)

Figure 3.1 Simplified turbidity conceptual model of candidate sources and potential pathways

3.2 Flow and Chemistry Measurements

3.2.1 Data Collection

Turbidity is a parameter that has a significant amount of variability associated with the measurement values reported. Unlike many water quality parameters which are a measurement of mass of constituents in a volume of water, turbidity is a measure of the optical properties of a water sample which causes light to be scattered and absorbed (Federal Water Pollution Control Administration, 1968). Differences in the constituents' response to light contribute to the variability in turbidity readings.

The Carlton County SWCD staff collected water quality information at five sites within the Deer Creek watershed with continuous flow measurements recorded at two of those five sites (Figure 2.1). Chemistry data including turbidity, pH, DO, temperature and specific conductance were collected using an YSI brand handheld sonde multiparameter probe at all five locations. Grab samples were also collected for TSS and turbidity lab measurements at the time of sonde field readings at the two flow gage stations. Continuous flow measurements were made using a hydraulic pressure transducer recording continuous stream stage data.

The five sites shown in Figure 2.1 include:

- **Lower Deer Creek** at State Highway 23 (S003-250) – Located 1 mile upstream from the confluence with the Nemadji River and downstream of the sediment volcanoes. A USGS streamflow station was operational near this location until 2001. In 2005 a continuous stream stage recorder was installed and chemistry data was collected starting in 2008.
- **Upper Deer Creek** at CSAH 3 (S004-929) – Located upstream of the sediment volcanoes. A continuous stream stage recorder was installed and chemistry data collection began in 2008.
- **Tributary at CSAH 3** (S004-930) – The first of two sampling locations located on an unnamed tributary to Deer Creek. Chemistry data collection began in 2008.
- **Tributary at CSAH 6** (S004-931) – The second sampling location on the unnamed tributary. Chemistry data collection began in 2008.
- **Deer Creek at CSAH 6** (S004-932). – Lies midway between the upper and lower Deer Creek sites and also downstream from the sediment volcanoes. Chemistry monitoring began at this site in 2008.

3.2.2 Turbidity to TSS conversion

In order to evaluate and establish the TMDL loading, a surrogate measure of TSS is used (MPCA, 2007b). This parameter shows a good correlation with turbidity, based on regressions done on the monitoring data. Lab turbidity and TSS measurements were recorded from grab samples at the Upper and Lower Deer Creek sites. The measurements were used to develop a NTU to TSS relationship. At the Lower Hwy 23 site, grab sample data were available for years 2004 to 2010. At the upstream Hwy 3 site, grab samples were available for years 2008 to 2010. A log-log relationship was developed for both the Hwy 3 (Figure 3.2) and Hwy 23 (Figure 3.3) sites. Statistical research has shown that a bias is introduced when the retransformation is computed to get TSS from the log-log relationship. Therefore the Duan's Smearing Estimator (Duan, 1983) was calculated for both locations. The smearing factor for the Hwy 3 and Hwy 23 locations were calculated as 1.026 and 1.036 respectively. The final equations used to convert turbidity (NTU) to a TSS concentration (mg/L) are detailed in Equation 3.1 for the Hwy 3 site and Equation 3.2 for the Hwy 23 site.

$$TSS\left(\frac{mg}{l}\right)=10^{1.3445*\log(NTU)-0.6343}*1.026 \qquad \text{Eq 3.1}$$

$$TSS\left(\frac{mg}{l}\right)=10^{1.1972*\log(NTU)-0.6597}*1.036 \qquad \text{Eq 3.2}$$

The NTU to TSS relationship was used to convert the 10 NTU standard to a TSS measurement for the water quality duration curves. For the Hwy 3 sampling location the 10 NTU standard is converted to a TSS concentration of 5 mg/L. At the Hwy 23 sampling location a concentration of 4 mg/L TSS represents the 10 NTU standard. The 4 mg/L standard will be applied to determine TMDL loading capacities since it is the most conservative surrogate concentration for the turbidity standard and the Hwy 23 sampling station is most representative of the overall watershed.

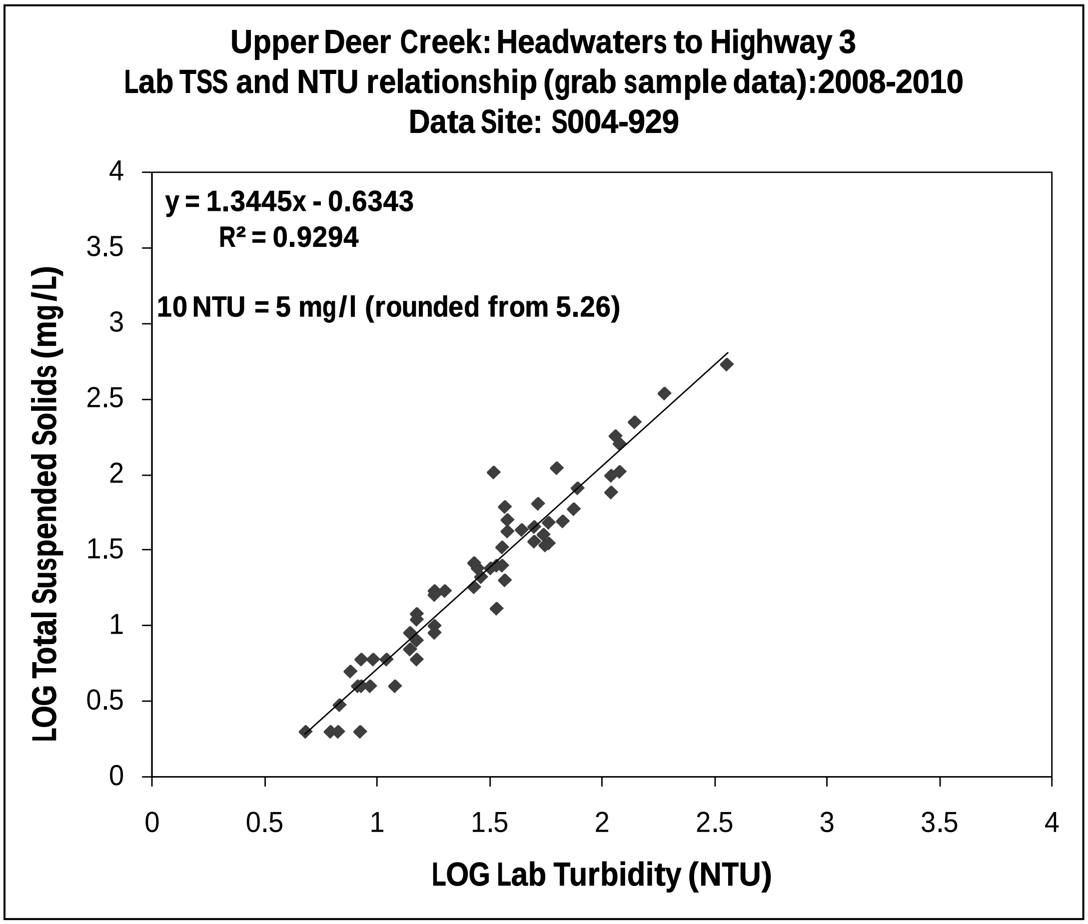


Figure 3.2 Upper Deer Creek at Hwy 3 NTU to TSS Relationship

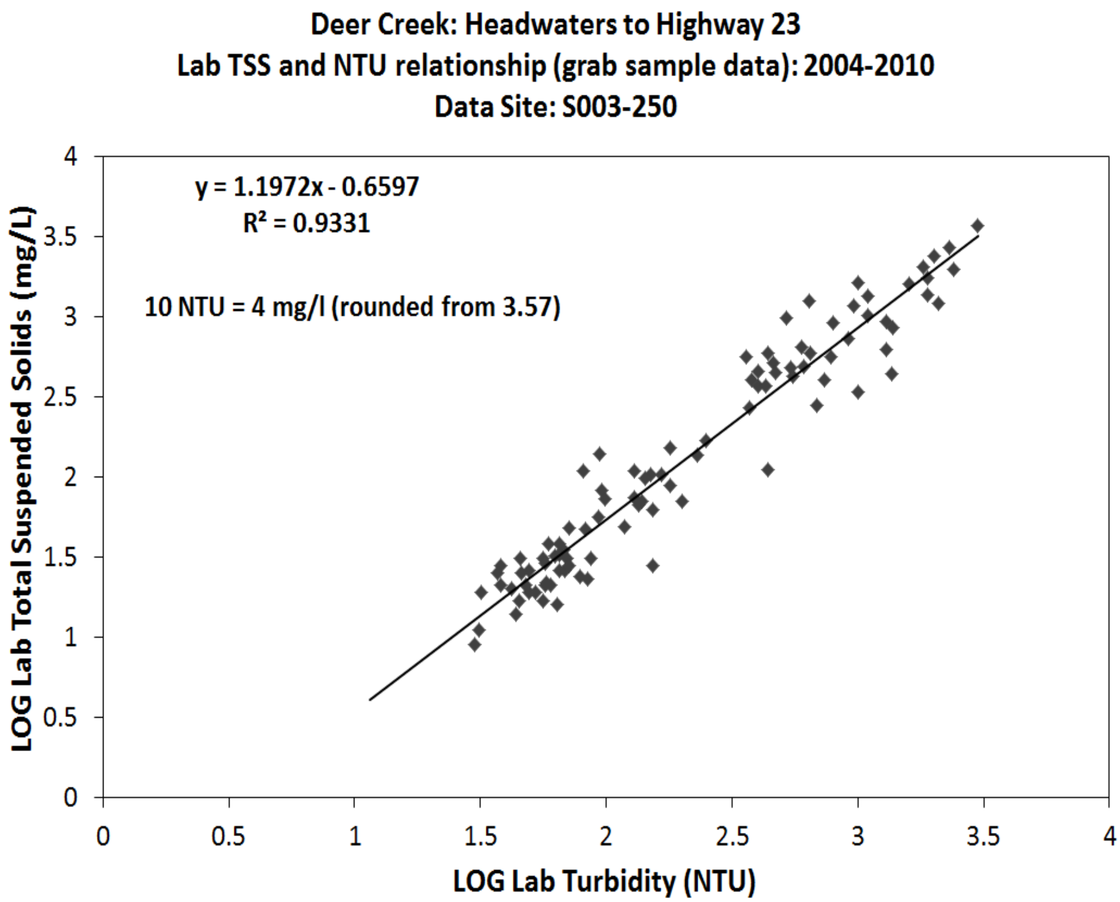


Figure 3.3 Lower Deer Creek at Hwy 23 NTU to TSS Relationship

3.3 Methodology for Load Allocations, Wasteload Allocations and Margins of Safety

The TMDL consists of three main components: WLA, LA, and MOS as defined in Section 1.0. The WLA includes four sub-categories: permitted wastewater facilities with TSS limits, the MS4 permitted stormwater source category, a construction permitted stormwater category and an industrial permitted stormwater category. The LA, reported as a single category, includes the nonpoint sources described in Section 3.1. The third component, MOS, is the part of the allocation that accounts for uncertainty in attainment of water quality standards.

