Poplar River Turbidity Assessment

Task Order No. 2006-36

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Table of Contents

List of Tables

List of Figures

List of Acronyms

AUAR	Alternative Urban Areawide Review
CFS	Cubic Feet per Second
DNR	Minnesota Department of Natural Resources
FNU	Formazin Nephelometric Units
GIS	Geographic Information Systems
LA	Load Allocation
LDC	Load Duration Curve
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
NRRI	Natural Resources Research Institute
NTRU	Nephelometric Turbidity Ratio Unit
NTU	Nephelometric Turbidity Unit
NWIS	National Water Information System
QAPP	Quality Assurance Project Plan
RTI	Research Triangle Institute
TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geologic Survey
WEPP	Water Erosion Prediction Project
WLA	Waste Load Allocation

Executive Summary

The lower Poplar River is listed as impaired due to exceedances of its 10 NTU turbidity standard. Sampling data demonstrate that exceedances occur frequently at flows greater than 68 Cubic Feet per Second (CFS); the 40% highest flow. Turbidity measurements are highly correlated to sediment measurements, indicating that fine sediment fractions are likely the primary cause of turbidity within the lower Poplar River.

Section 303(d) of the Clean Water Act and Chapter 40 of the Code of Federal Regulations Part 130 require states to develop Total Maximum Daily Loads (TMDLs) for waters not meeting designated uses under technology-based controls for pollution. The TMDL process quantitatively assesses the impairment factors so that states can establish water-quality based controls to reduce pollution and restore and protect the quality of their water resources. A TMDL quantifies the amount of a pollutant a water body can assimilate without violating a state's water quality standards and allocates that load capacity to known point and nonpoint sources in the form of wasteload allocations, load allocations, a margin of safety, and natural background conditions. The margin of safety accounts for uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. Conceptually, this definition is represented by the equation:

$$TMDL = \Sigma WLAs + \Sigma LAs + MOS$$ **Equation E1**

Where:

TMDL =	Total Maximum Daily Load (may be seasonal, for critical conditions, or have other constraints)
WLA =	Waste Load Allocations (point source)
LA =	Load Allocations (non-point source)
MOS =	Margin of Safety (may be implicit and factored into a conservative WLA or LA, or explicit)

This report provides a summary of information, results, and recommendations related to the turbidity impairment based on an analysis of water quality data, watershed modeling, and a physical stream assessment. This report presents and explains: 1) The current status of the turbidity problem in the Poplar River, 2) Historical and current sources of turbidity, including natural sources, and 3) Recommendations concerning appropriate loading of turbidity into the Poplar River to achieve water quality standards, including a loading capacity and allocations for point and nonpoint sources.

A variety of technical approaches and analyses were used to evaluate turbidity and Total Suspended Solids (TSS) sources in the Poplar River watershed. Water quality modeling, a physical channel assessment, and various statistical techniques were used to cover a range of project needs related to defining the source, nature, frequency, and magnitude of sediment loading in the river. The Load Duration Curve (LDC) approach plots flow and observed data to analyze the flow conditions under which excursions to the water quality standard occur and, for this project, was used to: 1) Provide a visual representation of streamflow conditions under which turbidity exceedances have occurred, 2) Assess critical conditions, 3) Identify potential sources of turbidity, and 4) Quantify the level of TSS reduction necessary to meet the surface water quality criteria for turbidity in the river. Table E1 provides the loading capacity for each flow zone as defined by the LDC approach. Given the nature of the LDC approach and that annual loading can vary significantly from year to year, the daily loading estimates provided in Table E1 should be considered gross estimates.

Table E1 Loading Capacity for Each Flow Zone Based on the LDC Approach

	Flow Zone				
	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Flow Interval (CFS)	> 260	260 – 68	68 – 41	41 – 18	< 18
Flow Interval (%)	0 – 10%	10 – 40%	40 – 60%	60 – 90%	90 – 100%
TMDL Capacity (lbs/day)	25,297	7,532	3,281	1,904	736
MOS (lbs/day)	8,408	3,135	609	712	722
Waste Load Allocation	106	106	106	106	NA[2]
Load Allocation (lbs/day)[1]	16,783	4,291	2,566	1,086	14

[1] Allocation is equal to the capacity less MOS.
[2] The permit for Caribou Highland's wastewater discharge does not specify discharge based on flow; however, it does specify that discharge may only occur during months when flow in the river provides sufficient dilution.

Analysis of the TSS data collected at the two stations on the lower Poplar River indicates that:

- 68% to 85% of the TSS load measured near highway 61 (station number S000-261) is originating from the lower Poplar River watershed.
- 51% of the turbidity exceedances (observed turbidity > 10 NTU) occur during the highest 10% of flows (i.e. flows greater than 260 CFS).
- 73% of turbidity exceedances occur during the 40% highest flows (i.e. flows greater than 68 CFS).
- 55% of the total sediment load reaches the stream during April and May of each year, indicating that a distinct seasonal trend is present.

The results of the data analyses, described above, suggest that the primary sources contributing to elevated levels of turbidity in the lower Poplar River originate from the lower watershed, are associated with high flow events, and are most prevalent during the spring.

In an effort to better understand and quantify sources of sediment in the lower Poplar River that likely contribute to elevated turbidity measurements, computer modeling and a geomorphological assessment were conducted to complement the data analyses conducted. The computer modeling was used to predict sediment loading from upland erosion and the geomorphological assessment looked at "near channel" sources. Nine distinct sources of sediment were identified during the physical channel assessment and computer modeling and quantified. These sources include:

Upland Sediment Sources

- Surface erosion from slumps
- Incision along valley slopes (erosion gullies and ravines)
- Localized erosion within the river valley related to land-use alteration, such as,
    - Ski Runs (including bare trails and roads)
    - Golf Course areas
    - Developed area
- Natural forested area

Near Channel Sediment Sources

- Channel bed incision
- Sudden channel migration (e.g., meander cut-off, channel avulsion, etc)
- Streambank erosion, such as the river impinging on a slump

Analysis of these sources indicated that the upland sources are most likely to occur during precipitation events when there is little vegetative cover and/ or when the ground is saturated. Soil particles are detached from the soil matrix and transported to the river via overland flow. Near stream sources likely occur when flow and stage are high and the stream impinges on the barren valley walls aggravating slumping and/ or mass wasting of existing slumps. Table E2 reports the estimated average, minimum, and maximum loads from each source and its percent contribution to the total load. While combining the upland and near channel sediment estimates may be somewhat of an "apples" to "oranges" comparison based on the different time periods they were derived from (e.g. the modeling averages loading estimates predicted from a 5 year long simulation and the near channel assessment was based on observations and photographs spanning decades) it is the best estimate available, and provides a quantitative comparison of all identified sources.

Table E2 Estimated Sediment Sources Contributing to Turbidity in the Lower Poplar River Watershed

Source	Median Sediment Load		Minimum Sediment Load		Maximum Sediment Load	
	Ton/year	%	Ton/year	%	Ton/year	%
Channel Incision	53	3%	18	2%	88	3%
Megaslump	522	26%	307	31%	737	25%
Other Landslides	204	10%	121	12%	287	10%
Golf	15.2	1%	7.6	1%	22.8	1%
Developed	25.2	1%	12.6	1%	37.8	1%
Ski Runs, Trails, and Roads	661	33%	330	33%	991	33%
Forest	280	14%	140	14%	421	14%
Gullies/ Ravines	225	11%	50	5%	400	13%
Total	1985		986		2983	

As previously discussed, one method of estimating the load reductions required to meet the water quality criteria utilizes the LDC. This approach is described in more detail in Section 6 and has been used previously by the Minnesota Pollution Control Agency (MPCA) to establish load targets (TMDLs) (MPCA, 2007a). The LDC approach applied to the Poplar River data set results in large percent reductions to the existing loads under high and mid-range flow conditions. Table E3 reports the percent reduction required for the flow ranges associated with the watersheds "critical conditions" flow zones are 89% (High Flows), 68% (Moist-Conditions) and 89% (Mid Range Flows).

Table E3 Loading Capacity and Required Reductions for Each Flow Zone Based on the Load Duration Curve (with MOS) Approach

	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Flow Interval (CFS)	> 260	260 – 68	68 – 41	41 – 18	< 18
Flow Interval (%)	0 – 10%	10 – 40%	40 – 60%	60 – 90%	90 – 100%
% Reduction Needed	89%	68%	89%	3%	None

The estimated reductions required to meet the 10 NTU water quality criteria are fairly large; however, they are consistent with TMDLs conducted for other Minnesota Rivers (MPCA, 2007a). When compared to the estimated loads (Table E2) they indicate the possibility that the standard may not be met during some loading events; however, the uncertainties in the load estimates are large enough that we can not conclude that the standard is not achievable.

The estimated loads reported in Table E2 were developed via field investigations and computer modeling. Thus, there are limits to their accuracy and uncertainty related to the magnitude and frequency of sediment load from these sources. For example:

- An annual average load is reported for each source; however, the load from these sources likely varies significantly from year to year.

- A known weakness of the Water Erosion Prediction Project (WEPP) computer model is that it may over predict loads at the watershed scale.
- Reported accuracy of the WEPP computer model is 50%

The water quality criteria of 10 NTU is linked to the designated life use for the river. While often conceptualized as a numeric criteria that must be met under all conditions, it is feasible that the aquatic life present in the river can thrive with limited excursions (short durations and limited magnitudes) above the criteria. However, if a site specific standard is eventually considered it would at most be set at the “natural” level. Hence, control of anthropogenic sources would still be required.

1 Introduction

The primary purpose of this report is to integrate results of the data analysis, watershed modeling and physical stream assessment components of this project into a single concise summary document. This report consolidates information, results, and recommendations from deliverables completed under this project to present and explain: 1) the current status of the turbidity problem in the Poplar River; 2) historical and current sources of turbidity, including natural sources; and 3) recommendations concerning appropriate loading of turbidity into the Poplar River to achieve water quality standards, including a loading capacity and allocations for point and nonpoint sources. Deliverables completed under this project are appended and are summarized in the following section.

1.1 Description of Deliverables Submitted

The Poplar River Turbidity Assessment project was initiated in October 2006 and included eight tasks:

- Quality Assurance Project Plan (QAPP)
- Summary of existing water quality data and information
- Evaluation of existing Water Erosion Prediction Project (WEPP) computer model
- Data assessment summary
- Additional characterization and estimation of turbidity impairment (WEPP computer modeling)
- Physical channel assessment
- Source identification summary (provided in this document)
- Poplar River Turbidity Assessment Report (this document)

A brief description of task objectives and significant conclusions follows.

Quality Assurance Project Plan

The QAPP (attached report titled "Quality Assurance Project Plan") provides a description of the work and outlines procedures for assessing existing water quality data, evaluating model results, and conducting the physical channel assessment. The purpose of the QAPP is to ensure that data collected, steps taken to collect and assess data, and reports developed as part of this project are scientifically valid and defensible. In addition, the QAPP addresses the use of secondary and third-party data collected by the United States Environmental Protection Agency (USEPA) for other purposes or collected by organizations not under the direction of USEPA to support the development of this Report. An extensive amount of data and information was gathered to diagnose causes of turbidity, quantify the level of existing impairment, and provide a foundation on which restoration activities may be identified and implemented. The QAPP sets forth objectives, responsibilities, protocols, procedures, and methods for obtaining and assessing data through a variety of methods.

Summary of Existing Water Quality Data and Information

The purpose of this task is to identify and describe existing water quality data and information available in the Poplar River watershed (attached report titled "Summary of Existing Water Quality Data and Information"). Specifically, data and information related to impairment of the river's designated uses, and water quality criteria that may be valuable during development of the turbidity source and loading analyses are summarized. Included in the summary are data sources, period of record, and existing data and information such as parameters analyzed, and the availability of results. Data sources considered for this task included: MPCA, Cook County Planning and Zoning Department, United States Geologic Survey (USGS), Lakesuperiorstreams.org, the University of Minnesota Library, and Soil and Water Conservation District of Cook County. This task is one of two tasks aimed at summarizing existing water quality data and information in the Poplar River watershed and was a preliminary step to the second data summary task, the Data Assessment Summary.

Evaluation of Existing WEPP Computer Model

In 2005, the Forest Service's simplified, on-line WEPP model was used to estimate sediment loads to the river (SE Group, 2005). The 2005 modeling was conducted for the portion of the lower Poplar River watershed known as the gorge to establish a link between potential sources of sediment in the gorge and instream turbidity measurements. The Poplar River Gorge is the area of steep relief adjacent to the river and covers approximately 274.9 acres. The computer modeling conducted by the Research Triangle Institute (RTI) Team included the entire lower Poplar River watershed which includes approximately 1,200 acres. Erosion modeling of the gorge area resulted in an average annual estimate of soil detachment; a rough estimate of sediment delivered to the Poplar River.

The RTI Team reviewed the existing WEPP model to assess inputs, results, and conclusions reported by Lutsen Mountain Resorts and their consultants (attached report titled "Evaluation of Existing WEPP Computer Model"). The review indicated that the WEPP model provides useful information about relative soil erosion and detachment within the Poplar River gorge area. The review also identified several concerns related to the use of the WEPP model for development of a Poplar River Total Maximum Daily Load (TMDL). Based on these concerns additional WEPP modeling was recommended.

Data Assessment Summary

This report provides an analysis of data within the entire Poplar River watershed with specific focus on the lower, impaired 2.73-mile portion of the river located between the

Superior Hiking Trail bridge (upstream station) and the confluence of the river with Lake Superior (attached report titled "Data Assessment Summary"). Data identified in the "Summary of Existing Water Quality Data and Information" report were analyzed to assess potential sources and key stressors of turbidity, temporal and spatial trends, the magnitude and frequency of turbidity criteria exceedances, the magnitude and frequency of discharges from sources, critical conditions, the geographic extent of water quality issues, and significant data gaps.

