Deer Creek Total Maximum Daily Load
Data Summary Report
December 2010

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1.0 Introduction

Sediment load monitoring for the Deer Creek Turbidity Total Maximum Daily Load (TMDL) Study began in the spring of 2008 and ended in the fall of 2010. A monitoring committee met during the course of the study in order to discuss issues, share updates, and provide guidance during the study. The committee was comprised of MPCA, DNR, and SWCD staff. Karen Evens of the MPCA served as MPCA project manager for the study. Greg Johnson of the MPCA provided guidance and technical support. Jenny Magyar of the MPCA provided technical support including flow monitoring. Tom Schaub of the MPCA led the stable isotope study. Deserae Henderickson of the DNR provided current and historical fisheries information. Brad Matlack, Carlton SWCD Manager, provided project guidance and Kirstin Swenson, Carlton SWCD, collected field data and grab samples for lab analysis and served as the local project lead.

This report summarizes the past data collected in Deer Creek and the newly gathered sediment loading data for 2008-2010. In 2008, a data summary was completed in preparation for the Deer Creek and Nemadji River Turbidity TMDL Projects. The document, "Deer Creek/Nemadji River Total Maximum Daily Load Summary of Existing Water Quality Data," provided detail on the data collected on Deer Creek and the Nemadji River prior to 2008. The document included review of 43 reports, with the earliest dating back to 1925. Total Suspended Solids (TSS) and turbidity data for both Deer Creek and the Nemadji River was summarized for each report and given a data quality rank based on quality and usefulness for the upcoming TMDL studies. Locations of past study sites are also provided in the report.

This report begins with an updated summary on data that may be used for loading estimates that was collected prior to and during the TMDL study. Following the updated summary, this report contains a more in depth summary of the data collected during the TMDL study. Included in the section is a preliminary data analysis including turbidity trends/comparisons by site, a first look at a preliminary TSS-turbidity relationship, single-event sediment loading estimates, and quality control information. The section on sediment source tracking includes a summary of isotope, geomorphic, and other sediment source inventories that will be pertinent to the development of the TMDL document that will be completed during 2011-12. Additional data collection is described in the next section which includes fisheries and other water quality information that is relevant to understanding the overall watershed health of Deer Creek. The remaining section describes challenges during the TMDL study that will be important to recognize during data analysis. Future monitoring plans are also described in the last section, providing information on ongoing efforts in the watershed.

2.0 Existing Data Update

The data reported in Table 1 includes TSS, TSVS, turbidity, flow, and precipitation data collected during the TMDL load monitoring and the data previously summarized in the 2008 report. Data rankings are based on criteria developed for the 2008 report as follows:

1: Data in this category will be used directly in the TMDL study. A QAPP (Quality Assurance Project Plan) was in place for the project when the data was collected. Lab and field methods were carried out according to EPA requirements. Data may be used to develop the LDC (Load Duration Curve), wasteload and load allocations, identify water quality indicators such as development of a TSS and turbidity relationship, and assess and identify sources. Data found in STORET may be ranked in this category based on the number of data points and relative age of the data.

2: This data will be used as supportive data and not used directly for the LDC and load allocations. Data may have been collected in support of a peer reviewed scientific journal article with a QA plan or SOP (Standard Operating Procedures) but does not include an EPA or MPCA approved QAPP. This includes any other data that was collected with a QA plan but does not include an EPA or MPCA approved QAPP that will help in the determination of sediment loading. Data found in this category may have standard methods of data collection such as geomorphology work using stream metrics. This data may be used in modeling.

3: Data in this category will not be used to develop the LDC and allocations. Data may help in determining trends, identify needs for additional data, and assist in the identification of pollution sources. Data in this category may be quantitative data but may lack number of data points and/or may be older data. No QA or QAPP exists on the data, yet information was collected by an agency that has trained staff and SOP.

Table 1

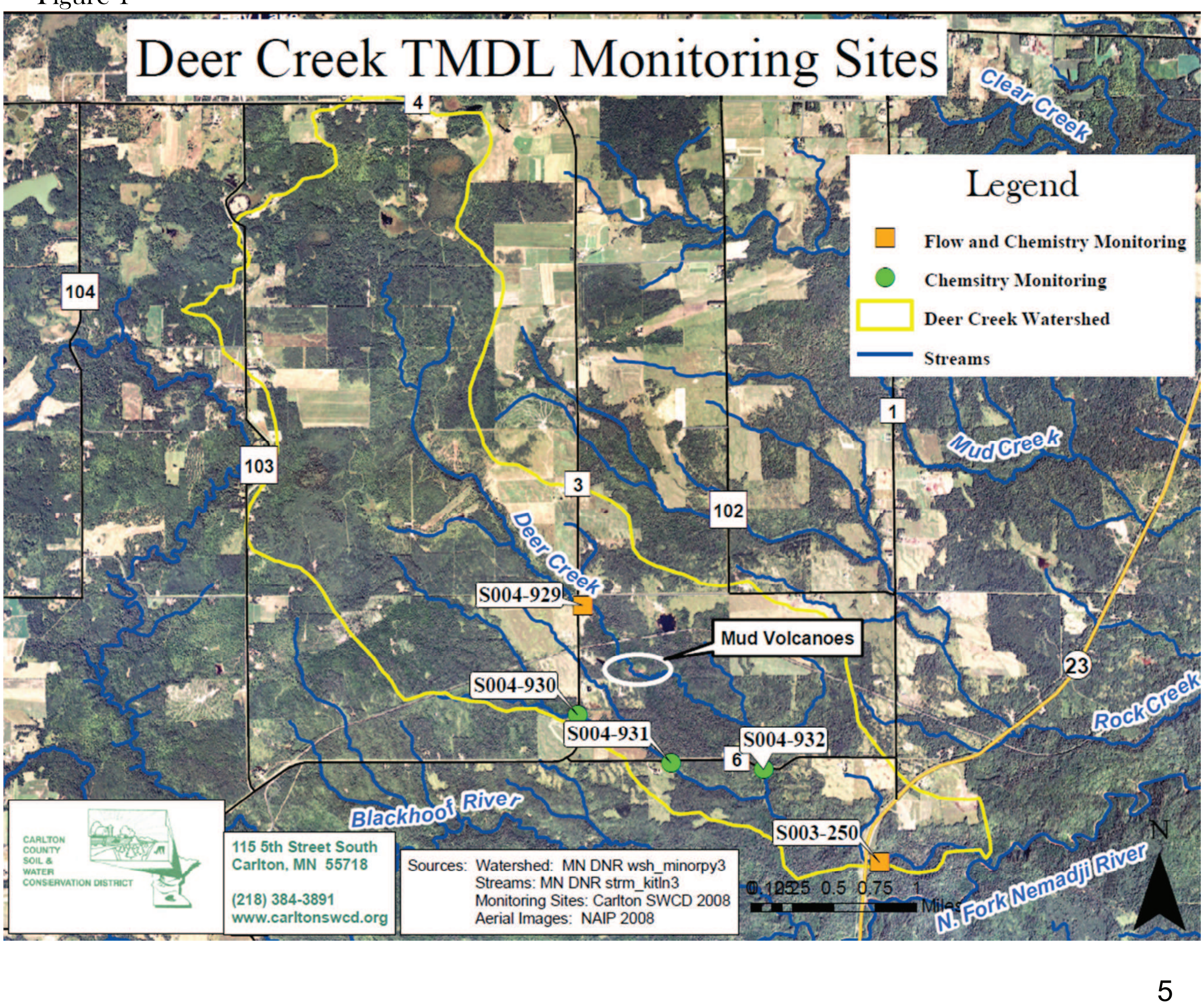
Stream	Location	Site Code		TSS (*TSVS also summarized in this section)						Turbidity						Flow		Rainfall		Notes
		USGS	STORET	Period of Record	Number of Samples	Lab or Field	Units	Data source	Rank	Period of Record	Number of Samples	Lab or Field	Units	Data source	Rank	Period of record	Data Source	Period of Record	Data Source	
Deer Creek-Unnamed Tributary	Hwy 3		S004-930							2008-10	22	field	FNU	STORET/Carlton SWCD	1					TMDL Monitoring
Deer Creek-Unnamed Tributary	Hwy 6		S004-931							2008-10	53	field	FNU	STORET/Carlton SWCD	1					TMDL Monitoring
Deer Creek	Hwy 3		S004-929	1993-4	3	Ukn	mg/L	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109	3	1993-4	3	Ukn	NTU	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109	3	1993-4 (Instantaneous /3 data pts)	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109			May be used for comparison. 3 data points only. Not found in STORET
				2008-10 (TSS)	61	lab	mg/L	STORET/Carlton SWCD	1	2008-10	60/62	field/lab	FNU/NTU	STORET/Carlton SWCD	1	2008-10 (continuous)	MPCA	2008-10	MPCA	TMDL Monitoring
				*2010 (TSVS)	1	lab	mg/L	STORET/Carlton SWCD	1											TSVS data may be used with corresponding TSS data to determine organic content to load
Deer Creek	Hwy 6		S004-932							2008-10	53	field	FNU	STORET/Carlton SWCD	1					TMDL Monitoring
Deer Creek	75ft Upst Hwy 23	04024098	S002-602	1977-79	7	lab	mg/L	USGS	3	1976-8	22	Ukn	JTU	USGS	3	1976-2001 (daily mean)	USGS			May be used for historical comparison.
				1991	16	lab	mg/L	STORET	2	1991	16	lab	NTU	STORET	2	1991 (instantaneous/ 16 data pts)	STORET			May be used for historical comparison.
Deer Creek	Hwy 23	04024098	S003-250	1965-66	2	lab	mg/L	1966 Report "Nemadji River Study" p.20	3	1965-66	2	lab	Ukn	1966 Report "Nemadji River Study" p.20		1965 (December, 1 data point)	1966 Report "Nemadji River Study" p.10			May be used for historical comparison. Data not found in STORET.
				1993-4	3	Ukn	mg/L	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109	3	1993-4	3	Ukn	NTU	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109	3	1993-4 (Instantaneous /3 data pts)	1994 Report "Soil Mass Movement in the Nemadji River Watershed" p. 109			May be used for comparison. 3 data points only. Not found in STORET.
				2001-3	28	lab	mg/L	STORET	1											Data may be helpful in calculation of sediment loads or as comparison data.
				*2002(TSVS)	4	lab	mg/L	STORET	1											TSVS data may be used with corresponding TSS data to determine organic content to load
				2004-5	32	lab	mg/L	STORET/Carlton SWCD	1	2004-5	33	lab	NTRU	STORET	1	2005-7	DNR/MPCA			Data may be helpful in calculation of sediment loads or as comparison data.
				*2004-5(TSVS)	2	lab	mg/L	SORET	1											TSVS data may be used with corresponding TSS data to determine organic content to load
				2008-10	64	lab	mg/L	SORET/Carlton SWCD	1	2008-10	62/63	field/lab	FNU/NTU	STORET/Carlton SWCD	1	2008-10 (continuous)	DNR/MPCA			TMDL Monitoring
				*2010 (TSVS)	3	lab	mg/L	SORET/Carlton SWCD	1											TSVS data may be used with corresponding TSS data to determine organic content to load