Federal regulation 40 CFR 130.3 states that *TMDLs can be expressed in terms of either mass per time, toxicity, or other appropriate measure*. The three components (WLA, LA, and MOS) were calculated as a total daily load of TSS. As described in Section 3.2.2, this parameter is used as a surrogate for turbidity. While it was noted that nutrients (i.e., phosphorus) may play a small role in turbidity during portions of the year, we lack a robust enough dataset to establish an adequate correlation between nutrients, algae and turbidity upon which to base loading allocations. However, reducing the delivery of sediment will also reduce the delivery of nutrients and nutrient reduction should be considered when sediment reduction practices are implemented.

The methodology to derive and express the TSS load components is the duration curve approach. For each impaired reach and flow condition, the total loading capacity or “TMDL” was divided into its component WLA, LA, and MOS. It should be noted that this method implicitly assumes that observed stream flows and flow regimes remain constant over time. The available load allocation was determined by subtracting the WLA and MOS from the loading capacity. Details of the process for computing each component of the TMDL is further described below.

3.3.1 Wasteload Allocation

This TMDL assumes that 0.1% of the land area is designated for construction/industrial activities at any given time. Permitted effluent concentration limits ensure that these sources do not have a reasonable potential to cause or contribute TSS above the applicable water quality standard. Appropriate measures for achieving compliance with the TSS wasteload allocation are described as follows.

Industrial & Municipal Wastewater Treatment Facilities: Individual WLAs

No industrial or municipal wastewater treatment facilities area actively discharging into Deer Creek.

Construction Stormwater: Categorical WLA

The wasteload allocation for stormwater discharges from sites where there is construction activities reflects the number of construction sites ≥ 1 acre expected to be active in the watershed at any one time, and the Best Management Practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local construction stormwater requirements must also be met.

Industrial Stormwater: Categorical WLA

The wasteload allocation for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES industrial stormwater permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains coverage under the appropriate NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. It should be noted that all local stormwater management requirements must also be met.

Municipal Separate Storm Sewer Systems (MS4s)

No municipality is subject to a MS4 Permit in the Deer Creek watershed.

3.3.2 Margin of Safety

The purpose of the MOS is to account for uncertainty that the allocations will result in attainment of water quality standards. For this TMDL an explicit ten percent (10%) MOS is applied. This is expected to provide an adequate accounting of uncertainty.

3.3.3 Load Allocations

The LA includes nonpoint pollution sources that are not subject to NPDES permit requirements, as well as “natural background” sources. These background sources sometimes include low levels of soil/sediment erosion from both upland areas and the stream channel. The nonpoint pollution sources were described previously and include the sediment volcanoes, upland and riparian erosion and bank/bed/mass wasting erosion, as well as the other sources. Because only 0.1% of the land area is subject to NPDES permitting and therefore classified as a wasteload allocation, the remaining 99.9% of land area was classified under the load allocation.

3.4 TMDL Allocation Results

This section details the TMDL allocation process and results as well as the reduction percentages needed in the creek to meet the TMDL requirements.

3.4.1 Flow Duration Curve

Flow duration curves were developed for the Lower Deer Creek station for years 2008-2010. This dataset was compared with historical data collected by both the MPCA and the USGS for years 1976-2010 (Figure 3.4). The flow duration curves rank each flow based on its percentile rank. A flow duration interval of 10% represents a value where only 10% of the flow rates are higher. A 90% interval represents a low flow rate where 90% of measurements are higher. The results show flow rates during 2008-2010 as generally lower than the historical data. High flows and flow rates under dry and low flow conditions more-closely match historical values, while moist condition and mid-range flows are slightly lower during 2008-2010 than previous years. For development of the TMDL rates were divided into five categories: high flows (0-10%), moist conditions (10-40%), mid-range flows (40-60%), dry conditions (60-90%) and low flows 90-100%).

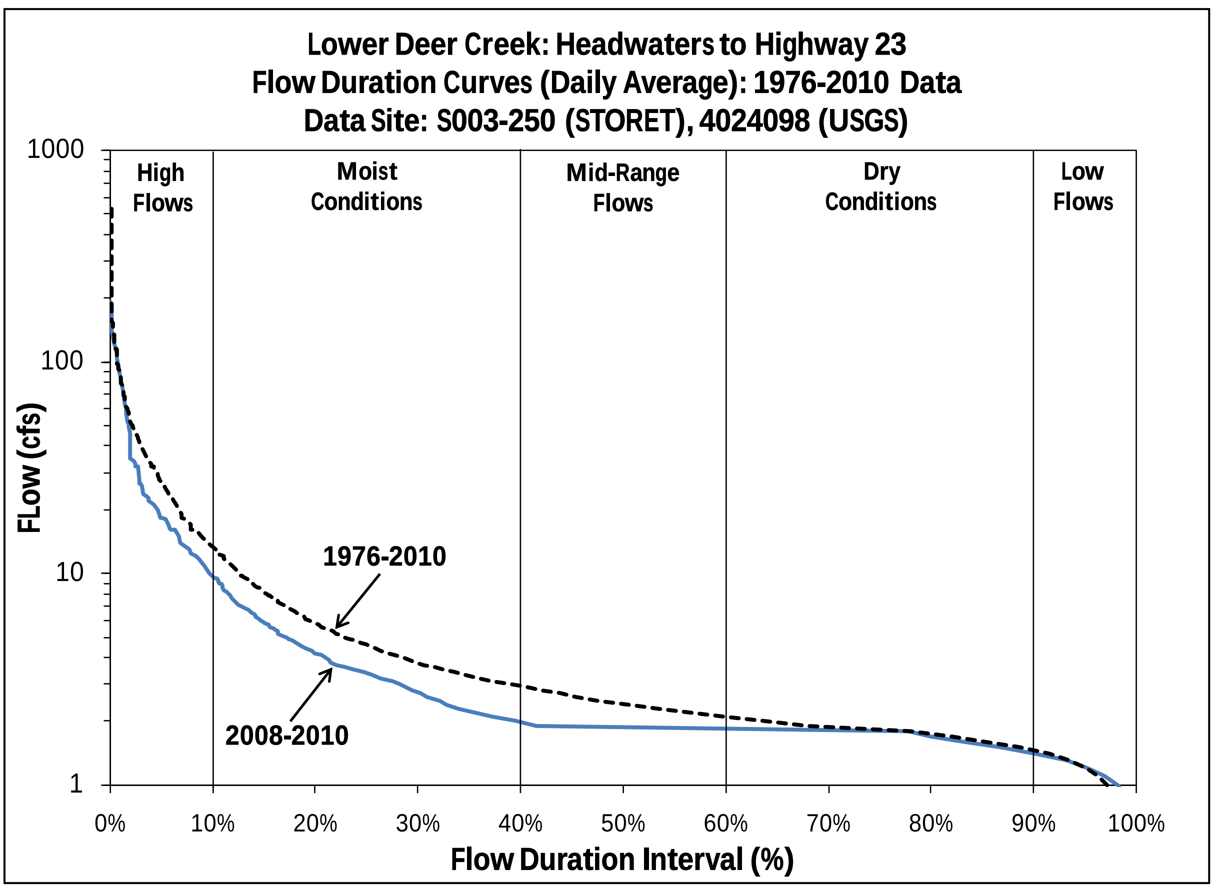


Figure 3.4 Flow duration curve: Lower Deer Creek station

3.4.2 TSS Daily Loading Capacity

The five flow rate categories were used to calculate the total suspended solid loading capacities and allocations for Deer Creek (Table 3.1). The total daily loading capacity was calculated using the mid-point flow rate for each of the flow zones and the 4 mg/L TSS concentration which corresponds to the 10 NTU standard, as defined in Figure 3.3. This analysis results in total daily load capacities for the high, moist, mid, dry and low flow zones at the monitoring location. The monitoring location represents 7.7 mi^2 of the total 7.9 mi^2 of watershed area therefore the loading capacities were adjusted to the entire watershed. Using this adjustment the total daily load capacities for the entire Deer Creek watershed were 429, 73, 40, 40 and 27 lbs/day for the high, moist, mid, dry and low flow zones respectively. This loading capacity was then divided between MOS, WLA, and LA components. In this analysis only MOS, LA, and construction and industrial stormwater activity requirements were apportioned, resulting in 89.9% of the capacity allocated to non-point sources as a load allocation requirements, 0.1% allocated to construction and industrial stormwater and 10% applied to the MOS.

Table 3.1 Total suspended solids loading capacities and allocations (AUID: 04010301-531)

	Flow Zone				
	High	**Moist**	**Mid**	**Dry**	**Low**
	lbs/day				
TOTAL DAILY LOADING CAPACITY	429	73	40	40	27
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0	0	0	0	0
Communities Subject to MS4 NPDES Requirements	0	0	0	0	0
Construction and Industrial Stormwater	0.43	0.07	0.04	0.04	0.03
Load Allocation	385.8	65.8	35.8	35.8	24.4
Margin of Safety	42.9	7.3	4.0	4.0	2.7
	Percent of total daily loading capacity				
TOTAL DAILY LOADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities	0%	0%	0%	0%	0%
Communities Subject to MS4 NPDES Requirements	0%	0%	0%	0%	0%
Construction and Industrial Stormwater	0.1%	0.1%	0.1%	0.1%	0.1%
Load Allocation	89.9%	89.9%	89.9%	89.9%	89.9%
Margin of Safety	10%	10%	10%	10%	10%

3.4.3 Load Duration Curve

Load duration curves were created for three years of combined data (2008-2010) at the Lower Deer Creek station located near Hwy 23 (Figure 3.5 and Figure 3.6). Load duration curves plot the corresponding TSS load (lbs/day) calculated using the 15 minute interval flow rate (cfs) and TSS concentration (mg/L), converted from the NTU turbidity measurement, against the flow percent rank (%) for each measurement. At the Deer Creek Highway 23 station the highest TSS loads occurred during the high and moist flow zones. Median loads over the three year period were calculated as 13314, 810, 94, 228, and 128 lbs/day for the high, moist, mid, dry and low flow zones respectively.