Additional Characterization and Estimation of Turbidity Impairment: WEPP Computer Modeling

To develop a more comprehensive understanding of the sediment detachment and transport mechanisms in the entire lower watershed at a finer spatial and temporal scale, additional complex computer modeling was conducted using a more detailed version of WEPP (Attached report titled "Additional Characterization and Estimation of Turbidity Impairment"). The modeling performed under this task utilized the WEPP model updated in 2006 (version 2006.5). WEPP was selected because of its ability to simulate sediment erosion and transport in a steep sloping, predominantly vegetated watershed. To assess how well the model represented conditions in the lower Poplar River watershed, model results were compared to observed loads and sensitivity analyses were conducted. The model was then used to compare sediment loading under four scenarios (pre-development, existing conditions, full build-out, and existing conditions with nonpoint source runoff controls), and develop distributions of annual sediment loading by land use type.

Physical Channel Assessment

The goal of the physical channel assessment study was to better understand the evolution and present condition of the overall stream system, identify the causes of turbidity, and estimate the stream related erosion areas and the relative contribution of suspended sediment from each major source. Field observations and measurements were focused on the stream itself, defined as the area of active flow area, and the stream valley, a much larger (i.e., wider and deeper) feature that evolved over geological time as a result of streambed incision.

The Physical Channel Assessment identified six potential localized sources of suspended sediment in the Lower Poplar River watershed to be channel bed incision, sudden channel migration (e.g., meander cut-off, channel avulsion, etc), streambank erosion, landslides (slumps) near active channel, incision along valley slopes (erosion gullies and ravines), and localized erosion within the river valley related to land-use alteration. Of these, landsides, incisions along valley slopes, and localized erosion were highlighted in the report as sources of greater concern in the Poplar River. Estimated annual average suspended sediment contributions from these three sources are provided in the report.

2 Watershed Assessment and Pollutant of Concern

2.1 Watershed Description

The Poplar River watershed is located in the Lake Superior Basin (northeast Minnesota) near Lutsen, MN (Figure 1). The entire watershed covers an area of approximately 114 square miles with a river distance of approximately 25.5 miles. The Poplar River originates at the Boundary Waters Canoe Area, Hilly Lake area, and ends at its confluence with Lake Superior. Its watershed includes the Tait Lake/Tait River, Pike Lake, and Caribou Lake (MPCA, 2002).

The upper watershed of the Poplar River is located on an elevated plateau. The typical elevation in the upper watershed is about 1,300 feet and the average stream gradient is less than 1 percent. The channel is relatively wide (100 feet or more) and characterized by wide meanders. Dense vegetation consisting of willows, reeds, and other hydrophilic grasses buffer the banks which show little signs of erosion. Impressive falls (rapids), approximately 150 feet high, mark the transition from the upper watershed to the lower watershed. Downstream of the headwaters area, the watershed narrows considerably as it flows over the escarpment. In this lower watershed area the gradient increases greatly and the channel is defined by bedrock, lacustrine beach, and glacial deposits. These most downstream portions of the Poplar River and watershed are characterized as having significant drops in elevation with an average gradient of nearly 4% and containing both forested and cleared steep slopes. For the purposes of this report, the "Lower Poplar River" will describe the watershed area downstream of the Superior Hiking Trail Bridge.

Predominant soil groups in the watershed include Dusler-Duluth and Rock outcrop-Quetico-Barto. Predominant land uses include forest (77%), ski runs (14%), golf course area (4.8%), and other developed area (3%). A detailed description of soils, land use/cover, climate, and topography is provided in Section 4 of the WEPP modeling report (attached report titled "Additional Characterization and Estimation of Turbidity Impairment").

2.2 General Stream Characteristics

The Lower Poplar River has more in common with mountain streams than with the typical lowland streams of the Midwest. Like many of the mountain streams, the Lower Poplar River does not fall into a general category of braided or meandering streams. A sharp change in bed elevation is noticeable near the mouth where a succession of falls is present (upstream and downstream of Highway 61). Upstream from these falls, the average longitudinal slope is approximately 0.03 (3 percent) and the general shape is flat or slightly convex up. Such longitudinal shapes are common in cases of relatively young rivers developed in glacial valley. Given this, it is fitting to use the process based channel-reach classification of mountain streams of Montgomery and Buffington (1997).

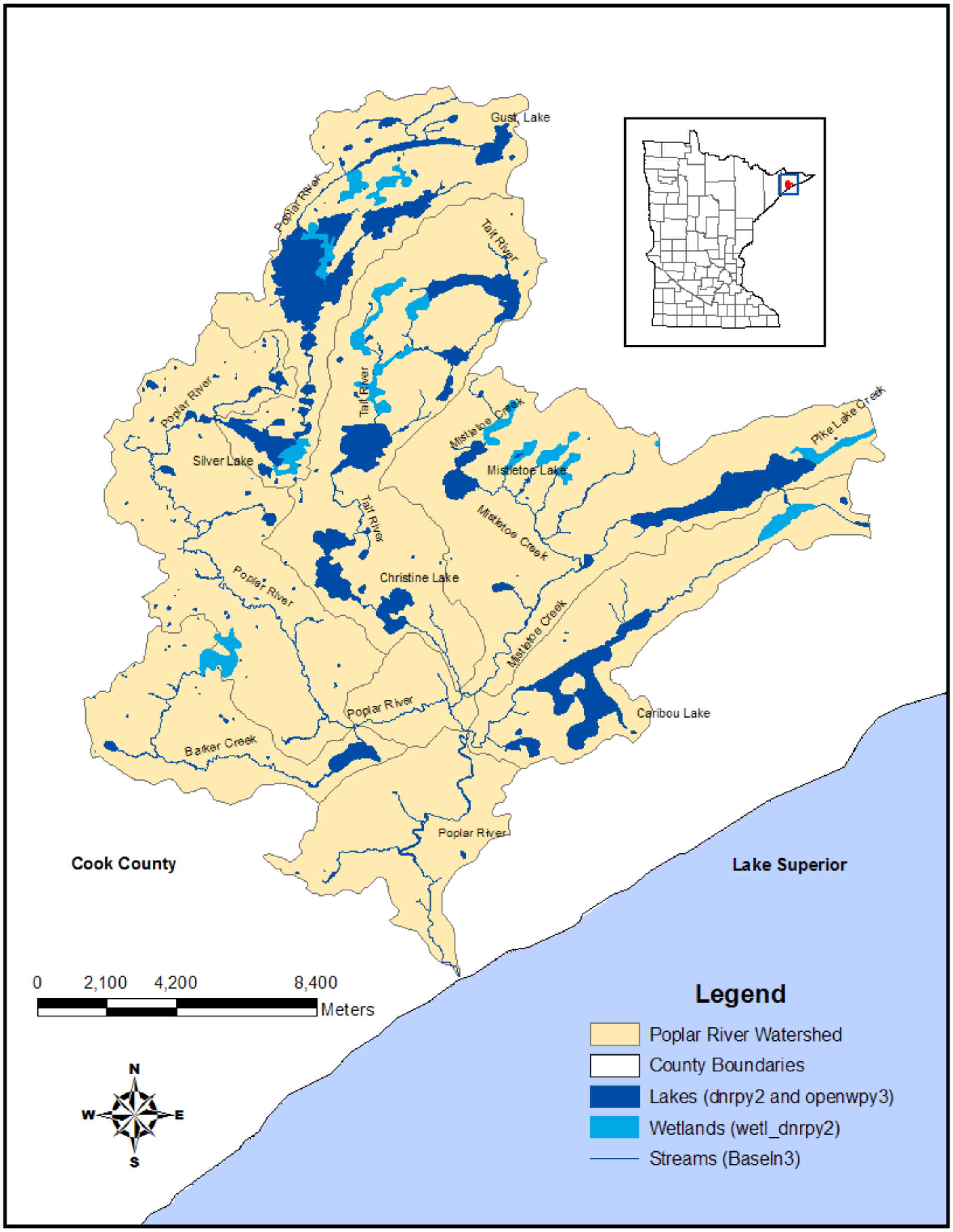

Figure 1 Poplar River Watershed

The authors identify seven types of channel reaches that are commonly encountered in mountain drainage basins: bedrock, cascade, step-pool, plane-bed, pool-riffle, dune-ripple, and colluvial. These channel reach types can be found in progression in many of the mountain streams. In the case of the Lower Poplar River, four of these channel reach types, namely bedrock, cascade, plane-bed, and step-pool were identified. An explanation of each of these four channel reaches is provided in the Physical Channel Assessment Report (Attached report titled "Physical Channel Assessment").

The Lower Poplar River flows through a valley that is approximately 120 to 250 feet deep and 500 to 1000 feet wide. The average side slopes of the valley (where many of the ski trails are located) vary between 10 and 25 degrees (18% to 50%). The valley near the golf course is, however, less steep and varies in width from 100 to 400 feet. The channel lacks a well defined floodplain and, for the most part, is confined by the topography of the valley. In some places, one side of the channel is flanked directly by the valley slopes. In other places, however, valley is sufficiently wide and flat and it could be looked upon as a narrow floodplain. The channel displays some lateral mobility and several entrenched meanders have developed as result.

2.3 Pollutant of Concern

Turbidity is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended organic and inorganic particles. In streams, turbidity refers to the cloudiness of the water due to the presence of suspended particles such as silt and clay, dissolved solids, stains, microscopic organisms, and other organic matter. These materials can originate from natural sources as well as from human activities. In the case of suspended sediment, the supply of suspended sediment to a river system is controlled by the characteristics of the soils in the catchment and the erosion and transport mechanisms in the watershed. While some level of turbidity is a function of a stream's natural processes, activities which result in increased erosion, exposure, or transport of sediment to the stream will likely cause increased turbidity. Excessive turbidity, whether through natural processes or human-induced activities, can result in a number of physical, chemical, and biological impacts to a river. In a waterbody like the Poplar River, the most significant and direct impacts can include:

- Alteration of the substrate composition, clogging channel bed interstices and reducing habitat space for small fish and invertebrates
- Marginal changes to the instream channel morphology, and general habitat availability
- Reduction to the permeability of the bed material
- A decline in the intergravel concentration of dissolved oxygen
- Reduction in the depth of light penetration into the water column, thereby decreasing rates of photosynthetic activity and thus primary productivity in submerged plants
- Physical damage to leaf surfaces by abrasion and by smothering

- Interference with the behavior, feeding, and growth of fish from reduction/ changes to the invertebrate population
- Damage to fish gills by abrasion (hyperplasia) and clogging
- Increase of fish disease
- Increased surface water temperature

Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but has also been measured in Jackson Turbidity Units (JTU) or Formazin Nephelometric Units (FNU). With the addition of new measurement technologies over the years, there can be differences in meter types and configurations that will result in different turbidity values. The USGS has developed a table of reporting categories providing for type and configuration specific turbidity values (i.e., NTU, Nephelometric Turbidity Ratio Unit (NTRU), FNU, etc.) (Anderson 2005).

3 Background Information and Existing Studies

The Poplar River watershed has been, and continues to be, the focus of a variety of watershed, water quality, and biological studies. Table 1 provides a partial list of recent studies, both completed and in-progress, with the intent to bring attention to the valuable work that has been produced or is being produced by various agencies and entities in Minnesota. Additional information for several of these reports is available at: http://lakesuperiorstreams.org/general/reports_NShore.html.

Table 1 Partial List of Completed and Ongoing Reports and Studies in the Poplar River Watershed

Project Status	Report Title, Date, Authors, and Agency[1]
Ongoing	*Slope Stabilization Work Plan for Poplar River Management Board*. 2007. Minnesota's Lake Superior Coastal Program. Prepared by North American Wetland Engineering, LLC (NAWE), Draft Report. January 18, 2007.
Ongoing	*2006 Automated, in situ, Water Quality Data: Preliminary Analysis*, February 20, 2007. Axler, R., Henneck, J., Ruzycki, E., Will, N. Center for Water & the Environment, Natural Resources Research Institute, University of MN-Duluth.
Ongoing	*Biological Sampling for the Poplar River*. Center for Water and the Environment, Natural Resources Research Institute, University of Minnesota Duluth, Dan Breneman, Valerie Brady, and Lucinda Johnson. Work conducted through the Cook County Soil and Water Conservation District. Project period: Feb 2007 – Nov 2008.
Completed	*Summary of E coli test results for the Poplar River 2005 and 2006*, Stark, D., September, 2007. Cook County Soil & Water Conservation District.
Completed	*LakeSuperiorStreams: Community Partnerships for Understanding Water Quality and Stormwater Impacts at the Head of the Great Lakes*, 2005. lakesuperiorstreams.org. University of Minnesota-Duluth, Duluth, MN.
Completed	Environmental Report, 2005. Prepared for Lutsen Mountain, Cook County, Minnesota. Prepared by North American Wetland Engineering, P.A. (NAWE) and SE Group. October 18, 2005.
Completed	*Preliminary Summary, Poplar River Impairment Study*. Memorandum to Charles Skinner. Prepared by SE Group. October 13, 2005.

[1] This table provides a partial list of reports and surveys and is not intended to be an exhaustive list.

4 Applicable Water Quality Standards

Section 303(d) of the Clean Water Act and Chapter 40 of the Code of Federal Regulations Part 130 require states to develop TMDLs for waters not meeting designated uses under technology-based controls for pollution. The TMDL process quantitatively assesses the impairment factors so that states can establish water-quality based controls to reduce pollution from both point and nonpoint sources, and to restore and protect the quality of their water resources.

Minnesota's Surface Water Quality Standards provide information on beneficial uses assigned to waterbodies, numeric and narrative standards for pollutants, and non-degradation provisions assigned to high-quality and unique waters. Minnesota Rules, Chapter 7050.0470, identify classifications for waters in major surface water drainage basins, including those applicable in the Poplar River. Per Chapter 7050.0470, classifications applicable to the Poplar River include Classes 1B, 2A, and 3B. The turbidity standard associated with each of these Classes is provided in Table 2. Of the three, Class 2 is the most restrictive and applicable Class and will be used as the water quality target in this report.