3.0 Deer Creek TMDL Monitoring 2008-2010

This section provides a project-specific summary of water quality data collected in Deer Creek by Carlton SWCD staff during 2008-2010 as part of the Deer Creek/Nemadji River Turbidity TMDL Study. Summaries include minimum, maximum and quartile values for each parameter monitored as well as percentage of samples exceeding 10NTU standard for each site. Preliminary data analysis is also included in this section, including turbidity comparisons by site and year, TSS-turbidity relationship, and basic sediment load calculations for a baseflow and rain event scenario.

The study included five monitoring stations located in the Deer Creek watershed (Figure 1). Two of the five stations served as sediment load monitoring sites where grab samples for TSS and turbidity and field chemistry data were collected and continuous stage recordings were made. Flow measurements were taken at these two sites by MPCA and DNR staff in order to develop a flow/discharge relationship. The upper flow monitoring station was located at County Highway 3 (STORET ID S004-929), upstream of the sediment volcanoes, a known source of groundwater sediment contribution. The lower load monitoring station was located downstream of the sediment volcanoes, at the crossing of State Highway 23 (STORET ID S003-250).

Figure 1



In 2010 Total Suspended Volatile Solids (TSVS) was added as a parameter in order to characterize the relative amount of organic content of the TSS concentration. Due to the highly forested nature of the watershed, TSVS data on organic content of the suspended load may be valuable information regarding the natural load of the system. TSVS data was collected at the two load monitoring sites for a limited number of flow conditions during the months of July through September, when stream productivity is highest.

Field data was taken at one additional station on Deer Creek (STORET ID S004-932) and two stations on an unnamed tributary to Deer Creek (STORET ID S004-930 and S004-931). Field data parameters collected at all five stations include turbidity, conductivity, dissolved oxygen, pH, temperature, water clarity and field observations.

For more details on monitoring plans, including site descriptions, site selection rationale, sampling methods, and other monitoring detail, please refer to "Deer Creek/Nemadji River Turbidity TMDL Monitoring Plan 2008-2011 (2010 Update)" All data was collected under quality assurance project plan guidelines as outlined in the "Deer Creek/Nemadji River Turbidity TMDL Quality Assurance Project Plan" (Fischer, 2009)

3.1 Yearly and Combined Years: General Sampling Statistics

The following tables summarize data collection statistics for each of the three years and then for the combined years. Each table describes statistics for all five sites for each of the following parameters: lab turbidity, field turbidity, total suspended solids, and transparency. The 2010 table includes a TSVS summary table as this was the only year TSVS data was collected for this study. The combined year tables summarize the parameters listed above as well as dissolved oxygen, pH and specific conductivity. For each table, sites are listed in order of upstream to downstream. Duplicates are not included in the data summaries.

Table 2

Deer Creek TMDL 2008

Lab Turbidity (NTU)	min	25%	median	75%	Max	Avg	# samples
Deer-Upstream/hwy3	4.8	8.5	18.0	37.8	115.0	30.9	22
Deer-trib/hwy3							
Deer-trib/hwy6							
Deer-hwy6							
Deer-downstream/hwy23	26.0	48.0	78.0	134.0	539.0	121.2	21

Field Turbidity (FNU)	min	25%	median	75%	Max	Avg	#samples
Deer-Upstream/hwy3	5.0	10.5	21.6	40.7	115.6	32.4	21
Deer-trib/hwy3	6.7	29.6	46.8	82.2	150.6	61.3	16
Deer-trib/hwy6	25.5	55.6	80.4	101.8	480.1	101.6	20
Deer-hwy6	31.7	38.2	63.2	112.9	322.9	106.0	21
Deer-downstream/hwy23	31.3	52.2	86.5	153.7	466.6	126.5	21

Total Suspended Solids (mg/L)	min	25%	median	75%	Max	Avg	#samples
Deer-Upstream/hwy3	1.0	4.0	14.5	42.8	179.0	32.4	22
Deer-trib/hwy3							
Deer-trib/hwy6							
Deer-hwy6							
Deer-downstream/hwy23	11.0	19.0	29.5	94.8	483.0	86.0	22

Transparency (cm)	min	25%	median	75%	Max	Avg	#samples
Deer-Upstream/hwy3	10.0	20.5	33.0	67.5	101.0	46.4	23
Deer-trib/hwy3	6.0	17.0	28.0	39.8	101.0	34.9	18
Deer-trib/hwy6	3.0	10.5	16.0	24.3	37.0	17.0	22
Deer-hwy6	5.0	9.3	15.0	21.8	33.0	15.6	22
Deer-downstream/hwy23	4.0	7.5	12.0	17.0	28.0	13.0	23

Note: Transparency values of 101cm indicates reading >100cm taken with 100cm t-tube
Gray cells indicate no data available
Duplicates are not included in summary (2 sets of duplicates taken in 2008)