The 10 NTU standard was calculated by taking the product of the 4 mg/L TSS equivalent and the flow rate at various percentages. This curve is displayed with an orange line in Figure 3.5. Also present on Figure 3.5 are the 90th percentile and median loads for the 5 flow zones. All measurements recorded between 2008 and 2010, at the lower Deer Creek station, were above the turbidity standard.

The higher loads in the moist and high flow zones are the result of both increased flows and elevated TSS concentrations (see Figure 3.6). Median concentrations for the three year period were recorded as 79, 31, 9, 20 and 24 mg/L for the high moist, mid, dry and low flow zones, respectively. The 90 percentile TSS concentrations were 604, 74, 9, 78 and 38 mg/L for the high moist, mid, dry and low flow zones respectively. Figure 3.6 also shows that the TSS observations in the three lower flow zones were significantly higher than the TSS concentration that corresponds to the turbidity standard, resulting in TSS loads that were also higher than the loading capacity (as shown in Figure 3.5) for the mid-range to low flow conditions.

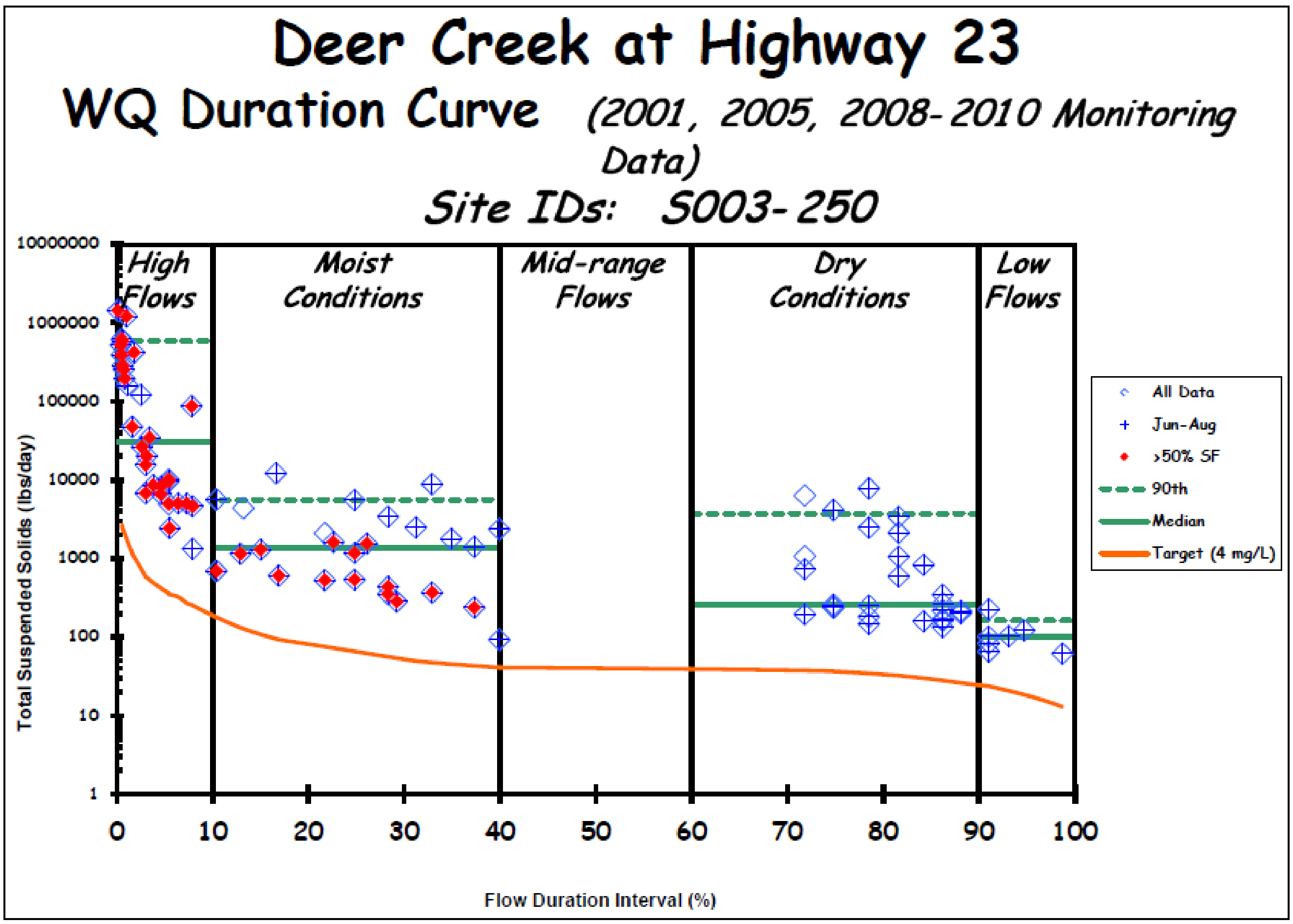


Figure 3.5 TSS Load duration curve for Lower Deer Creek (2008-2010)

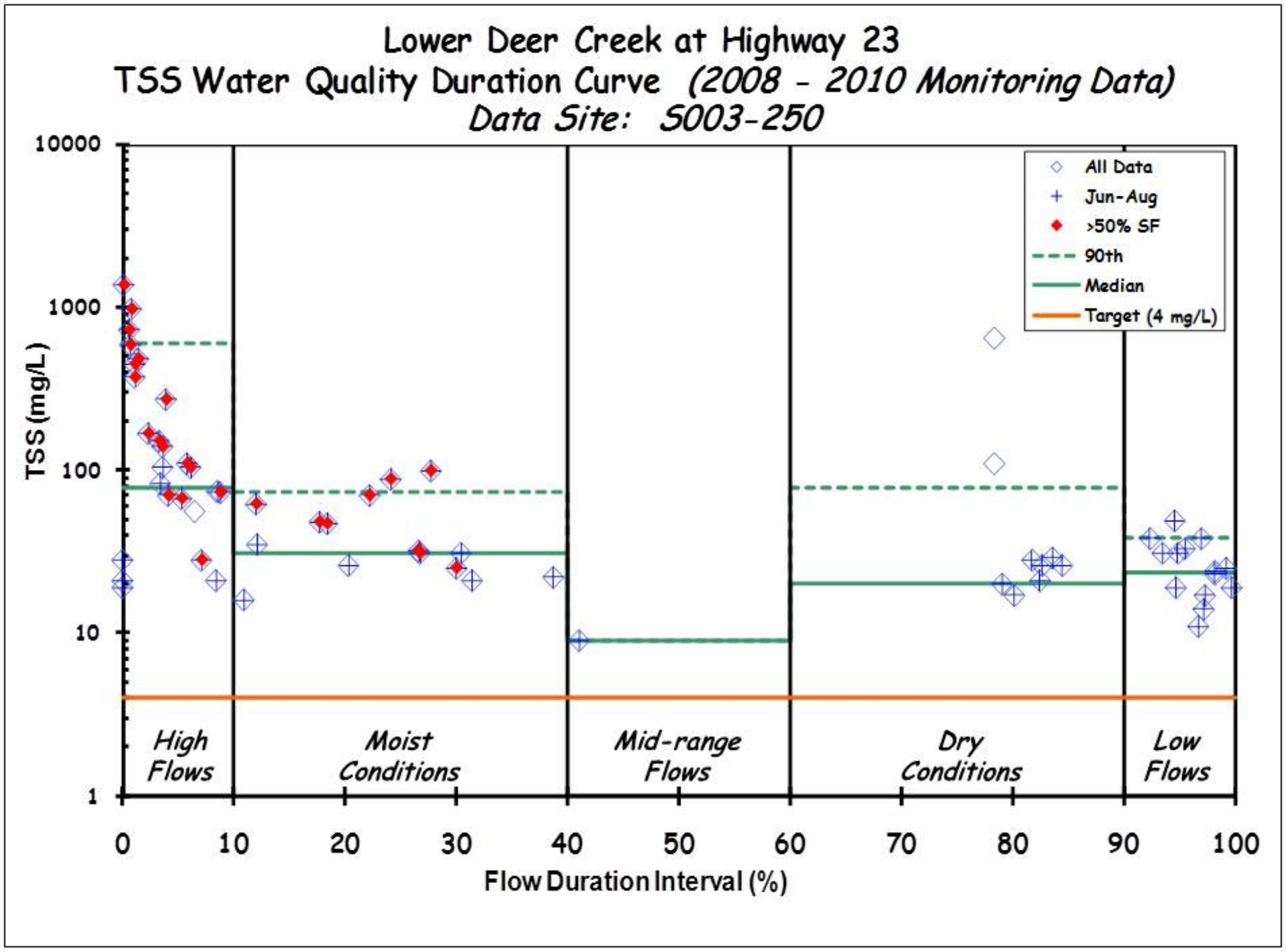


Figure 3.6 TSS water quality duration curve for Lower Deer Creek (2008-2010)

3.4.4 Field Turbidity Station Comparison

Field turbidity measurements were made at all sampling locations displayed in Figure 2.1. Field turbidity duration curves in units of formazin nephelometric units (FNU) for each site are shown in Figure 3.7 to Figure 3.11. Median values for each flow regime at the various locations are summarized in Table 3.2. Median turbidity values increase by at least 100% for four of the five flow regimes between CSAH 3 and CSAH 6 on the Deer Creek main stem. This section of Deer Creek contains sediment volcanoes which are a significant source of sediment in the watershed. Values at all other locations are comparable to the CSAH 6 site. No comparison was made between the field turbidity data and the turbidity standard given that the field FNUs are not equal to the NTUs of the turbidity standard; however, the preponderance of values well above 10 indicate high turbidity levels.