Table 2 Turbidity Standards Associated with Water Classifications 1B, 2A, and 3B

Water Classification	Minnesota Rules, Chapter	Turbidity Standard (NTU)
Class 1B	7050.0221, subpart 3	Not applicable
Class 2A	7050.0222, subpart 2	10 NTU
Class 3B	7050.0223, subpart 3	No Turbidity Standard

Assessment of Impairment

In 2004 a portion of the Poplar River in the Lake Superior Basin was listed on Minnesota's 303(d) list of impaired waterbodies. The impaired segment (Assessment Unit ID: 04010101-613) includes a 2.73-mile segment of the Poplar River from Superior Hiking Trail bridge to Lake Superior (Figure 2). In 2008, both the turbidity and mercury impairments in this portion of the Poplar River were carried through on the Draft 2008 303(d) list of impaired waterbodies. The impaired segment and related listing information from Minnesota's draft 2008 303(d) list are provided in Table 3. Although the 2008 List includes both turbidity and mercury as pollutants of concern, this report will address turbidity only.

Table 3 Poplar River Impaired Segment in Minnesota's Draft 2008 303(d) List

Reach	Description	Year Listed	River ID#	Affected Uses	Pollutant/ Stressor
Poplar R.	Superior Hiking Trail bridge to Lake Superior	1998	04010101-613	Aquatic consumption	Hg Water Column
Poplar R.	Superior Hiking Trail bridge to Lake Superior	2004	04010101-613	Aquatic life	Turbidity

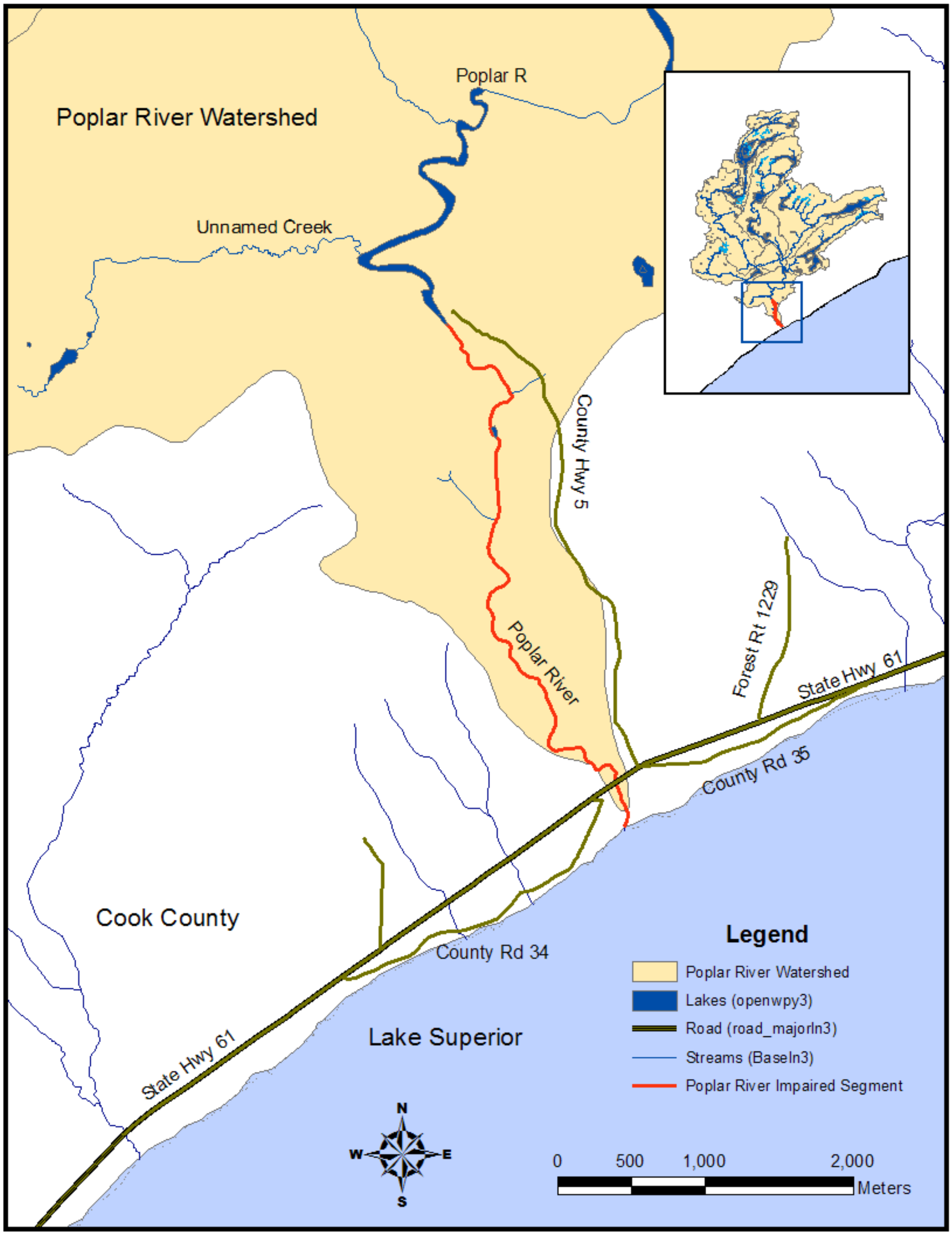

Figure 2 Lower Poplar River Watershed Showing 2.73-Mile Impaired Stream Length. GIS Information Obtained from the DNR Data Deli Online at http://deli.dnr.state.mn.us/index.html

5 Source Identification Summary

5.1 Information used to Complete the Source Assessment

A variety of technical approaches and analyses were used to evaluate turbidity and TSS sources in the Poplar River watershed. The approaches outlined in this section cover a range of project needs related to defining the source, nature, frequency, and magnitude of sediment loading in the river. Sources of existing water quality, streamflow, soil survey, modeling, and meteorological data used to assess turbidity in the Poplar River are provided in Table 4. Technical and statistical approaches applied by the project team, and the intended purpose of each approach in this project, are provided in Table 5.

Table 4 Existing Data Used to Support the Assessment of Turbidity and TSS Sources in the Poplar River Watershed

Data Category	Source
Water quality data	MPCA - Environmental Data Access database
Streamflow data	USGS - Poplar River at Lutsen, MN gage station (04012500)
Streamflow data	MPCA - Poplar River near Lutsen, MN station (01101001)
Soil Survey Information	Soil Survey of North Shore of Lake Superior Coastal Zone Management Area 1977 USDA SCS & MN Ag and NRCS STATSGO
Water quality data	MPCA - Poplar River flow, stage, turbidity data, and maps that are processed and no longer provisional status
Model Results	North American Wetland Engineering and SE Group, Environmental Report for Lutsen Mountain, Cook County, Minnesota, Report for Lusten Mountain Resort
Meteorological data	Climatology Working Group, University of Minnesota
Land use/cover data, Soil data	Minnesota Department of Natural Resources (DNR) Data Deli

Table 5 Technical Approach or Analysis Used for Source Assessment

Analysis or Technical Approach	Project Purpose
Correlation coefficients, linear regressions, and simple statistics	Relationship between turbidity and other water quality parameters
	Assess variability between turbidity methods
	Relationship between TSS and flow
	Estimate streamflow in the Poplar River during 1976-2001
	Snowmelt and snow pack influence on sediment loading
Cumulative frequency histograms.	Poplar River temporal and spatial trends and assesses the use of Pigeon River gage data in estimating Poplar River streamflow (1976-2001).
Drainage Area Ratio method	Estimate flow at upstream monitoring station
U.S. Army Corps of Engineers FLUX model	Seasonal and annual loading estimates at the upstream and downstream locations
	Evaluate average monthly load at upstream and downstream stations
	Evaluate sediment load originating in Lower Poplar Watershed area.
	Critical conditions

Analysis or Technical Approach	Project Purpose
Load duration curve	Provide a visual representation of streamflow conditions under which turbidity exceedances occur
	Assess turbidity conditions under different flow conditions, including the rise and fall of the hydrograph, duration and magnitude of water quality criteria exceedances, seasonality, and critical conditions
	Assess snowmelt, event runoff, and base flow contributions to flow and turbidity levels
	Identify potential sources of turbidity by the conditions under which they occur
	Calculate TSS loads
WEPP 2006.5 modeling	Assess upland sources of sediment
	Assess sediment loading under four scenarios: pre-development conditions, current conditions, current conditions with nonpoint source runoff controls, and build-out conditions.
	Comparison of total and average simulated and observed sediment loads (annual and monthly)
	Assess critical conditions
	Land use contributions of sediment
	Long-term sediment load analysis
Stream cross section measurements, width/ depth measurements, photographs, soil and substrate characteristics, and vegetation observations	Identify and quantify the primary sources and processes responsible for suspended sediment in the system
	Understand the evolution and current condition of the stream channel
	Document locations of landslides and ravines and other erosion processes contributing sediment to the Poplar River
	Document grain size distribution
	Document visible signs of erosion
	Classify the river under Montgomery and Buffington (1997)

5.2 Data used for Current Conditions Analysis

Turbidity and TSS are the primary water quality constituents of concern in this project. Data for these parameters are available at three locations in the Poplar River watershed (station S000-753, LakeSuperiorStream project sonde located upstream of the State Highway 61 overpass, and station S001-261) through the United States Forest Service (USFS) – Region 9, Natural Resources Research Institute's (NRRI) LakeSuperiorStreams project, and MPCA monitoring programs.

The primary source of turbidity and TSS data in the Poplar are data collected by the MPCA at stations S000-753 and S001-261 through the Minnesota Milestone River Monitoring Program and North Shore Load Project. The Minnesota Milestone River Monitoring Program is MPCA's ambient water quality program. This program is a long term monitoring program with the goal of understanding the overall trend of water health in Minnesota. Water quality data collected in the Poplar River as part of the ambient program were collected periodically between 1973 and 1999 at station S000-261. The purpose of the North Shore Load Project is to assess current water quality conditions using state of the art monitoring techniques, provide baseline information for detection of water quality trends over time, and assist in the development of stream protection and remediation management options for public, private, and commercial interests.

Historic and recent streamflow data in the lower Poplar River are available through the USGS National Water Information System (NWIS) and DNR/ MPCA Cooperative Stream Gaging websites. Daily data are available between 1912 – 1968 and 2002 – 2006. Because streamflow is an important component in assessing sediment loading and turbidity impairment and developing the load duration curve, the RTI Team took steps to estimate flows for the 1969 – 2002 period missing from the flow record. Three USGS stations, each located in close proximity to the Poplar River station, were analyzed by the RTI Team as potential reference stations for the Poplar River. Based on the use of correlation coefficients and linear regressions, the Pigeon River at Middle Falls, Minnesota, was found to be the best source for estimating flow during periods when flow data are not available at the Poplar River near Lutsen, MN station.

Water quality and flow data are presented and discussed in the Data Assessment Report (attached report titled "Data Assessment Summary"). Historically, turbidity has been measured in the Poplar River using different types of meters but the measurements have been reported simply as NTU. Recent evaluations by the USGS of the various meters in use identified the need for separate reporting units for the different meter types and configurations (Pavelich 2002, Ankcorn 2003, Miller 2004, and Anderson 2005). The turbidity data for the Poplar River is present mostly in NTU and NTRU reporting units. A recent comparison of paired NTU and NTRU values, conducted by MPCA's Environmental Review and Technical Assistance Section, indicated that there was not significant difference between the two, such that the units are assumed to be equivalent in this report (Attached report titled "Evaluation of Paired Turbidity Measurements").

5.3 Water Quality Data Analysis

Turbidity was found to correspond closely with TSS at both the upper and lower stations. Correlation coefficients were found to be high between turbidity and total solids (0.98) and turbidity and TSS (0.97). Given these relationships, TSS is considered the most direct contributor to turbidity impairment in the Poplar River. A detailed discussion on the relationship between TSS and turbidity follows in section 5.4.

Streamflow was observed to play an important role in contributing to turbidity impairment. At the downstream station higher values of turbidity and greater concentrations of TSS were more frequent as flow increased. Turbidity standard exceedances were evident under dry conditions and mid-range conditions; however, the majority of exceedances during 2001 – 2006 occurred under moist conditions (68 – 260 CFS) and high flow conditions (260 – 1600 CFS) (Figure 3).

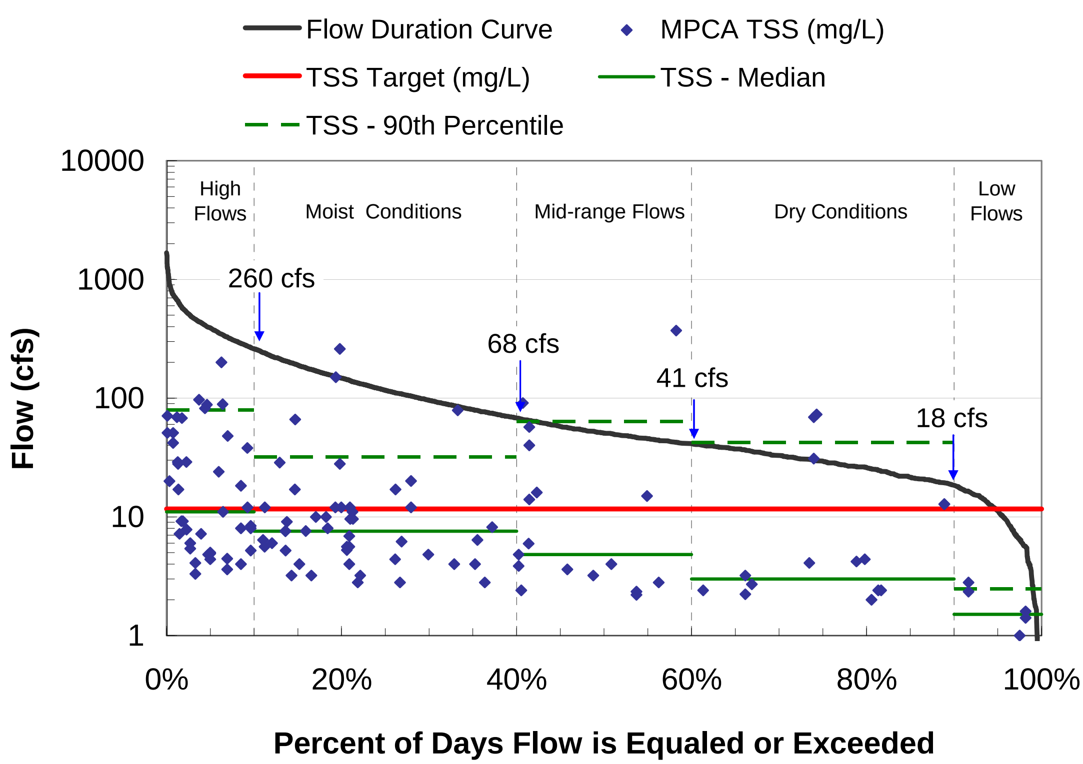

Figure 3 Turbidity Standard Exceedances as a Function of Flow Exceedance. The TSS Target Concentration (mg/L) is based on the Equivalent TSS Concentration for 10 NTU using a Linear Regression on 2002-2006 TSS and Turbidity Data

The Data Assessment report identified several key conclusions about the temporal and spatial extent of turbidity measurements and TSS concentrations. On a seasonal basis, TSS loads were found to be highest at the upstream station during the months of April and May and highest at the downstream location during April, May, and June. Turbidity values were found to increase significantly between the upstream and downstream stations during the spring and summer months. The lower Poplar River watershed was found to contribute 66-89% of the load observed at the downstream station between April and October. Using FLUX, annual TSS loading from the lower Poplar River was estimated to vary from 994 tons to 2,194 tons and from 68% to 85% of the total load estimated at the downstream sampling station. Turbidity exceedances were observed primarily under moderate and high-flow conditions with most exceedances occurring under flows greater than or equal to 60 CFS (60 CFS is equivalent to a flow recurrence interval of ~ 45% at the downstream station). Long term trends in turbidity at the downstream station, based on ambient data during 1973 – 2006, revealed no significant increasing or decreasing trend (Figure 4).