Table 3

Deer Creek TMDL 2009							
Lab Turbidity (NTU)	**Min**	**25%**	**Median**	**75%**	**Max**	**Avg**	**# Samples**
Deer-upstream/hwy3	8.5	30.5	50.0	62.5	140.0	52.1	19
Deer-trib/hwy3							
Deer-trib/hwy6							
Deer-hwy6							
Deer-downstream/hwy23	32.0	57.0	67.0	119.0	1100.0	163.6	19
Field Turbidity (FNU)	**Min**	**25%**	**Median**	**75%**	**Max**	**Avg**	**# Samples**
Deer-upstream/hwy3	10.0	31.5	44.2	57.9	138.0	50.1	19
Deer-trib/hwy3	20.0	39.4	58.8	78.2	97.6	58.8	2
Deer-trib/hwy6	11.4	40.4	75.8	98.2	179.7	76.1	14
Deer-hwy6	28.8	43.8	62.8	83.7	180.2	75.6	14
Deer-downstream/hwy23	20.2	59.3	70.0	130.9	598.0	138.0	19
Total Suspended Solids (mg/L)	**Min**	**25%**	**Median**	**75%**	**Max**	**Avg**	**# Samples**
Deer-upstream/hwy3	6.0	20.5	35.0	54.5	221.0	50.8	19
Deer-trib/hwy3							
Deer-trib/hwy6							
Deer-hwy6							
Deer-downstream/hwy23	26.0	31.5	38.0	91.0	650.0	116.3	19
Transparency (cm)	**Min**	**25%**	**Median**	**75%**	**Max**	**Avg**	**# Samples**
Deer-upstream/hwy3	8.0	15.0	18.0	23.5	71.0	23.1	19
Deer-trib/hwy3	12.0	24.3	36.5	48.8	61.0	36.5	2
Deer-trib/hwy6	6.0	10.0	12.0	21.3	30.0	15.2	14
Deer-hwy6	6.0	10.3	15.5	19.8	33.0	15.7	14
Deer-downstream/hwy23	2.0	7.5	13.0	15.0	21.0	11.4	19
Note:	Transparency values of 101cm indicates reading >100cm taken with 100cm t-tube						
	Gray cells indicate no data available						
	Duplicates are not included in summary						

Table 4

Deer Creek TMDL 2010

Field Turbidity (FNU)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	8	11	14	40	253	42	20
Deer Creek trib-Hwy3	49	49	51	108	275	106	4
Deer Creek trib-Hwy6	45	64	101	132	343	122	19
Deer Creek-Hwy6	20	49	59	112	658	131	18
Deer Creek-State Hwy23	30	45	83	171	946	189	22

Lab Turbidity (NTU)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	8	11	15	50	360	54	21
Deer Creek trib-Hwy3							
Deer Creek trib-Hwy6							
Deer Creek-Hwy6							
Deer Creek-State Hwy23	30	47	93	200	1900	245	23

Total Suspended Solids (mg/L)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	2	6	9	36	342	43	20
Deer Creek trib-Hwy3							
Deer Creek trib-Hwy6							
Deer Creek-Hwy6							
Deer Creek-State Hwy23	9	22	56	146	1380	208	23

Volitale Solids (mg/L)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	43	43	43	43	43	43	1
Deer Creek trib-Hwy3							
Deer Creek trib-Hwy6							
Deer Creek-Hwy6							
Deer Creek-State Hwy23	2	6	10	25	40	17	3

Transparency (cm)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	5	20	50	73	101	49	20
Deer Creek trib-Hwy3	5	18	23	24	24	19	4
Deer Creek trib-Hwy6	4	8	10	14	28	12	19
Deer Creek-Hwy6	2	8	13	17	20	12	18
Deer Creek-State Hwy23	1	5	9	20	26	11	23

Note: Transparency values of 101cm indicates reading >100cm taken with 100cm t-tube
Gray cells indicate no data available
Duplicates are not included in summary

Table 5

Deer Creek TMDL 2008-2010

Field Turbidity (FNU)	min	25%	median	75%	max	avg	#samples	#>10NTU	%>10NTU
Deer Creek-Hwy3	5	12	30	50	253	41	60	51	85
Deer Creek trib-Hwy3	7	35	50	92	275	69	22	21	95
Deer Creek trib-Hwy6	11	57	86	114	480	102	53	53	100
Deer Creek-Hwy6	20	43	61	113	658	107	53	53	100
Deer Creek-State Hwy23	20	53	78	163	946	152	62	62	100

							#samples				
Lab Turbidity (NTU)	min	25%	median	75%	max	avg	total	low flow	high flow	#>10NTU	%>10NTU
Deer Creek-Hwy3	5	14	31	54	360	45	62	20	42	49	79
Deer Creek trib-Hwy3											
Deer Creek trib-Hwy6											
Deer Creek-Hwy6											
Deer Creek-State Hwy23	26	51	77	140	1900	179	63	21	42	63	100

							#samples		
Total Suspended Solids (mg/L)	min	25%	median	75%	max	avg	total	low flow	high flow
Deer Creek-Hwy3	1	6	21	48	342	42	61	20	42
Deer Creek trib-Hwy3									
Deer Creek trib-Hwy6									
Deer Creek-Hwy6									
Deer Creek-State Hwy23	9	25	38	110	1380	139	64	21	43

							#samples		
Volitale Solids (mg/L)	min	25%	median	75%	max	avg	total	low flow	high flow
Deer Creek-Hwy3	43	43	43	43	43	43	1	0	1
Deer Creek trib-Hwy3									
Deer Creek trib-Hwy6									
Deer Creek-Hwy6									
Deer Creek-State Hwy23	2	6	10	25	40	17	3	1	2

Transparency (cm)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	5	16	26	61	101	40	62
Deer Creek trib-Hwy3	5	16	24	37	101	32	24
Deer Creek trib-Hwy6	3	10	12	20	37	15	55
Deer Creek-Hwy6	2	9	14	19	33	14	54
Deer Creek-State Hwy23	1	6	12	17	28	12	65

Dissolved Oxygen (mg/L)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	7.31	9.26	9.78	10.98	14.26	10.22	53
Deer Creek trib-Hwy3	3.03	8.74	9.30	9.90	14.70	9.41	18
Deer Creek trib-Hwy6	6.46	8.39	9.18	10.16	16.00	9.43	47
Deer Creek-Hwy6	6.37	9.06	9.57	10.57	15.75	9.90	47
Deer Creek-State Hwy23	6.35	9.36	9.71	10.72	17.16	10.10	54

pH	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	7.04	7.86	7.98	8.11	8.64	7.96	58
Deer Creek trib-Hwy3	7.12	7.50	7.78	7.85	8.40	7.71	22
Deer Creek trib-Hwy6	7.31	7.66	7.80	7.89	8.04	7.77	53
Deer Creek-Hwy6	7.76	7.96	8.08	8.19	9.71	8.09	52
Deer Creek-State Hwy23	7.74	7.97	8.05	8.16	8.52	8.06	61

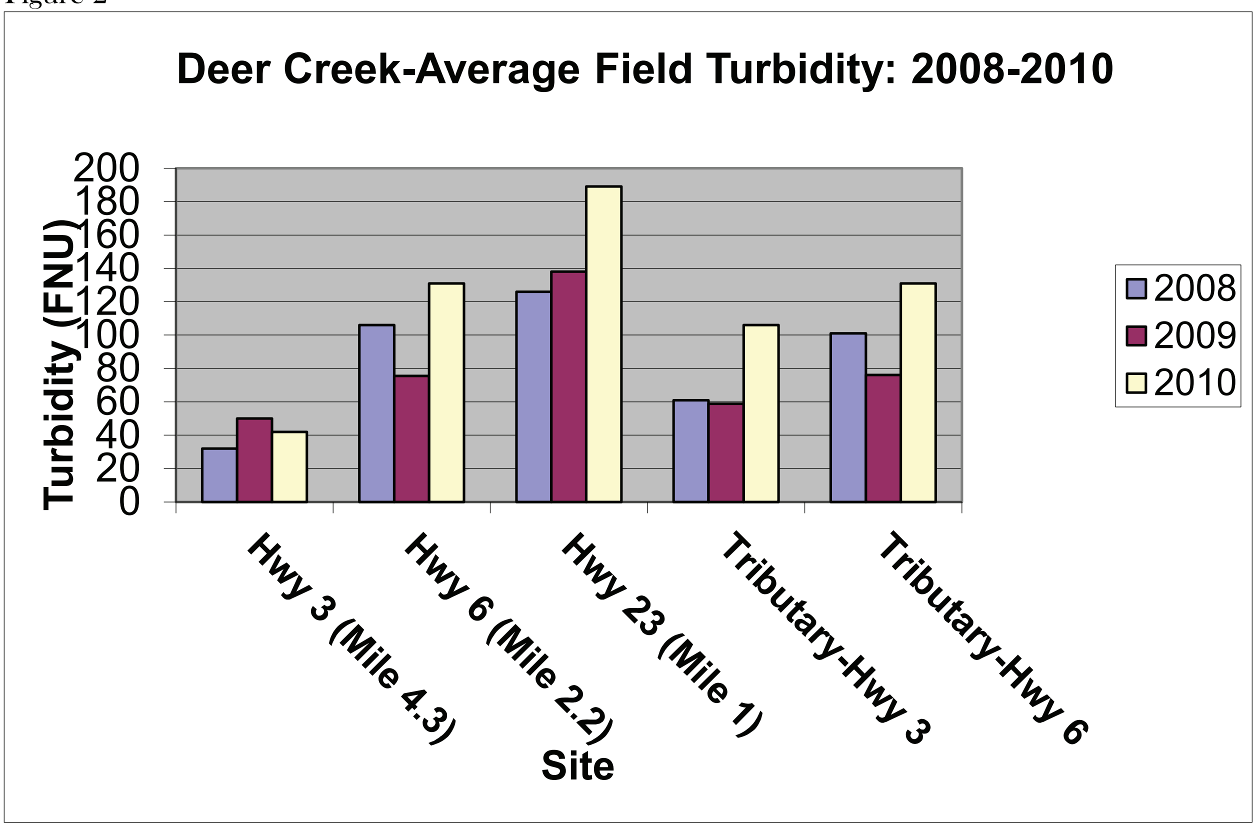
Specific Conductance (uS/cm)	min	25%	median	75%	max	avg	#samples
Deer Creek-Hwy3	89	181	303	337	386	267	60
Deer Creek trib-Hwy3	57	100	125	193	274	144	22
Deer Creek trib-Hwy6	79	147	207	250	314	202	53
Deer Creek-Hwy6	117	205	267	287	308	246	52
Deer Creek-State Hwy23	97	203	276	300	324	249	62