Table 3.2 Median field turbidity at each sampling location

	Median Field Turbidity measurements (FNU)				
	High Flow	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Deer Creek at CSAH 3	57	14	25	14	21
Deer Creek at CSAH 6	113	51	40	59	42
Deer Creek at Highway 23	125	63	30	56	51
Tributary at CSAH 3	102	38	--	50	13
Tributary at CSAH 6	114	90	83	49	42

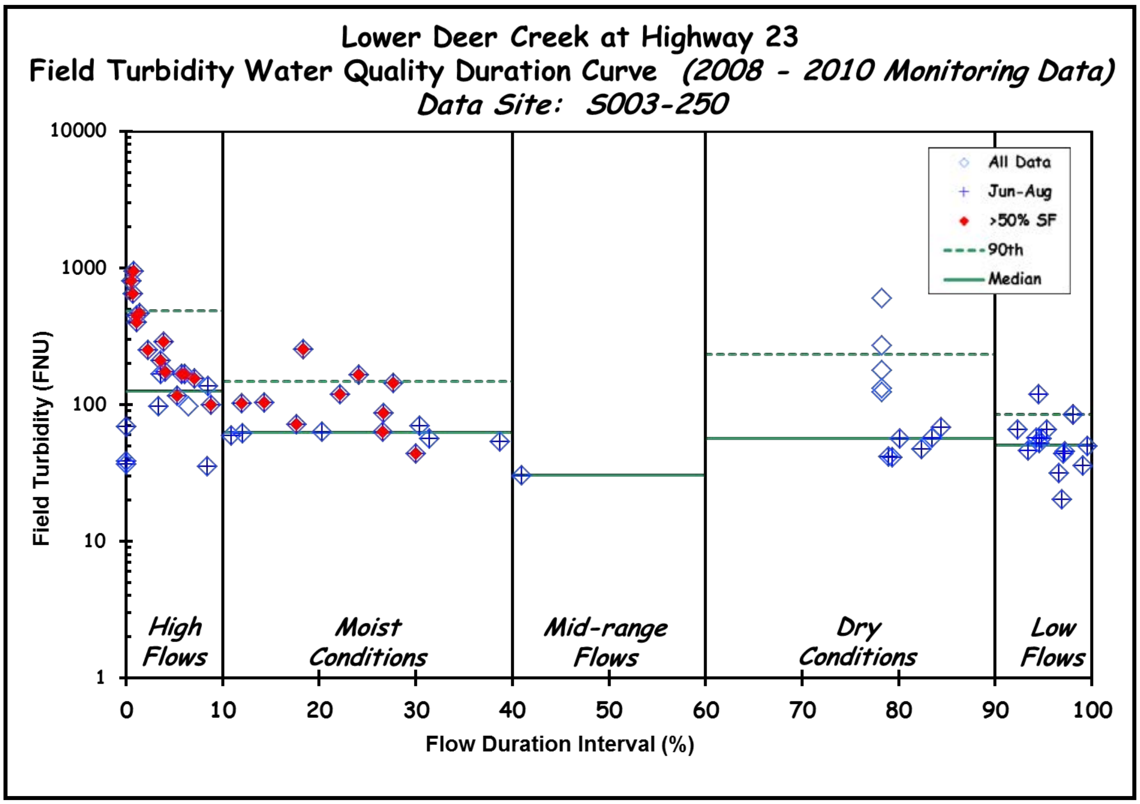


Figure 3.7 Field turbidity duration curve for Lower Deer Creek at CSAH 23 station (2008-2010)

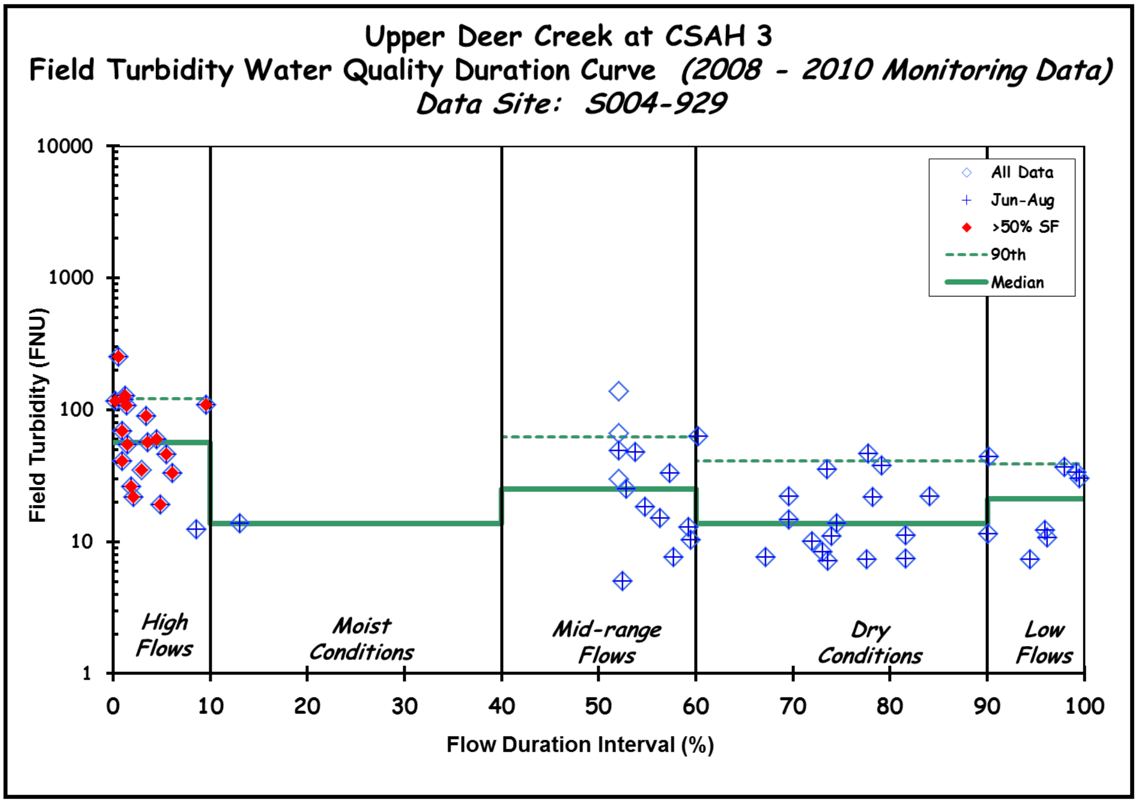


Figure 3.8 **Field turbidity duration curve for Upper Deer Creek at CSAH 3 station (2008-2010)**

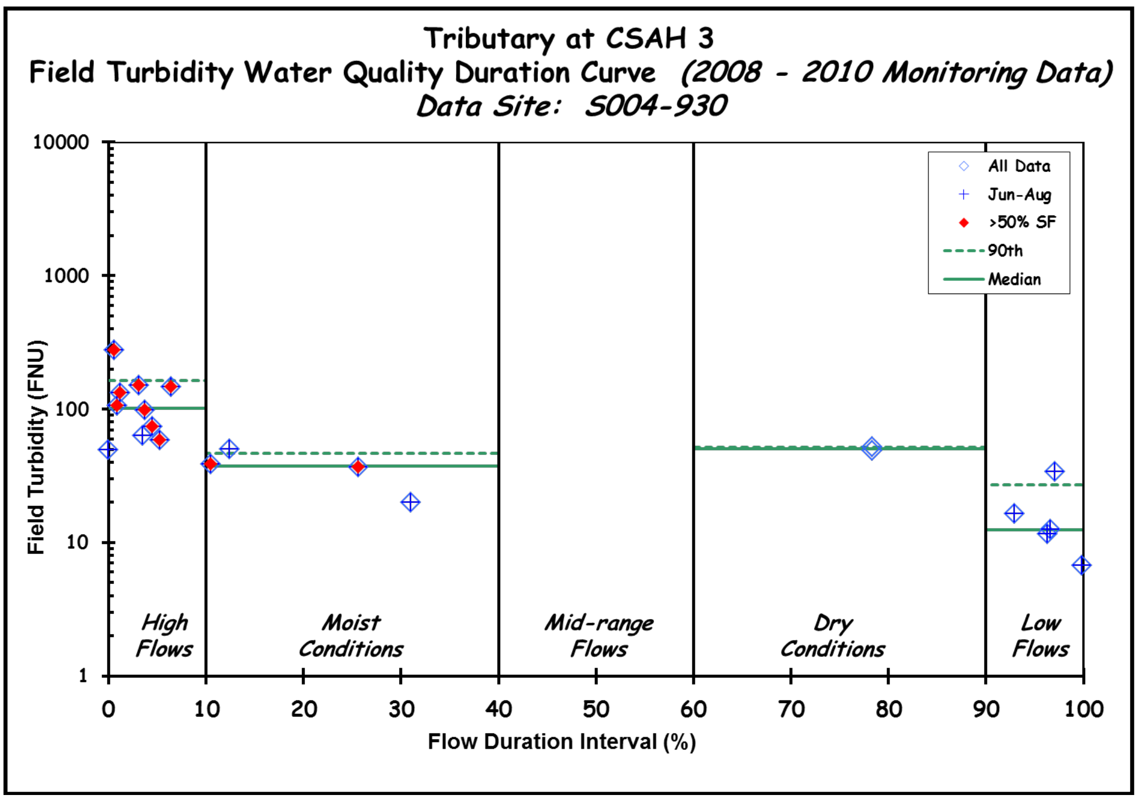


Figure 3.9 **Field turbidity duration curve for Tributary to Deer Creek at CSAH 3**