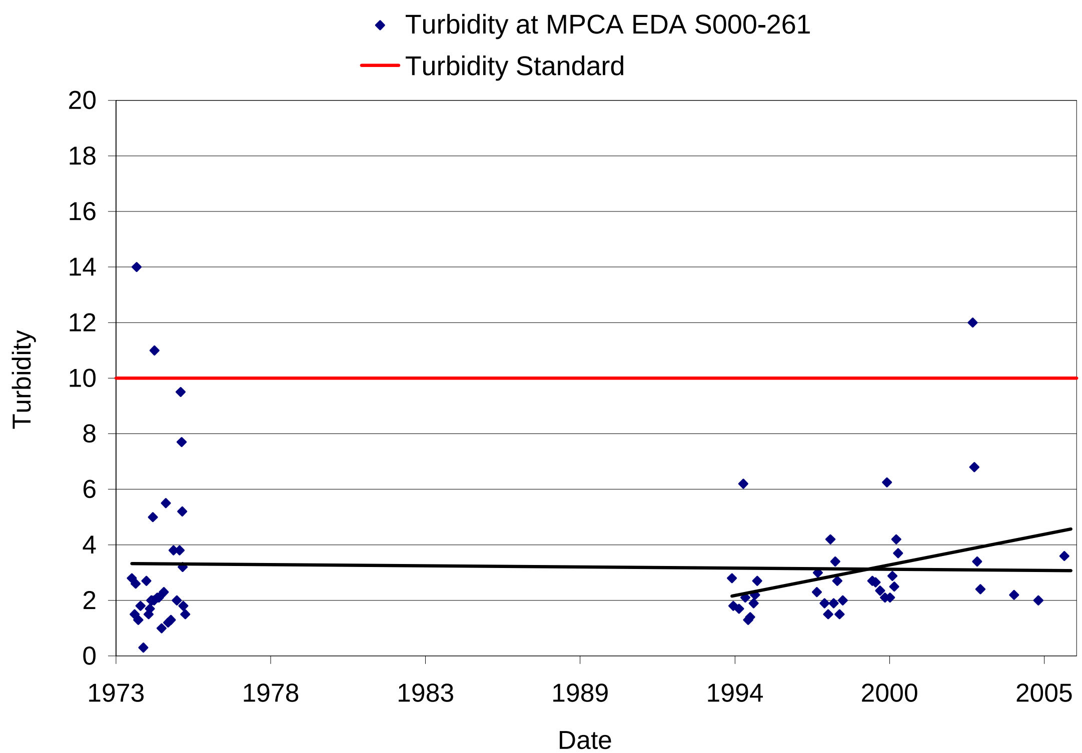

Figure 4 Turbidity collected at station S000-261 using ambient monitoring program data. Note: one data point is excluded from view and from use in the regression lines: 9/19/05, Turbidity = 67 NTRU. Inclusions of this data point results in much greater increase over time in the linear regression trend lines.

Depending on soil saturation in the fall and overall winter and spring natural snow and rainfall totals, snow pack and snowmelt are potential contributors to elevated turbidity in the Poplar River. On average, snow pack in the Lutsen area lasts until mid-April. Based on DNR records during 2001 – 2005, an average of 76.2 million gallons/year has been withdrawn by Lutsen Mountain Ski Resort. If used in snowmaking, this amount of water is equivalent to 11.7 inches if applied equally to the 239 acres of ski runs maintained by Lutsen Resorts. Because snowmaking involves evaporation and other water losses, the amount of runoff from this activity is expected to be less than 76.2 million gallons/year. Based on the Minnesota High Density Network, snow pack in the Grand Marais and Lutsen areas is typically gone by the end of April. The month of April is typically characterized by high concentrations and loads of TSS and was shown in FLUX modeling to be the month of highest TSS loading. A portion of this load is likely delivered by melting snow; however, other factors, such as lack of ground cover and forest canopy, likely contribute to increased sediment detachment and transport to the Poplar River.

5.4 Sources of Suspended Solids

A source assessment is used to identify and characterize the known and suspected sources of turbidity in the Poplar River watershed. Data sources used to assess turbidity and TSS sources are identified in Tables 4 and 5.

Point Sources

USEPA's water discharge permits website (www.epa.gov/enviro/html/pcs/index.html) was consulted to obtain information on permitted facilities in the Poplar River watershed. Of the permitted facilities present, only one requires monthly monitoring for turbidity and flow. The Caribou Highlands Lodge (MN0053252) wastewater treatment facility maintains a treatment lagoon that periodically discharges to the Poplar River. The treatment facility has maintained compliance with their discharge permit since 1999. In 2003, the permit was modified to increase the monthly average limit of allowable TSS from 24 kg/day to 48 kg/day and to increase the maximum weekly average from 35 kg/day to 70 kg/day. Other TSS and flow limits remained consistent with pre–2003 requirements.

Annual and monthly TSS loads from the Caribou Highlands discharge were calculated for the 2001- 2007 period. The range of annual loads was found to be between 0.4 tons/year to 1.9 tons/year. Results of this analysis suggest that the Caribou Highlands discharge contributes very little (<1%) to the overall TSS load in the river.

Nonpoint Sources

Nonpoint sources include various erosional processes, including sheetwash, gully and rill erosion, wind, and landslides that contribute sediment during storm or runoff events. Sediments are also often produced as a result of stream channel and bank erosion and channel disturbance. Potential sources of suspended sediment specific to the Lower Poplar River watershed include:

- Surface erosion from slumps
- Incision along valley slopes (erosion gullies and ravines)
- Localized erosion within the river valley related to land-use alteration, such as,
    - Ski Runs (including bare trails and roads)
    - Golf Course areas
    - Developed area
- Natural forested area
- Channel bed incision
- Sudden channel migration (e.g., meander cut-off, channel avulsion, etc)
- Streambank erosion, such as the river impinging on a slump

Streambank and streambed erosion processes often contribute a significant portion of the overall sediment budget. The consequence of increased streambank erosion is both water quality degradation as well as increased stream channel instability and accelerated sediment yields.

Upland soil erosion from the principal land types in the watershed was evaluated using the WEPP model. Upland erosion, for the purposes of this study, includes erosion on land surfaces influenced by precipitation and runoff. It does not include stream bank erosion, such as at the slumps, from high stream stage; however, upland erosion does include sheet, rill and interrill erosion from slump areas. Upland erosion sources provide sediment laden runoff during rainfall events that result in surface runoff. Larger runoff events typically result in larger sediment load to the Poplar River.

The Physical Stream Channel Assessment looked at “near stream” sources of sediment, such as bank erosion, slump erosion, channel migration, channel bed incision, and incision along valley slopes. The Physical Channel Assessment used a variety of field techniques to assess the characteristics of the stream and estimate erosion from “near channel” sources. The attached "Physical Channel Assessment" reports on this investigation in detail. The channel assessment provided estimates of sediment from each “near channel” source on an annual average basis; however, sediment from these sources are likely the result of high flow and/or precipitation events that provide a large sediment load infrequently.

The LDC analysis, in conjunction with the WEPP modeling and Physical Channel Assessment was used to assess the streams loading capacity, critical condition, and allocations. The LDC analysis shows that most of the turbidity exceedances occur at higher flows, supporting the conclusions that upland erosion is contributed during rainfall events and that near channel sources may be more prevalent during high stage/flow events. Given the nature of the estimation procedures, measurements, and data inputs, the loading estimates made in the project are fairly gross estimates and need to be evaluated as such.

5.5 Turbidity-Total Suspended Solids Relationship

Turbidity is measured in turbidity units, not as a concentration, so another parameter that is measured as a concentration must be used to represent turbidity for the calculation of loadings in the watershed. To accomplish this, correlation coefficients were determined for several parameters at the Poplar River downstream station. TSS was found to have a high correlation with turbidity (0.97) based on a data set of 85 values collected during 2002–2006. Given this finding, laboratory data collected during the period 2001–2006 were used to develop a correlation between turbidity and TSS at the Poplar River downstream location. Figure 5 provides a linear regression on 101 paired, log-transformed TSS and turbidity measurements. The regression resulted in the following TSS-turbidity relationship:

Log TSS (mg/L) = (0.9953 * Log Turbidity (NTRU)) + 0.0705
R^2 = 0.8973

Using this correlation, the 10 NTU water quality standard was determined to be equivalent to 11.64 mg/L TSS.

One approach to limiting variability in developing the turbidity-TSS relationship is to develop the correlation using paired samples under conditions where the turbidity value is less than or equal to 40 NTU (MPCA, 2006b). Measurement of turbidity in samples with very high NTU values can increase error. Turbidity as a standard analytic method was designed to be limited to a measurement range of 0 to 40 NTU but, using dilution, has been used by several practitioners to measure turbidity above 40 NTU (MPCA, 2006b). Figure 6 provides a linear regression on TSS and turbidity data collected downstream using NTRU methods only, and under conditions where the turbidity value is less than or equal to 40 NTU. Based on this correlation, the 10 NTU standard is equivalent to 12.39 mg/L TSS. Given the correlations of 11.64 mg/L TSS using all data and 12.39 mg/L TSS using turbidity data less than 40 NTU, **for the purposes of this report, a value of 12 mg/L TSS will be used as the equivalent TSS concentration for the 10 NTU.**

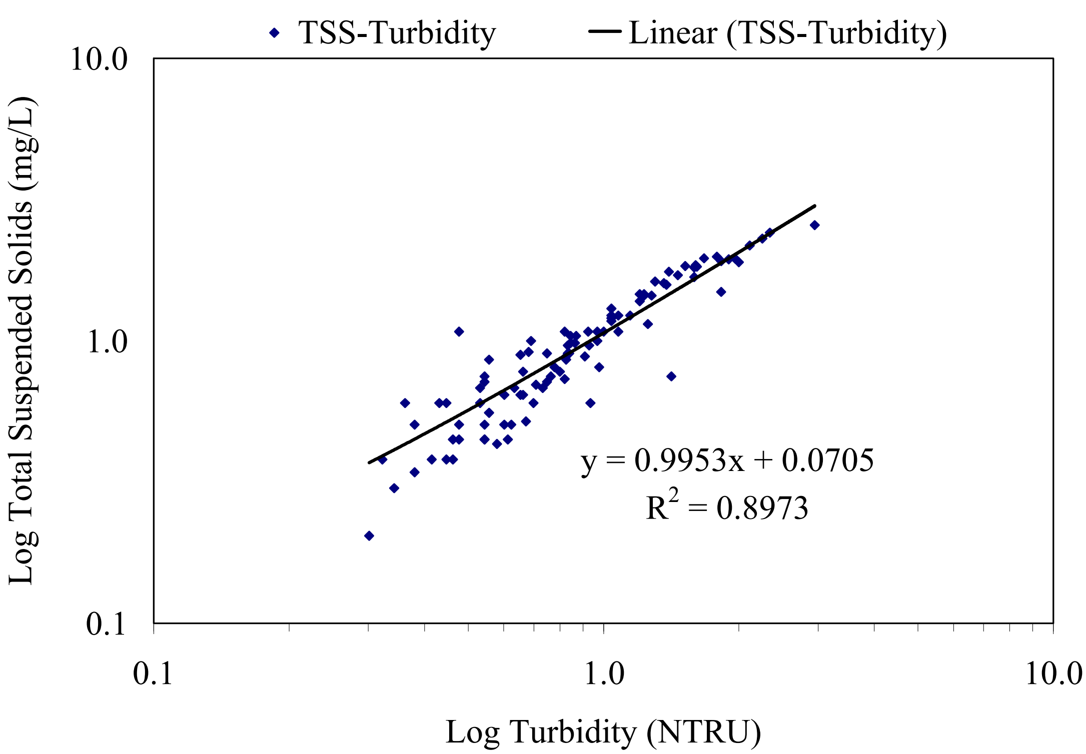

Figure 5 **Turbidity-TSS Correlation Using All Available Data at the Downstream Site (S000-261) Using Log-Transformed Data Collected During 2001–2006**