3.2 Turbidity Data-General Trends

Figure 2 displays a graph of the average field turbidity reading for each of the three monitoring years. Sites are presented from upstream to downstream and the indicated miles are number of miles from the mouth of the stream. The general trend is an increase of turbidity values moving downstream, especially beyond the mud volcanoes such as mile 2.2 (Hwy 6) and mile 1 (State Hwy 23). Data at the Hwy 6 tributary site shows general match to Hwy 6 site. 2010 data shows highest turbidity averages. 2010 is influenced by larger number of rain events compared to 2008 and 2009, which were dryer years.

Note that in 2009, the Hwy 3 site had the highest average turbidity for the site out of the three years, yet the other sites show 2010 as highest average. In 2009 the Hwy 3 site was influenced by large beaver dam just upstream of the monitoring station. It was noted that during low flows turbidity values were higher than when the dam was not there.

Figure 2



3.3 TSS-Turbidity Relationship (Preliminary)

Turbidity is a qualitative measurement of the scattering of light particles. In order to complete sediment loading calculations, a quantifiable number needs to be used. Total suspended solids, which is a quantitative measurement of the concentration of the total suspended solids in the water, was chosen as a quantitative surrogate to turbidity for this study. A relationship between turbidity and TSS will be established through the pairing of the data order to define a relationship between the 10NTU standard and a load number.

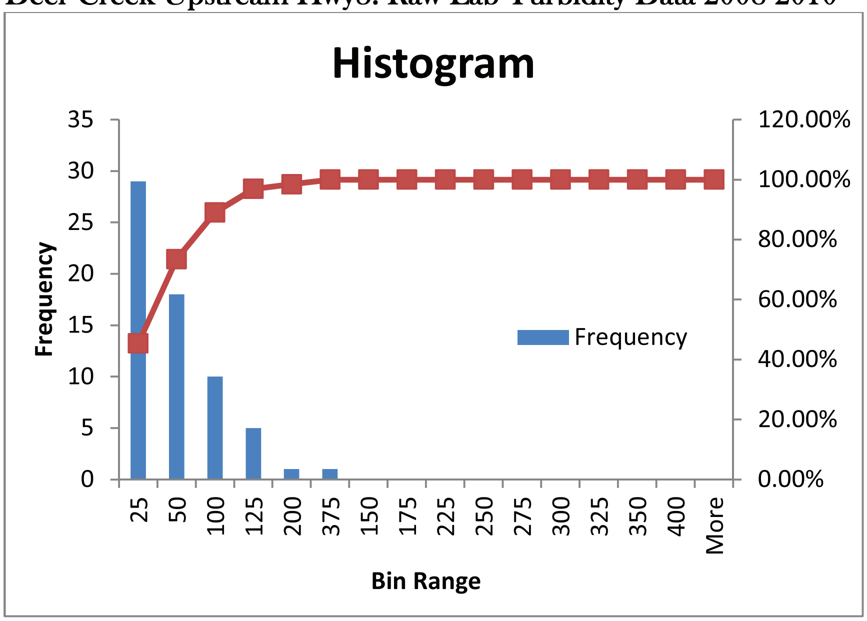
The data analysis in this section is based on the lab analysis data collected at the two load monitoring station in Deer Creek over the three years of the TMDL study. Data analysis in this section is preliminary and will be more fully developed in the TMDL document.

TSS-Turbidity Raw data analysis: Histogram and Descriptive Statistics

Raw data for each station was analyzed in order to determine if it was normally distributed. TSS and turbidity water quality data is typically not normally distributed and log transformations are done in order to approximate a normal distribution for linear regression analysis. Microsoft Excel's Descriptive Statistics and Histogram data analysis tools were used to analyze the raw data for distribution for each of the two Deer Creek sites. The graphs and supporting charts below show that the raw data for both sites is not normally distributed. A histogram with a normal distribution curve would be bell-shaped, with equal amounts of data on each side of the mean. The turbidity data in the histograms below shows a right skew, indicating that there is a larger proportion of turbidity data on the lower end of the data range. The TSS and lab turbidity data are not normally distributed, making it appropriate to log-transform the data.

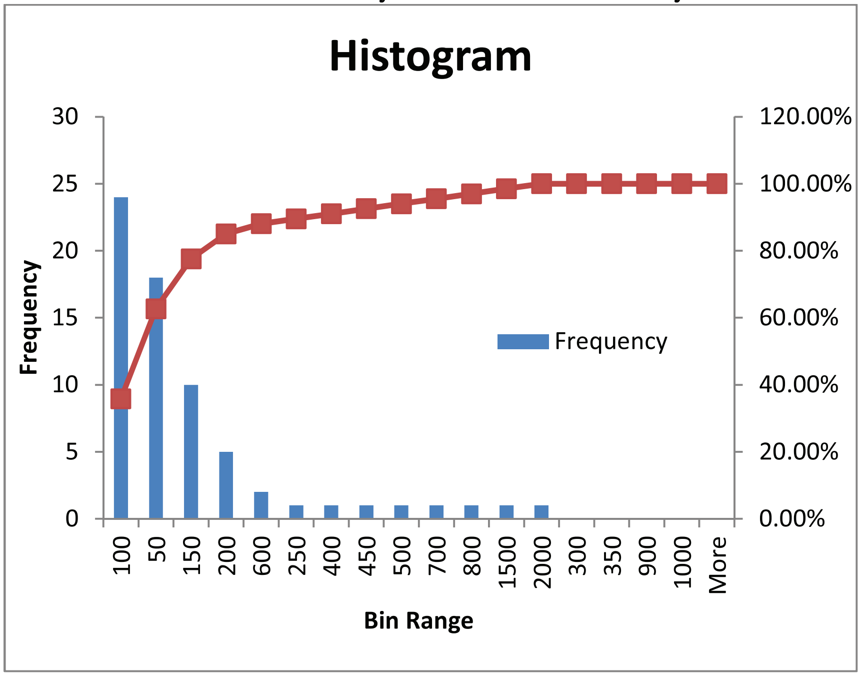
Figure 3

Deer Creek-Upstream-Hwy3: Raw Lab Turbidity Data 2008-2010



	TSS	Lab Turb
Mean	45	42
Standard Error	10	7
Median	20	27
Mode	6	15
Standard Deviation	81	54
Sample Variance	6606	2882
Kurtosis	22.20	19.39
Skewness	4.34	3.82
Range	530	355.2
Minimum	1	5
Maximum	531	360
Sum	2896	2719
Count	65	65

Figure 4
Deer Creek-Downstream-Hwy 23: Raw Lab Turbidity Data 2008-2010



	TSS	*Lab Turb*
Mean	135	173
Standard Error	30	35
Median	38	77
Mode	19	36
Standard Deviation	243	287
Sample Variance	58922	82304
Kurtosis	12.09	20.95
Skewness	3.29	4.17
Range	1371	1874
Minimum	9	26
Maximum	1380	1900
Sum	9030	11593
Count	67	67

TSS-Turbidity Relationship/Regression Charts

Using the data collected 2008-2010, a preliminary TSS-turbidity relationship has been developed. As described above, the data was log-transformed in order to arrive at a TSS-turbidity relationship where 10NTU can be correlated to a TSS concentration. The final regression analysis for the TSS and turbidity data will be subject to additional raw data analysis decisions and possible error factors.

