Effect of Historical Logging on Geomorphology, Hydrology, and Water Quality in the Little Fork River Watershed

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Minnesota Pollution Control Agency and Ellen River Partners

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Executive Summary

The Little Fork River begins in lowlands near Lake Vermilion in northeast Minnesota. It drains a watershed of 1,843 square miles, flowing 160 miles before it enters the Rainy River on the U.S. – Canadian border. Land cover in the watershed is predominantly forest and wetland where the river flows through lacustrine and reworked till of the former glacial Lake Agassiz basin. The watershed is sparsely populated and remote where principal industries include forest products harvesting and tourism. Extensive stands of pine and pulp-wood were historically logged from the 1890's to 1937. Currently the Little Fork River is impaired for turbidity in the lower (most downstream) reach from the town of Littlefork to the Rainy River. Because several waterbodies in Minnesota have been listed as impaired without sufficient monitoring and assessment, this study was designed to further document the turbidity and sediment concentrations in the mainstem of the River from the Rainy River confluence to the headwaters; and to provide information needed to determine the scope and likely sources of the turbidity impairment for the upcoming Total Maximum Daily Load study. Our study included water quality sampling at seven representative reaches, a detailed analysis of the long term climatology and US Geological Survey streamflow datasets, an analysis of watershed landcover, and initial stream geomorphology surveys. Our results indicate that the turbidity impairment extends from the Rainy River confluence upstream for at least 142 river-miles. The primary cause of the excessive turbidity is suspended sediment likely resulting from erosion of the mainstem river banks- which, in turn, is due to increased streamflows. A detailed analysis of the US Geological Survey streamflow gage dataset indicates that 1.5 year 'bankfull' flows (i.e. the streamflow that defines the size and shape of the channel) have significantly changed over the 80 year period of record. Using a weight of evidence approach, we hypothesize that these changes in bankfull flow are due to the impacts of historical logging and the influence of local geology and vegetation. Trends in bankfull discharge in the Little Fork River are independent of the effects of annual precipitation; we infer the changes to be driven by watershed factors (i.e. land cover). Normalized bankfull flows in the adjacent and similarly sized Big Fork River watershed are significantly lower ($p<0.001$) than those on the Little Fork River. We hypothesize that the factors explaining this include: a greater percentage of peatlands in the Big Fork watershed (that were never historically logged) which dampen flood flows and reduce flashiness; a greater number of headwater lakes in the Big Fork providing more watershed storage; earlier and comparatively less historical logging in the Big Fork; and a greater proportion of pasture / open land in the Little Fork watershed. A regional curve analysis indicated that the Little Fork River and its tributaries have approximately twice the water yield when compared to other area streams. The Little Fork River is likely still recovering from the hydrological and geomorphic impacts associated with historical logging- by the years of increased runoff (water yield) following initial harvest, as well as the geomorphic impact of using the river to transport logs. The former is supported by numerous visual observations, an aerial over-flight, and initial geomorphology surveys; however significant study remains to substantiate this hypothesis. Several proposed next steps for the upcoming TMDL and long-term Little Fork / Big Fork Rivers paired watershed study are identified.

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Introduction and Environmental Setting

The Little Fork River begins in lowlands near Lost Lake, south of Lake Vermilion and drains a watershed of 1,843 square miles. The 160 mile mainstem of the river begins in St. Louis County, winds its way northwest through Koochiching County finally reaching its confluence with the Rainy River approximately 11 miles west of International Falls, Minnesota. Major tributaries along the length of the river are the Rice, Sturgeon, Willow, and Nett Lake Rivers, and Beaver Brook. From its headwater in Lost Lake to the mouth at the Rainy River, the Little Fork drops 300 feet giving it an overall mean gradient of two feet per mile between the towns Cook and Littlefork (Waters, 1977). Average width of the upper reach is 28 feet and 255 feet for the lower reach of the river (Anderson, 2001).

The Little Fork River flows through an area known as the “big bog” country in Northern Minnesota and lies within the basin of Glacial Lake Agassiz, a glacial lake which covered much of northwestern Minnesota approximately 12,000 years ago near the end of the last great ice age. The river runs through lake-washed glacial till which is a mixture of clay, silt and sand, except where bedrock is exposed. Flowing across Agassiz Lake bed sediments, the Little Fork has cut a channel with steep sides of slumping gray clay (Waters, 1977). Area rivers are actively eroding and have cut down through 6-20 meters of lake sediments and glacial till (Severson et. al, 1980). Soil types range from peat over clay at the headwaters to glacial till and ledge rock and finally silty clay downstream of the town of Littlefork (Anderson, 2001). Overall visible water quality characteristics are repeatedly noted as dark and muddy. A distinct plume of sediment is evident for miles downstream as the Little Fork River enters into the Rainy River. Even with flow levels at low water stages, visibility remains one foot, or less (Anderson, 2001). In 2000 the Minnesota Department of Natural Resources (Anderson, 2001) conducted the most complete assessment of the River’s fisheries to date. Previously, biological information was lacking, particularly on lake sturgeon- a species of special concern in Minnesota. It was concluded that a diverse fishery is present, indicating a relatively healthy river system. The River provides a sanctuary for spawning lake sturgeon from the Rainy River / Lake of the Woods population (Anderson, 2001).

Notably the oldest known settlement in the Little Fork valley is the Nett Lake Village on the Nett Lake Indian Reservation. The reservation lies in what is now Koochiching County and was the main Chippewa village in north-central Minnesota. (Winchell, 1891). Radiocarbon dating indicates that the site was inhabited as early as 600 B.C. European settlement in the community of Littlefork began in 1901, though temporary prospecting residents may have been around in 1899. The greatest influx of European settlers to the area came between 1910 and 1920; most settled along the Big Fork, Little Fork, Rat Root, Rapid, Black and Rainy Rivers (Drache, 1992). Currently, principal industries for the watershed include forest products harvesting and manufacturing, and tourism. Farming is located primarily in the lower portions of the watershed (MPCA, 2001) and is principally pastureland. The towns of Cook and Littlefork are located along the banks of the River. The remainder of the watershed can be classified as sparsely populated and remote. Land ownership in the Little Fork River watershed is 47.7 % state, 21.4 %

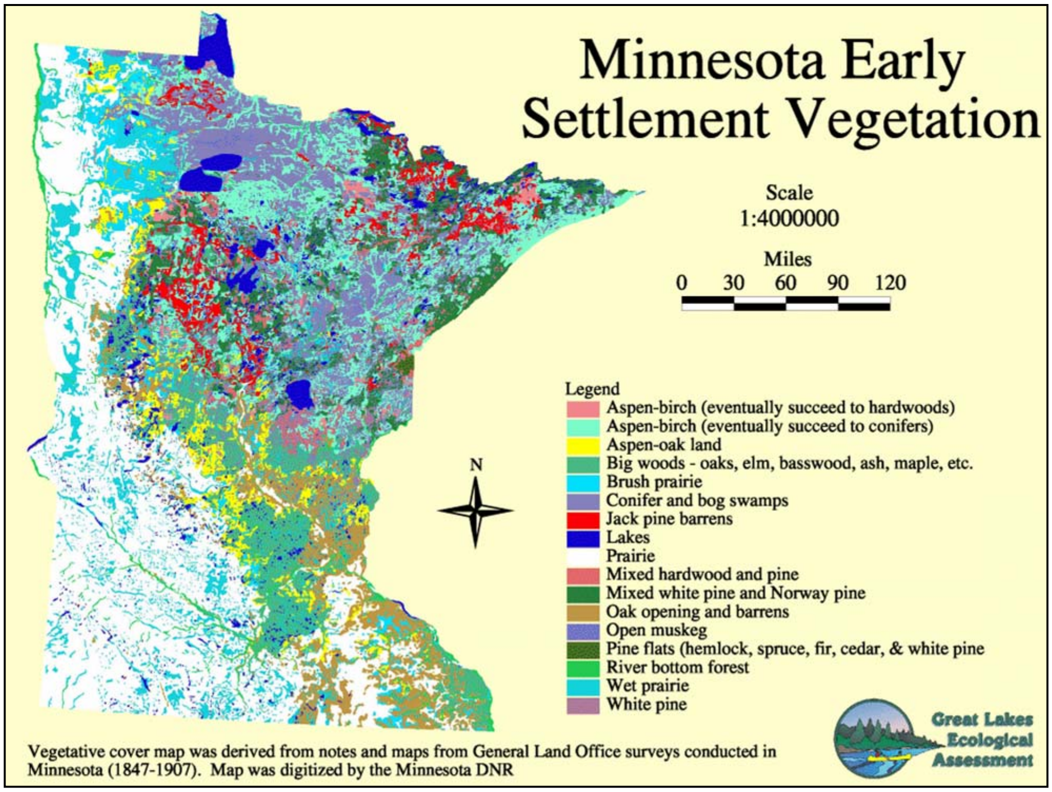
private, 18% tribal, 10% private industrial (forest industry), and 3.1 % federal (Anderson, 2001).

Pre-settlement vegetation in the Little Fork River watershed included large extensive stands of mixed conifers- jack pine, Norway pine, white pine, black spruce, and various hardwood species such as poplar, maple, elm and oak (see Figure 1). Historical logging took place in the Little Fork River watershed from the 1890's to 1937. In the 1890's Canadian logging firms had camps on Rainy River and its U.S. tributaries without fear of reprisal; in June of 1891 it was reported that there were 2 million logs on the banks of just the Little Fork River (Drache, 1983). During the peak period from 1910 to 1937 the Minnesota and Ontario Paper Company operated a total of approximately 200 logging camps in the vicinity, most of which were within a 75 miles radius of International Falls, Minnesota (Pollard, 1960).

Surveyors from the early 1900's classified the Little Fork as the "best driving stream in Minnesota"; streams and railroads made the area a prime forestry region (Drache, 1983). However, river drives were not an inexpensive way to move timber- each drive had 3 crews: the watering crew which got the logs moving as soon as the river started to flow, the bends and rapids crew which kept the timber moving, and the rear crew which cleaned the timber lying along the banks (Drache, 1992).

The last big pocket of virgin timber in the Little Fork watershed was near the southwestern portion of Koochiching County within the Nett Lake Reservation. The Minnesota and Ontario Paper Company harvested this timber in 1936 and 1937, although title to the timber was secured in the early 1900s. By March of 1937 approximately 30,000 cords of pulpwood and 13,000,000 feet of pine logs were delivered to the Little Fork and Nett Lake River landing areas (Pollard, 1975). A fascinating account of how these logs were transported downriver that spring, the last major river log drive in Minnesota history, is provided by Pollard (1975) and listed in Appendix 1. Photos of the historical log drives and jams in the vicinity of the town of Littlefork are shown in Figures 2 and 3. Logs often covered the entire stream channel and large portions of the banks and floodplain; the 1937 log drive had a jam that backed up logs for 6 miles upstream (Pollard, 1975). The geomorphic impact to the Little Fork River and banks from these log drives was almost certainly enormous. Potential impacts include greater peak flows; significant bank erosion and sedimentation; and overall channel destabilization and incision. The Albion River (Northern California) Total Maximum Daily Load for Sediment (USEPA, 2001) stated, "The greatly increased peak flows, combined with the battering-ram effect of thousands of logs, would likely have caused channel erosion and incision." The TMDL goes on to state that in other watersheds, "…the log drives resulted in channel incision… (and) that valley fills have been converted from long-term sediment sinks (floodplains) to substantial sediment sources…" similar to conditions observed along the Little Fork River mainstem. Fitzpatrick et. al (1999) found that historical logging, followed by agricultural activity, significantly altered the hydrologic and geomorphic conditions of North Fish Creek, a tributary to Lake Superior near Ashland Wisconsin (about 150 miles south east of the Little Fork River), and sediment loads were 2.5 times greater than under modern land cover (58% forest) and may have been 5 times greater than under pre-settlement forest cover. Riedel et. al (2002) found that historical increases in water yield, particularly bankfull discharge, brought on by historical logging and land use conversion, initiated channel incision in the Nemadji River Watershed in northeast Minnesota.

Figure 1. Minnesota Early Settlement Vegetation, (USDA, North Central Research Station, MN DNR; http://www.ncrs.fs.fed.us/gla/



Vegetative cover map was derived from notes and maps from General Land Office surveys conducted in Minnesota (1847-1907). Map was digitized by the Minnesota DNR

Figure 2. Log Jam on the Little Fork River, circa 1920. Note log piles along river banks are either pushed into the river manually or by rising spring flood waters. Image courtesy of the MN Historical Society.

Figure 3. Log Jam on the Little Fork River, 1937. This log drive contained 30,000 cords of pulpwood and 13 million feet of pine logs. Image courtesy of the MN Historical Society.

Study Design and Rationale

The historical water quality data record for the Little Fork River is effectively limited to the Minnesota Pollution Control Agency's (MPCA) long-term monitoring site at Pelland, one half mile upstream of the confluence with the Rainy River. Data from the MPCA's 2002 water quality assessment indicated an approximate 20% exceedance rate of Minnesota's water quality standard for turbidity (Minnesota Rules, Chapter 7050). Data are lacking in the remainder of the river.

In Minnesota when a river reach exceeds a water quality standard the reach is placed on the federal Impaired Waters List (303[d] Report to Congress), then on the Total Maximum Daily Load (TMDL) List with scheduled TMDL start and completion dates. Generally a TMDL Work Plan is developed based on available information and data. This approach was not appropriate for the Little Fork River, given the lack of water quality and watershed data.

Turbidity in the Little Fork River appeared to be related to sediment and to extend upstream far beyond the upstream extent of the reach to be listed (15 miles, Rainy River confluence to Beaver Brook). The available data did not provide information needed to determine if the turbidity and sediment sources were the mainstem, tributaries or both. MPCA staff decided more study was necessary to develop an appropriate TMDL work plan, an EPA requirement. An initial water quality study was conducted from April through September 2004 in an effort to fill this data-gap.

This study was designed to build on the 2001 Little Fork completion Report (Anderson, 2001), scope the severity, extent and potential causes of the turbidity and sediment problems for a future TMDL as follows:

1. Document turbidity (NTU- nepthelometric turbidity units) and sediment (TSS-total suspended solids) concentrations on the mainstem from the Rainy River confluence to the headwaters,
2. Determine potential sources of sediment loading to the mainstem by recording turbidity and sediment concentrations (and, if possible, loads using the Littlefork gage, USGS # 05131500) from the Rainy River confluence to the headwaters,
3. Provide information needed to determine the scope of the TMDL study, including geographic extent (part or all of mainstem, tributaries, etc.), and potential causes of erosion (land use, stream channel destabilization, etc.).

The study included collection and analysis of historical water quality and stream flow data, water quality sampling, geomorphology and hydrology field measurements, and a filmed aerial over-flight.