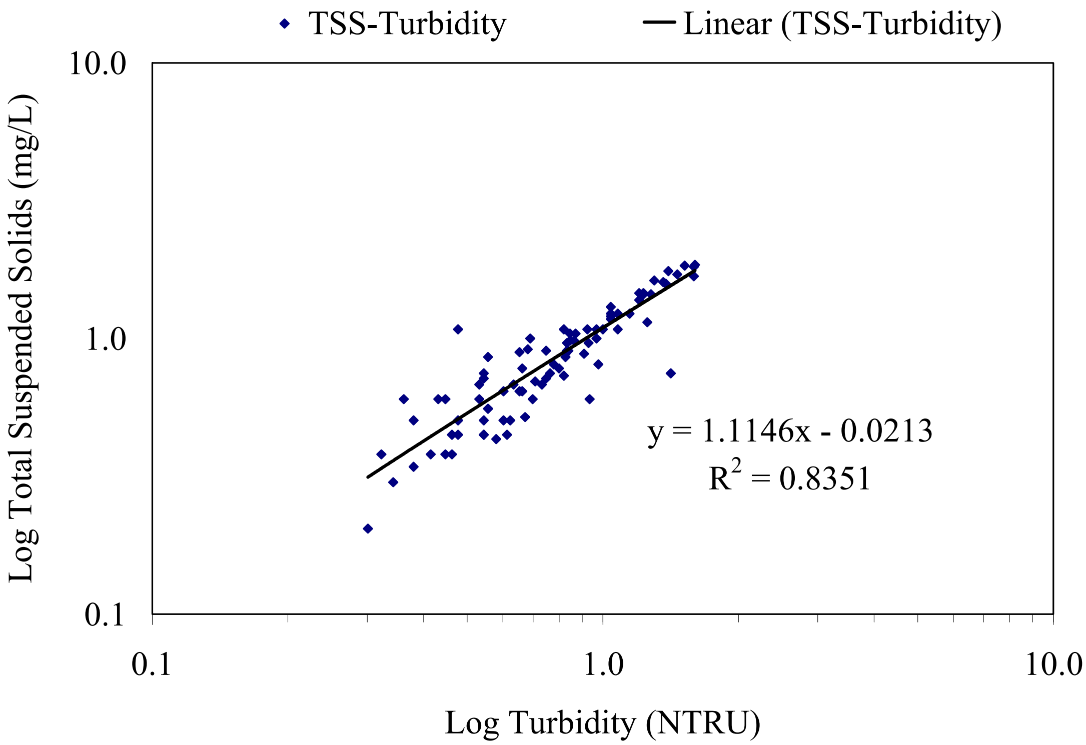

Figure 6 Turbidity-TSS Correlation Using only Values Less Than or Equal to 40 NTU at the Downstream Site (S000-261) Using Log-Transformed Data Collected During 2001–2006

5.6 Load Duration Analysis

When streamflow gage information is available, a Load Duration Curve (LDC) is useful in identifying and differentiating between storm-driven and steady-input sources (Stiles, 2001, 2002; Cleland, 2002, 2003). The LDC method is based on comparison of the frequency of a given flow event with its associated water quality load. Values that plot below the curve represent samples below the concentration threshold; whereas, values that plot above represent samples that exceed the concentration threshold. For this project, a LDC was used to: 1) Provide a visual representation of streamflow conditions under which turbidity exceedances have occurred, 2) Assess critical conditions, 3) Identify potential sources of turbidity, and 4) Quantify the level of TSS reduction necessary to meet the surface water quality criteria for turbidity in the river. Given the nature of the LDC method, loading estimates are fairly gross and need to be evaluated as such.

A flow duration curve analysis was performed to identify the flow regimes during which excursions of the water quality criteria occur. This step determines the relative ranking of a given flow based on the percentage of time that the flow is historically exceeded. Figure 7 is a flow duration curve developed for the Poplar River station at Lutsen, MN. Thirty years (1976-2006) of measured and estimated flow were used to generate the flow duration curve. Flow data between 1976 and 2002 were estimated using flow data at the Pigeon River near Grand Portage, Minnesota, USGS gage and flows measured by MPCA were used for the period between 2002 and 2006. A detailed explanation of the approach used to estimate flows in the Poplar River is provided in The attached Data Assessment Summary Report, Section 3.1.

Using TSS as a surrogate for turbidity, the streams' loading capacity under each flow condition was determined by multiplying the TSS-equivalent (12 mg/l) of the turbidity water quality standard by flow.

Once the relative rankings were calculated for flow, monitoring data were matched to flow by date to compare observed water quality to the flow regime during which it was collected (Figure 8). This analysis can help define the flow conditions under which excursions occur and identify the sources of the impairment. Concentrations that plot above the target TSS concentration of 12 mg/l and in the region between 90% and 100% of days in which flow is exceeded; indicate the possible influence of a steady-input source contribution. Concentrations that plot in the region between 10% and 60% suggest the presence of storm-driven and steady-input source contributions. A combination of both storm-driven and steady-input sources occurs in the transition zone between 60% and 90%. Concentrations that plot above 95% or below 10% represent values occurring during either extreme low- or high-flow conditions. As observed in Figure 8, the majority of TSS measurements over 12 mg/L occurred at higher flows that have a frequency of occurrence of about 45% of the time. This frequency of flow event is equivalent to a streamflow of 60 CFS. The loading capacity, along with the median load allowable under high and low flow ranges (25,297 to 736 lbs/day or 12.64 to 0.37 tons/day) is shown in Figure 9.

Table 6 provides a summary of 2001-2006 turbidity data, including the number of exceedances to the turbidity standard under each flow range. As previously discussed, the relative proportion of turbidity from upland, riparian, and in- or near-stream sources can also be assessed using the LDC. During the 2002-2006 period, over half of the measurements found to exceed the 10 NTU threshold were present in the highest flow zone suggesting the importance of addressing near stream sources when identifying measures to reduce turbidity.

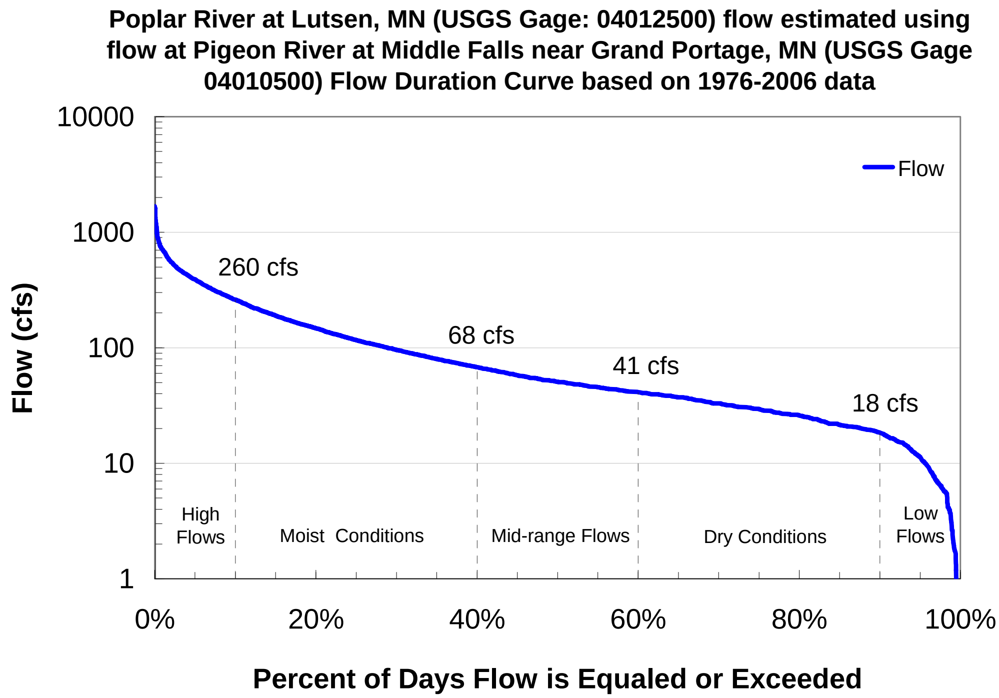

Figure 7 Flow Duration Curve for the Poplar River at Lutsen, MN. A Thirty-Year Flow Period (1976-2006) in the Poplar River was used to generate the Flow Curve. Flows Between 1976 and 2001 were Estimated in the Poplar River Using Pigeon River at Middle Falls Near Grand Portage, MN Flows and an Established Flow Correlation Between the Two Gage Stations

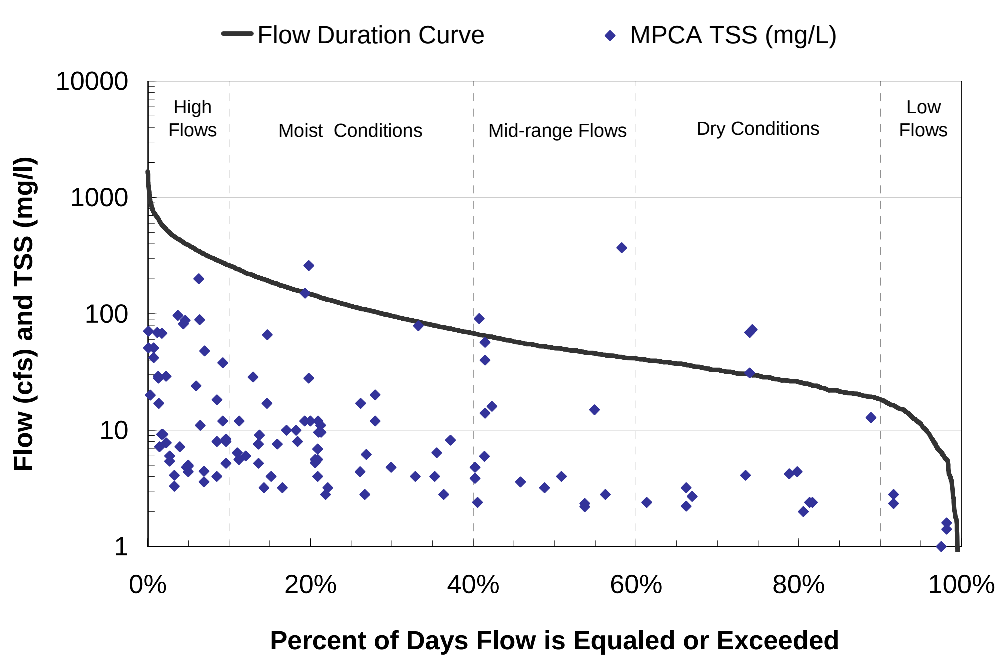

Figure 8 Flow Duration Curve for the Poplar River at Lutsen, MN and TSS Data Collected at the Lower Poplar MPCA Station (S000-261) During 2001-2006

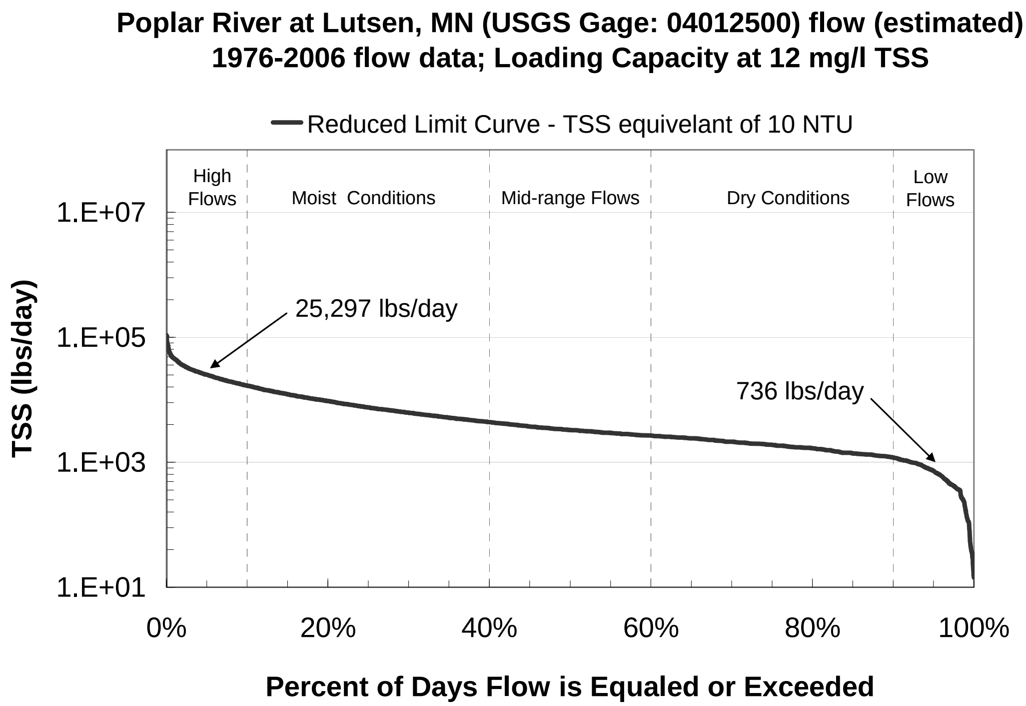

Figure 9 Load Capacity Curve for the Poplar River at Lutsen, MN using TSS as a Surrogate for Turbidity in the Poplar River. Load values shown at the arrows represent the median values for the low and high flow ranges

Table 6 Summary of Turbidity Samples and the Number of Samples Above 10 NTU Within Each Flow Range of the LDC. This Table Includes Measured Turbidity Values Collected During 2001-2006

Flow Range (% of days flows are equaled or exceeded)	Flow Range (CFS)	Number of Turbidity Samples	Number of Turbidity Samples > 10 NTU	Percent of Samples > 10 NTU
0–10%	Above 260	36	18	50%
10–40%	260–68	40	9	23%
40–60%	68 – 41	14	7	50%
60–90%	41 – 18	8	1	13%
90-100%	Below 18	3	0	0%

5.7 Upland Sources of Sediment (WEPP Erosion Computer Modeling)

The purpose of developing a WEPP computer model of the lower Poplar River is to provide a scientifically defensible assessment of upland sediment sources. A detailed modeling report is contained in The attached “Additional Characterization and Estimation of Turbidity Impairment” report. To assess the upland sources of sediment several computer model scenarios were evaluated. The scenarios allowed the unit area loading of each land use to be calculated and four alternate land use scenarios to be evaluated. The scenarios included:

- Existing conditions, which as the name implies, represents the lower watershed as it exists currently.
- Pre-Development conditions scenario represents the watershed in pre-development conditions (e.g. it is 100% covered with mature forest).
- Build-Out conditions scenario represents the watershed with additional development as described in the AUAR.
- Stormwater control scenario represents existing conditions with the addition of erosion control measures.