Figures 5 and 7 show a plot of TSS and turbidity raw data without log transformation for each load monitoring site. The charts serve as another visual example of the skew of the data toward the lower end of the values. Figures 6 and 8 show a plot of the TSS and turbidity data with log-transformed data. The surrogate was calculated for 10 NTU using the shown regression equation and rounded to the nearest whole number. Using all TSS and turbidity data from 2008-2010, the TSS surrogate for 10 NTU resulted in 5 mg/L for the County Highway 3 station and 4 mg/L for the State Highway 23 station.

Figure 5

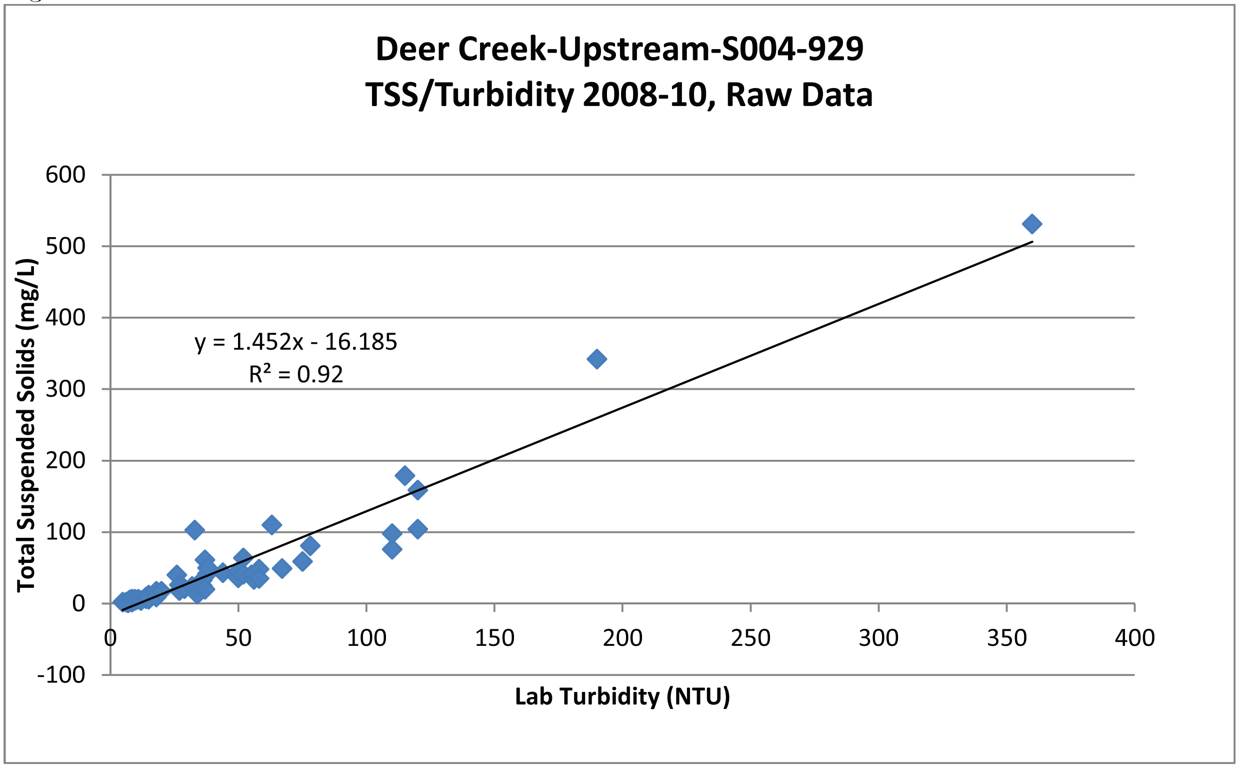


Figure 6

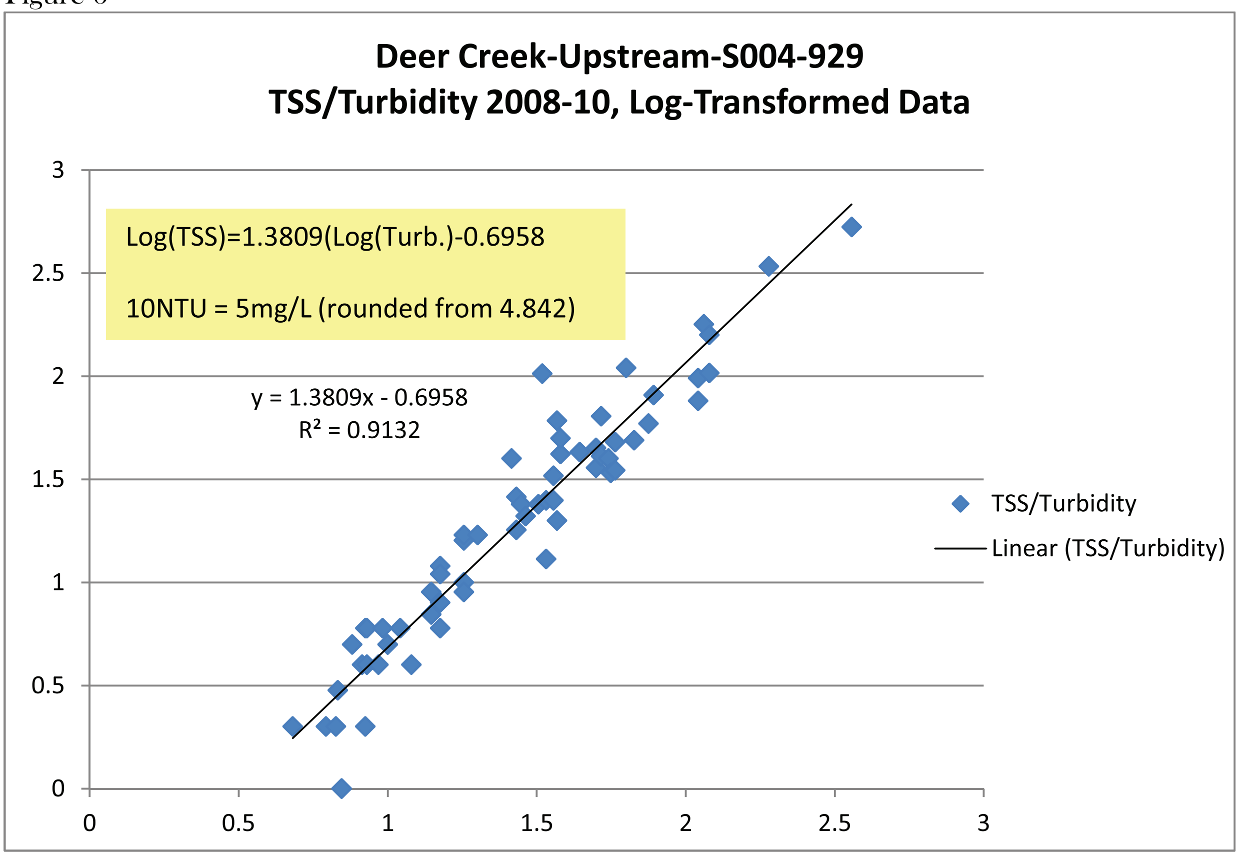


Figure 7

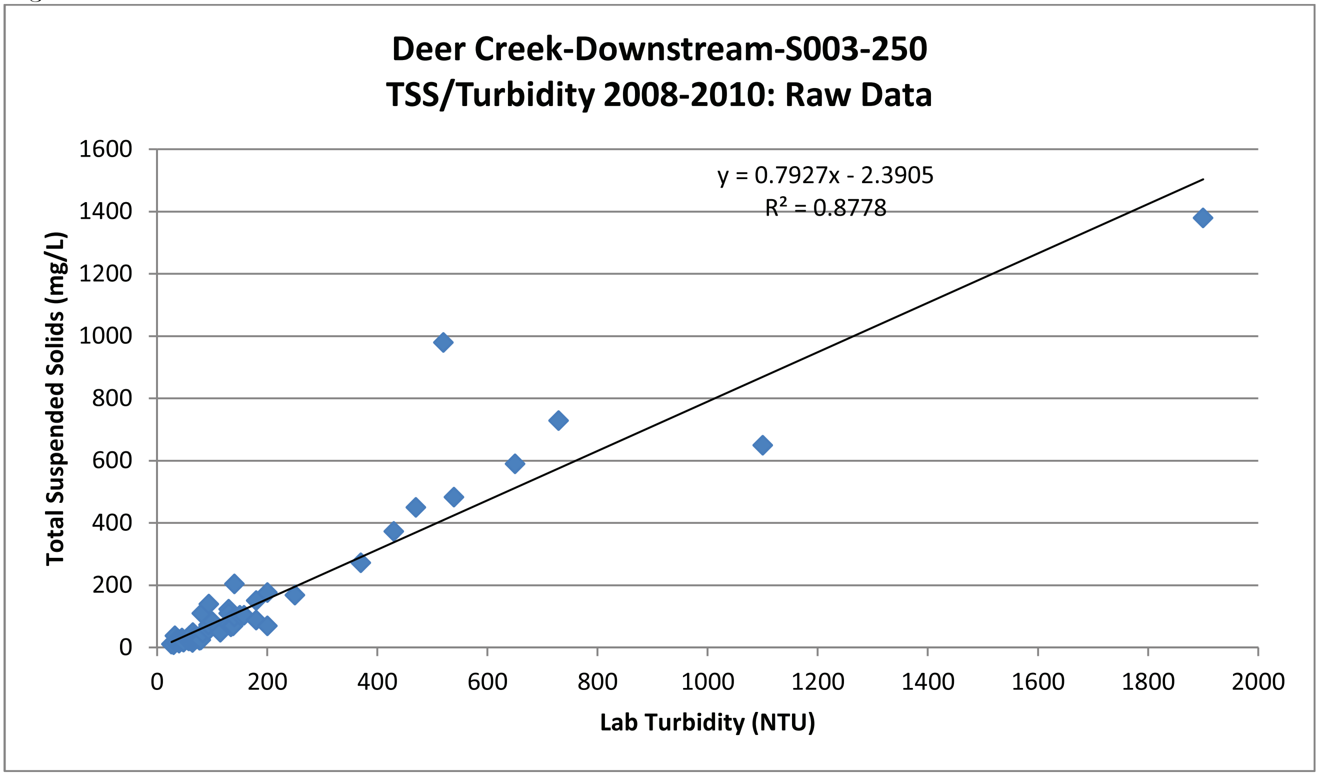
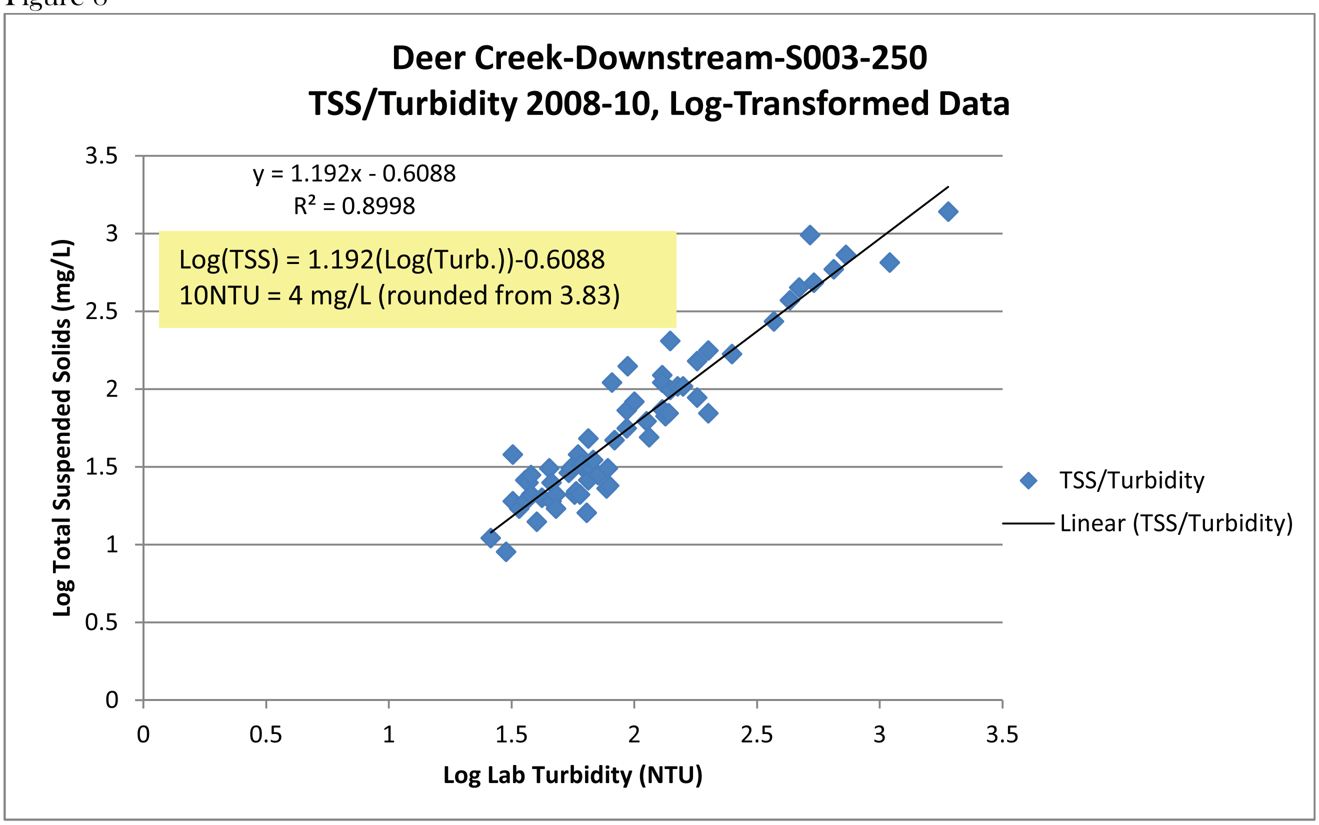


Figure 8



3.4 Preliminary Loading Estimates for Baseflow and a Storm Event

The continuous flow monitoring station at State Highway 23 was established before the TMDL study began and a stage-discharge relationship has been previously established. This allows for reasonable preliminary estimates for calculating sediment loads at discrete points in time using grab sample analysis data and comparing it to gage height at time of sampling. The table below summarizes two different scenarios for sediment loading in Deer Creek at State Highway 23, which is the lowest downstream monitoring station in the watershed. Previous data analysis has approximated that baseflow occurs at the site when the stage is approximately 1.5 to 2.0 feet. A