Water Quality Sampling

Methods

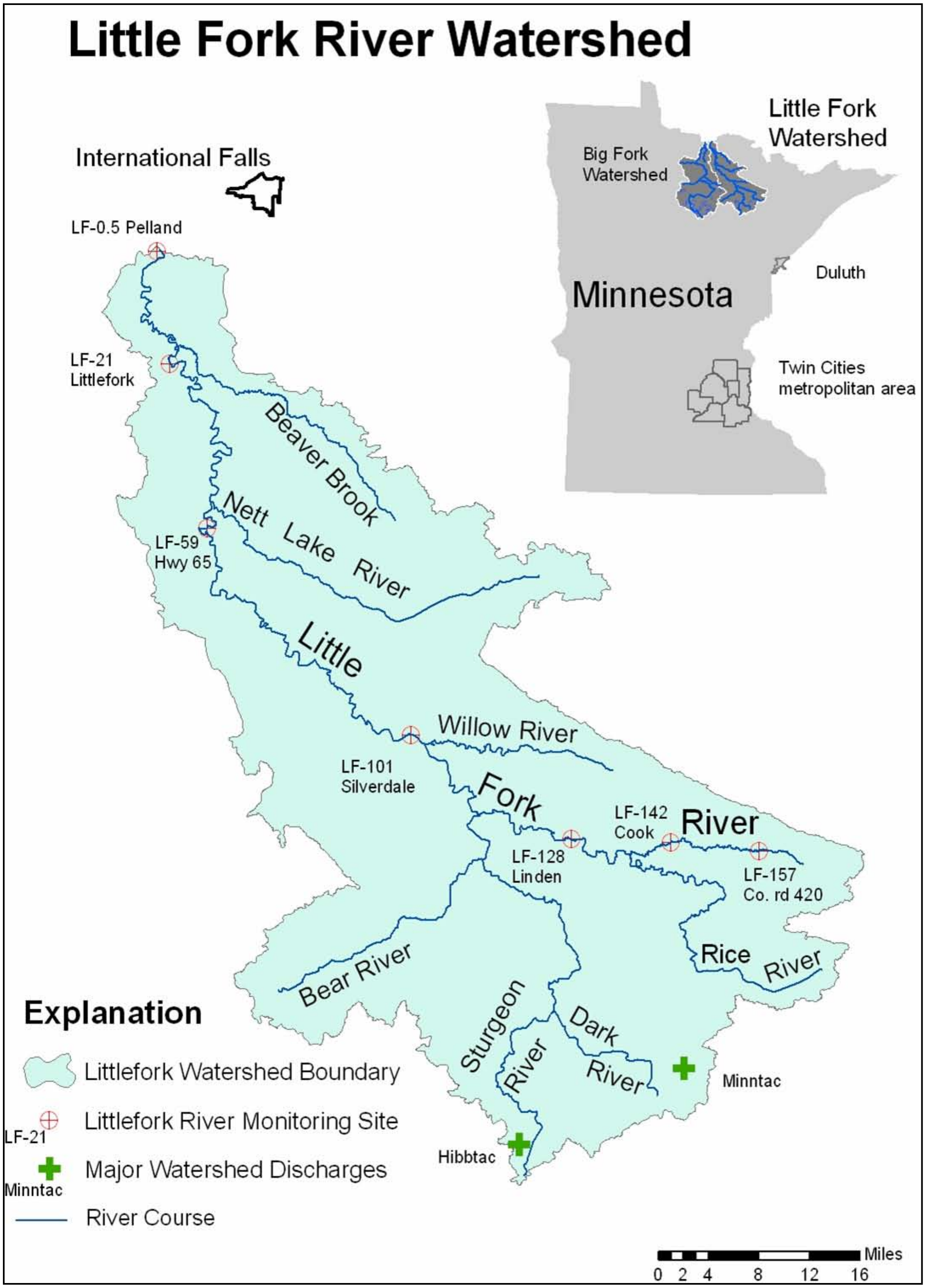
The purpose of this study was to document turbidity and total suspended sediment concentrations in the mainstem of the Little Fork River from the Rainy River confluence to the headwaters. Water samples were collected at several sites (Figure 4); primary site selection criteria included safe bridge access at representative reaches of the River.

- River mile 157 at St. Louis Co. Rd. 420 bridge
- River mile 142 at U.S. Highway 53 bridge in Cook
- River mile 128 at MN Highway 73 bridge at Linden Grove
- River mile 101 at MN Highway 65 bridge near Silverdale
- River mile 59 at MN Highway 65 bridge S. of Littlefork
- River mile 21 at MN Highway 217 bridge in Littlefork
- River mile 0.5 at MN Highway 11 at Pelland

Water quality sampling was conducted by MPCA staff according to approved quality assurance procedures (MPCA, 2006). Specifically, grab samples were taken at middle depth in the water column without disturbing streambed materials. For the two most upstream sites, samples were collected at a point that the sampler judged most likely to reflect the thalweg. For larger sites (Linden Grove – Pelland) sub-samples were collected at three cross sections (equal width), then mixed completely with a churn splitter to ensure a representative sample. Turbidity and total suspended sediment sample bottles were kept on ice and shipped the same day to the Minnesota Department of Health Laboratory in Minneapolis for certified analysis. For more information on the study's quality assurance (QA) plan, see Appendix 2.

Sampling started during the spring snowmelt period and continued throughout the summer of 2004. Efforts were made to collect samples over a range of streamflows, such as following significant rain events and summer low-flows. Approximately 10 samples were collected at each site in 2004, plus appropriate quality assurance samples (blanks and duplicates). All results are shown in Appendix 3.

Figure 4. Little Fork River watershed, with monitoring sites and major tributaries noted

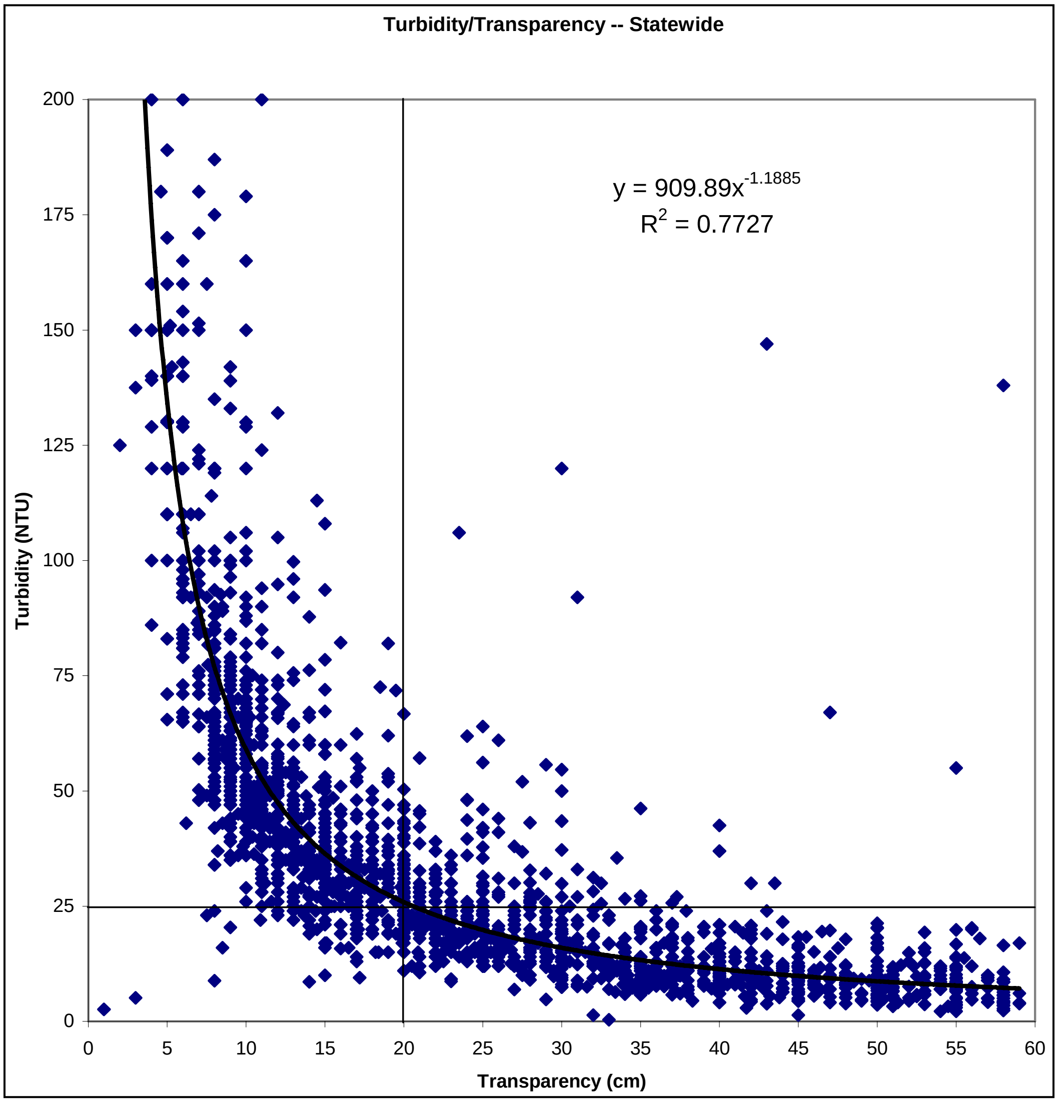


Implicit in this paper are the relationships between two similar measures of water quality-turbidity and suspended sediment concentrations. Turbidity is an optical measure of light scattering by particles suspended in the water column (Davis-Colley and Smith, 2001) and is measured in nepthelometric turbidity units (NTU). Suspended sediment comprises any material (such as silt, clay, sand, or organic matter) held in suspension in a water column (Perry and Vanderklein, 1996) and is determined on a mass per unit volume basis, typically milligrams per liter of water (mg/L). Turbidity is measured by an optical sensor, with higher readings meaning more light scatter, and hence cloudier water. There are broad correlations between turbidity, water clarity, and suspended sediment concentrations (Davis- Colley and Smith, 2001), including in Minnesota streams (Sovell, et al., 2000).

In Minnesota, the turbidity water quality standard in warm-water streams (including the Little Fork River) is 25 NTU (Minnesota Rules, Chapter 7050.0222 Subp. 4). There is no standard for total suspended solids (TSS); however the MPCA has developed “expected” values (McCollor and Heiskary, 1993), which are defined as the 75th percentile of data collected from 1970-92 at designated minimally impacted sites for each ecoregion in Minnesota. Though not enforceable, these values are used as guidelines to gage water quality in a particular stream with others of similar watershed attributes (i.e. land use, vegetation, soils and geology). The Little Fork River watershed is in both the Northern Lakes and Forests and Northern Minnesota Wetlands ecoregions. The TSS ecoregion expectations for these areas are 6 and 16 mg/L respectively.

In Minnesota, stream water clarity is measured by a transparency tube, a clear 60 or 100 cm-long tube with a colored disk on the bottom for measuring the depth at which the disk is visible. The transparency tube is the cornerstone of the MPCA’s Citizen Stream Monitoring Program (see http://www.pca.state.mn.us/water/csmp.html). Since the late 1990’s MPCA staff have gathered a significant dataset (collecting nearly 2,000 samples throughout Minnesota) of concurrent measurements of turbidity and transparency. There is a statistically significant relationship between these variables state-wide (see Figure 5); however more data is desired to develop specific regressions on the watershed scale. The Ohio Environmental Protection Agency, using the MPCA’s transparency tube and two similar instruments, found that transparency tubes provide a rapid and statistically accurate field estimation of TSS concentrations or NTU turbidity in streams (Anderson and Davic, 2004). A transparency of less than 20 centimeters likely corresponds to a violation of the 25 NTU standard (Figure 5). This criterion has been incorporated into the MPCA’s formal water quality assessment process used in reporting the state’s water quality to Congress and determining its list of impaired waters.

Figure 5. Relationship between turbidity and transparency for 80 Minnesota streams, 1999-2003. N= 1,939. (Dave Christopherson, MPCA).



Suspended sediment concentration data along with the corresponding USGS measurements of mean daily streamflow (http://waterdata.usgs.gov/nwis/) were used to estimate annual loads of suspended sediment. Loading calculations were determined using the computer model FLUX, a standard assessment technique developed by the US Army Corps of Engineers (Walker, 1999). In order to estimate loads using FLUX, two input files (daily flows and sample concentrations) are required. FLUX is an interactive program designed for use in estimating the loadings of water quality parameters passing a tributary sampling station over a given time period. Using six calculation techniques, FLUX maps the streamflow / concentration relationship developed from the sample record onto the entire flow record to calculate total mass discharge and associated error statistics (Walker, 1999).

An important concept in the study of rivers and streams is that of bankfull discharge. In many streams the bankfull stage is associated with the flow that just fills the channel to the top of its banks and at a point where the water begins to overflow onto a floodplain (Leopold, et. al, 1964). The bankfull concept was first identified by Leopold and Maddock (1953), and described the discharge at the bankfull stage as the most effective at forming and maintaining average channel dimensions; and associated it with a flow which, on average, has a recurrence interval of 1.5 years (i.e. usually occurring 2 out of 3 years) as determined using a flood frequency analysis (Dunne and Leopold, 1978); it can range from 1.1 to 1.8 year return intervals (Rosgen, 1996).

Because the bankfull discharge is defined as the channel forming streamflow, it is important to determine if this 1.5 year flood flow is changing with time. The channel is self-adjusting, for if the time and volume characteristics of its water or debris (i.e. sediments) are altered by human activity, by climatic change, or by alterations of the protective vegetative cover on the land of the basin, the channel systems adjusts to the new set of conditions (Dunn and Leopold, 1978).

The bankfull flow calculation is essentially a non-parametric statistical rank test, where annual peak flows are arranged in descending order, and the bankfull flow is the 1.5 year recurrence interval value, which is the 67% probability of exceedance value. For the rank test this corresponds to the 33rd percentile of the ranked peak flows. Bankfull flow values were calculated on a 25 year moving window for the Little Fork and adjacent Big Fork River. They yield a value for a given year that is calculated from the 12 years previous, the given year, and the 12 years following. The Big Fork was selected because it shares many features in common to the Little Fork such as similar watershed size, precipitation rates, mean temperature, soils, land use and land cover, small population size and low development density; and it has historical USGS streamflow data.

The next step in our analysis was to develop a regional curve for bankfull discharge for streams in the Little Fork and Big Fork physiographic vicinity. Regional curves were developed by Dunn and Leopold (1978) and relate bankfull discharge to drainage area and other hydraulic geometry variables. Regional curves are developed by regression analysis of the bankfull characteristics and drainage area, and provide estimated bankfull channel dimensions and streamflow when drainage area is known (Cinotto, 2003). We obtained records at long term USGS streamflow gaging stations in the vicinity of the study area, and graphed bankfull streamflow (estimated by the Q 1.5) versus drainage area.

Results and Discussion

Turbidity, Transparency, and Total Suspended Solids

MPCA surface water quality assessment methodology (MPCA, 2004) states that for conventional pollutants (including turbidity) if greater than 10 percent of water samples collected in the last 10 years exceed standards, that particular reach of river is classified as impaired. Mean, median, minimum and maximum values for turbidity, TSS, and transparency data are shown in Table 1. A few observations are of note: 1- the spread in the data (min – max) illustrate the variability in the River; 2- the proximity of the mean and median value indicate that our sampling regime was representative of conditions throughout the season; 3- the similar patterns in TSS, turbidity, and transparency data among sites reinforce their comparability in assessing water quality. In general, water quality tends to decrease in a downstream direction. However, water quality was shown to improve from Littlefork to Pelland, as seen by a decline in TSS concentrations. The high turbidity values at Cook may be a function of high algal growth which was commonly observed in mid-summer during low flows when the water was nearly stagnant, or from natural runoff from nearby wetlands. Those site locations in bold in Table 2 indicate violations of the state guidelines or standards, and are therefore impaired for turbidity or its surrogate, TSS. All sites with sufficient data are impaired for one or both of these parameters (Table 2). At several sites the *median* TSS value (corresponding to at least a 50 % exceedance rate) exceeded the guideline. Historical TSS data from the MPCA long term monitoring station at Pelland are shown in Table 3. Both the 2003 and the longer term (1971-2002) average values exceed the guideline of 16 mg/L. In summary, all of these data suggest a systemic water quality impairment for turbidity and / or TSS in the Little Fork River mainstem.

Table 1. Statistical summary of 2004 Little Fork River water quality data.