Figure 10 and 11 report the results of the existing conditions scenario. Figure 10 reports the annual predicted loads from 2001 through 2005 and demonstrates the range of loads that are expected. The variations in annual load are the result of climatic conditions and extreme events. Figure 11 is a breakdown of the average annual load by land use. It shows the proportion of load from each land use. For this analysis “Slump” includes only the surface erosion component of the slumps. Figure 11 demonstrates that the WEPP computer model predicts that on average 65% of the upland sediment load originates from ski runs, 27% from forested lands, 5% from slumps and 3% from developed and golf course areas. Table 7 reports the annual average loads by land use. These results are described in more detail in The attached “Additional Characterization and Estimation of Turbidity Impairment” report.

Table 7 Annual Average Sediment Delivery for Major Land uses Within Lower Poplar River Watershed from WEPP Modeling

	Golf	Developed	Slumps	Ski Runs	Forest
Sediment Delivery (Tons/Acre)	0.25	0.80	18.8	4.0	0.32
Sediment Delivery (Tons)	15.2	25.2	48.8	660.5	280.4
Area (Acres)	61.1	31.5	2.6	164	877.6

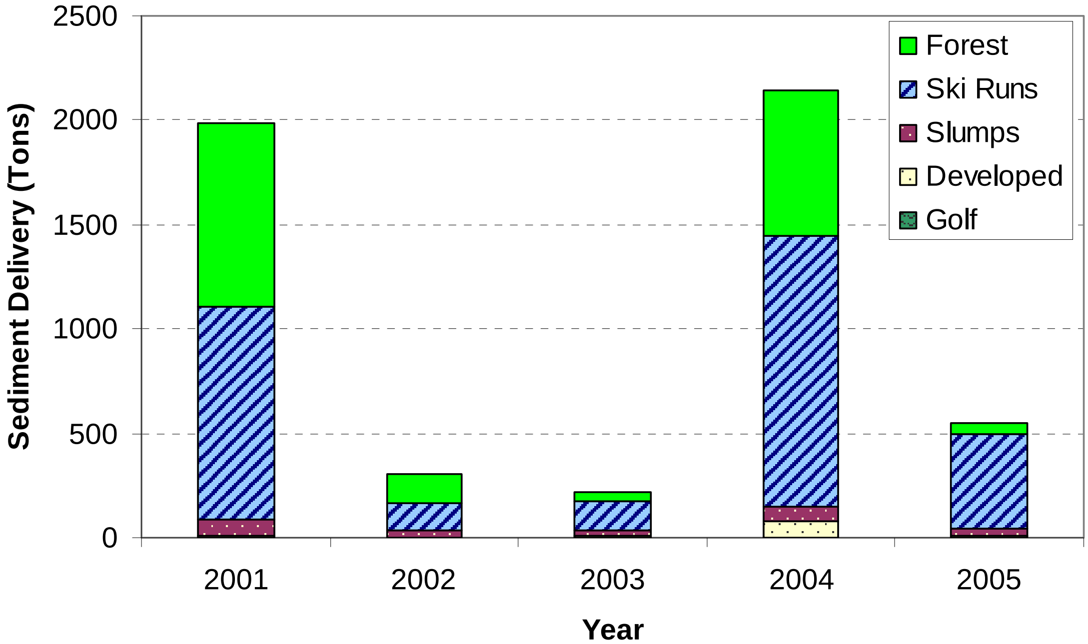

Figure 10 Land Use Contributions of Sediment to the Lower Poplar River for 2001 Through 2005 by Upland Erosion Processes. Note: Developed and Golf Land Uses are Included but their Contribution is Small Compared to Forest and Ski Runs and they do not show on Chart for Some Years.

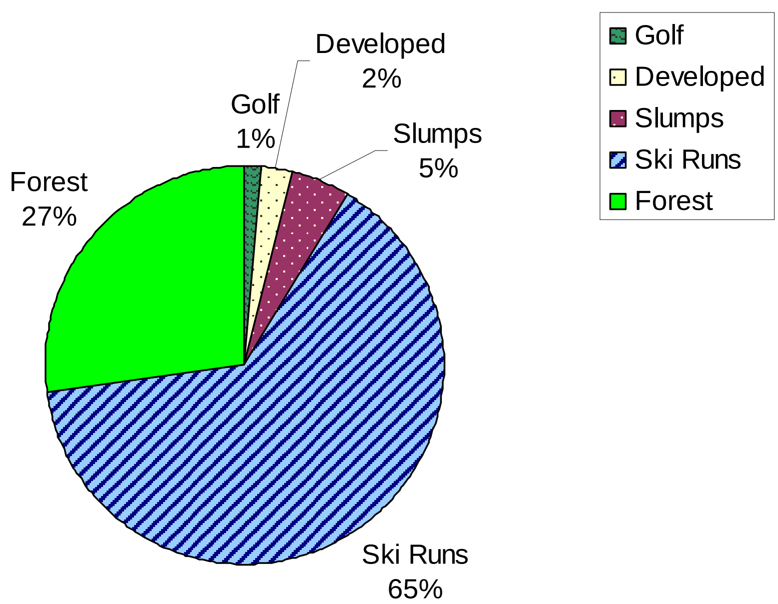

Figure 11 Land Use Contributions of Average Sediment Delivery to the Lower Poplar River by Upland Erosion Processes

The predicted sediment load from the four scenarios of alternate land uses are reported in Figure 12. They indicate that additional development, as described in the AUAR, may contribute to increased sediment load if no nonpoint source controls are implemented. The scenario "Stormwater Control" indicates that with improved vegetative cover and runoff controls that erosion can be reduced well below existing conditions. It does not indicate that these are regulated stormwater sources. The "Predevelopment" scenario was completed to provide a prediction of the sediment load if no resort or ski area existed within the watershed. This scenario demonstrates that even with no land use alteration a significant amount of sediment would be delivered to the Poplar River.

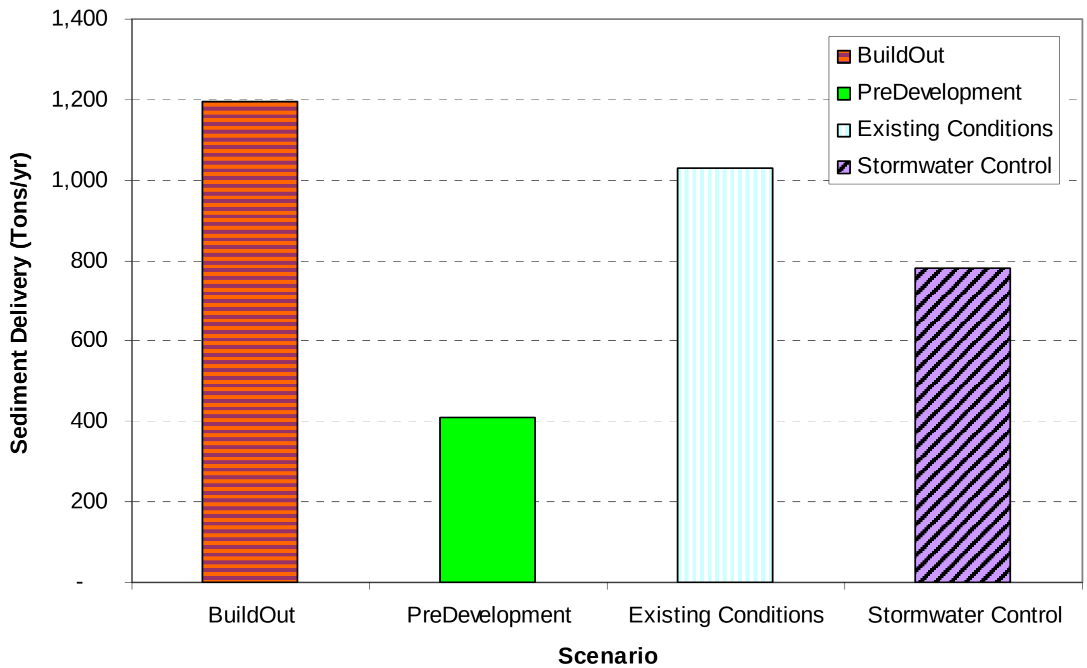

Figure 12 Comparison of Average Sediment Delivery (Tons/Year) Predicted by WEPP for Four Land Use Scenarios

The WEPP computer modeling provided predictions for erosion from upland sources, but did not include near channel sediment sources. These sources were estimated as part of the Physical Channel Assessment.

5.8 Near Channel Sediment Sources (Physical Channel Assessment)

Six types of localized sediment sources were observed and are discussed in this document: channel bed incision and stream lateral migration are found to not be a significant source of fine sediment. However, when these processes occur in the vicinity of the valley slopes, they can be a factor in the formation and expansion of landslides which in turn can mobilize large amount of fine, suspended sediment from the walls of the valley. The erosion associated with a sudden channel migration such as meander cut-offs can mobilize a significant amount of material, including some fine, suspended sediment but their effect is rather short lasting. Other potential sources of suspended sediment are within the river valley and not directly related to stream activity. The erosion ravines formed at points of concentrated runoff are an important source of suspended sediment. Finally, the recreational development appears to have resulted in a multitude of surfaces that are vulnerable to erosion. These include ski trails, ATV trails, hiking trails, utilities road surfaces, road embankments, and roadside ditches. The potential erosion from these areas is encompassed in the WEPP modeling described above.

Channel Bed Incision

Channel incision is an ongoing geological process which characterizes all high-gradient North Shore streams flowing into Lake Superior. These streams continue to cut down in the glacial till material, slowly adjusting the shape and slope of the longitudinal profile. This process, however, takes place at a relatively slow rate and, on an annual basis, will not result in the mobilization of significant amounts of suspended sediment from the streambed. While the channel bed itself is not a significant source of suspended sediment, channel incision may play a role in the occurrence of landslides observed in the vicinity of the channel. Channel bed incision may occur simultaneously with the gradual streambank migration discussed below.

Sudden Channel Migration (e.g. Meander CutOff)

Aerial photographs taken in 1934, 1991, and 2003 suggests that rapid lateral migration has taken place at certain locations. The meander cut-offs and channel diversions have likely entrained a significant amount of sediment including a suspended load fraction. However, these kinds of sudden channel migrations are one-time events associated with abnormally high flow rates. Most of the suspended load that would have been generated this way was dispersed throughout the stream and flushed out of the system. Empirical evidence and laboratory study indicate that pulses of fine sediment in streams are dispersed rather fast (Cui et al., 2003).

Streambank Erosion

Stream bank erosion implies gradual channel migration, as opposed to major sudden changes, such as channel avulsions or meander cut-offs, which are one time processes associated with extreme flow events. Generally speaking, stream bank erosion in alluvial streams could greatly increase the amount of suspended load due to the local degradation and collapse of the banks. However, in the case of the Lower Poplar River the banks are armored with large size particles and there is little evidence of active, on-going bank erosion.

Landslides Near the Active Channel

In places where the active channel is near the valley wall, landslides are likely to form and become larger as the channel shifts laterally. Such places, most notably the meander bend at the Megaslump, could be considered the equivalent of the gradual streambank erosion except that it is the slope of the valley that is being eroded and not the streambank.

Presently a meander of the Poplar River is impinging upon the relatively steep side of the valley. The stream flows adjacent to the slope failure. Water discharge, or leakage from the discharge conduit from the nearby water treatment ponds may contribute to the expansion of the exposed failure surface if the permit requirements related to proper use of the flexible discharge pipe and diffuser are not strictly followed. The unvegetated soil surface of the land slide appears to be highly erodible. Given its size and proximity to the channel, the Megaslump area is a likely major source of fine sediment. The translation of the eroded surface mentioned above suggests that the sediment delivery mechanism was a progressive slope failure, the collapsed material being washed into the stream. Stream observations in the vicinity of the Megaslump reveal that the embeddedness is above the average and the larger cobble size particles are buried into finer sand-sized sediment in a proportion 25 to 40 percent suggesting a higher influx of sediment.

Two other landslides, both smaller in size than the Megaslump, were documented in the east side of the valley. These landslides are located 1) a short distance downstream of the Megaslump on the east side and 2) in the upstream ski hill area (approximately 2 miles upstream from the mouth) also on the east bank along a major meander bend (which based on aerial photographs migrated approximately 80 feet towards southeast between 1934 and 2003). In the vicinity of each of these landslides and a short distance downstream, the proportion of finer sediment trapped in the streambed (i.e., embeddedness) is higher than the typical average suggesting on-going erosion at all of these places.

Other landslides, even smaller in size, are located in an upstream forested area where there has been little to no change in the land use. A series of three near-channel landslides have been documented within a short distance downstream of the Poplar Rapids, all on the west side of the valley. This area is densely forested. Field observations and aerial photographs indicate no logging or other type of land alteration. This suggests that landslides could occur regardless of the changes in land use. To verify this assertion, a short trip to the Onion River, documented a landslide of considerable dimensions. The Onion River is a smaller stream flowing into Lake Superior with a watershed that is densely forested and experienced little to no land use alteration.

Incision along Valley Slopes – Gullies and Ravines

Gullies and ravines are common erosion features in places of concentrated runoff along steep slopes. Such features are a common natural occurrence and part of the drainage basin denudation process. However, the gullies that are naturally occurring evolve relatively slowly into ephemeral tributaries to the main stream. By contrast, the erosion gullies that formed as the result of concentrated storm water discharge from developed areas are fast evolving and can mobilize large amounts of sediment.