sampling event that took place in June 2009 during a relatively dry period where the stage was 1.78 feet was used to estimate a baseflow sediment load. About 25.6 pounds per hour was estimated for the baseflow loading rate on this date.

A high flow event from June of 2010 was chosen in order to demonstrate a typical summer rain event and the effects on the loading capacity. 19,800 pounds of sediment per hour was the resulting estimation for this event. The large magnitude of this number characterizes both the flashiness and large sediment loading capacity of the stream during a typical storm event.

Table 6

Site:	**Deer Creek-Hwy 23**	
Flow Conditions:	**Baseflow**	**High Flow (1" rain event)**
Sample Date:	8/6/2009	6/11/2010
Gage Height:	1.78ft	4.15ft
Approx. Flow:	3 cfs	120 cfs
TSS:	38 mg/L	729 mg/L
Loading Rates:	0.007 lbs/s	5.5 lbs/s
	0.42 lbs/min	330 lbs/min
	25.6 lbs/hr	19800 lbs/hr

3.5 Sampling and Analytical Precision: Relative Percent Difference

One quality control grab sample duplicate was taken each monitoring year in order to determine sampling and laboratory analytical precision. Precision can then be measured by calculating the relative percent difference (RPD) of the two samples.

$$RPD = (A - B) / ((A + B)/2) \times 100$$

The Deer Creek/Nemadji River Turbidity TMDL Project QAPP indicates that the quality objective criteria for the % RPD is not to exceed 30%. Table 7 summarizes the RPD for grab sample duplicates taken each of the three monitoring years. All RPD values meet the RPD criteria.