Site (River Mile)	**Turbidity (NTU)**				**Transparency (cm)**				**Total Suspended Solids (mg / L)**			
	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max	Min
LF-0.5 (Pelland)	20	18	47	11	24	24	39	10	22	16	86	6
LF-21 (Littlefork)	26	25	51	10	26	21	53	10	33	31	80	2
LF-59 (Hwy 65)	18	15	35	9	32	30	58	12	22	22	53	5
LF-101 (Silverdale)	17	15	33	7	32	25	70	14	18	15	35	2
LF-128 (Linden)	N/A [1]	N/A	N/A	N/A	26	27	36	15	N/A	N/A	N/A	N/A
LF-142 (Cook)	27	18	69	7	24	24	52	8	15	14	25	7
LF-157 (Co.rd 420)	N/A	N/A	N/A	N/A	53	57	79	19	N/A	N/A	N/A	N/A

1. N/A – Water samples not collected, only a field measurement of transparency

Table 2. Exceedances of the turbidity standard or its surrogates – TSS concentrations and transparency. Those values in **bold** are in violation of water quality standards or guidelines.

Site (River Mile)	**Turbidity (NTU) Standard = 25**		**Transparency (cm) Guideline = <20 cm.**		**Total Suspended Solids (mg / L) Guideline = 6 or 16 mg/L [1]**	
	Number of Samples	Number of Exceedances	Number of Samples	Number of Exceedances	Number of Samples	Number of Exceedances
LF-0.5 (Pelland)	10	**2**	10	**4**	10	**5**
LF-21 (Littlefork)	10	**5**	10	**5**	10	**6**
LF-59 (Hwy 65)	7	**2**	7	1	7	**4**
LF-101 (Silverdale)	10	**2**	10	**3**	10	**7**
LF-128 [2] (Linden)	0		10	1	0	
LF-142 (Cook)	10	**3**	10	**4**	10	**10**
LF-157 [2] (Co.rd 420)	2	0	10	1	2	2

1. 6 mg/L is the ecoregion guideline for the Northern Lakes and Forest Region (includes sites LF-157, LF-142, LF-128, and LF-101. 16 mg/L is the guideline for the Northern Minnesota Wetlands Region (including sites LF-59, LF-21, and LF-0.5)
2. At LF-128 and LF-157 insufficient water quality samples were collected to determine impairment. Sampling at these secondary sites included field measurements only.

Table 3. Historical TSS Data from MPCA's Monitoring Site LF-0.5; Little Fork River @ Pelland

Year	**TSS (mg/L)**			
	Mean	Median	Max.	Min.
2003 (n= 8)	37	30	85	8
1971-2002 (n= 86)	22	11	350	1

Figure 6 shows the statistical relationship between transparency and turbidity for the data collected during this study. In general, the relationship is similar to the state-wide trend shown in Figure 5, but variability is reduced since the dataset is smaller and watershed specific. For these data, a transparency value of less than 20 centimeters likely corresponds to a violation of the 25 NTU turbidity standard.

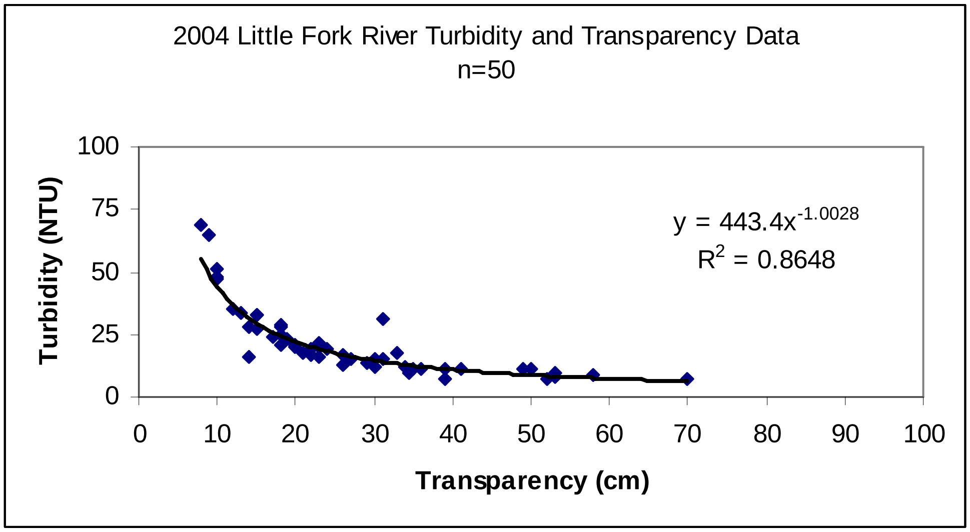


Figure 6. 2004 Little Fork River Turbidity and Transparency Dataset.

Sediment Loads and Modeling

The US Geological Survey (USGS) collected a very thorough suspended sediment concentration (SSC) dataset in the 1970's from their streamflow gauge site in the town of Littlefork. The two years with the most samples collected were 1973 and 1974, with 124 and 98 samples taken during the ice-free season respectively. These data were collected nearly on a daily basis, and provide resource managers with the best estimate of historical sediment levels.

The results from 1973 and 1974 are shown in Table 4. Runoff and streamflow varied for each year, and are reflected in the sediment loads. 1973 was comparatively a dry year- 28th driest in 77 years of record, while 1974 was a wet year- the 14th wettest year on record. An approximate 60% increase in runoff in 1974 resulted in an analogous increase in sediment loads and a doubling of the flow weighted mean sediment concentration (Table 4). These results illustrate the influence of precipitation on stream water quality, and that the majority of the sediment in the Little Fork is coming from diffuse (non-point) sources.

The USGS (Tornes, 1986) has estimated sediment yields (defined as load divided by drainage area) on 33 Minnesota streams (including the Little Fork), based on their long term monitoring program. Using data from 1971-79 the estimated annual sediment yield for the Little Fork River at Littlefork is 33 tons / mi^2, which equates to a load of 57,000 tons / year. This estimate was computed from sediment transport curves developed from the statistical relationship between suspended sediment concentrations and streamflow. The author did note that the Little Fork had substantially higher sediment yields than adjacent watersheds, probably the result from the transport of clay during high flows (Tornes, 1986). The USGS long term average load from the 1970's is quite close to the FLUX estimate from 1973 (53,500 tons). Hence, we have some confirmation in FLUX's accuracy in estimating historical sediment loads and flow weighted mean concentrations.

These historical sediment loads were compared to present-day (2003) sediment loads from the 4 permitted point source dischargers in the watershed. These facilities are the domestic wastewater treatment plants in Cook and Littlefork, and the taconite tailings basins from Minntac and Hibbing Taconite plants. The wastewater plants discharge directly into the Little Fork River; while the taconite plants discharge at the headwaters of tributaries of the Little Fork River - the Dark and Shannon Rivers - respectively. Wastewater quality and quantity data were retrieved for 2003 from the MPCA's DELTA database. Estimated loads were calculated by multiplying average yearly flow by average TSS concentration. The four permitted wastewater dischargers contribute a very small portion of the total annual sediment load- only 0.05 % when compared to total river loads at Littlefork (see Table 5).

Table 4. Flux Model suspended sediment loading estimates from the 1970's at the USGS Little Fork River gage in Littlefork, MN (derived from USGS streamflow and SSC data)

Year	Number of SSC Samples Collected	Suspended Sediment Load (Tons)	Flow Weighted Mean Concentration (mg/L)	Annual Runoff (inches- USGS data)
1973	124	53,510	65	7.47
1974	98	88,741	143	11.73

Table 5. Comparisons of point and non-point source discharges and sediment loads in Little Fork River Watershed (MPCA data unless noted).

Facility	Year	Avg. Discharge (million gallons / day)	Avg. Sediment Load (tons per year)
Hibbing Taconite	2003	2.1	12.46 [1]
Minntac	2003	3.8	13.3 [1]
Littlefork Wastewater Treatment Plant	2003	0.12	1.19 [1]
Cook Wastewater Treatment Plant	2003	0.68	3.28 [1]
Little Fork River @ Littlefork (Tornes, 1986; USGS data)	1971-79	786	57,000 [2]

[1] Calculations derived from TSS data

[2] Calculation derived from SSC data

The method used by the US Geological Survey to measure sediment levels in streams is suspended sediment concentration (SSC), and the method used by the MPCA is total suspended sediment concentration (TSS), which are not interchangeable. USGS research has shown that as the sand-size material in samples exceeds about a quarter of the sediment dry weight, SSC values tend to exceed the corresponding TSS values (Grey et. al., 2000). The TSS analysis normally entails withdrawal of an aliquot of the original sample for subsequent analysis; the SSC analytical method measures all sediment and the mass of the entire water-sediment mixture (Gray et. al., 2000). If a sample contains a substantial percentage of sand size material (diameters greater than 0.062 millimeters), then stirring, shaking, or otherwise agitating the sample before obtaining a sub-sample will rarely produce an aliquot representative of the SSC and particle size distribution of the original sample (Gray et. al, 2000).

The USGS does have a dataset that describes the suspended sediment size diameter, collected at their station in Littlefork (Table 6). Looking at the dates of sample collection, it appears they were collected over a variety of seasons and streamflow conditions. As can be seen from Table 6, the sediment samples are composed of mostly (> 90 %) fine materials - silts and clays- and not sand. With these data as consideration, it is our best professional judgment that TSS and SSC can be used for comparison purposes, but not used interchangeably for the purposes of this report. Further study is needed to address this issue across Minnesota, and MPCA and USGS staff have had preliminary discussions on this matter.

Table 6. USGS suspended sediment size data, Little Fork River @ Littlefork. Percent silt and clay (finer than 0.062 millimeters). http://webserver.cr.usgs.gov/sediment/

Date	Suspended Sediment, Sieve Diameter Percent Finer Than 0.062 Millimeters
7/21/1982	98
9/13/1982	97
11/2/1982	96
3/1/1983	93
4/26/1983	93
8/16/1983	96
10/12/1983	79
1/31/1984	94
5/22/1984	92
7/17/1984	95
10/30/1984	97
1/23/1985	87
4/17/1985	96
8/21/1985	99
11/12/1985	97
2/4/1986	100
5/5/1986	95
9/8/1986	87

Water Quality Summary

Looking at the 2004 and 1970’s turbidity, TSS, and transparency data as a whole it is apparent from multiple lines of evidence that the Little Fork River is systemically impaired for turbidity and its surrogates. In 2004, five of the seven sites had impairments for either or both turbidity and TSS. The two sites that did not (Linden Grove and Co. Rd. 420) had only transparency data (no water samples were sent to the lab because of budget limits). The 1970’s estimated flow weighted mean concentration was 65 mg/L, greatly exceeding the ecoregion expectation of 16 mg/L. This 2004 dataset substantiates anecdotal visual evidence of high turbidity / low visibility cited previously (Anderson, 2001; Waters, 1977), and those seen in this investigation.

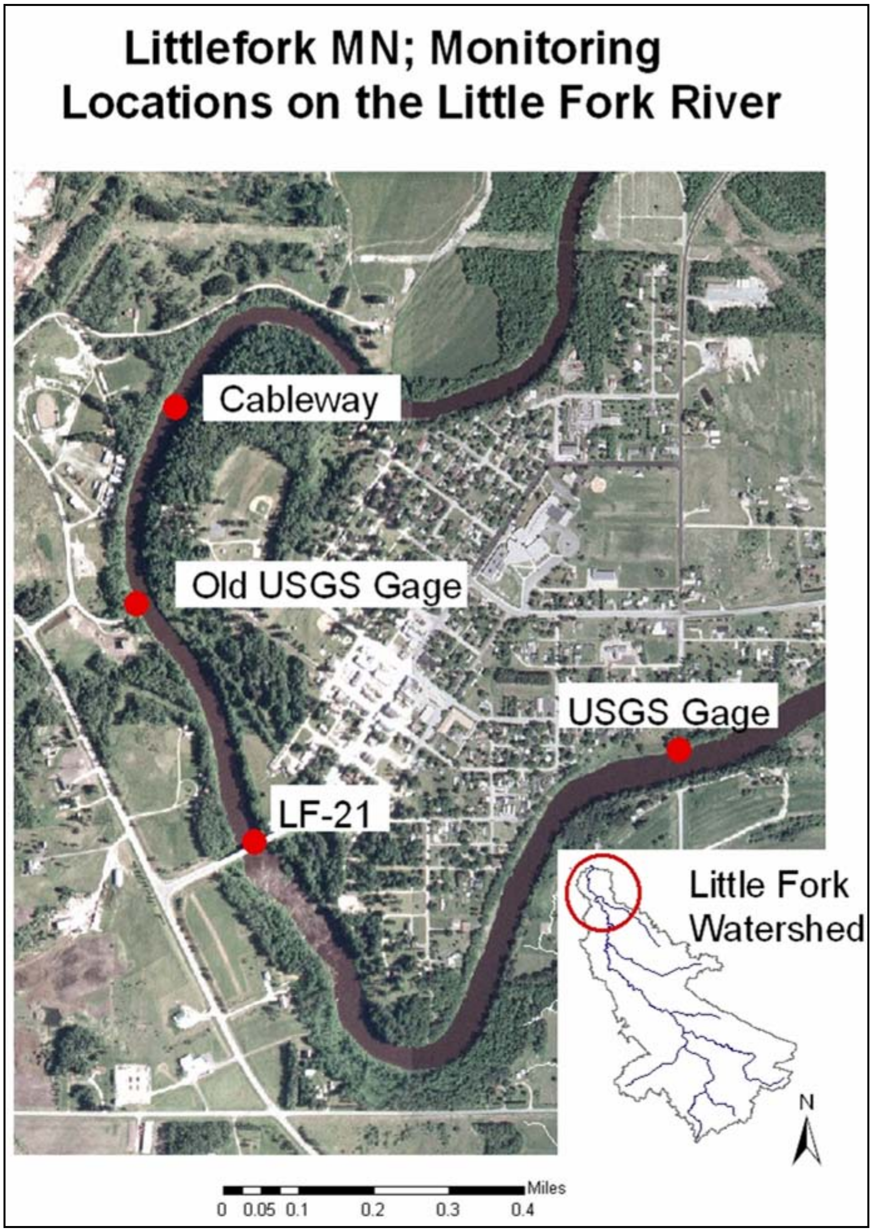
Hydrology

Trends

The USGS started operating a streamflow monitoring gage on the Little Fork River in the town of Littlefork in 1909, and have had continuous operation there since 1937 (Mitton, et al. 2002). USGS personnel visit the site several times per year, and conduct streamflow measurements at a cableway near the gage to check the accuracy of the rating curve (a stream stage / discharge relationship). An aerial photo of the Little Fork River in Littlefork, MN is shown in Figure 7. The confluence of the Little Fork and Rainy Rivers is approximately 21 river miles downstream from the town of Littlefork.

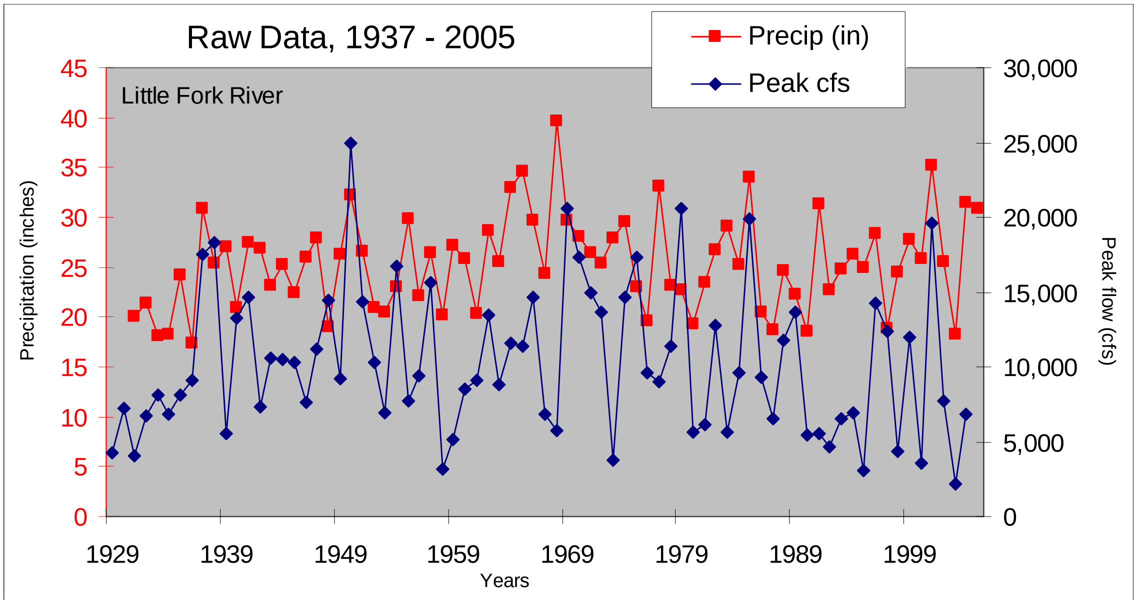
Daily mean streamflow values and annual summary statistics are published on their internet site (http://waterdata.usgs.gov/nwis). This USGS dataset is the foundation of many analyses in this paper.