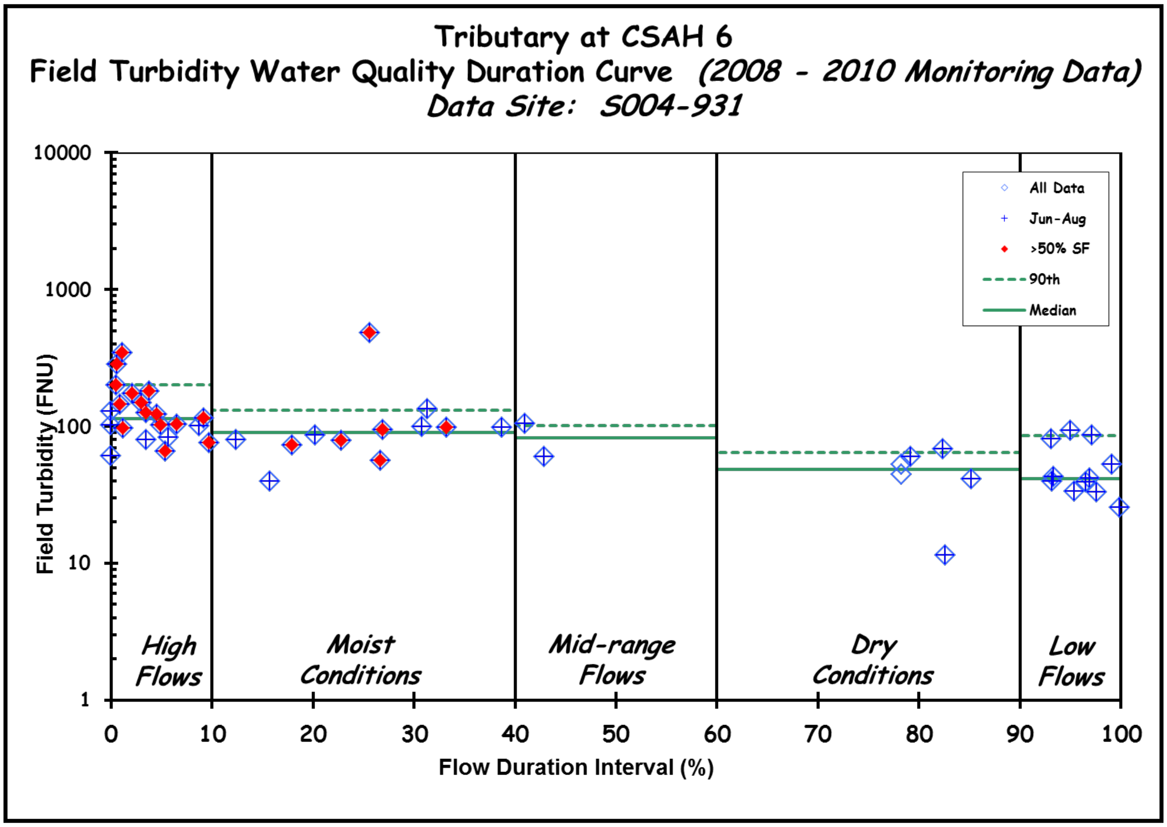


Figure 3.10 Field turbidity duration curve for Tributary to Deer Creek at CSAH 6

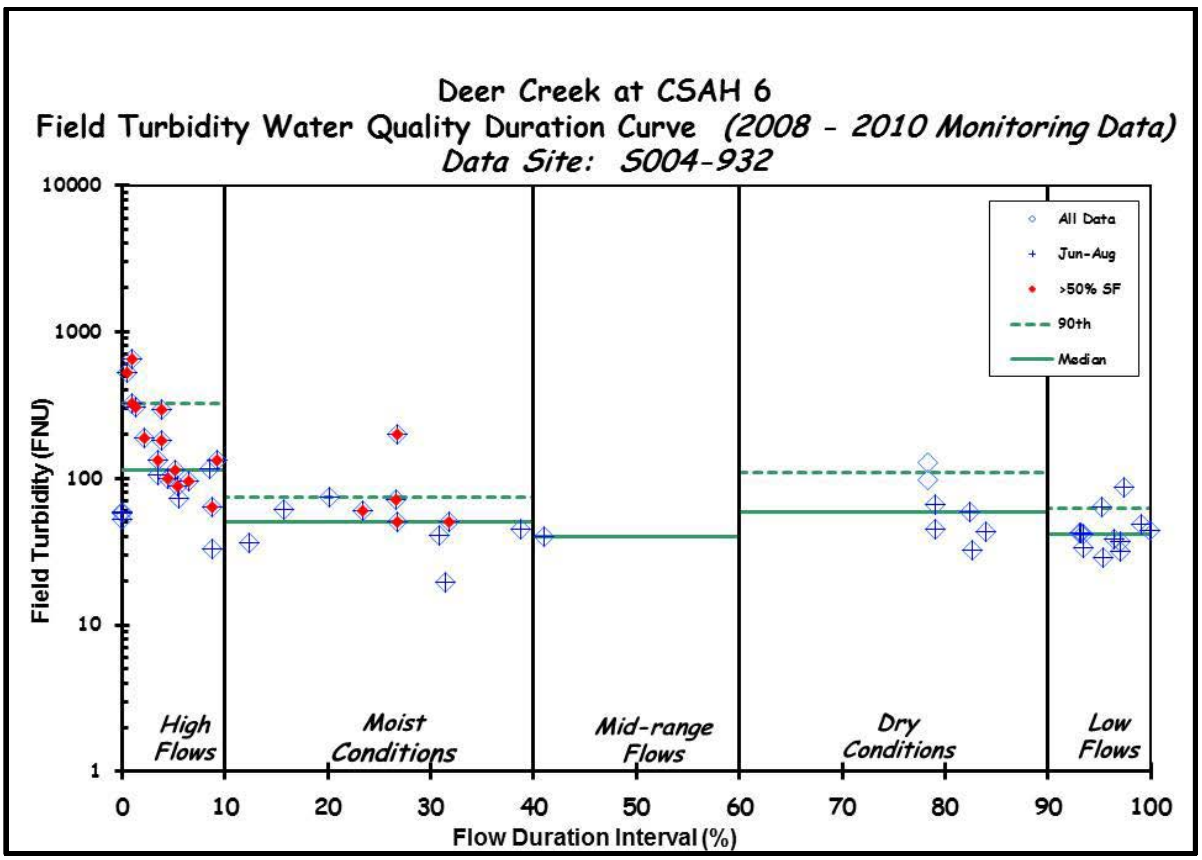


Figure 3.11 Field turbidity duration curve for Deer Creek at CSAH 6

3.5 Overall Conclusions from Turbidity-Related Monitoring and Sediment Sources Requiring Load Reductions

Some of the conclusions to be drawn from the project monitoring experience, data and assessments discussed in Sections 3.1, 3.2 and 3.4 are the following:

- Based on the available data, the turbidity impairments in the watershed are significant when viewed across the entire sampling season. Turbidity readings at the Deer Creek outflow station (at Highway 23) are significantly higher than the 10 NTU standard for all parts of the flow regime.

- Median TSS loads at the Highway 23 station were recorded at 13314, 810, 94, 228, and 128 lbs/day for the high moist, mid, dry and low flow zones respectively. To meet the requirements of the TMDL, daily loads of 429, 73, 40, 40 and 27 lbs/day for the high moist, mid, dry and low flow zones respectively are required.

- Primary sources contributing TSS within this watershed are mass-wasting and erosion of slumping stream banks, livestock grazing in riparian areas, watershed-wide land use changes, and sediment volcanoes. Failing "Red Clay Dam" structures were also identified as TSS sources. The relative amounts of sediment loading from each of the primary sources will be evaluated in more detail as a part of future watershed modeling developed for the implementation planning phase of the TMDL project.

- The calculated Total Maximum Daily Load (TMDL) of TSS that serves as the loading capacity for each reach is based on the TSS concentration equivalent to the 10 NTU standard. For implementation planning purposes, an overall load reduction percentage can be made by comparing the existing dataset to the listing/delisting criteria for turbidity.

- Increased turbidity values were observed in all flow regimes between CSAH3 and CSAH6. This section of Deer Creek contains the sediment volcanoes which are a significant source of sediment. As shown in Table 3.2, field turbidity was twice as high downstream of the sediment volcanoes under low flows.

3.6 Critical Conditions and Seasonal Variation

EPA states that the critical condition *"…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence"* (USEPA, 1999). As usually seen with sediment related impairments, the highest turbidity levels occur during snowmelt and storm runoff events. The unique geology and resulting soils and hydrology in the Deer Creek watershed make the whole range of stream flows subject to elevated turbidity levels. The duration curve methodology addresses the critical conditions and seasonal variation issues for this TMDL.

3.7 Consideration for Growth and Land Use Change

3.7.1 Land Use Change

The Deer Creek watershed is sparsely populated with the majority of the land cover and use in the watershed associated with wooded areas. Changes to the existing land use/cover from wooded areas would result in increased surface runoff contributing to the stream bank erosion currently present. Examination of land use data provided by the USGS (NLCD2001 and NLCD2006) and the USDA (2006-2010) showed no significant land use changes since 2001.

However, land cover changes were observed in the watershed through an aerial photographs comparison between the years 2008 and 2010. Figure 3.12 displays the removal of trees over a large, previously forested area. This land cover change produced exposed soils capable of contributing TSS to Deer Creek and also changes the hydrology of the watershed. The timber harvest at this site followed the Minnesota Forest Resources Council (MFRC) Forest Management Guidelines that are intended to protect water quality of nearby water bodies (Bernu, 2012).

Through the implementation of this TMDL, recommendations to landowners on how to best manage land use and/or land cover changes will be made to minimize the impact on TSS loads.

3.7.2 Growth

Land use categories in the watershed have remained constant over the time period 2001-2010 based on the USGS and USDA data reviews mentioned above. It is not expected that urbanization, and any associated MS4 or wastewater treatment plant permit requirements, will occur in the foreseeable future.

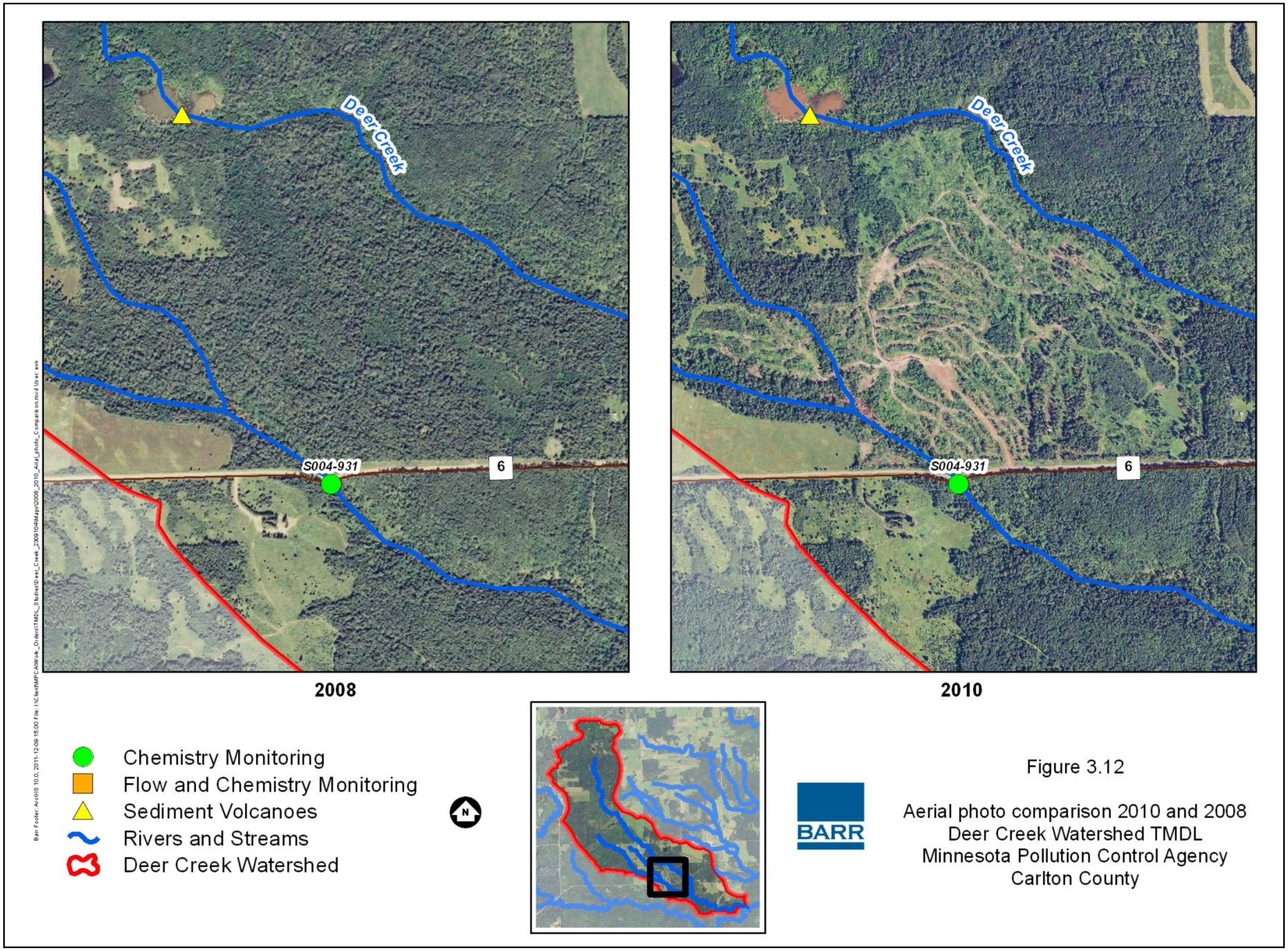


Figure 3.12 FSA aerial photo comparison showing land cover changes between 2008 and 2010