There are several places of concentrated runoff within the Lower Poplar River valley that emerged as a result of the recreational-based development (ski trails, ATV trails, access roads, ski lifts, resorts, facility buildings, etc). In some places visible efforts have been made in recent years to limit, eliminate, or mitigate the gully erosion and to convey the runoff flow to the stream in a controlled, non-erosive way. Most notably, the runoff from the eastern tributary valley near Eagle Mountain where many of the ski trails and local roads are located is routed across a series of swales. These swales were landscaped across the slope with the apparent intent to break the slope surface into smaller segments and control the erosive power of the runoff. Small size drains have been installed along the swales and efforts to vegetated and stabilize the sloped surfaces between swales have been made.

A place of concentrated runoff that resulted in a large erosion ravine was identified in the very upstream part of the river. A 320-foot long ravine spans through a forested area from the north end of the main road (Ski Hill Road) to the edge of the stream. This ravine is approximately 10 to 20 feet deep. The average longitudinal slope is approximately 21 degrees (40%). To a certain extent, the bottom of the ravine appears to be have been reinforced with debris and boulder rock material. The side slopes, however, are unvegetated and very steep (over 45 degrees) with potential for future soil erosion. Given its size and proximity to the river, this erosion ravine is likely to contribute a significant amount of fine sediment to the stream. The stream bottom at the bottom of this ravine shows a higher than average proportion of finer sediment (i.e., higher embeddedness, approximately 25 to 30 percent).

Another erosion ravine, smaller in size (approximately 180 feet long and 10 feet deep) is located in the main ski area on the east side of the valley. It extends from a ski lift post to the most upstream bridge before the rapids.

Erosion Estimates from These Sources

Rough estimates of the amount of sediment eroded from these sources were made using measurements made in the field and from available aerial photography. The estimation methods are described in The attached report titled “Physical Channel Assessment”. The estimates are shown in Table 8.

The estimates, while approximate, suggest that the channel itself represents only a minor source of suspended sediment while the landslides could generate an amount of suspended sediment that is an order of magnitude higher.

Rough estimates of suspended sediments from the major erosion ravines indicate a total quantity between 1500 and 2800 tons. However, the age of these erosions ravines is largely unknown. It could vary between several years to forty years (i.e., since the beginning expansion of skiing areas) resulting in annual suspended sediment rates that could range from 40 to 500 tons. It would be fair to conclude that the largest erosion ravine documented upstream of the ski hill is relatively young and represent a significant source of sediment.

Table 8 Estimates of Annual Average Suspended Sediment From Near Channel Sources

	Eroded Volume Estimates 1934 - 2003 (CY)[2]		Typical Bulk Density (pcf)[3]	Proportion of Eroded Soil that becomes Total Suspended Solids %		Time Interval (years)	Average Annual Suspended Sediment Flux (tons/year)	
	Min	Max		Min	Max	1934 - 2003	Min	Max
Channel Incision and Gradual Lateral Migration[1]	16,593	41,111	110	5%	10%	69	18	88
Megaslump	57,037	85,556	110	25%	40%	69	307	737
Other Landslides	22,500	33,333	110	25%	40%	69	121	287

[1] Meander cutoffs not included.
[2] CY = cubic yards.
[3] pcf = pounds per cubic foot.

6 Loading Analysis and Selected Allocations

6.1 Summary of Loads from Non Point Sources

Nonpoint sources in the lower Poplar River watershed include both upland and "near channel" sources. Critical conditions for these categories of non point sources are related, but distinct. Upland sediment erosion is the result of many factors including: intensity and magnitude of precipitation, antecedent conditions, cover, soil texture, slope, and land uses. Erosion from upland sources was predicted by the WEPP model to occur during large rainfall events, or when smaller rainfall events occurred during wetter conditions and areas with less cover and greater slope were more prone to erosion. Near channel erosion includes erosion originating from the erosive power of the stream. The critical conditions for these sources are during high flow/stage. These sediment loads were estimated via a field investigation. The upland and near channel sources identified as contributing to turbidity in the lower Poplar River are listed below.

Upland Sediment Sources

- Surface erosion from slumps
- Incision along valley slopes (erosion gullies and ravines)
- Localized erosion within the river valley related to land-use alteration, such as,
  - Ski Runs (including bare trails and roads)
  - Golf Course areas
  - Developed area
- Natural forested area

Near Channel Sediment Sources

- Channel bed incision
- Sudden channel migration (e.g., meander cut-off, channel avulsion, etc)
- Streambank erosion, such as the river impinging on a slump

One goal of this study was to define and quantify the sources of sediment within the lower Poplar River watershed. While the sources described above were estimated using different methods, different approaches, and may represent differing time frames; each provides an estimate of the annual average load from each source. Combining these loading estimates provides an estimate of the proportion of each source. Figure 13 shows the percentage each source contributes to the total sediment load of the lower Poplar River and Figure 14 shows the magnitude of each source within the lower Poplar River.

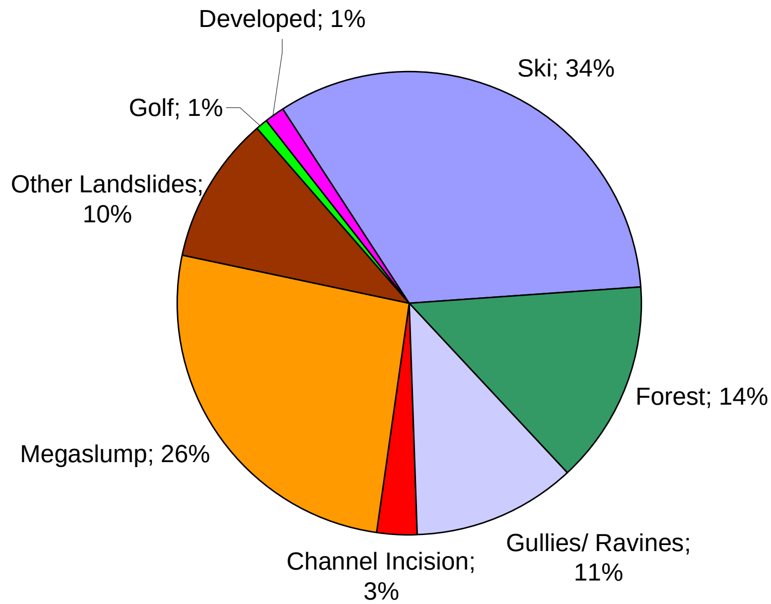

Figure 13 Percentage of Each Source (Upland and Near-Channel Source) Contributes to Sediment Load in Lower Poplar River. Percentage Calculated using Median Loading Estimate

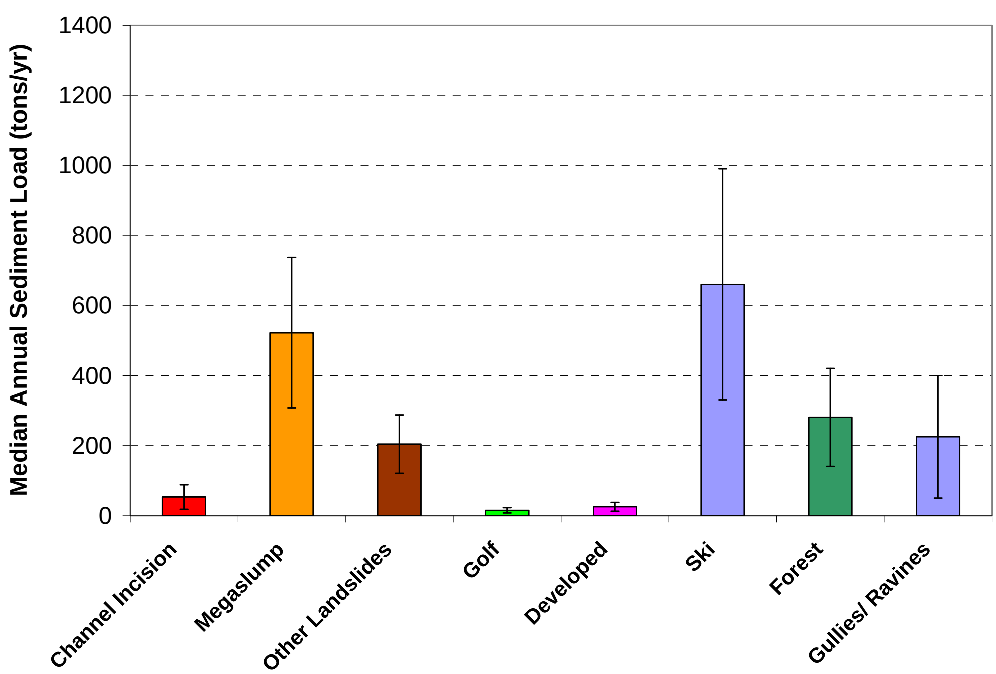

Figure 14 Summary of Median Annual Sediment Load (Tons/Year), by Land Use, Estimated using WEPP 2005.6 and the Physical Channel Assessment Field Investigation. Bars Represent Estimated Maximum and Minimum Annual Average Loads

Of the eight sediment sources identified and quantified six may be controlled to some extent. Slumps, runoff from golf course, developed areas, and ski runs can be controlled and gullies/ ravines formed from concentrated runoff can mitigated to varying degrees. These sources contribute an average of 83% of the sediment load to the lower Poplar River. Slumps and gullies/ ravines are all naturally occurring processes; however, land use changes may have contributed to the enlargement of the megaslump and several ravines. Natural sediment sources contribute between 17% and 64% of the total sediment load, depending on whether slumps and gullies/ravines are deemed natural. Forty-six percent (46%) of the sediment load originates from altered land use cover types. Table 9 summarizes all of the identified and quantified loads in the lower Poplar River watershed.

Table 9 Five Year Modeled Sediment Sources Contributing to Turbidity in the Lower Poplar River Watershed

Source	Median Sediment Load		Minimum Sediment Load		Maximum Sediment Load	
	Ton/year	%	Ton/year	%	Ton/year	%
Channel Incision	53	3%	18	2%	88	3%
Megaslump	522	26%	307	31%	737	25%
Other Landslides	204	10%	121	12%	287	10%
Golf	15	1%	8	1%	23	1%
Developed	25	1%	13	1%	38	1%
Ski Runs, Trails, and Roads	661	33%	330	33%	991	33%
Forest	280	14%	140	14%	421	14%
Gullies/ Ravines	225	11%	50	5%	400	13%
Total	1,985		987		2,984	

While combining the upland and near channel sediment estimates may be somewhat of an “apples” to “oranges” comparison based on the different time periods they were derived from (e.g. the modeling averages loading estimates predicted by a computer model run using 5 years of data and the near channel assessment was based on observations and photographs spanning decades) it is the best estimate available, and provides a quantitative comparison of all identified sources.

6.2 Summary of Loads from Point Sources

As previously discussed, four NPDES-permitted facilities are located in the Poplar River watershed. Of these, only one is subject to TSS limits. The Caribou Highlands Lodge (MN0053252) wastewater treatment facility maintains a treatment lagoon that periodically discharges to the Poplar River. This treatment facility is subject to a monthly average limit of 48 kg/day TSS (106 lbs/day TSS) and a maximum weekly average limit of 70 kg/day TSS (154 lbs/day TSS). While the facility generally discharges TSS well below this limit, the permitted load represents a very small fraction (<1%) of the total daily load exiting in the watershed. For the purposes of this report, the recommended wasteload allocation for the treatment lagoon is based on the permitted TSS load limit and does not result in an additional reduction for the facility.

6.3 Reductions Required to Meet Water Quality Standards

Figure 15 shows TSS data paired with flow data in relation to the load capacity curve. Median and 90th percentile values are calculated on the data available within each flow zone. Percent reductions required under each flow zone are based on a comparison between the "Allocation" to the "Current Load" (the 90th percentile of the TSS data within each flow zone).

A MOS for each of the five flow zones was calculated by subtracting the lowest allowable load within each zone from the median load within each zone. This method for calculating MOS has been used in previous, approved turbidity TMDLs in Minnesota. In the Poplar River, this method of assigning MOS results in a large allocation for all flow ranges. In particular, under "low flow" conditions the MOS is 98% of the allocated load thereby requiring a percent reduction of 95% under low flow conditions (Table 10). During other flow conditions the MOS ranges from 19% to 42%. This level of uncertainty reduces the allowable allocations for each flow condition.

Table 10 Loading Capacity for Each Flow Zone Based on the Load Duration Curve Approach

	Flow Zone				
	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Flow Interval (CFS)	> 260	260 – 68	68 – 41	41 – 18	< 18
Flow Interval (%)	0 – 10%	10 – 40%	40 – 60%	60 – 90%	90 – 100%
TMDL Capacity (lbs/day)	25,297	7,532	3,281	1,904	736
MOS (lbs/day)	8,408	3,135	609	712	722
Waste Load Allocation[1]	106	106	106	106	NA
Load Allocation (lbs/day)[2]	16,783	4,291	2,566	1,086	14

[1] The permit for Caribou Highland's wastewater discharge does not specify discharge based on flow; however, it does specify limits on months during which discharge is allowable and these months were specified based on expected flows.

[2] Allocation is equal to the capacity less MOS.