Figure 7. Little Fork River in Littlefork, MN showing locations of streamflow and water quality monitoring stations (LF-21). Image taken in 2003 and courtesy of the NRCS.



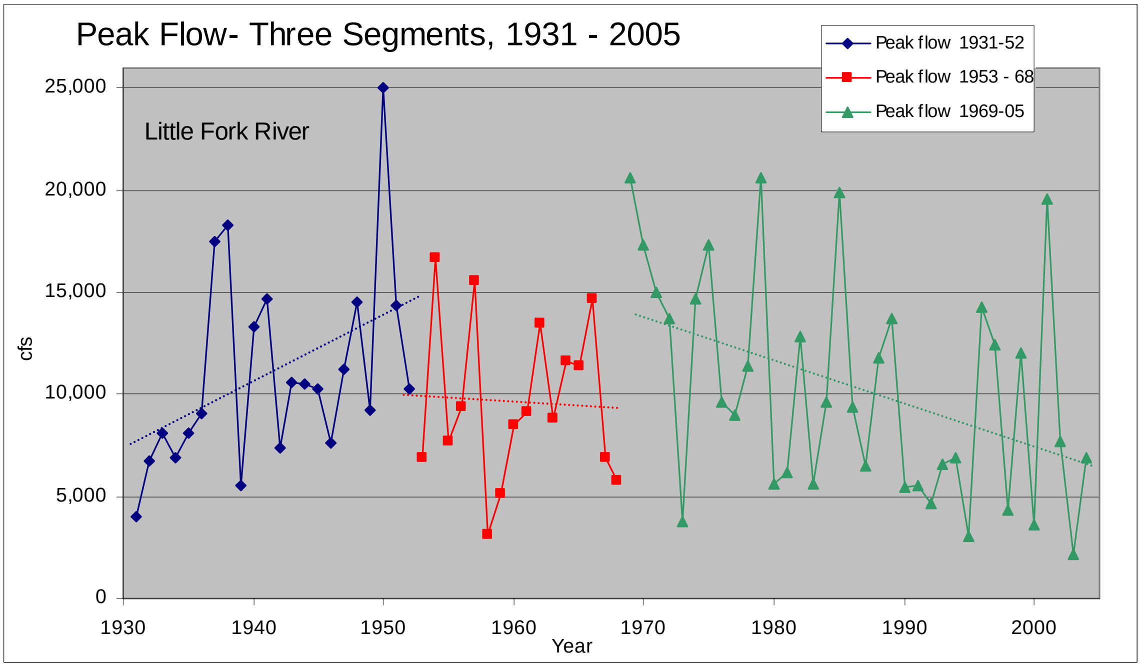
The annual peak flow data from the Little Fork River at the USGS gage, and annual precipitation data from the town of Littlefork are shown in Figure 8. The precipitation data was accessed from the Minnesota state climatology office web page- http://climate.umn.edu/doc/historical.htm).

Figure 8. Annual peak flow and precipitation data, Little Fork River @ Littlefork



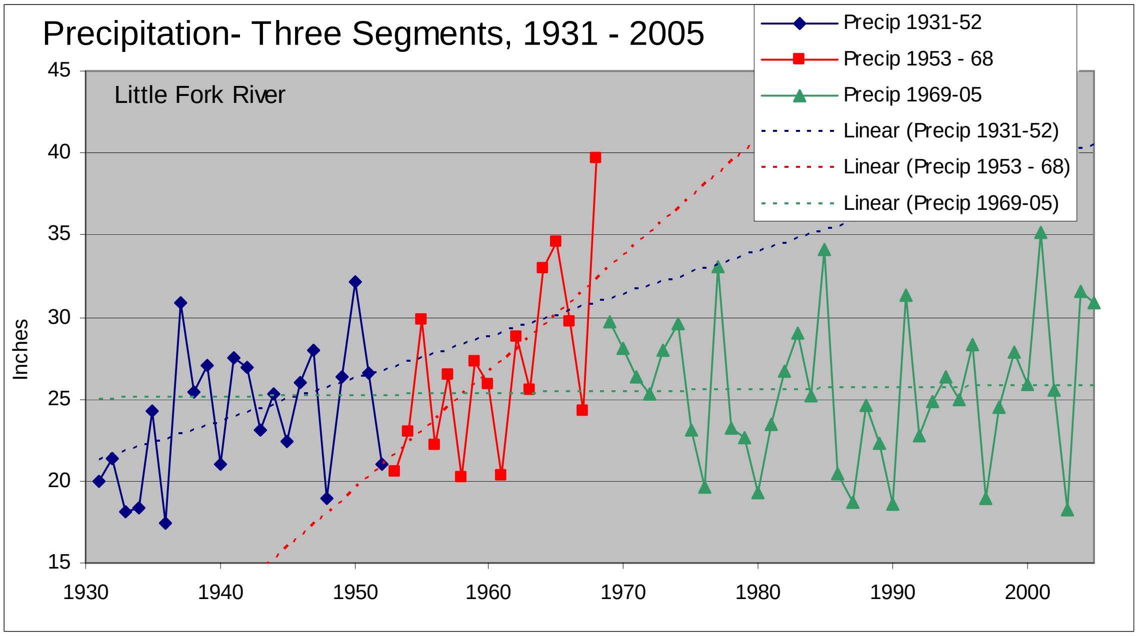
The historical record indicates that original logging activities associated with European settlement ended in 1937 in the Little Fork watershed. In order to test the hypothesis that logging activities had an impact on peak stream flow, we had to divide the raw data set into intervals, and determine if the annual peak flow values were influenced by precipitation. The first division was chosen from 1931-1952 to coincide with 15 years after the termination of major logging. This 15 year interval was chosen based on the work by (Verry et. al, 1983, Verry 1986) who showed that increased peak stream flows from snowmelt persisted for the next 15 years after logging in the Marcell Experimental forest in Marcell, MN (<30 miles from the Little Fork River watershed). The second division was chosen from an inspection of the records; both precipitation and peak flow time series data show a change in slope coinciding with the end of the 1970's (Figure 9).

Figure 9. Annual peak streamflow data, Little Fork River at Littlefork, MN broken into three intervals.



The precipitation data broken down into the same three intervals is shown in Figure 10.

Figure 10. Annual Precipitation Total, Littlefork, MN. Data courtesy of the Minnesota Climatology Office.



Peak flow and precipitation are in-sync (both increase) in the first portion of the record, but appear to diverge in the later portions of the data. We preformed the non-parametric Mann-Kendall trend test and Sens Method (Helsel and Hirsch, 1991) to determine if there was a significant difference in trends between peak flow and precipitation. The results are shown in Table 7. The sign of the trend indicates its direction. Positive trends indicate an increase in peak flow or precipitation, negative indicates a decrease.

Table 7. Mann-Kendall & Sens Method Trend tests on Little Fork River Peak Flows and Precipitation @ Littlefork, MN. Bold values indicate statistical significance at α = .05

	Precipitation			**Peak Stream Flow**		
Year Interval	Test Z	Significance (α)	Sign	Test Z	Significance (α)	Sign
1931 - 1952	1.75	0.1	Positive	2.17	0.05	**Positive**
1953 - 1968	2.03	0.05	**Positive**	0.0	> 0.1	Flat
1969 - 2005	-0.04	> 0.1	Flat	-2.68	0.01	**Negative**

Precipitation and peak stream flow trends initially show similar results, both increasing. The precipitation trends are only statistically significant at the 90% confidence interval (α = 0.1), while the increasing trend in streamflow is statistically significant at the 95% confidence interval. Starting in the 1950's these trends start to diverge (Table 7 and Figures 9 and 10). First precipitation trends continue to increase, while trends in peak flows flatten (i.e. no trend); then in the last interval of the dataset, precipitation flattens, while annual peak streamflow declines with statistical significance. Since precipitation and peak stream flow trends are not in synch we hypothesize that the reductions in peak stream flow are not climate driven, instead driven by changes in land cover (i.e. forest recovery and regeneration following historical logging).

We preformed a series of tests to demonstrate that our calculations are insensitive to the potentially subjective selection of divisions between the 2nd and 3rd time interval. Specifically, by moving the divisions from 1968-69 to 1973-74 and then again to 1978-79. This yielded no change in the overall conclusion that trends for precipitation and peak streamflow initially show the same trend (i.e. are in synch), but then become decoupled starting in the 1950's.

Historical clear cut logging ended in approximately 1937, and it is assumed that the watershed (i.e. forest) recovery began at that time. This would affect the amount of biomass in the watershed, and the ability of the watershed to absorb more runoff. Clear-cutting the hardwood and coniferous boreal forests of the Great Lakes region increased annual streamflow by 30-80% during wet and dry years respectively (Verry, 1986). Verry's research at the Marcell Experimental Forest (Verry et. al, 1983; Verry, 1986) showed that clearing more than 2/3 of a watershed caused snowmelt peak flows to as much as double, and the impact can last 10 to 15 years. Analysis of annual peak flow data on the Little Fork indicates that in most years the annual peak flow is in response to snowmelt runoff, versus following an intense summer or fall rain event. The hydrological impact of historical logging was likely not limited to solely clearing large portions of previously forested land; changes in forest type following disturbance may help explain our observed trends in peak flows and precipitation. The conversion of mature pine forests to aspen can increase net annual precipitation by 15% by simply reducing the canopy interception of rainfall and snowfall (Verry, 1976; as cited by Riedel et. al, 2005). The Little Fork River was logged incrementally over 30-40 years, which probably dampened the watershed-wide impact of higher annual runoff peaks. However, the geomorphic impact of log transport on the river and floodplain may have confounded the impact of increased runoff, by initiating a process of channel destabilization. This hypothesis is discussed in a later section of this paper.

Bankfull Streamflows, Little Fork versus Big Fork Rivers

In addition to the Little Fork River, bankfull flows (Q 1.5) were also calculated on the adjacent Big Fork River (Figure 4- inset) for comparison purposes. They were calculated using the same 25 year moving window method described above.

The bankfull discharges for the Little Fork and Big Fork Rivers at the USGS gage locations are 6,900 and 3,750 cfs respectively, based on a flood frequency analysis over the period of record (through 2004). Both rivers show an initial increase in bankfull flow until the late 1930’s and then a decline to present (Figure 10). However, the Big Fork River bankfull flows are approximately half of those found in the Little Fork - despite a modest 12% difference in drainage area at the USGS gages (Little Fork = 1,680 mi^2, Big Fork = 1,480 mi^2). The Big Fork River bankfull flows have steadily declined for approximately 20 years, at least a decade before those in the Little Fork (Figure 11, Table 8).

Figure 11. Calculated bankfull flows (Q 1.5) on the Little Fork and Big Fork Rivers; derived from USGS annual peak flow data.

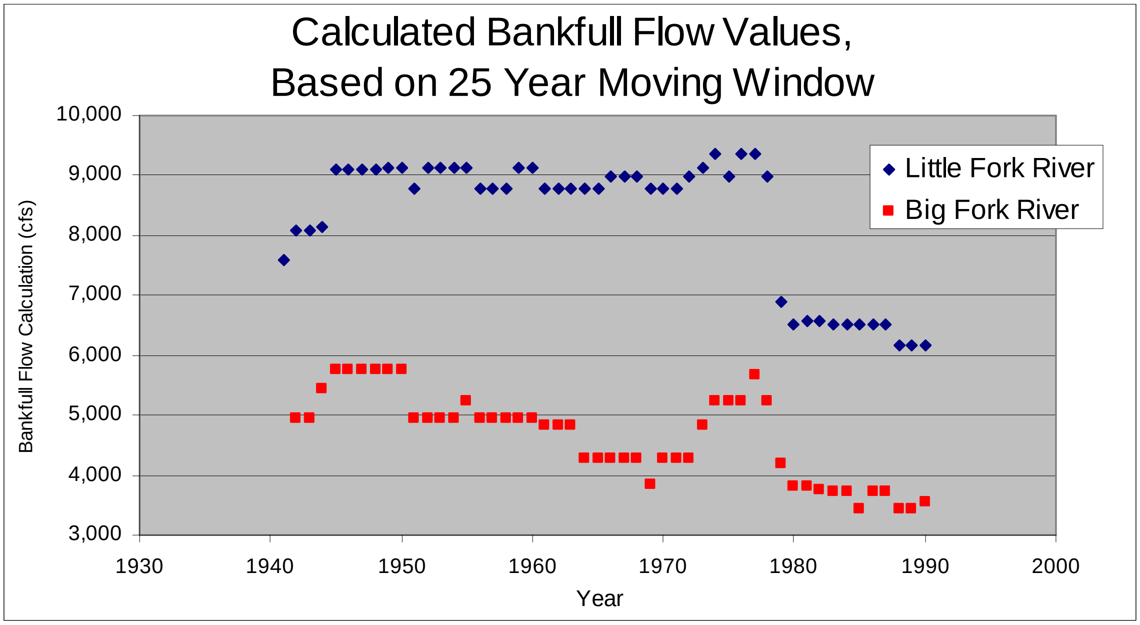


Table 8. Changing bankfull flows in the Little Fork and Big Fork Rivers. Figures are derived from USGS streamflow data from gages at Littlefork and Big Falls, Minnesota

Time Interval	Little Fork River Bankfull Discharge- Q 1.5 (cfs)	Big Fork River Bankfull Discharge- Q 1.5 (cfs)
1930-1947	7,360	3,700
1947-1964	9,120	4,840
1965-1982	8,990	5,250
1983-2003	6,520	3,430

We performed the non-parametric Mann Whitney test to determine if there was a statistically significant difference in the median bankfull streamflow between the two rivers. Data were first normalized by drainage area; Little Fork values were multiplied by 0.88 to account for its larger drainage area (at the USGS gaging station), Big Fork data were unchanged. Forty-nine pairs of bankfull flow values, each calculated on a 25 year moving window (as described above) were inputted into the model. Results indicate a statistically significant ($p=<0.001$) difference in bankfull streamflows between the two watersheds (Table 9.)