4.0 Monitoring

The goals of follow-up monitoring are generally to both evaluate progress toward the water quality targets provided in the TMDL and to inform and guide implementation activities. The Minnesota MPCA has recently begun implementation of a 10-year rotation for watershed work. MPCA employs an intensive watershed monitoring schedule that provides comprehensive assessments of all of the major watersheds (HUC 8 digit) on a ten-year cycle. This schedule provides intensive biological monitoring of streams and lakes within each major watershed to determine overall health of the water resources, to identify impaired waters, and to identify those waters in need of additional protection to prevent future impairments. Based on the watershed assessment, a TMDL study and/or protection strategy is completed. This is followed up with an implementation plan for restoration of impaired waters, and an implementation strategy to ensure healthy waters will remain so. Local resource managers and landowner partners then engage in completion of best management practices to achieve the goals identified for water improvement or protection. Once BMPs are completed, the evaluation cycle begins again. The Nemadji watershed began this rotational cycle in 2011. Monitoring at this intensive level will occur again in 2021. More specific monitoring plan(s) will be developed as part of implementation efforts. The impaired water body will remain listed until water quality standards are met. Additional monitoring will primarily be conducted by local staff, citizen volunteers, MPCA and DNR staff.

4.1 Turbidity specific monitoring

At a minimum, monitoring will be continued at the Deer Creek downstream site at Highway 23 for assessment/study purposes. This monitoring will occur during the open water season and at a frequency and timing similar to previous turbidity assessment monitoring.

Additional monitoring sites may be needed to further investigate the sediment sources from the sediment volcanoes. Stations directly upstream and downstream of the sediment volcanoes can be used to determine how sediment loads at the outflow are impacted by the sediment volcanoes.

4.2 Geomorphology

Slumping, erosion, and the relation to land use practices has been studied extensively in the Nemadji River watershed, including Deer Creek. Watershed characteristics that influence the slumping and stream erosion have been documented. This data includes streambank erosion and vegetation analysis, stream metric data, roadside erosion and slump inventories, as well as slump and land use mapping and analysis. Figure 4.1 shows several of the significant features that have been identified throughout the Deer Creek watershed, including the stream survey locations from 2011.

If stabilization of the erosion sites is not undertaken immediately, they should be monitored to determine the rate of erosion. This could be accomplished by establishing benchmarks and performing high-definition laser scanning of the erosion sites, which would be difficult to survey using traditional methods. The survey should be repeated every 2 to 3 years and following severe runoff events. Monitoring the sites over a period of years will provide a better picture of which erosion sites are most active. In addition, a geotechnical investigation should be performed to gain insight into the role soils and groundwater play in the mass-wasting processes. Finally, a more detailed investigation of local sources of runoff to the eroding areas should be performed to determine if upland best management practices can be implemented to reduce the rate and volume of runoff, as well as the likelihood of erosion in the headwater channels.

Down cutting and bank erosion were observed in some reaches of the stream. It is recommended that a more detailed survey of the stream be repeated, with a survey of the thalweg profile and periodic cross-sections. Several cross-sections have been surveyed in the past and those cross-sections should be re-surveyed for comparison. This survey should be performed during leaf-off season so that GPS readings can be recorded.

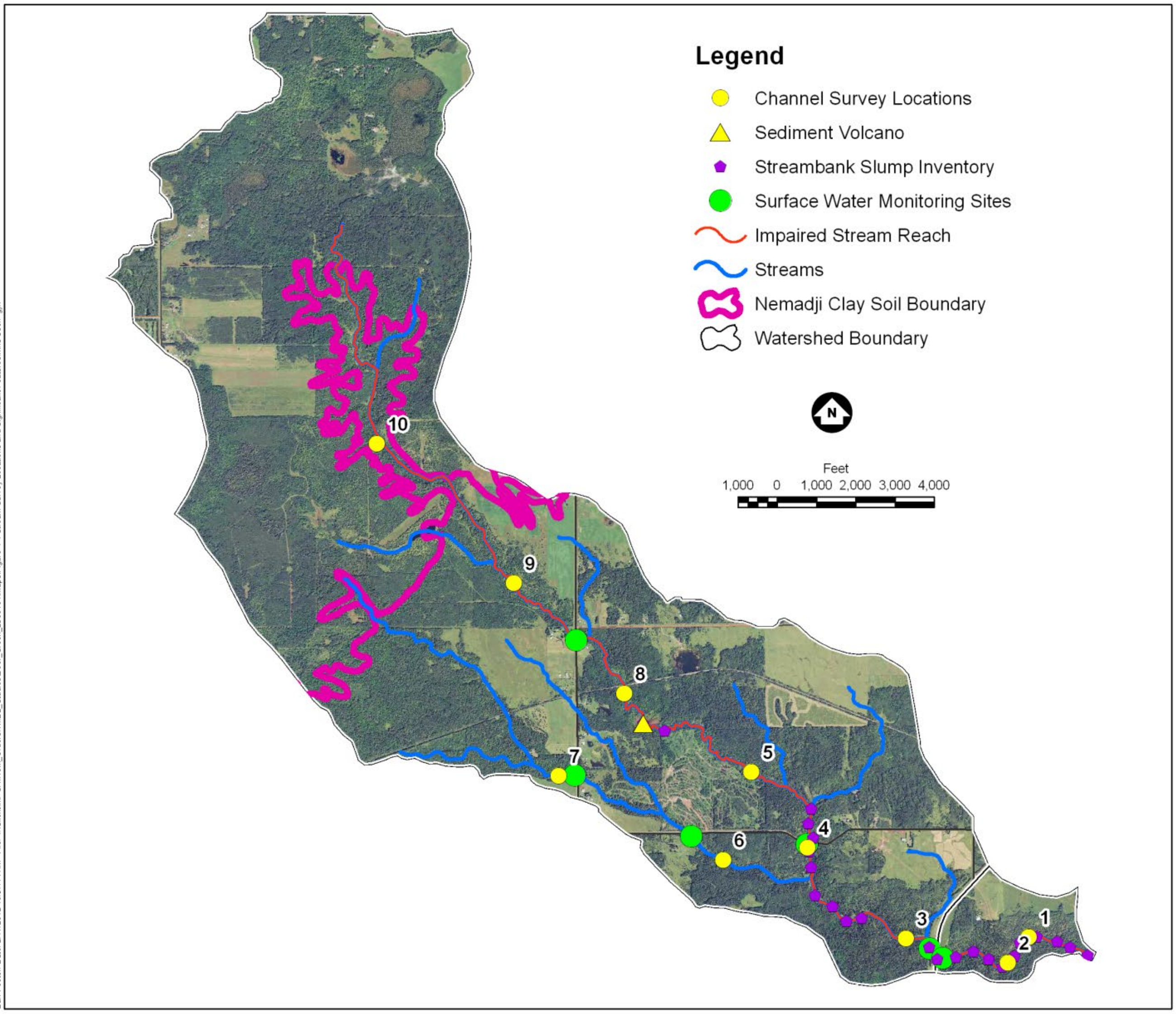


Figure 4.1 Deer Creek stream survey locations and significant features

5.0 Implementation Objectives and Priority Management

5.1 Implementation Objectives

A number of recommendations are made below to provide implementation strategies associated with each of the significant sediment loading sources within the Deer Creek watershed. Detailed watershed modeling will also be completed in conjunction with the future TMDL implementation planning effort to identify and prioritize more specific BMPs to put into practice. The recommended implementation objectives are defined following a five-component framework for evaluating the health of a stream system that has been adopted by the Minnesota Department of Natural Resources (DNR) in their *Watershed Assessment Tool* (http://www.dnr.state.mn.us/watershed_tool/index.html). The five components are hydrology, connectivity, biology, geomorphology, and water quality.

5.1.1 Hydrology

The objective is to attain a hydrologic regime that better supports geomorphic stability and ecological function by restoring or increasing stream base flows and reducing storm event flows to more closely resemble the hydrologic patterns of a non-impacted watershed. To improve hydrological function in the watershed we plan on focusing on possible land cover changes associated with silviculture.

Silviculture

Land cover changes between 2008 and 2010 in an area of Deer Creek point to the presence of silviculture in the area. During silviculture operations it is recommended that appropriate BMPs are implemented for each site and process. Carlton County SWCD is developing a logging BMP fact sheet with input from the forestry committee of the Nemadji River Basin Project.

Carlton County implements all recommendations of the MN Forest Resources Council Forest Management Guidelines (FMGs), where applicable, for harvesting public lands in the Nemadji River basin. Past recommendations to private landowners in the watershed have been made to carry no more than 15% of ownership in forested cover types less than 15 years of age. This recommendation has been difficult to follow for some private land owners that may have to subject the entire property to harvesting due to economies of scale. In general, annual State Guideline Monitoring results in the Nemadji basin have shown greater than 90 percent compliance with the implementation of the FMGs for water quality and soil stabilization. Other projects within the watershed include Carlton County's pursuit of reestablishing long lived tree species. In addition, the NRCS Great Lakes Restoration Initiative (GLRI) project to re-vegetate private land open areas, and scrublands, has specifically targeted the Deer Creek watershed as an area for grants.

Watershed modeling completed for this study will be used to assess the relative impacts on surface runoff and sediment contributions, depending on various expected watershed land area percentages that are subject to logging and the associated BMP implementation.