Table 7

Site	Site Number	Date	Conditions	TSS	Lab Turbidity	TSS RPD	Turbidity RPD
Deer Creek-Hwy3	S004-929	9/19/2008	Baseflow	1	7		
Deer Creek-Hwy3	S004-929	9/19/2008	Baseflow	1	7	0.0%	0.0%
Deer Creek-State Hwy23	S003-250	9/19/2008	Baseflow	23	77		
Deer Creek-State Hwy23	S003-250	9/19/2008	Baseflow	24	79	4.3%	2.6%
Deer Creek-Hwy3	S004-929	5/28/2009	Baseflow	6	8.5		
Deer Creek-Hwy3	S004-929	5/28/2009	Baseflow	6	8.4	0.0%	1.2%
Deer Creek-State Hwy23	S003-250	5/28/2009	Baseflow	26	36		
Deer Creek-State Hwy23	S003-250	5/28/2009	Baseflow	28	38	7.4%	5.4%
Deer Creek-Hwy3	S004-929	7/26/2010	Baseflow	5	10		
Deer Creek-Hwy3	S004-929	7/26/2010	Baseflow	5	10	0.0%	0.0%
Deer Creek-State Hwy23	S003-250	7/26/2010	Baseflow	19	32		
Deer Creek-State Hwy23	S003-250	7/26/2010	Baseflow	19	36	0.0%	11.8%

4.0 Deer Creek TMDL Sediment Source Tracking

In addition to sediment loading data collected through in-stream measurements, data exists in varying forms regarding hydrogeology, stream morphology, and land use that may aid in identifying sediment sources for Deer Creek. Stable isotope data has been collected as part of the TMDL study in order to delineate the sources and quantify groundwater sediment source contribution. This data will support previous groundwater studies that have taken place in Deer Creek. Additionally, stream geomorphology data has been collected through various past studies and was collected during this project. Mapping projects have also been completed, including a land use inventory and several slump inventories. This section summarizes these types of data that exist in the Deer Creek watershed which may aid in identifying and quantifying sediment sources. Table 8 summarizes existing groundwater, geomorphological research and mapping projects that has been completed in Deer Creek.

4.1 Groundwater Study

Groundwater contribution to the sediment load in Deer Creek has been explored prior to and during the TMDL project through an initial seepage/refraction investigation, groundwater and slump modeling, and isotope data collection. Existing groundwater research that has been conducted on Deer Creek in recent years is summarized in Table 8 along with geomorphological reports and other slump/erosion reports and inventories.

Stable isotope data collection was completed for the TMDL and led by the MPCA.
Grab samples for isotope analysis were collected from precipitation, groundwater, and surface water sources in the Deer Creek watershed during the course of the TMDL study. Samples were taken during spring snow melt, spring rainfall, summer rainfall, fall rainfall, fall snow melt and

winter snow pack. Samples will also be taken at base flow conditions both during evapotranspiration (ET) and post ET.

4.2 Geomorphological Data collection

Slumping, erosion, and the relation to land use practices has been studied extensively in the Nemadji River watershed, including Deer Creek. Reports have been produced that may be useful in defining sediment sources for the TMDL project. Data contained in the reports detail watershed characteristics that influence the slumping and erosion in the stream. Such data includes streambank erosion and vegetation analysis, stream metric data, roadside erosion inventory, slump inventories and slump mapping, and land use mapping and analysis. Many of the reports listed in Table 8 are drawn from the list of reports produced in "Deer Creek/Nemadji River Total Maximum Daily Load Summary of Existing Water quality Data" (2008).

During the course of the TMDL study, watershed characteristic and stream channel data was gathered in Deer Creek to further understand current conditions of the system. In 2008, high-resolution aerial photos were taken over the length of Deer Creek. During the same timeframe, SWCD and MPCA staff walked much of the stream corridor, collecting photos and waypoints of channel and bank features, such as slumps, beaver dams, and other channel stability characteristics. A GIS project was produced using the aerial photos and waypoints hot-linked to the ground photos, and is included in the inventory on Table 8.

A stream survey was also conducted during 2009 and 2010 in order to investigate noticeable channel aggradation that took place at the Highway 3 monitoring site in the spring of 2009. The 2009 survey included longitudinal profile on approximately 540ft of stream and four cross-sections. Pebble counts were taken at all cross-sections and along the entire reach. Pfankuch channel stability rating was also conducted along the surveyed reach. In 2010, the longitudinal profile was repeated and six cross-sections were surveyed along the same reach.

Table 8

Report/Project	Year	Predominant Data Type
"Red Clay Project: Impact of Nonpoint Pollution Control on Western Lake Superior-Final Part II" prepared for EPA	1980	Final reports on research conducted by UW-Superior, Center for Lake Superior Environmental Studies. Includes turbidity and stream velocity data. Also includes **roadside and stream bank erosion report and vegetation analysis.**
"Soil Mass Movement in the Nemadji River Watershed" by Wayne Wold	1994	Suspended sediment and discharge data Deer Creek. Correlation between turbidity and suspended sediment concentrations. Land cover characteristics. **Assessed number of beaver dams and slumps.**
"Analysis of Soil Mass Wasting in the Nemadji River Watershed" by Wayne Wold, Lloyd Queen, and Kenneth Brooks (1994)….followup report**"Assessing Cumulative Effects in the Nemadji River Basin, Minnesota"** by Wayne Wold, Lloyd Queen, and Kenneth Brooks summarizes 1994 report)	1995	Continuation of previous report. Includes **GIS database with slump inventory** for nine subwatersheds, including Deer Creek.

"Land Use Impacts on Stream Channel Processes in the Nemadji Watershed" by Mark Reidel	1998	**Stream flow, channel hydraulics, slump inventory, and land use.**
"Erosion and Sedimentation in the Nemadji River Basin-Nemadji River Basin Project Final Report" completed by Natural Resources Conservation service and U.S. Forest Service (1999) (Phase I)	1992	This report established the goals that became the basis of the initial Clean Water Partnership Phase II implementation project funded by the MPCA in 2000 and the Clean Water Partnership Phase II Continuation project begun in 2004. Two EPA Section 319 grants focused on implementing the 1998 NRCS reports recommendations have also been completed in the Nemadji River Basin. A **sediment budget** was developed which includes estimations of sediment contribution of all tributaries in the Nemadji River Basin, including Deer Creek.
"EPA 319 Final Report" submitted by Carlton County SWCD (2003) **"Nemadji river Watershed-Minnesota Potion Landsat Based Open Land Inventory"** completed by Community GIS, Duluth	2000	Report outlines accomplishments of 1999-2000 workplan. Includes summary of completed **forest inventory GIS project**. Accompanying ArcView project includes maps of 0-15 year age class forest land and open lands identified on a sub-sub watershed level for the entire Nemadji River watershed, including Deer Creek. Outcome of project was to assist in prioritization of high erosion potential areas for tree planting and other erosion control practices.
"Nemadji River Basin Sediment Transport Modeling for Two Subwatersheds" by Biard and Associates completed for US Army Corps of Engineers	2000	**Surface water model providing sediment budget** information for the Nemadji River Basin based on data from Deer Creek and Skunk Creek.
"Nemadji River Basin Project Final Report for 2001 319 Parntership Grant" submitted by Carlton County Water Management Plan Coordinator	2001	Outlines accomplishments of NRBP 2001. Completed **GIS project inventorying Red Clay dam sites**. Flow and water quality monitoring includes TSS data for Deer Creek and N. Fork Nemadji River.
"Land Use Impacts on Fluvial Processes in the Nemadji River Watershed" by Mark Reidel, Sandy Verry, and Kenneth Brooks	2002	**Stream metric evaluation**. Study sites were N. Fork Nemadji River, Deer Creek, Skunk Creek, and Blackhoof River. Four study sites for channel metrics were chosen for each stream.
"Channel Stability Across Scale in the Nemadji River Basin" by Joe Magner	2004	Study established new study sites in addition to Reidel's work (see **"**Land Use Impacts on Stream Channel Processes in the Nemadji Watershed" by Mark Riedel (1998) above**). Includes 5 stream survey stations on Deer Creek.**
"Deer Creek Groundwater Seepage" by Howard Moores and Nigel Wattrus (UMD)	2005	**Groundwater investigation** included an analysis of regional stratigraphy and landforms, hydraulic potential mapping, site mapping of beaver pond perimeter and seepage points (8), stream discharge above and below beaver pond/discharge area, geophysical survey and failure analysis.
"Stream Bank Stability Assessment in Grazed Riparian Areas" by Mark Reidel, Kenneth Brooks, and Elon Verry (2006)	2006	**Assesses stream bank stability in grazed riparian areas along Deer Creek using Pfankuch method and mechanical estimates.**
"Predicting stream channel erosion in the lacustrine core of the upper Nemadji River, Minnesota (USA) using stream geomorphology metrics" by Joe Magner and Kenneth Brooks	2007	Use of stream geomorphology metric information obtained at past study locations to **predict stream channel erosion** in the upper portion of the Nemadji River.
"Deer Creek Field Tour" Carlton SWCD and MPCA staff	2008	**GIS project contains waypoints and hotlinked photos of large slumps, sediment volcanoes, tributary confluences, and beaver dams layered over high resolution aerial photos**