Table 9. Normalized Bankfull streamflow data on the Little Fork and Big Fork River. Mann-Whitney Rank Sum Test showed statically significant differences in the median values ($p<0.001$)

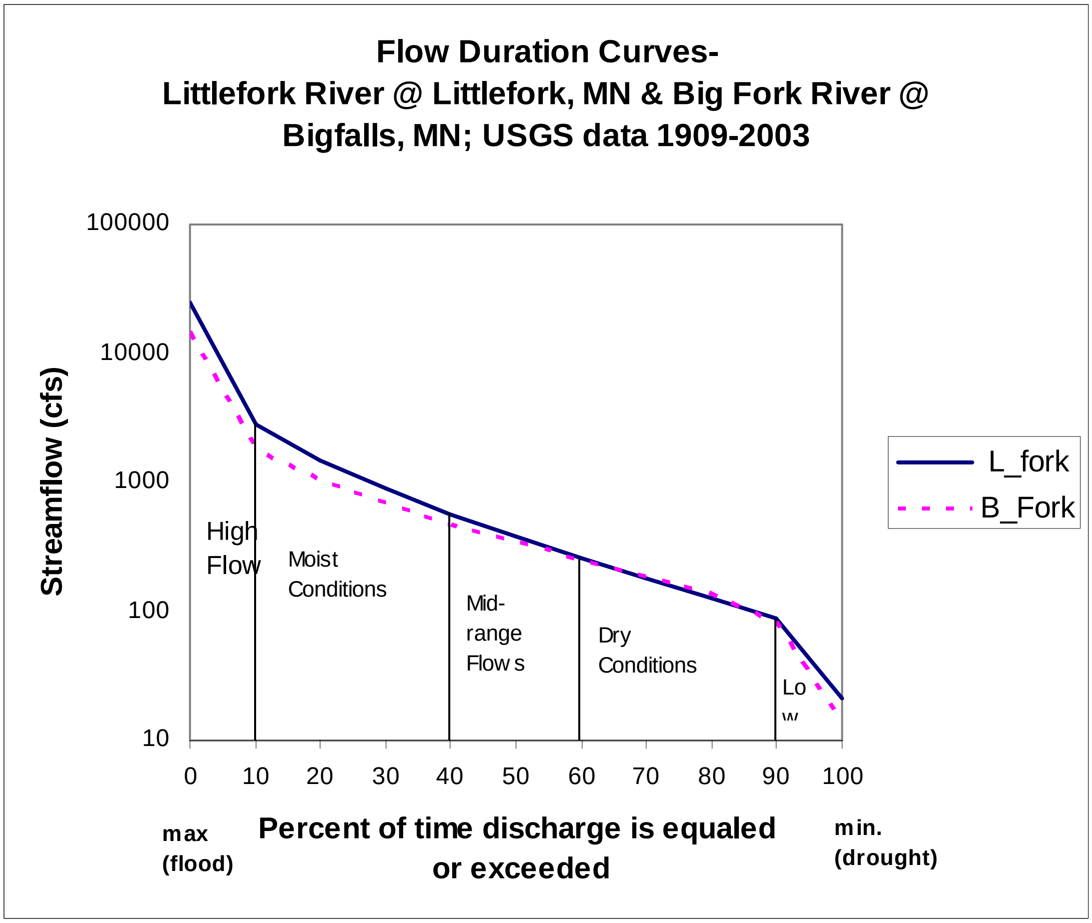
Watershed	**Number of Q 1.5 Calculations** [1]	**Median of normalized Q1.5 (cfs)**	**25th Percentile – Normalized Q 1.5**	**75th Percentile – Normalized Q 1.5**
Little Fork	49	7,735	6,846	8,005
Big Fork	49	4,840	4,110	5,250

[1] Each bankfull flow value (i.e. Q 1.5) was calculated on a 25 year moving window, centered on that particular year, including12 years previous and 12 years following.

Streamflow Duration and Flashiness

We searched the scientific literature for a list of factors that can help explain the differences in peak streamflow between the Little Fork and Big Fork Rivers. The percentage of time where specific streamflows are equaled or exceeded can be evaluated using a flow duration curve (Leopold, 1994). Duration curve analysis identifies intervals, which can be used as a general indicator of hydrologic condition (wet versus dry and to what degree); this indicator can help point problem solution discussions towards relevant watershed processes, important contributing areas, and key delivery mechanisms (Cleland, 2004). The flow duration curve for the Little Fork and Big Fork Rivers are shown in Figure 12. It was calculated from a frequency analysis of the USGS' 30,137 daily streamflow readings over the period of record (1909-2003). Streamflows have varied dramatically over the period of record, peaking at 25,000 cfs on 4/18/1916 and reaching a minimum of 21 cfs on 8/26/1936 on the Little Fork. Referring to Figure 12, the slope of the line is greater during periods of extreme high and low flows, indicting the stream can rise (and fall) rapidly in response to runoff and precipitation. On the Little Fork River, 80% of the time streamflows range between 87 - 2780 cfs. The slope of the lines for both watersheds is similar, except at the extreme high and low flows. During extreme events, flows are higher in the Little Fork, likely because of its larger drainage area at the USGS gaging locations. However during dry conditions the flow duration curves are nearly identical for the two streams despite the Little Fork's larger drainage area, showing the higher base flows in the Big Fork.

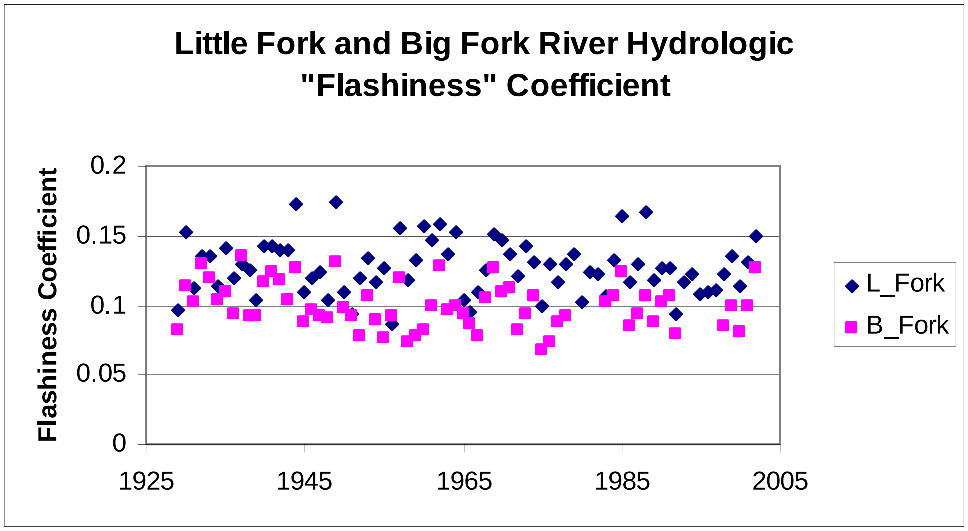
Figure 12. Flow Duration Curve for the Little Fork and Big Fork Rivers (after Cleland, 2003)



The term "flashiness" reflects the frequency and rapidity of short term changes in streamflow and is an important component of a stream's hydrological regime (Baker et al., 2004). Climate, topography, geology, soils, vegetation, watershed size and shape, stream pattern, land use, water use, and dams all impact the timing of water movement to and through streams and the stream's flow regime (Baker et al., 2004). A mathematically defined index has been developed by Baker and others, which measures oscillations in daily discharge relative to annual total flow.

This "flashiness" index was calculated annually, for the Little Fork and Big Fork Rivers using USGS mean daily streamflow data. The Flashiness Index for each river is shown in Figure 13. The Little Fork (blue symbols) are consistently higher than the Big Fork (pink symbols) over the period of record. This indicates that water levels in the Little Fork rise and fall faster than in the nearby Big Fork. The Big Fork has a greater density of lakes and wetlands in its headwaters which may moderate or dampen these runoff impacts (Table 10). For instance, the Big Fork watershed has about 420 lakes, ponds, or open water wetlands (greater than 5 acres) in its headwaters, versus 165 for the Little Fork. Flashiness in the Little Fork and Big Fork Rivers is comparatively low when compared to other streams throughout the Midwest (Baker, et. al, 2004), which ranged from 0.1 to > 1.2.

Figure 13. Flashiness Index for the Little Fork and Big Fork Rivers, after Baker et al., 2004)



Land Cover Analysis

The differences in peak streamflow data and hydrologic flashiness between the two watersheds are likely due to variations in land cover and surficial geology in the watersheds. General land use / land cover classifications in the watersheds is shown in Table 10. In an effort to explain these in greater detail, we examined data from two pertinent geographic information system coverage maps - the Geomorphology of Minnesota (MnDNR, and University of Minnesota Duluth Department of Geology, 1997), and the National Wetland Inventory (MN DNR, 1994).

Table 10. Little Fork and Big Fork River watershed land use data (data derived from USGS, 1999)

Land Use / Land Cover Category	**Little Fork Watershed (Percentage of Drainage Area)**	**Big Fork Watershed (Percentage of Drainage Area)**
Agriculture [1]	4.7	4.1
Forest [2]	51.0	38.5
Wetland [3]	38.5	50.9
Open Water	3.1	5.0
Urban [4]	0.5	0.4
Other [5]	2.0	0.9

1. Pasture / Hay + Row Crops + Small Grains
2. Deciduous + Evergreen + Mixed Forest
3. Woody + Emergent Herbaceous Wetlands; further wetland analysis follows in Table 10.
4. Residential + Commercial / Industrial + Transportation (i.e. roads)
5. Bare Rock + Gravel Pits + Transitional

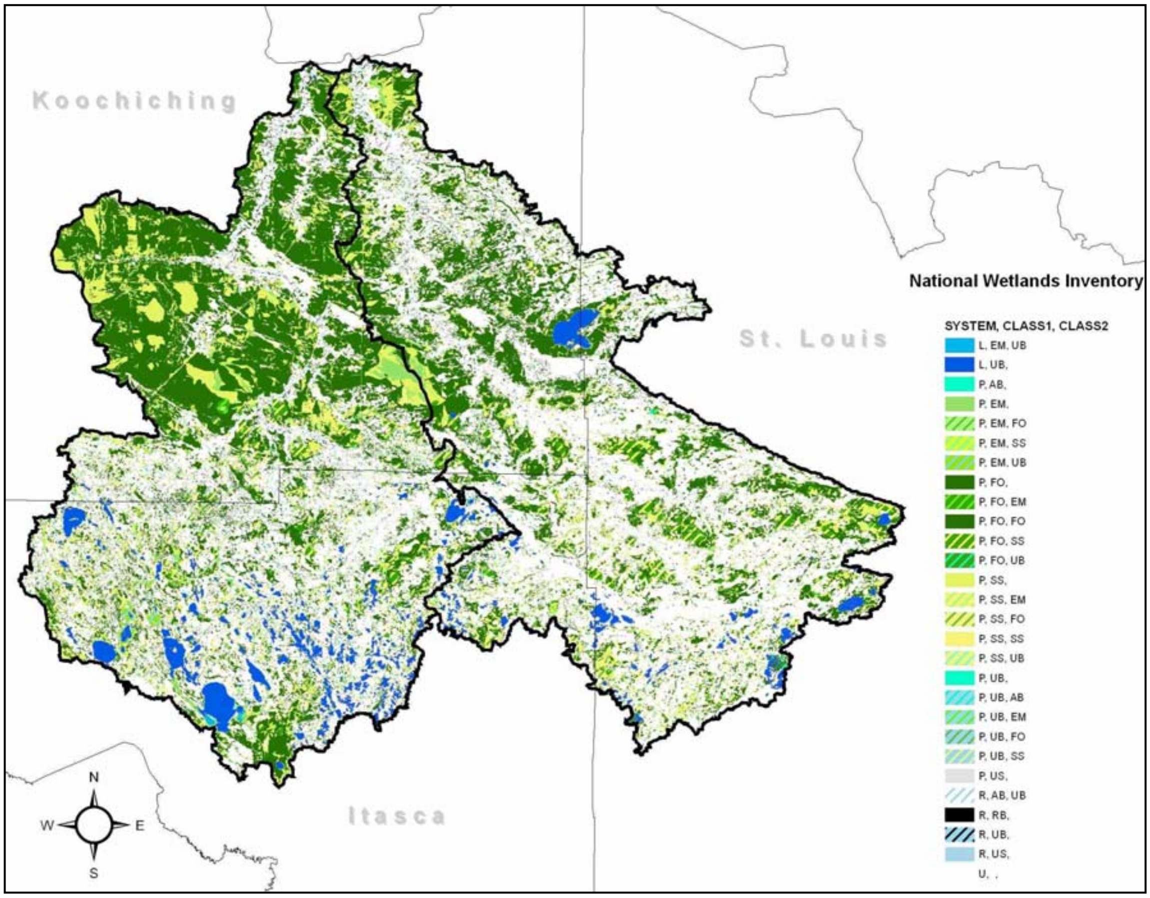
The National Wetland Inventory classification for the Little Fork and Big Fork Rivers is shown in Table 11, a map of the data is shown in Figure 14. Overall the Big Fork watershed has more lakes and wetlands (56% of the watershed area), compared to 41% in the Little Fork. However the relative proportions of wetland types seem to be similar between the two watersheds. The most common wetland classification is forested, which makes up 65 % and 61% of all wetlands in the Little Fork and Big Fork respectively (this equates to 27% and 35 % of the *entire* watershed area respectively).

Table 11. Land cover classification and wetland classification from the National Wetland Inventory (Minnesota DNR, 1994). Analysis courtesy of John Genet and Mark Gernes, Biological Monitoring Unit, MPCA

Land Cover Classification	**Little Fork Watershed (Percent of Watershed Area)**	**Big Fork Watershed (Percent of Watershed Area)**
Upland	59.21	43.93
Wetland	40.79 [1]	56.07 [1]
Wetland Classification		
Emergent Vegetation Wetlands	4.99	5.98
Forested Wetlands	65.65	61.76
Scrub - Shrub	23.46	24.03
Unconsolidated Bottom	8.22	8.22

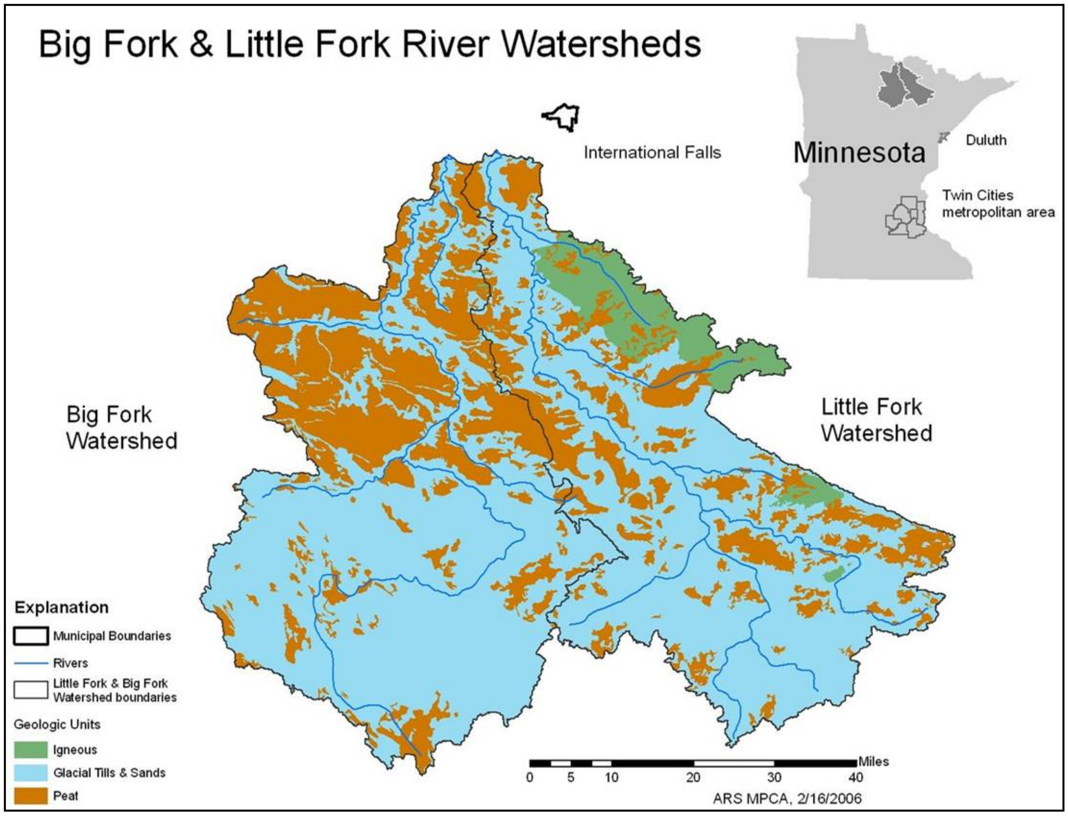
1. Includes Lakes, Littoral Zone Wetlands, and Deepwater Habitats. These “Lacustrine” wetland classifications makes up 3.78 % of the Big Fork Watershed, and 1.86 % of the Little Fork Watershed

Figure 14. National Wetland Inventory Classifications, Little Fork and Big Fork Watersheds. L = Lacustrine (Lakes & Deep Water Wetlands); P= Palustrine (trees & shrubs); R= Riverine; U = Upland (white areas of map). Source: Minnesota DNR, 1994



The geomorphology coverage in the Little Fork and Big Fork Rivers is shown in Figure 15. For illustrative purposes, we divided the numerous geomorphic categories into 3 groups- Igneous, Glacial Till & Sands, and Peatlands. These categories are mapped for each watershed in Figure 15.