5.1.2 Connectivity

The objective is to evaluate and restore the connectivity in the watershed system including fish passage and sediment transport in the stream. This will be conducted through a culvert inventory.

Culvert Inventory

Identify stream crossings and culverts that block fish passage and/or are contributing sediment or channel instability to the stream.

5.1.3 Biology

The biological objective is to improve the ecological function of the stream ecosystem through the support of aquatic life use for cold water fish designated by Minnesota's water quality standards (MN R. 7050). This will be completed through the implementation of the objective of the four other watershed system components, while also evaluating the ecological condition of the stream and identifying functional needs for the ecosystem (pools, riffles, habitat, channel and bank stability, etc.).

5.1.4 Geomorphology

The objective is to restore and maintain channel stability of Deer Creek where necessary and feasible. Stability is defined as maintaining the dimensions, pattern and profile of stream channels so that the channel neither aggrades or degrades over time and is able to transport its water and sediment. Four areas are highlighted as necessary to restore geomorphological features including livestock access to riparian areas and waterways, streambank destabilization and mass wasting, failing dam structures and the presence of sediment volcanoes.

Livestock Access to Riparian Areas and Waterways

Livestock producers should continue to implement measures to protect riparian areas and waterways, such as managing livestock access in riparian areas and providing off-site watering structures. Previous studies have shown hoof stresses in the riparian areas as a significant source of stream bank erosion in the Deer Creek watershed. Continuing the current practices of limiting livestock access to these areas can reduce stresses and stabilize the banks. It is recommended that an update to the last county feedlot inventory conducted in 1996 be completed in the next phase of implementation planning.

Streambank Destabilization and Mass Wasting

As discussed in Section 4.2, several streambank erosion and slumping features have been inventoried in the watershed and documented with vegetation analysis and stream channel metrics. While the severity of these sites will continue to be monitored in the future, the modeling completed for this study will be used to assess the relative magnitude of the sediment contributions from each source area. LiDAR data will also be used to prioritize areas for implementation.

Failing Dam Structures

As discussed in Section 3.1, at least 3 out of the 4 Red Clay Dam structures are failing and in need of repair in the Deer Creek watershed. The Carlton SWCD successfully obtained Clean Water Funds to address these failing structures. Engineering plans will be developed for erosion control measures on the three structures in the Deer Creek watershed in phase three of a three phase project.

Sediment Volcanoes

While several sediment volcanoes have been documented in the Deer Creek watershed, the monitoring data indicates that the feature shown in both Figures 2.1 and 4.1 is likely the major contribution to the turbidity impairment in this reach. The watershed and groundwater modeling completed for this study will be used to assess the relative contributions from the sediment volcanoes in the watershed and evaluate whether there are feasible options to improve their influence over stream water quality.

5.1.5 Water Quality

The water quality objective is to support aquatic life in a cold-water ecosystem by reducing sediment concentration in Deer Creek to meet TMDL targets. This objective will be met through integrating water quality activities with geomorphological activities for sediment control, implementing and maintaining silviculture practices to limit the water quality effects of land use changes in the watershed, and implementing construction and industrial stormwater practices.

Construction Stormwater Implementation

Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired water, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

Industrial Stormwater Implementation

Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

5.2 Evaluation of BMP Effectiveness and Priority Ranking for Sediment Reduction Strategies

With limited time, staff and funding opportunities for restoration efforts, an attempt should be made to determine what best management practices would be practical, economically feasible, and environmentally effective in reducing turbidity loading in the Deer Creek watershed. As a first step, the TMDL Implementation Plan should include a review of the cost-effectiveness of best management practices that should be undertaken, based on existing applicable knowledge. BMP cost-effectiveness, should be used to finalize a priority ranking system for implementing individual TSS reduction strategies throughout the watershed. An implementation plan will be constructed in 2013 organized by the five components of a healthy watershed discussed in Section 5.1.

The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [Minn. Statues 2007, section 114D.25]. Based on TMDL experience with the cost of implementing similar BMP improvements in other similar-sized watersheds, an expected range of overall project costs is estimated between $5 and $10 million for the Deer Creek watershed. This estimate will be refined when the detailed implementation plan is developed, following approval of the TMDL study.

6.0 Reasonable Assurance

The following should be considered as reasonable assurance that implementation will occur and result in sediment load reductions in the listed waters toward meeting their designated uses:

- Monitoring will be conducted to track progress and suggest adjustment in the implementation approach.

- An implementation plan will be finalized within one year following EPA approval of the TMDL, which will identify specific BMP opportunities sufficient to achieve the sector-specific load reduction and associated adoption schedule. Current work for the implementation plan includes an integrated process of LiDAR/GIS assessment, terrain analysis, cumulative Stream Power Index calculations and estimates of channel bank stress to predict mass wasting and stream instability. This assessment will occur at a geographic scale which will be more effective at identifying critical source areas and then targeting and prioritizing BMPs.

- The Nemadji River basin is a focus area for water quality work in the county. The Nemadji River, including the Deer Creek watershed, is part of the Carlton County water plan and SWCD annual plan of work. Inclusion of the watershed in county work plans makes project work in the watershed eligible for state funding resources from the Clean Water, Land, and Legacy Act and other state generated funding sources. In addition, two federal offices, the Natural Resources Conservation Service and Great Lakes Commission Erosion and Sediment Control Program list the Nemadji Basin as a target area for their funding programs.

- The Nemadji River is part of the St. Louis River Area of Concern (AOC), which was designated by the Great Lakes Water Quality Agreement (WQA) between the United States and Canada in 1972. Nine beneficial use impairments have been recognized: 1) Restrictions on fish and wildlife consumption; 2) Degradation of fish and wildlife populations; 3) Fish tumors or other deformities; 4) Degradation of benthos; 5) Restrictions on dredging activities; 6) Eutrophication or undesirable algae; 7) Beach closings; 8) Degradation of aesthetics; and 9) Loss of fish and wildlife habitat. Work is ongoing to "de-list" the impairments associated with the AOC. A Remedial Action Plan (RAP) was developed in 1987 for the AOC and is routinely reviewed and updated. The goal of the RAP is to define problems and their causes, and then recommend actions and timetables to restore all beneficial uses of AOCs. Restoring uses is to be achieved through implementation of programs and measures to control pollution sources and remediate environmental problems. Governments within the boundaries of the AOC, and an area citizen organization participate in furthering the goals of the RAP and evaluate progress toward those goals.

- The local community has invested 30 years of effort in this watershed. As projects evolved, more citizens have come forward as citizen volunteers. Project work in the watershed has been continuous over the past 10 years with large acreage tree plantings, culvert repairs, road repairs, sediment control structure assessments and repair, improved forestry management guidance for public and private lands, and other appropriate landowner BMPs.

7.0 Public and Stakeholder Participation

A number of opportunities were made for both public and stakeholder participation in the Deer Creek TMDL process during the last two years. These opportunities included:

- Updates in the SWCD newsletter distributed to 2600 landowners,
- Distribution of draft reports for review and comment to Stewardship committee members,
- Dialog at meetings of the Nemadji Stewardship Committee and SWCD board, both ongoing venues for public and watershed residents to voice issues or concerns,
- Continued and timely postings to the Nemadji River and Deer Creek web pages hosted by the SWCD, and
- An open house meeting to benefit public review of the final draft during the public notice period.

An "open house" style event was held to highlight the Deer Creek Turbidity TMDL report and to provide discussion of likely Best Management Practices to improve water quality. The event was titled "Deer Creek TMDL Open House Event, Improving the Deer Creek Watershed"and held on Wednesday, April 17th 2013, 6pm to 7:30pm, at the Carlton County Transportation building.

Outreach to advertise the event included a press release and informational flyer sent to the following local organizations: the Pine Journal newspaper, the Moose Lake Star Gazette newspaper, the clerks of Blackhoof Township and Wrenshall Township, the Nemadji Watershed Stewardship Committee, and the Carlton County Soil and Water Conservation District (SWCD) Board of elected officials. Personal invitations were extended to: Carlton County Land Department – Greg Bernu, Carlton County Transportation Department – Mike Tardy and Milt Hagen, Natural Resources Conservation Service – Dan Weber, Boreal Natives – Jeff West, Carlton County Commissioners and the county Zoning & Environmental Services staff. All who were invited by personal invitation attended the event.

In addition, notices were posted at the following community bulletin boards: the local grocery store, post office, barber shop, and well frequented town diner. The SWCD social media page, (Facebook), announced the open house. The Nemadji watershed newsletter, reaching 2,576 landowners, included an announcement for the open house. The newsletter generated 6 responses from citizens interested in stream/rain gage monitoring and membership in the stewardship committee. One individual stopped at the SWCD office to discuss how the TMDL report might affect local cattle producers or farmers. However, no official statement/comment was received on that subject. The open house meeting was sparsely attended. Weather reports for that evening indicated a significant snowfall was expected, and that might have been a deterrent to attendance.

The TMDL was public noticed from March 25 to April 23, 2013 via the State Register. Five responses were received via email. Two responders requested extensions to the comment period. Three submitted comments on various aspects of the TMDL report. MPCA staff provided responses for the three commenters. No extension was provided to the two requesting extensions. However, they were notified via email that any remarks are welcome at any time and the implementation plan effort that is underway would welcome their input.

References

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Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77(9):858-864.

Kemp, A.L.W., Dell, C.I., Harper, N.S., 1978. Sedimentation rates and a sediment budget for Lake Superior. J. Great Lakes Res. 4 (3–4), 276–287.

Koch, R.G., Kapustka, L.A., Koch, L.M., 1977. Presettlement vegetation of the Nemadji River Basin. J. Minn. Academy Sci. 43, 19–23.

Magner, J. 2004. Channel Stability Monitoring in the Nemadji River Basin.

Minnesota Pollution Control Agency (MPCA). 2007a. *The Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment.* http://www.pca.state.mn.us/publications/manuals/tmdl-guidancemanual04.pdf

MPCA. 2007b. Turbidity TMDL Protocols and Submittal Requirements. Accessed December 13, 2007 at http://www.pca.state.mn.us/publications/wq-iw1-07.pdf.

Mooers, H.D., and Wattrus, N.L., 2005. Results of Deer Creek Groundwater Seepage Investigation Report to Carlton County Planning and Zoning Department, 29p.

Mossberger, I.G. 2010. Potential for Slumps, Sediment Volcanoes, and Excess Turbidity in the Nemadji River Basin. M.S. Thesis. University of Minnesota.

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NRCS, 1998a. Nemadji River Basin Project Report. USDA Natural Resources Conservation Service, St Paul, MN.