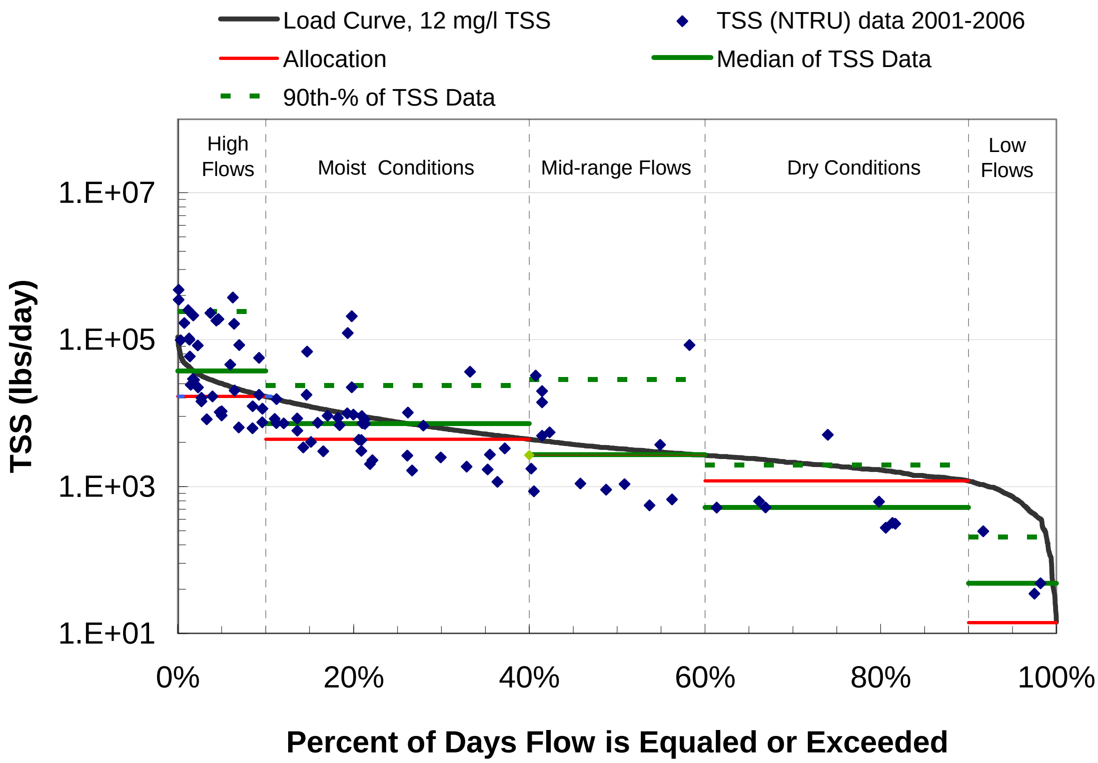

Figure 15 Load Duration Curve for Measured TSS at the Downstream Location. The TSS Target and TSS Values were Based on the Linear Regression with Turbidity Established in this Report

6.4 Seasonal Variation

Seasonal and annual loading estimates at the upstream and downstream locations were estimated using both FLUX and WEPP models. Using FLUX, TSS loads were found to be highest at the upstream station during the months of April and May and highest at the downstream location during April, May, and June. Monthly loading comparison showed that loading contributions from the lower Poplar River watershed varied seasonally. The lower Poplar River watershed contributed 66-89% of the load observed at the downstream station between April and October. Turbidity values were found to increase significantly between the upstream and downstream stations during the spring and summer months. Results from WEPP modeling confirmed the seasonal trends found using FLUX.

The water quality data collected between 2001 and 2006 also suggests seasonal variations in factors affecting turbidity levels. Table 11 reports the number of exceedances by month for 2001 through 2006 and demonstrates that 18 of 35 (51%) exceedances occurred during the month of April.

Table 11 Monthly Summary Statistics for Turbidity at Downstream Sampling Location (S000-261) for Years 2001-2006

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Downstream 2001 – 2006	Count			1	39	9	15	12	15	5	6		
	Average			2.8	28.1	25.6	9.4	78.5	16.9	19.2	4.3		
	Maximum			2.8	220	92.0	39.0	890	100	67.0	8.6		
	Minimum			2.8	3.5	2.4	2.3	2.8	2.0	2.6	2.2		
	Standard Deviation				47.6	32.2	10.6	256	26.2	27.0	2.3		
	Number > 10 NTU			0	18	4	4	1	5	3	0		

WEPP was used to evaluate relative source loading during spring and fall precipitation events from upland sources only. Results from this analysis are presented in Figure 16. During the spring event, TSS loading was highest from ski runs (52%) followed by developed areas (27%), forest (17%), slumps (3%) and golf (1%). In contrast, during the fall precipitation event, no appreciable loading was found from developed and golf land uses and loading was highest from the ski runs (64%), slumps (33%), and forest (3%).

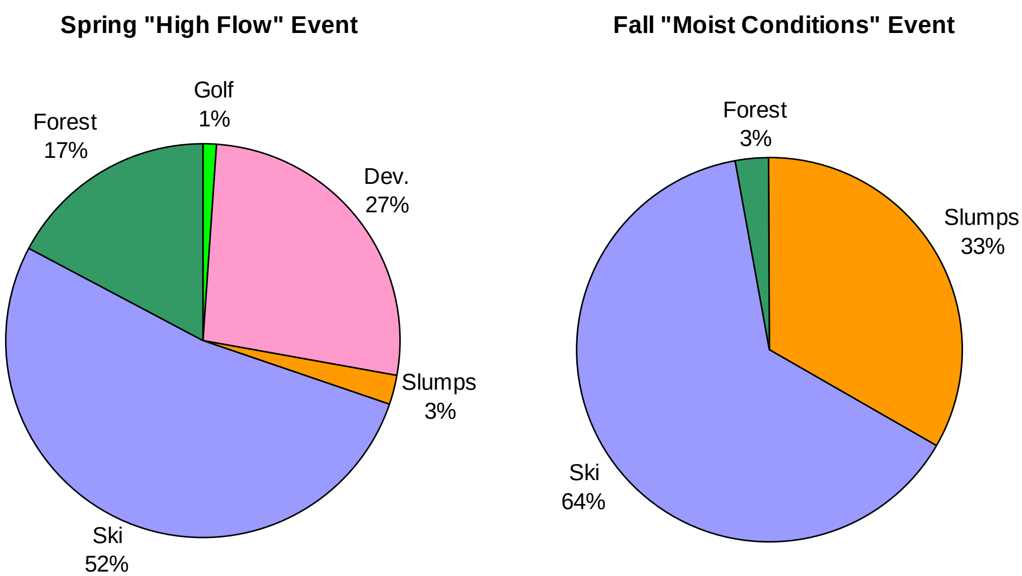

Figure 16 Percentage of TSS Load from Upland Sources During a Spring and Fall Wet Weather Event. Spring "High Flow Event" had a Total Load of 230 Tons and the Fall "Moist Conditions" Event was 22 Tons

6.5 Critical Conditions

Critical conditions indicate the combination of environmental factors that result in just meeting the water quality criterion and have an acceptably low frequency of occurrence. For this report, critical conditions represent the conditions under which the highest load reductions will be needed to protect aquatic life.

Turbidity data available between 2002 and 2006 at the downstream station were collected during spring, summer, and fall months under a wide range of flows and environmental conditions. Monthly turbidity averages during this period were found to be highest during April, May, and June. WEPP modeling predictions were consistent with the data and reported highest average monthly loads to occur in April and May.

Load duration curves are useful in identifying critical flow condition(s) under which the chance for violating the turbidity water quality standard is greatest. A load duration curve developed for the downstream location (see Section 5.7 for greater detail) showed that exceedances to the turbidity standard occur under moderate to high flow conditions (Figure 17). In general, few exceedances were observed under dry and low flow conditions below 40 CFS. Under conditions where flows were at or above 60 CFS (flow frequency of ~ 45% recurrence), the number of exceedances increased. Most turbidity violations occurred under high flows greater than 250 CFS (flow frequency of ~ 10% reoccurrence).

In developing the Lower Otter Tail River Turbidity TMDL in Minnesota (MPCA, 2006a), MPCA describes the use of a weight of evidence approach to understand the relationship between the load duration curve intervals and turbidity sources. MPCA's insight into source identification in the LOTR report is also applicable to assessing critical conditions. Given this, a portion of text that explains sources associated with three regions of the LDC (reference Figure 17 in this report) from the Lower Otter Tail River TMDL report has been included below.

Select text from the Lower Otter Tail River TMDL (MPCA, 2006a):

> *"... The discussions are developed as a weight of evidence application for known sources and expected occurrence in the watershed.*
>
> 1. *The purple dashed line ellipse indicates the area where materials are typically transported from close proximity erosion areas in the watershed. Mid-range flows usually represent the rise of a hydrograph as it progresses out of the dry condition range and enters into wetter conditions. The zone of land use that is most likely to contribute during this period would be the riparian corridor of the river. This is because limited upland soil saturation and quite possibly soil*

erosion has yet to take place during the early period of storm events or in smaller events that can only deliver localized eroded soils.

2. *The black solid line ellipse indicates the area where material loading typically originates from both upland soils which under these wetter conditions are now saturated and begin contributing to the more efficient transport of eroded materials and continuing to move riparian corridor eroded materials.*

3. *The red dotted line ellipse indicates the material loading which indicates bank or river bluff contributions. Sufficient energy exists at these flow regimes to cause mass wasting and the break down of consolidated materials such as glacial lake clay deposits.*

The assessment of sources using the duration curve analyses provides a general or typical evaluation of likely pollutant sources. A more detailed estimate of loads would require the use of a watershed assessment tool or model."

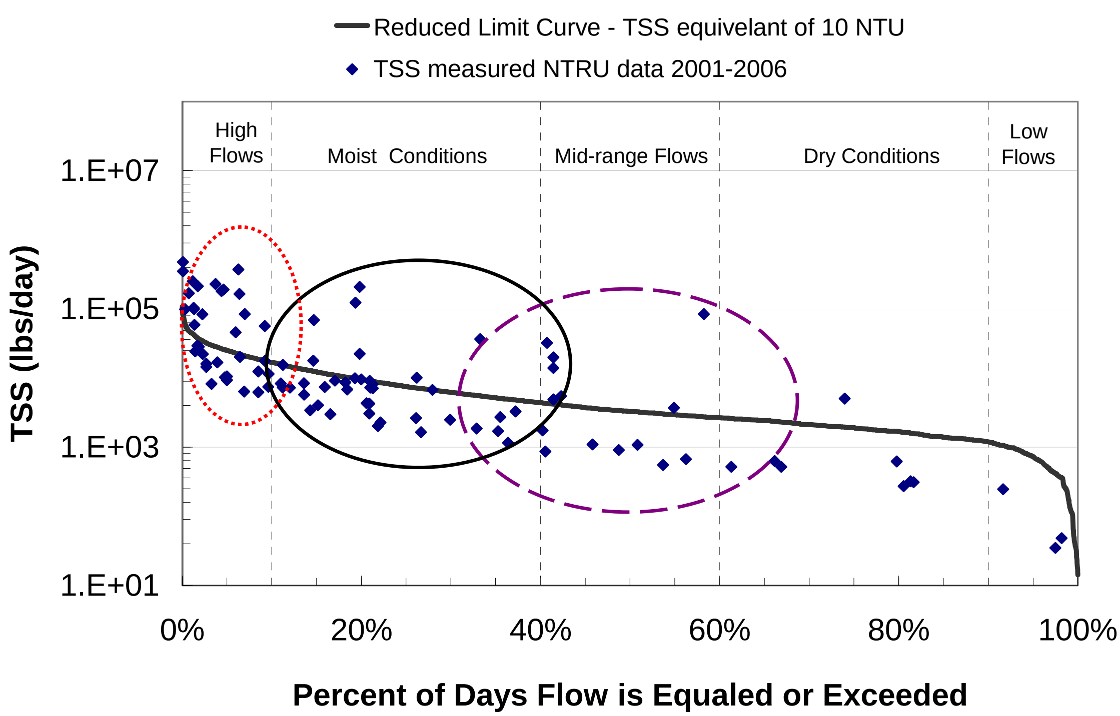

Figure 17 Load Duration Curve for the Poplar River at Lutsen, MN Identifying Flow Ranges for TSS Source Identification

Given these factors, critical conditions for turbidity impairment appear to be present during significant runoff events present under moist and high flow conditions that often occur during March, April, and May. During these high flow events, near-stream and instream sources are expected to contribute a significant portion of the total TSS load. Under mid-range to moist conditions, the relative proportion of near stream sources to upland sources may be expected to decrease.

6.6 Necessary Load Reductions

Table 12 provides percent reductions required under each flow zone based on the LDC approach. These percentages are based on a comparison of the 90th-percentile TSS load within each flow zone to the loading capacity at the mid-point of the respective flow zone. The percent reductions provide an estimate of the reductions needed to remove the Poplar River from the MN impaired waters list for turbidity (based on MPCA procedure to list waters that show greater than 10% exceedance of the 10 NTU aquatic life standard). These reductions should be considered only rough estimates needed to reduce sources and should not be confused with the allocation targets identified in Section 6.3 which are to meet the 10 NTU standard on all days.

Table 12 Required Reductions for Each Flow Zone Based on the Load Duration Curve Approach

	Flow Zone				
	High Flows	Moist Conditions	Mid-Range Flows	Dry Conditions	Low Flows
Flow Interval (CFS)	> 260	260 – 68	68 – 41	41 – 18	< 18
Flow Interval (%)	0 – 10%	10 – 40%	40 – 60%	60 – 90%	90 – 100%
Capacity (lbs/day)	25,297	7,532	3,281	1,904	736
Current Load (lbs/day)[1]	240,623	23,853	28,607	1,956	207
Percent Reduction Needed[2]	89%	68%	89%	3%	none

1 Current Load is equal to the 90th percentile value for each flow zone.
2 Percent Reduction needed is based on a comparison of the 90th percentile daily load to the capacity at the mid-point of the flow zone.

6.7 Implementation Recommendations

Based on the source assessment and observations regarding the critical conditions related to turbidity levels in the lower Poplar River several implementation activities should be considered. Many activities designed to minimize and control erosion are currently taking place within the watershed. Recommending detailed implementation activities is beyond the scope of this project; however, the following general guidelines are suggested:

- Ski runs appear to contribute significant amounts of sediment. Activities related to increasing vegetative cover and controlling erosion should be continued.
- The policy of evaluating dirt trails and roads within the property of Lutsen Mountain Resorts should be continued and actions designed to reduce erosion from these sources should be taken.
- The ravines and gullies identified in this report should be further investigated. If runoff from developed lands is contributing to these, erosion in the ravines should be mitigated by slowing and/or removing the flowing water and restoring the gully so further erosion does not occur.
- The megaslump should be stabilized to limit further erosion.
- Runoff from impervious areas, dirt roads, parking lots, and bare areas should be controlled and treated if found to have high turbidity levels, or contributes to the formation of ravines or gullies.

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