Figure 15. Simplified geological units in the Little Fork and Big Fork River watersheds. Data derived from MN DNR, 1997; "Geomorphology of Minnesota".



A few cursory observations include:

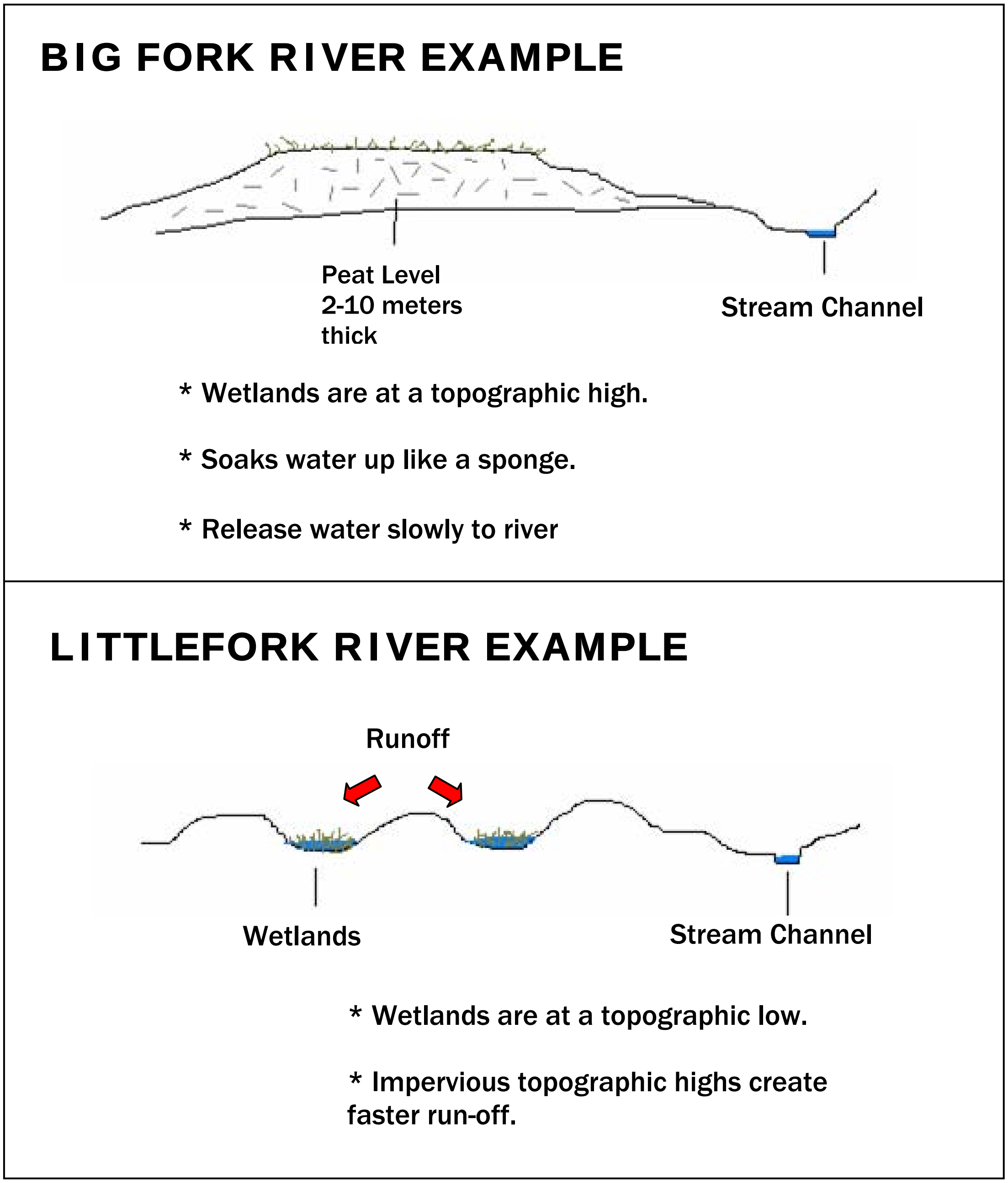
- There is a lack of igneous (i.e. 'bedrock' near the surface) geology in the Big Fork watershed, and it occurs only in a small area on the eastern border of the Little Fork watershed.
- The majority of the headwaters of each watershed is composed of glacial till
- Peatlands dominate the lower reaches of the Big Fork, and a portion of the Little Fork, where these streams flow through the bed of glacial Lake Agassiz. Glacial lake plains are ideal environments for peat formation (Severson, et. al, 1980).
- There are more peatlands in the Big Fork watershed (33 percent in the Big Fork watershed, versus 23 percent in the Little Fork watershed- Table 11). The peat polygons in the Geomorphology coverage are predominately classified as either forested or scrub / shrub wetlands in the National Wetland Inventory coverage. Emergent wetlands make up only a small portion of the peatlands, 4% and 3% in the Big Fork and Little Fork, respectively. The largest peatland area is west of the

town of Bigfalls in the Pine Island State forest, which is drained by the Sturgeon River.

The depressional wetlands in the glacial till behave hydrologically different than those in the peatlands. This is illustrated in Figure 16, provided by Dr. Howard Mooers at the University of the Minnesota Duluth, Department of Geology, an expert in the area's geology. Peatlands are at topographic highs, and slowly release water to stream channels. Conversely, the water in the 'typical' forested depressional wetlands, are at topographic low points, and receive water relatively quicker from the forested uplands. The peatlands are not as efficient at moving surface water to stream channels, therefore there are less stream miles in peatlands versus till areas. The Big Fork watershed area is about 10 % larger than the Little Fork at the confluence with the Rainy River, however there are about 10 % more stream miles in the Little Fork (1,849 versus 1,710 miles- Table 11). We infer that the Little Fork is more efficient at moving the water and sediment from its watershed, given the greater number of stream miles.

Taken on a large scale, variations in geology and land cover likely explain a significant portion of the hydrological differences we have documented in the Little Fork and Big Fork River watersheds. Because there aren't long term discharge monitoring stations upstream / downstream of a peatland dominated watershed in the study area, the actual hydrological effects of peatlands can't be documented further at this time. However, an analysis of long term USGS streamflow monitoring stations in the vicinity suggests the peatlands may have an impact on peakflows and runoff patterns.

Figure 16. Simplified schematic of hydrological differences in peat bogs versus forested depressional wetlands in the Little Fork and Big Fork watersheds, (Howard Mooers, University of Minnesota Duluth, Personal Communication, 2005).



BIG FORK RIVER EXAMPLE

* Wetlands are at a topographic high.

* Soaks water up like a sponge.

* Release water slowly to river

LITTLEFORK RIVER EXAMPLE

* Wetlands are at a topographic low.

* Impervious topographic highs create faster run-off.

Regional Curve Analysis

A regional curve for Q 1.5 was developed using USGS data from stations in the vicinity of the study area (Figures 17 and 18). Two distinct groupings are evident based on streamflow per unit drainage area (cubic feet per second per square mile – csm). One group, ('lower' flow), averages 2.3 csm with a range of 1.6 to 3.2. The other group, ('higher' flow) averages 4.8 csm with a range of 3.7 to 6.5 csm. The 'higher' flow group averages more than twice the discharge per given drainage area. The higher flow group is composed of streams in the Little Fork watershed (Little Fork River at Cook and Littlefork, and the Dark and Sturgeon Rivers) and Bowerman Brook and the Rapid River near Baudette, Minnesota. The watersheds of these last two streams are heavily influenced by agricultural land. The 'lower' flow grouping includes the Winter Road River, Warroad River, N. Branch of the Rapid, and the Big Fork River @ Big Falls, all influenced by peatlands; the remaining sites include the Big Fork River @ Bigfork, Vermilion River near Crane Lake and the Rainy River @ Manitou Rapids – all heavily influenced by upstream lake storage.

These findings support our hypothesis that peatlands and upstream lakes (i.e. watershed storage) have a significant impact on hydrology and likely explain some of the observed differences in streamflow and land cover (see Table 12).

Table 12. Select watershed attributes in the Little Fork and Big Fork River watersheds, derived from GIS data- USGS, 1999, and MN DNR, 1997.

Watershed Attribute	Little Fork Watershed	Big Fork Watershed
Watershed Area (square miles)	1,844	2,074
Number of Lakes & Open Water Wetlands (> 5 acres)	165	420
Total Length of Stream Miles	1,849	1,710
Percent Wetlands (Percent Peat- percent of entire watershed area)	41 (23)	56 (33)

Figure 17. Rainy River Basin Regional Curve Sites. All locations are current or historical USGS streamflow monitoring sites.

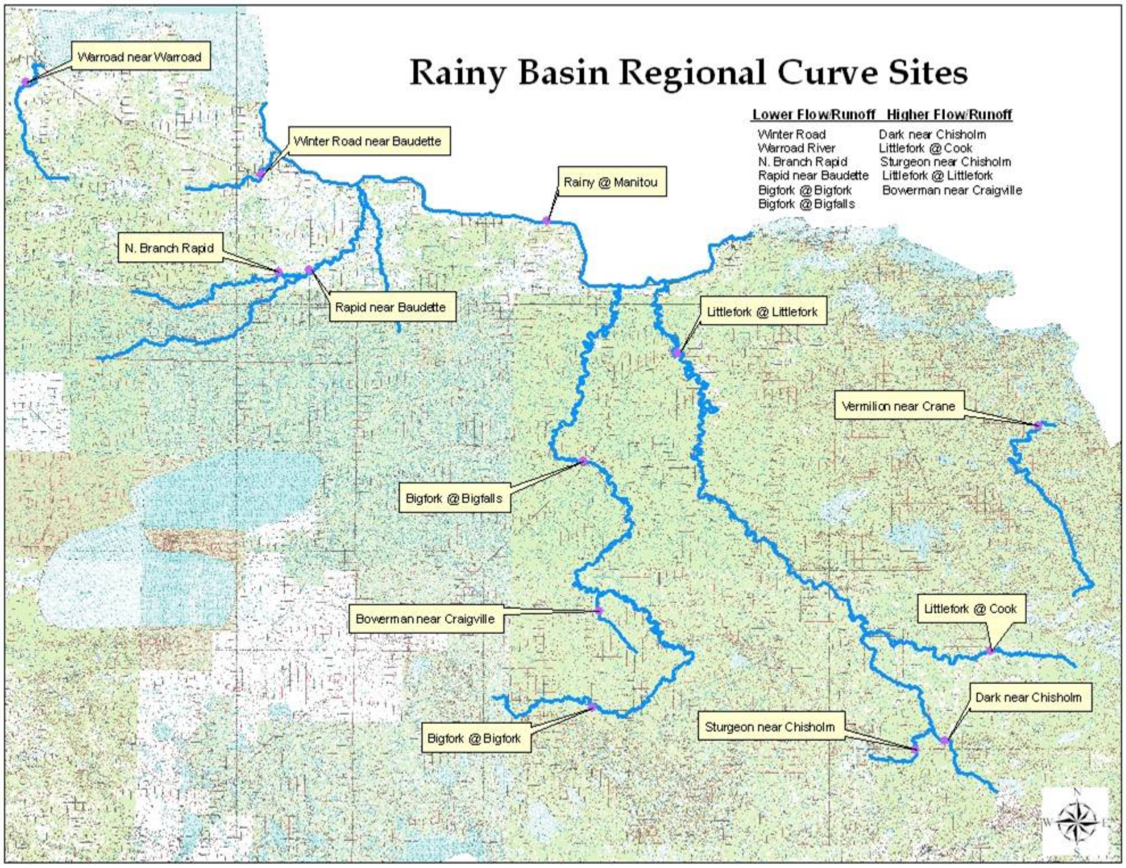
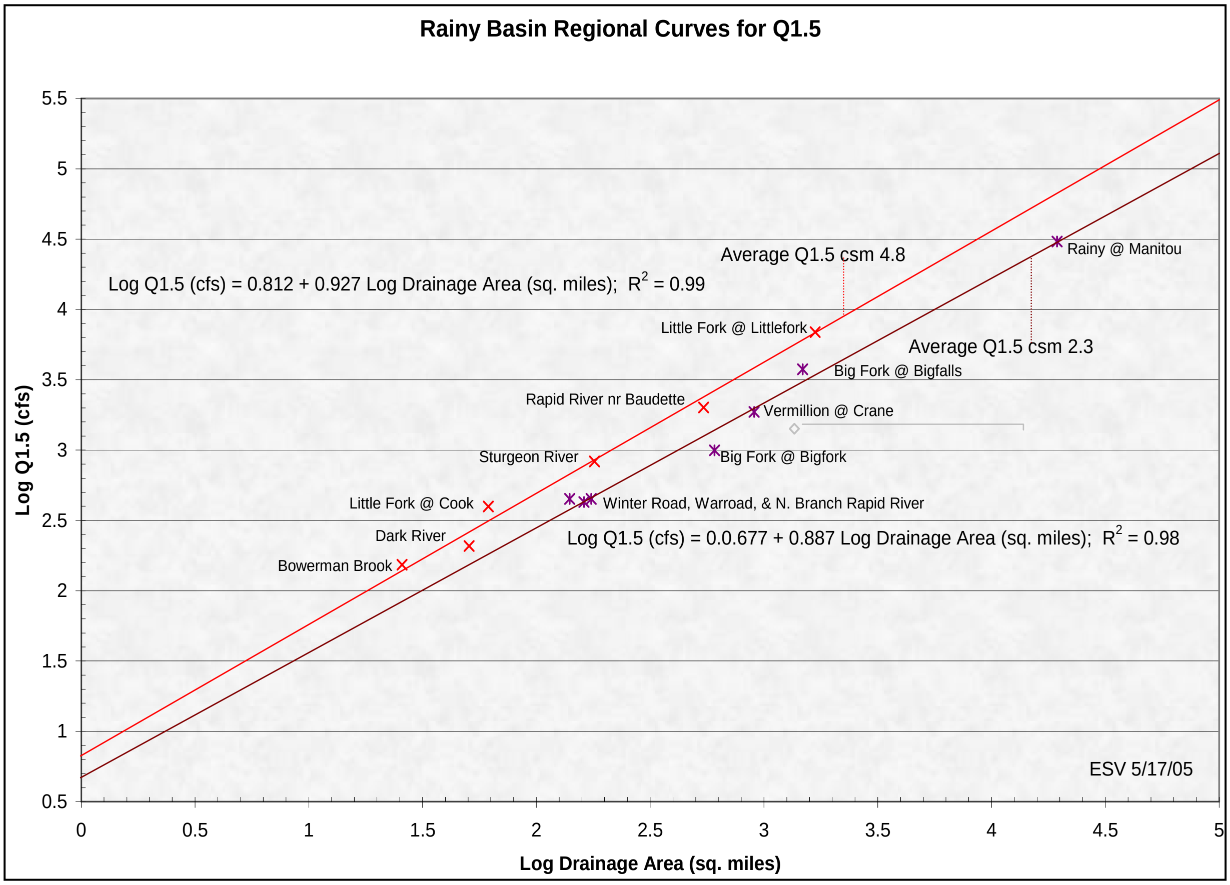