NRCS, 1998b. Appendix F—Sediment Budget Process. In: Nemadji River Basin Project Report.

USDA Natural Resources Conservation Service, St Paul, MN.

Riedel, M. S., Brooks, K. N., Verry, E. S. 2006. Stream Bank Stability Assessment in Grazed Riparian Areas. Proceedings of the Eight Federal Interagency Sedimentation Conference (8th FISC), April 2-6, 2006 Reno, NV.

Riedel, M. S., Verry, E. S., Brooks, K. N. 2005. Impacts of lake use conversion on bankfull discharge and mass wasting. Journal of Environmental Management. 76 326-337.

U.S. Environmental Protection Agency. 1999. *Protocol for Developing Sediment TMDLs, First Edition* EPA 841-B-99-004. Washington, D.C.

Appendix A

Deer Creek Watershed Total Maximum Daily Load Report: Turbidity Impairments

Annotated Bibliography

Anderson J (2002)

Estimated the load from the Nemadji River to Lake Superior was 6.5 times larger than all of the Minnesota's North Shore Lake Superior streams combines.

http://www.pca.state.mn.us/publications/reports/ls-ributarystreamassessment-2002.pdf

Andrews SC, Christensen RG, Wilson CD (1980) Impact of nonpoint pollution control on western Lake Superior. Red clay project final report part III. USEPA report 905/9-76-002, Washington, D.C.

Summarized monitoring data collected at Elim, Skunk and Deer Creeks. The report found that suspended sediment transported by the streams averaged around 70% clay, 27% silt and 3% sand. Bed material collected during low flow at Deer Creek consisted mainly of fine sand. In Deer Creek dissolved solid concentrations decreased with higher flows, however, concentrations of suspended solids, total nitrogen, total phosphorus, and bacteria increased with higher flows.

Baird and Associates (2000), Nemadji River Basin Sediment Transport Modeling for Two Subwatersheds. Prepared for USACE, Detroit MI.

A comprehensive sediment budget completed as part of the Nemadji River Basin Project (1998) determined that 98% of the sediment yield from the Nemadji Basin is derived from the erosion of the valley walls. In addition, the sediment delivery ratio (SDR) was found to be almost 98% – indicating almost all of the sediment that is eroded along the Nemadji Basin tributaries is transported to the mouth of the river. Forestry and timber harvesting practices may have had an impact upon this erosion. The turbidity in the river and dredging in the mouth have an impact on fishing and other recreational uses. A tool to assess the implication of land use planning and the merits of remedial measures is required. This report describes the development of a watershed based sediment transport model and addresses this requirement. It consists of hydrologic, hydrodynamic, erosion and sediment delivery models. Deer Creek and Skunk Creek were used for the models.

Banks G, Brooks K (1996) Erosion–sedimentation and nonpoint pollution in the Nemadji Watershed: status of our knowledge. University of Minnesota, Department of Forest Resources, St Paul

This report concluded that the root cause of turbidity in the upper Nemadji River is driven by erosion of inorganic cohesive-sediment banks consisting of lacustrine clays and mixed clay till (clay-silt-very fine sands). Soils mass movement, bluff and streambank erosion contribute the largest load of sediment to the Nemadji River and Lake Superior harbor.

Kemp, A.L.W., Dell, C.I., Harper, N.S., 1978. Sedimentation rates and a sediment budget for Lake Superior. J. Great Lakes Res. 4 (3–4), 276–287.

Sedimentation rates were calculated at 10 offshore locations in Lake Superior. Sedimentation rates in the Nemadji River basin were found to have increased from 0.89 mm/year during pre-historic post glacial period to 2.00 mm/year from 1890 to 1955.

Kingston, J.C., Engstrom, D.R., Swain, E.B., 1987. A paleolimnological record of human disturbance from the St Louis River estuary, Lake Superior. In: Proceedings of the 30th Annual Conference on Great Lakes Research, International Association of Great Lakes Research, May 11–14, 1987, A–35.

This report published results from sediment core analysis in the St. Louis River estuary. Using sediment cores it was determine that the rate of alluvial sediment deposition has increased in the past 150 years coinciding with intensive forest harvesting across the St. Louis and Nemadji watersheds.

Koch, R.G., Kapustka, L.A., Koch, L.M., 1977. Presettlement vegetation of the Nemadji River Basin. J. Minn. Academy Sci. 43, 19–23.
In the Mid 1800s the Nemadji Basin was dominated by vast stands of White Pine and Red Pine. Following logging, deciduous forests dominated by quaking aspen replaced the pine forests. The change in landuse would be expected to increase water yield.

Magner, J. A. and Brooks, K. N. (2007) *Predicting stream channel erosion in the lacustrine core of the upper Nemadji River, Minnesota (USA) using stream geomorphology metric.* Environmental Geology. 54(7) 1423-1434
Conclusions from this report included the following: "First, a limited supply of aggradable sediment (larger than clay size particles) will need to be transported from the beach ridge and moraine and accumulate in widened streambeds to reconnect channels to active floodplains. Second, high risk streams will need to erode from their current mean bankfull width, measured in 2001, 5-to-10 times assuming the base elevation of the channel remains stable and climate does not change. Third, mass wasting of bluff and bank material will need to occur until the valley beltwidth becomes several times larger than bankfull channel width. Fourth, the cohesive nature of the lacustrine clay-rich sediment will resist erosion except where fractures/conduits exist due to ground water discharge. Ground water discharge via factures will create weak zones of shear and the formation of a friction angle (the friction angle is a failure plane angle within the bluff/bank). Time and associated weathering, change in soil moisture content, increased bluff/bank height, and the gravitational forces of vegetative weight will cause bank failure. This suggests that mass wasting may always occur in the Nemadji River basin because pore pressures associated with ground water discharge will spatially change with mass wasting." This overall conclusion is that future bank erosion in the Nemadji River basin must occur before the channel can reach a stable form. The system will likely remain in fluvial disequilibrium well into the 22nd century.

Magner, Joe (2004) Channel Stability Monitoring in the Nemadji River Basin.
Established new study sites in addition to Riedel 1998. Concluded the following: "1. The cohesive nature of the red clay will resist erosion except where fractures or other weak shear zones exist due to ground water discharge. 2. The mass wasting of bank soil will need to occur until the valley beltwidth becomes several times larger than the bankfull channel width (Rosgen, 1994). Based on data in table 1, streams will need to erode 6-to-10 times their current bankfull width, assuming the base elevation remains stable and the climate does not change. 3. Additionally, a supply of aggradeable sediment (not clay size particles) will need to accumulate in the overwidened streambeds to build new active floodplains." Also stated that climate appears to be moving towards wetter conditions. Cause channel base elevations of the Nemadji system to down cut. Drive a new array of knickpoint migration throughout the basin.

Mooers, H, Wattrus, N. (2005) Results of Deer Creek Groundwater Seepage Investigation. Report to the Carlton County Planning and Zoning
This report summarizes the results of an investigation of groundwater seepage along a reach of Deer Creek, Carlton County, Minnesota. The groundwater seepage is causing excessive turbidity, which affects all aspects of stream ecology and contributes large amounts of sediment to the Nemadji River. The report does not conclusively state the cause of the seepage, but theorizes that the increased pores water pressure from the formation of a beaver pond lead to the failure of the clay by rotational slumping. This failure started a positive feedback system between dewatering and loss of aquifer material leading to volume loss and further slumping. The report concluded that the most reasonable solution is to leave the system as is so it can reach equilibrium between forces causing rotational failure and resisting forces stabilizing the clay.

Mossberger, I. G. (2010) Potential for Slumps, Sediment Volcanoes, and Excess Turbidity in the Nemadji River Basin. PhD Thesis. University of Minnesota Duluth.
This thesis discusses the formation of the sediment volcano in Deer Creek theorizing that the rapid pond drainage of the beaver pond and/or disturbances from explosives used to remove the beaver pond lead to the fracturing of a glacio-lacustrine clay confining layer over a locally extensive aquifer. Sediment erosion in the Nemadji River watershed is a natural process that has been accelerated since settlement in the last 200 years.

NRCS, 1998a. Nemadji River Basin Project Report. USDA Natural Resources Conservation Service, St Paul, MN.
This report concluded that the Nemadji river basin transports an average of 120,000 tons of sediment to Lake Superior annually. The vast majority of sediment leaving the Nemadji is from mass wasting. Watershed scale conversion of coniferous forest to agricultural land uses likely exacerbated mass wasting by increasing water yield, runoff and soil moisture. The Nemadji basin yields 42% of its annual precipitation as discharge which is among the highest in state of Minnesota approaching bedrock soils regions along North Shore. Subwatersheds in the Nemadji River basin have peak flow frequencies exceeding those of many similarly sized watersheds within the agricultural Minnesota River Basin.

NRCS, 1998b. Appendix F—Sediment Budget Process. In: Nemadji River Basin Project Report. USDA Natural Resources Conservation Service, St Paul, MN.
Max sediment yields of tributaries in the Nemadji river basin range between 200 to 80 metric tons/km^2 per day. The represents the highest annual average sediment loading per unit area of all the USGS gauged watersheds in Minnesota and Wisconsin. 90% of the sediment is generated through mass wasting and channel incision.

Queen LP, Brooks KN, Wold WL (1995) Assessing cumulative effects in the Nemadji River Basin, Minnesota. In: Watershed Management—planning for the 21st century, pp 239–249, Watershed Management committee of the Water Resources Engineering Division/ASCE, August 14–16, San Antonio
This report found that natural background rates of erosion and sediment transport in the Nemadji River basin have been accelerated by human activity.

Riedel, M. S., Brooks, K. N., Verry, E. S. (2006) Stream Bank Stability Assessment in Grazed Riparian Areas. Proceedings of the Eighth Federal Interagency Sedimentation Conference (8th FISC), April 2-6, 2006 Reno, NV.
Grazed riparian stretches were investigated along Deer Creek under a variety of cattle traffic scenarios over a 3 year period. In the Deer Creek watershed natural land cover of coniferous forest riparian areas were commonly converted to pasture by late 1800s. This article found that grazing significantly reduced stream bank stability. The cohesive strength of the lacustrine clay channels was generally sufficient to maintain stable channel geometry in ungrazed streams. The stream bank materials in the areas studied were generally stable from fluvial erosion. Hoof shear from cattle traffic had largest impact on steam bank stability. Instability of the stream banks only occurred with the removal of riparian vegetation and subsequent bank erosion caused by cattle traffic. Stabilization of cohesive clay stream banks in the region may be accomplished by simply excluding cattle.