		along Deer Creek beginning at Soo Line trail and ending at Hwy 23. Chemistry data collected at some points of interest.
"Deer Creel Groundwater Model"	2008	**Groundwater model** for Deer Creek. Model domain begins northwest of Deer Creek near Hay Lake and ends at the confluence with the Nemadji River.
Stable Isotope Data Collection-completed by MPCA	2008-10	**Stable isotope data collection** was completed for the TMDL and led by the MPCA. Grab samples for isotope analysis were collected from precipitation, groundwater, and surface water sources in the Deer Creek watershed during the course of the TMDL study.
Deer Creek-Hwy 3 Stream Survey-conducted by MPCA, DNR and SWCD staff	2009, 2010	**Stream survey data.** In 2009, longitudinal profile data was taken on 540ft of stream. 4 cross-sections were complete along with pebble counts at all cross-sections and along the longitudinal profile. Pfankuch channel stability rating was conducted along the surveyed reach. In 2010 the longitudinal profile was repeated along with 6 cross-sections.
"Carlton County Geologic Atlas-Part A-Geology" completed by Minnesota DNR and Minnesota Geological Survey	2009	**GIS maps of county geologic resources.** Includes bedrock geology, surficial geology, quaternary stratigraphy, bedrock topography, depth to bedrock, and sand distribution model, and mineral endowments for Carlton County, including Deer Creek watershed. Part B-Hydrogeology, which includes maps of hydrogeology and sensitivity to groundwater is still in progress.
"Potential for Slumps, Sediment Volcanoes and Excess Turbidity in the Nemadji River Basin" by Irvin Mossberger, University of Minnesota-Duluth	2010	Examines the relationship between the slumps and sediment volcanoes, and develops a **predictive model of the potential for slope failure in the lacustrine clay portions of the basin**. A 3-D model of stratigraphy and hydraulic potential from more than 300 wells is used, along with slope stability analysis with the stress-slope and Mohr-Coulomb equations in a GIS.

5.0 Other Data collection

This section describes fisheries and additional water quality information that is relevant to understanding the overall watershed health of Deer Creek.

5.1Fisheries Data Collection

Deer Creek is listed as a designated trout stream and the Minnesota DNR recently monitored the stream to track the health of the fish population. Data collected by the DNR during the TMDL study will aid in understanding the presence of the fish population, the suitability of the habitat, and its relation to the varying turbid conditions of the stream. The current 10NTU turbidity standard is based on the designation of Deer Creek as a cold water/trout stream.

In 2009, a population assessment was conducted on Deer Creek at three locations beginning downstream of the mud volcanoes at State Highway 23 and ending upstream of the mud volcanoes at County Highway 3. A population assessment gives a general understanding of the abundance of game fish through data collection during fish counts. Data from the 2009 assessment indicated that several fish species exist at all three monitored reaches. The identified species are those that are typically tolerant of warm water and high turbidity such as creek chub and common shiners. No trout were found present in Deer Creek.

In 2009 the DNR began monitoring temperature at the same general locations as the assessment monitoring sites. Water temperature is an indicator of fish habitat suitability. Temperature is assessed over a three-year period in order to collect data over a range of conditions. Temperatures are categorized into the range below which growth occurs, the range of growth, and range of thermal stress. Initial data has indicated that temperatures entered the range of stress in the lower portion of the creek. The third year of monitoring will be completed in 2011and a final report will be available later in the year. Data will be evaluated by DNR staff and decisions may be made about trout stream designation changes in the coming years.

5.2 Other Water Quality Parameters (field turbidity, specific conductivity, dissolved oxygen, pH, temperature, and water clarity)

Field data was taken at five locations in Deer Creek (see Figure 1 map). Three locations are on the main stem of Deer Creek and include both sediment load monitoring stations. The two additional stations are located on an unnamed tributary to Deer Creek. Field data parameters collected at all five stations include turbidity, specific conductivity, dissolved oxygen, pH, temperature and water clarity.

This supporting data may be used in comparing different parameters and correlations, and to examine the relative health of the stream at varying locations. Field turbidity data can be compared to lab sample turbidity in order serve as a field check for lab turbidity results. Additionally, the turbidity data can be compared to water clarity data collected by transparency tube in order to establish a turbidity/transparency relationship for each site. Conductivity results can be compared to flow data in order to evaluate if a correlation exists for low flows and high conductivity. Groundwater baseflow contribution often has higher conductivity than surface water runoff contribution to the stream. This type of information can be used as a simple ground water tracer.

As with turbidity, additional data collected in the field including dissolved oxygen, pH and temperature is useful for gaging the relative health of the stream conditions for aquatic life. Each parameter has an associated water quality standard based on needs for conditions for aquatic life. Similarly, these parameters can aid in understanding results of the recent fish assessment and future biotic assessments.

6.0 Challenges and Future Monitoring

6.1 Site Challenges and Data Gaps

During the course of the study, data collection was occasionally disrupted due to issues with beaver dams, site vandalism, and equipment failure. This section discusses general challenges and resulting data gaps.

During the summer of 2009, a beaver dam was constructed just downstream of County Highway 3 crossing of the Unnamed Tributary to Deer Creek, causing water to back up the stream for several hundred feet. Field sampling was not conducted while the beaver dam was in place due to the lack of flow and lack of alternative sampling site near the location. Sampling continued at the existing site located less than a half a mile downstream on the tributary and will serve as the more complete set of representative data for the tributary to Deer Creek.

Another beaver dam was constructed in 2009 just above the culvert on Deer Creek at the County Highway 3 sediment load monitoring site. Turbidity results for that year showed slightly different trends that may or may not be related to the beaver dam. Additionally, sediment filling at the gaged pool downstream of the culvert took place that year, resulting in the need for rating curve adjustments. Channel survey data was completed in 2009 and 2010 to aid in understanding the channel adjustment trends of the site.

In September 2009, the flow monitoring site located at County Highway 3 was vandalized and some continuous flow data was lost. Data was disrupted during late September and early October 2009 when the sensor became buried in sediment. In 2010, the flow monitoring site located at State Highway 23 reported disruptions in data due to equipment malfunction during the months of June, July, August, October and November. More details can be found on the year end summary reports provided with flow data on the DNR/MPCA Cooperative Stream Gaging website.

6.2 Future Monitoring

Grab sampling and field data collection will continue at the two sediment loading stations on Deer Creek in order to continue to track the sediment load of the system after the study is completed. Ten samples per year will be taken over a range of hydrologic events. The flow gaging equipment will remain at the Hwy 23 monitoring site. The flow gaging equipment will be removed from the Hwy 3 monitoring site. The staff gage will remain in order to continue to relate sampling data to the stream stage height and established rating curve.

A biological assessment will be conducted by the MPCA in the greater Nemadji River watershed during 2011 through their developed watershed approach. The approach places Minnesota's major watersheds on a 10-year cycle of condition monitoring that includes the collection of chemistry, flow, and biological data. Chemistry data is being collected by SWCD staff and volunteers during 2010-2011 at ten locations throughout the watershed for condition monitoring. For more detail on chemistry condition monitoring, please refer to the 2010 update of the Deer Creek/Nemadji River TMDL Monitoring Plan. Biological data collection will be conducted by MPCA and sites have not yet been selected.