Figure 18. Rainy River Basin Regional Curve. Based on data from USGS gaging stations in the Little Fork and Big Fork River physiographic region

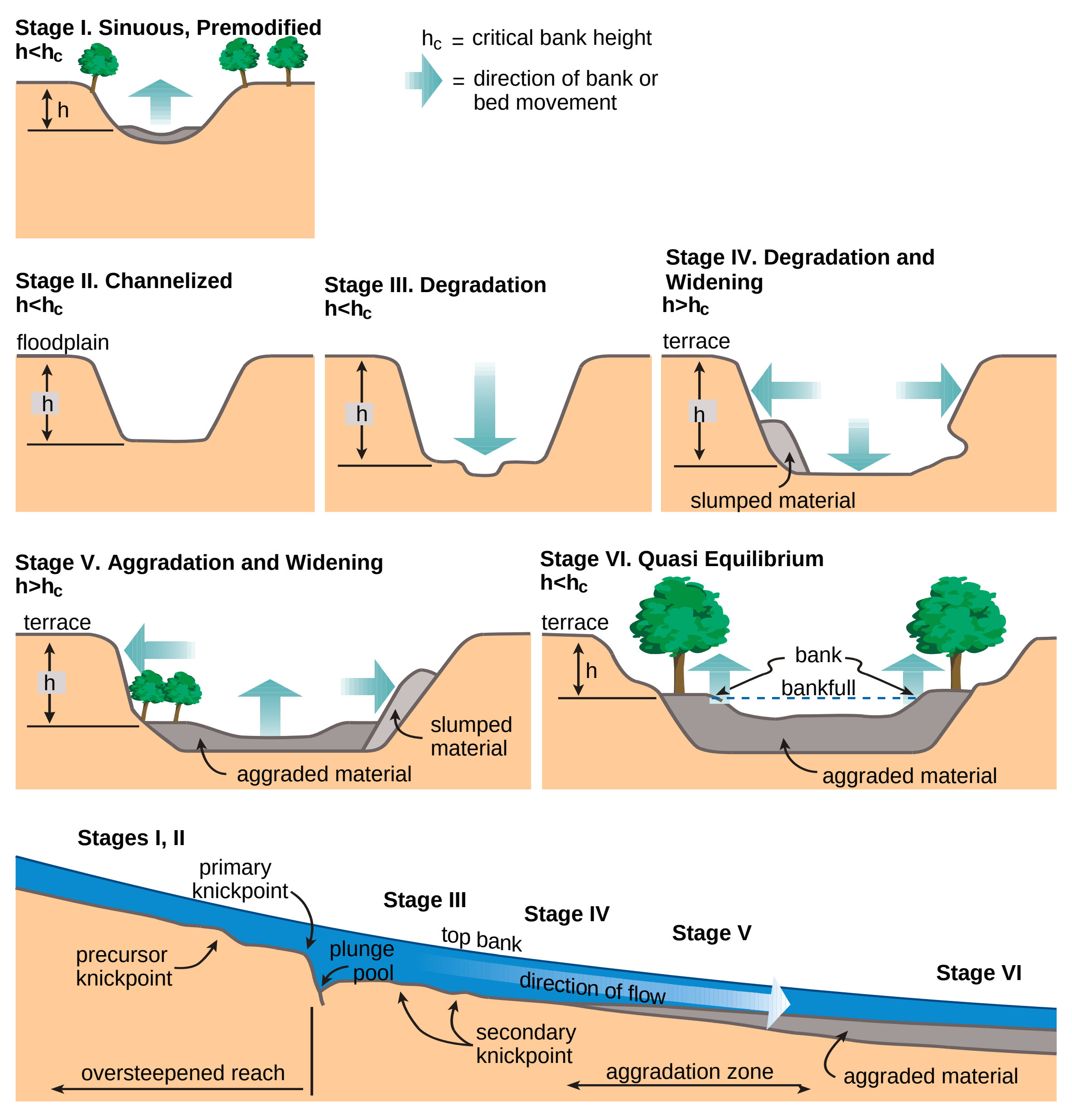


I. Geomorphology

Stream Channel Evolution:

In addition to hydrologic analysis, stream channel geomorphology is also a critical component toward understanding rivers and their watersheds. Andrew Simon of the US Department of Agriculture, National Sedimentation Laboratory, had developed a model of stream channel evolution based on work throughout the United States on channelized streams (Simon, 1986; Simon, 1989). The model (Figure 19) has been successfully used to rapidly identify dominant channel processes in watersheds impacted by various human and natural disturbances via aerial reconnaissance or ground observations in diverse regions of the United States and Europe (Simon and Castro, 2003). In general, a disturbed stream channel responds to watershed changes through several stages by becoming channelized, degrading (lowering from original base water level), widening, and eventually creating a new floodplain formed from deposited eroded material in the watershed. This process can occur over a variety of time frames, from months to centuries depending on the size of the watershed and severity of the disturbances.

Figure 19. Simon's Stream Channel Evolution Model (modified from Simon and Hupp, 1986; Simon, 1989; Courtesy of Andrew Simon)



2004, 2005 Stream Geomorphology Reconnaissance

In August of 2004 and 2005, preliminary stream geomorphology surveys were conducted on several sites in the Little Fork River. This work fulfilled one of the goals of this study: provide information needed to determine the scope of the upcoming TMDL study, including geographic extent (part or all of mainstem and tributaries), and potential causes of erosion as they relate to land use and channel destabilization. Surveys were conducted during periods of lowflow (mid-August), which allowed wading and detailed survey work.

Channel geometry was surveyed at several locations providing baseline data for comparison to potential future changes in channel geomorphology. Many of these sites were at locations where local resource managers have anecdotal evidence of stream instability. These sites included

- Near St. Louis Country Road 114 bridge, downstream of Linden Grove
- Adjacent to Koochiching Country Road 75 near Silverdale
- Downstream of State Highway 65 bridge, near Silverdale
- MN Highway 65 bridge south of Littlefork
- Highway 217 bridge and USGS cableway, town of Littlefork
- US Highway 71 bridge downstream of Littlefork

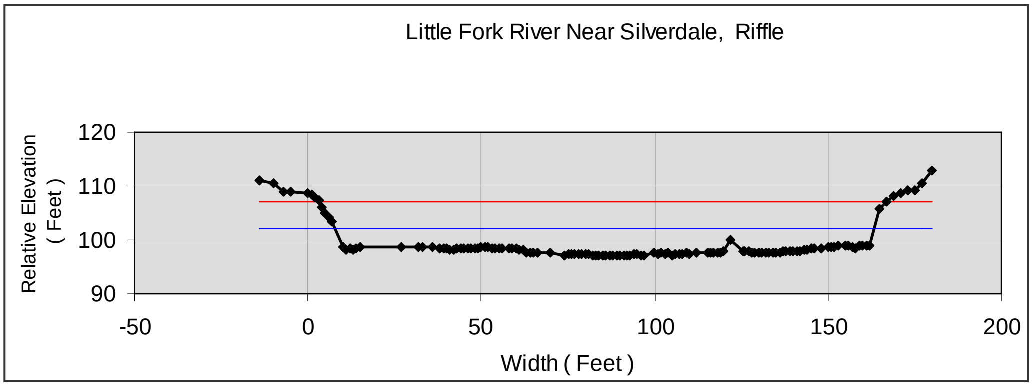
Only preliminary conclusions regarding channel morphology and disturbance can be drawn from these initial surveys. However, strong anecdotal and visual evidence of disturbance / destabilization were observed at the time of the survey. The river appears to be degrading and widening in several locations (which may correspond to Stage 3 and 4 of Simon’s channel evolution model- Figure 19). This was perhaps most prominent at the cross section near Silverdale, which we highlight in this paper.

Stream systems are dynamic, and change due to a variety of natural and anthropogenic factors. One such variable is the geometry, or shape, of the stream channel in cross section. The shape of the cross section of any river channel is a function of the flow, the quantity and character of the sediment in motion through the section, and the character or composition of the material (including vegetation) that make up the bed and banks of the channel (Leopold, 1994). An important finding on the Little Fork near Silverdale is the incised nature / shape of the channel. During moderate high flow events (approximately between the 1.5 and 50 year floods), the stream is still confined to its channel (Figure 20). These high energy events likely cause significant bank erosion or bank failures. The River’s historic floodplain (currently a terrace) is easily seen in Figure 21. Near Silverdale, we estimate that the Little Fork River has degraded approximately 8-12 feet from its historical (pre-modified) position to current baseflow water levels (Figure 21). The majority of the erosive clay material that comprised the former streambed has eroded downstream and likely contributed to the present in-stream turbidity impairment. The clay streambanks at this location are highly erodible; fine sediments were even released during low water levels at the time of the survey. How long it took the River to evolve into its present location is unknown, and is a key question to address as this project moves forward.

In natural channels there is an equilibrium between erosion and deposition, and the form of the cross section is stable (more or less constant) but the position of the channel is not (Leopold, 1994). Adjustment of cross sectional form is primarily by bank erosion and lateral channel migration (Simon 1992, Simon and Darby 1997) and channel banks generally erode by mass failure (Simon and Castro, 2003). In the loess (fine silt and clay) area of the Midwest United States, bank material contributes as much as 80% of the total sediment eroded from incised channels (Simon, et al, 1996). In searching the scientific literature, there are a few site specific examples of streambank erosion rates and their relation to the total sediment supply to a river. Rosgen (1973) found that on the E. Fork River in Colorado, three miles of unstable, braided channel contributed 49% of the total sediment yield of a 54 square mile watershed. Simon and Pollen (2004) cite that often more that 50% of the sediment from a watershed comes from bank failures, and one specific case where a 1.0 meter failure along a 5 meter high bank , along a 100 meter reach of river released 400 tons of sediment. In N. Fish Creek, 122 km. Wisconsin Tributary to Lake Superior, (Fitzpatrick, 1999; and Rose and Graczyk, 1996) stream bank and bluff erosion rates alone are estimated at 14,100 tons / year. Although these examples may be considered extreme, they point to the significance of bank erosion in the context of a stream’s total sediment load, which may be overlooked in conventional monitoring investigations.

In the course of our investigations, we have observed that the storm and snowmelt runoff originating in the upland forests and peatlands of the Little Fork and Big Fork watersheds is relatively clean and free of suspended sediment, and the majority of the sedimentation is originating from stream bank erosion and stream channel adjustment. During the TMDL study, detailed measurements of stream bank stability and bank erosion rates are needed. They are beyond the scope of this report.

Figure 20. Riffle cross section, Little Fork river near Silverdale, August 2005.
red - flood prone elevation (~ 50 year flood stage)
blue - bankfull elevation (~ 1.5 year flood stage)

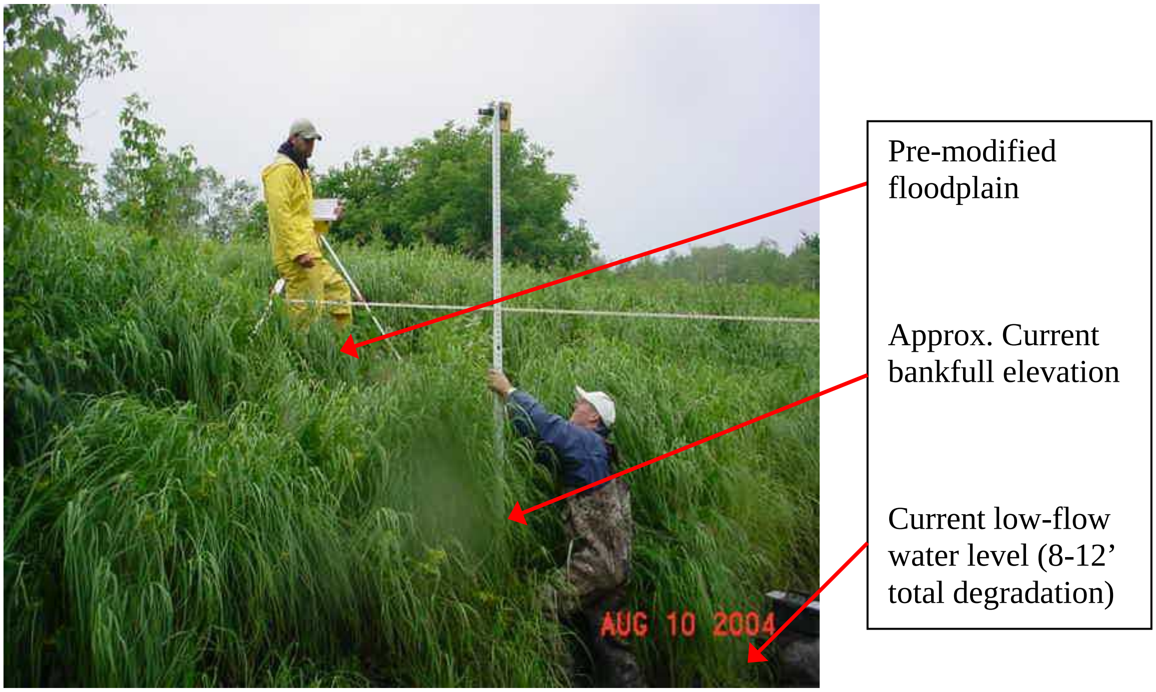


We estimated the bankfull elevation using field techniques, notably the depositional flat immediately adjacent to the current floodplain. Field determinations of bankfull stage (i.e. estimating it without the benefit of long term streamflow records) are difficult in unstable channels. As such, the elevations in Figure 20 and corresponding data in Table 12, should be considered approximate, based on the best professional judgment of the field crews. It is evident from Figure 20, that this section of the Little Fork is trapezoidal shaped and entrenched (entrenchment ratio = 1.1 ; Table 12). Long term monitoring of channel dimensions at select locations, such as this one near Silverdale, will allow us to track stream channel stability, and provide insight into stream bank erosion rates and other geomorphic characteristics related to the in-stream turbidity impairment.

Table 13. Select stream geomorphology data, riffle cross section, Little Fork River near Silverdale, August 2005. Calculations from "The Reference Reach Spreadsheet", Dan Mecklenburg, Ohio DNR. http://www.ohiodnr.com/soilandwater/streammorphology.htm

Flood prone width – 163 feet	Cross Sectional Area – 614 ft^2	Shear Stress – 0.227 pounds / ft^2
Bankfull width – 156 feet	Entrenchment Ratio – 1.1	Unit Stream Power – 0.62 pounds / feet / second
Mean Depth @ Bankfull – 3.94 feet	Estimated velocity @ bankfull flow – 2.6 ft / sec.	Median Grain size @ riffle– 36 mm. (D_{50})
Max Depth @ Bankfull – 5.0 feet	Estimated discharge @ bankfull flow – 1,600 cfs	Stream Slope 0.096 %
Width / Depth Ratio – 39.6		Rosgen Stream Type – F 4

Figure 21. Evidence of channel incision on the Little Fork River near Koochiching County Highway 75. This section of stream is approximately 8 miles upstream from the site near Silverdale.



From our aerial over-flight in November of 2004 we observed the following:

- Channel incision / bank instability is most prominent downstream of Hannine Falls to the confluence with the Rainy River. It is our hypothesis that this 15' bedrock waterfall stopped the upstream migration of the primary nick-point (Figure 19).

- Further evidence of down-cutting in the mainstem of the Little Fork River was seen at the confluence with small tributaries. Several tributaries had severe gully erosion adjacent to the main channel because of the gradient change brought on by the vertical degradation of the Little Fork River (Figure 22). These gullies proceeded upstream to a confining area, such as a road crossing (where perched culverts were occasionally seen). An example is shown in Figure 22. In the lower gradient landscape in the downstream half of the Little Fork River watershed, small tributaries should be classified as Type E channels (Rosgen, 1996).
- Channel instability and incision were most prevalent in the lower half of the watershed. This part of the stream likely saw the greatest historical log transport, because the stream is wider and has greater flow rates. Our hypothesis that log driving started the “domino effect” of channel / streambank instability we see today needs to be substantiated.

Although anecdotal, the following photos in Figures 23-28 support our hypothesis of physical destabilization in the Little Fork River. More detailed surveys are a necessity as the project moves forward (see Scoping Study – below).

Figure 22. Channel incision and reduced sinuosity resulting from a culvert on a tributary to the Little Fork River, from 2004 over-flight.

Figure 23. Severe channel erosion, small tributary adjacent to USGS gage in Littlefork.

Figure 24. Streambank failure, Little Fork River, near Silverdale (Al Anderson, Minnesota DNR)

Figure 25. Streambank Failure, Sturgeon River, the Little Fork's largest tributary (Amy Phillips, MPCA)

As stated previously, there are many locations along the mainstem of the River with clear bank failures and resultant erosion. Where is the final destination of this sediment? At first glance it may appear that it is settling in the mainstem of the River in Littlefork, downstream of the rapids at Highway 217 bridge, since this is the last rapid until the river reaches the Rainy River- 21 miles downstream. However, under low flow conditions in August 2004 and 2005 at the cableway cross section, cobble and gravel were common, and there was little evidence of siltation and fine material (Figure 26). USGS staff have documented that the rating curve for their gage in Littlefork is stable over the 80 year period of record; however in 1979 the gage was moved 1.2 miles upstream to eliminate backwater effects from the Rainy River at high flows (Kevin Guttormson and Greg Melhus, personal communication, 2004; Figure 7). The ultimate source of this sediment is an important component of the TMDL- for instance how much settles out at the confluence (Figure 28), versus in the Rainy River, versus further downstream in Lake of the Woods?

Figure 26. View of right stream bank at USGS cableway cross section. Note slumping material and cobble material on stream bed.

AUG 10 2004

Figure 27. Little Fork River at lowflow, looking downstream towards left bank at cableway. Note steep floodplain below tree-line- evidence of erosion.

AUG 10 2004

Figure 28. Satellite image of confluence of Little Fork and Rainy Rivers. Note mixing sediment plume, and island of sediment in mid-channel of Rainy R. Image courtesy of NRCS, taken Summer 2003.

Figure 29. Further example of down-cutting and bank instability, near USGS gage in Littlefork. Note high turbidity of water during spring snowmelt.

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Initial Scoping for the Long Term Paired Watershed Study

As this study progressed, it was determined that conditions in the Little Fork River watershed should logically be compared to those in the Big Fork River, the adjacent watershed to the west (Figure 4- inset). This would provide a unique opportunity for a detailed paired watershed study, at a large scale (approximately 2000 mi^2) not commonly studied in the scientific literature. The paired watershed study would be long term in scope (> 10 years), and require input and expertise from area government / land management agencies, stakeholders, and the forest products industry. The Paired Watershed Study will technically be separate from the TMDL study on the Little Fork, but will provide data and information needed for the TMDL. The authors have recently formed the Little Fork / Big Fork Interagency Work Group to advise this effort. The preliminary objectives of the project are 1) to determine the present hydrologic, geomorphic, and water quality status of the two watersheds, and 2) to further evaluate the influence of land use change, watershed storage, surficial geology and vegetation upon them. The results of the study will be used in a more detailed and comprehensive weight of evidence approach to determine the impact of historical logging on hydrology, geomorphology, and turbidity/sediment impairment in the Little Fork and Big Fork Rivers. The project will also calculate current sediment loads for each watershed, differentiating natural versus anthropogenic sources of turbidity / sediments. Efforts will be made to determine what watershed characteristics are responsible for the observed differences in watershed recovery, and feasible options for restoration on the Little Fork and protection of the Big Fork (water quality data collected by the authors and other resource managers indicate that the Big Fork has comparatively lower concentrations of turbidity and suspended sediments).

Therefore, this report serves two main purposes- 1. A scoping document for the Little Fork River turbidity TMDL study, described in the Introduction; and 2. Describe the issues, environmental setting, and provide the initial data assessment that is the foundation of the more detailed Paired Watershed Study.

Conclusions / Next Steps

Summary, Weight of Evidence Approach

In summary, the following conclusions were based on our analysis of the historical USGS hydrology data, and available land use / land cover data in the Little Fork and Big Fork River watersheds. We collectively attribute these findings, in a weight of evidence approach, to hypothesize that initial historical logging had a significant impact on these rivers; particularly the Little Fork, and likely caused the turbidity impairment that we observe presently in the Little Fork River watershed.

- Bankfull flows (Q 1.5) on the Little Fork and Big Fork Rivers increased in response to historical logging. The best (and only) set of environmental data collected during historical logging (early 1900's) was daily streamflow data at the long term USGS monitoring stations.

- Both watersheds have since seen a decline in bankfull flows; likely due to the forest recovering (i.e. re-growth) from historical logging. For the Little Fork River, trends in bankfull flows are independent of effects of precipitation; we infer the changes to be land cover driven.
- Bankfull flows recovered (i.e. declined) on the Big Fork River at least 10 years before the Little Fork. This is likely due to later original logging in the more remote Little Fork basin (as referenced by Pollard- 1960, 1977).
- Normalized bankfull flows are statistically greater in the Little Fork River.
- Bankfull flows on the Little Fork were sustained at a higher level for a longer period; and were approximately double those on the Big Fork, despite a modest 12% difference in contributing watershed area (at the USGS stations). Simply, more water is getting to the Little Fork River, and it's getting there faster (i.e. it's more "flashy") than in the Big Fork. This is likely due to at least four main factors:
    - There are more peat lands in the Big Fork watershed, these large peat lands dampen flood flows and sustain higher baseflows. These peatlands were not historically logged; likely for economic reasons – mainly difficult access and slower tree growth. A dominant tree species in the peat bogs is the black spruce, a mature black spruce averages 40-65' tall and a 9" diameter on good sites (Burns and Honkala, 1999); fire swept through the area in the 1860's.
    - a greater amount of pasture land in the Little Fork basin, which yields more runoff than older (> age 16) forest lands
    - There are many more lakes in Big Fork watershed (420 versus 165 in the Little Fork), particularly in the headwaters. These provide a more stable streamflow regime.
    - Geological differences between the two watersheds- more igneous geology in the Little Fork which yields faster runoff, and a greater proportion of glacial Lake Agassiz influenced geology in the Big Fork. Average stream gradients are 2 feet per mile on the Little Fork and 1.5 feet per mile on the Big Fork (Waters, 1977).
- A Rainy River Basin regional curve analysis yielded two distinct groupings of streams in the study area. A 'higher' flow group, with double the water yield, made up primarily of the Little Fork River and tributaries, and the 'lower' flow group, made up of the Big Fork River and other streams dominated by upstream peatlands and large lakes.
- Today, both watersheds are still primarily managed for forest harvest, they remain sparsely populated, and have the majority of their pre-settlement wetlands remaining- St. Louis and Koochiching Counties have 93.9 and 98 percent, respectively (Minnesota Board of Water and Soil Resources, 2001).

It's our hypothesis that the Little Fork River is destabilized and still in the process of recovery from the impact of historical logging, and the impacts observed at present are due to a combination of increased runoff from initial logging (i.e. incrementally clearing the landscape), as well as the geomorphic impact of using the river and floodplain to transport the logs. This conclusion is based on numerous visual observations, anecdotal evidence seen by the authors and local resource mangers, and our initial geomorphology surveys (Figures 22-28).

On-going questions to be addressed

- i) Determine sediment loading sources (upland, gully, streambank, stream channel etc.) particularly the importance of streambank erosion as a percentage of total watershed load.
    - (1) Include the influence of potential turbidity impairment resulting from natural tannin runoff from area wetlands, and algal growth during summer low-flows.
- ii) Determine cause(s) of channel destabilization, and whether this separated the river from its historic floodplain.
- iii) Can zones of erosion, transition, and deposition be defined on the Little Fork mainstem, as defined by Schumm (1977)?
- iv) Can the sediment in the floodplain be aged to determine if the River degraded or the floodplain aggraded (from watershed sources of sediment)
- v) Decreasing streamflows appear to correspond with the end of the initial logging period in 1937. Does this mean:
    - (1) The Little Fork River is still evolving from the 1910 – 1937 logging or is something else destabilizing the system?
    - (2) When can we expect the Little Fork River to reach Simon’s Stage VI, Quasi Equilibrium?
    - (3) How much sediment will be eroded and delivered to the lower reaches of the Little Fork River and to the Rainy River?
        - (a) What will be the impact to the Rainy River and Lake of the Woods?
        - (b) What will be the impact on the fisheries and benthic macroinverterbrates?
    - (4) Can we substantiate our hypothesis that Hannine Falls is acting as a barrier by preventing down-cutting from continuing further up-river? What are the areas that act as sediment sources and sediment sinks upstream / downstream of Hannine Falls, town of Littlefork, and Rainy River confluence?
- vi) Comparison of the Little Fork River’s hydrology to that of the Big Fork River indicates that the Little Fork exhibits more flashiness and is still evolving to quasi equilibrium whereas the Big Fork seems to have already reached Stage VI (or it was never physically destabilized).
    - (1) What are the differences between these watersheds, beyond those introduced in this study?
    - (2) Is the Big Fork River at Stage VI, and if so why is the Little Fork River still evolving?
    - (3) How is this related to the comparatively better water quality observed in the Big Fork River?
- vii) Does the Little Fork impairment justify the need for a physical impairment (which may set a precedent in MN) or at least a TSS impairment?

viii) How do current logging practices affect turbidity levels, sediment concentrations, nutrient loadings, streamflows, and channel destabilization and geomorphology?

ix) If the cause of the destabilization of the Little Fork is determined to be increased flows, the TMDL report may be establishing a precedent for classifying increased stream flow as a "pollutant". What does this mean for Minnesota's Impaired Waters (TMDL) program?

Next Steps for Development of the TMDL, and Paired Watershed Study

List the Little Fork on the 2006 Impaired Waters List

Develop a TMDL Work Plan that addresses the following:

(1) Determine and document (through Geographic Information System mapping) evolutionary stages of mainstem and destabilized reaches of tributaries for the Little Fork and Big Fork Rivers.

(2) Determine causes of destabilization. Consider land uses (conversions, practices, etc.), climate change and weather patterns, historical activities and other activities that might increase runoff and flows.

(3) Analyze effects of runoff from initial logging (late 19th century through early 20th century) verses current practices (Voluntary Site Level Guidelines).

(4) Compare current Little Fork TSS loading to USGS 1970s SSC data (i.e. has the rate of sediment loading changed over time?).

(5) USFS Color Infrared photos of entire mainstem.

(6) Analyze representative samples from stream banks and sediment for phosphorus concentrations, because of nutrient loading concerns in downstream Rainy River and Lake of the Woods.

(7) Determine why the Little Fork has not yet stabilized or has destabilized and other similar rivers haven't. This is necessary to determine how we can prevent destabilization of other rivers (i.e. protection vs. restoration).

(8) Effects of the Little Fork sediment loading on aquatic life, especially Special Concern Mussels (*Ligumia recta* and *Lasmigona compressa*).

(9) Document Effects of Little Fork sediment loading on the Rainy River.

(10) Determine restoration alternatives, include a null alternative, and various restoration options allocating loadings throughout the watershed.

Develop a network to monitor precipitation throughout the watershed, and explore options for adding additional stream flow gages in the upstream portion of the Little Fork and Big Fork Rivers.

Figure 30. Logging Practices observed during November, 2004 Arial Survey of the Littlefork River

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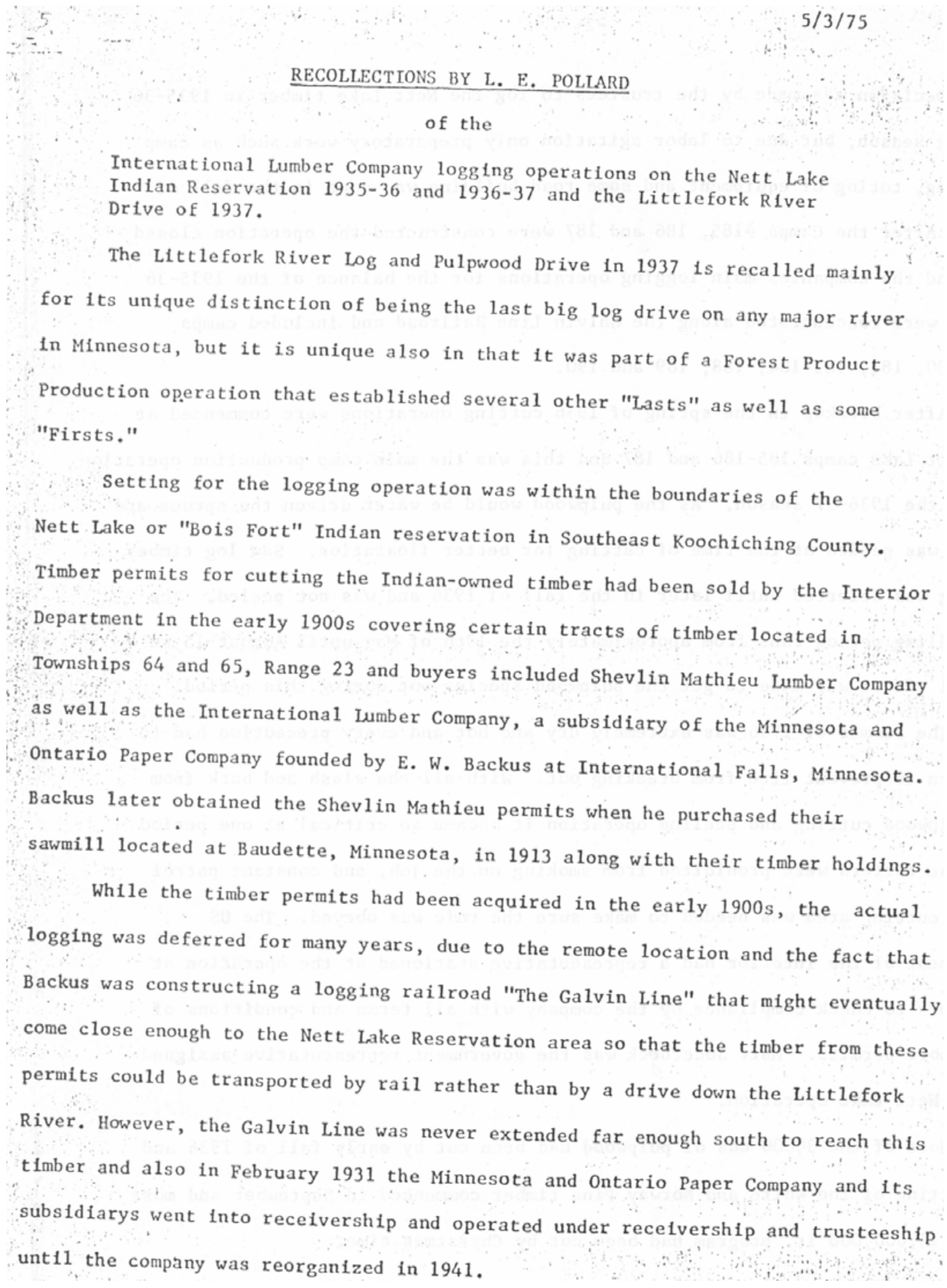
Appendix 1. Lester Pollard’s Account of 1937 Little Fork River Log Drive (From Minnesota Historical Society’s Manuscript Collection)



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RECOLLECTIONS BY L. E. POLLARD

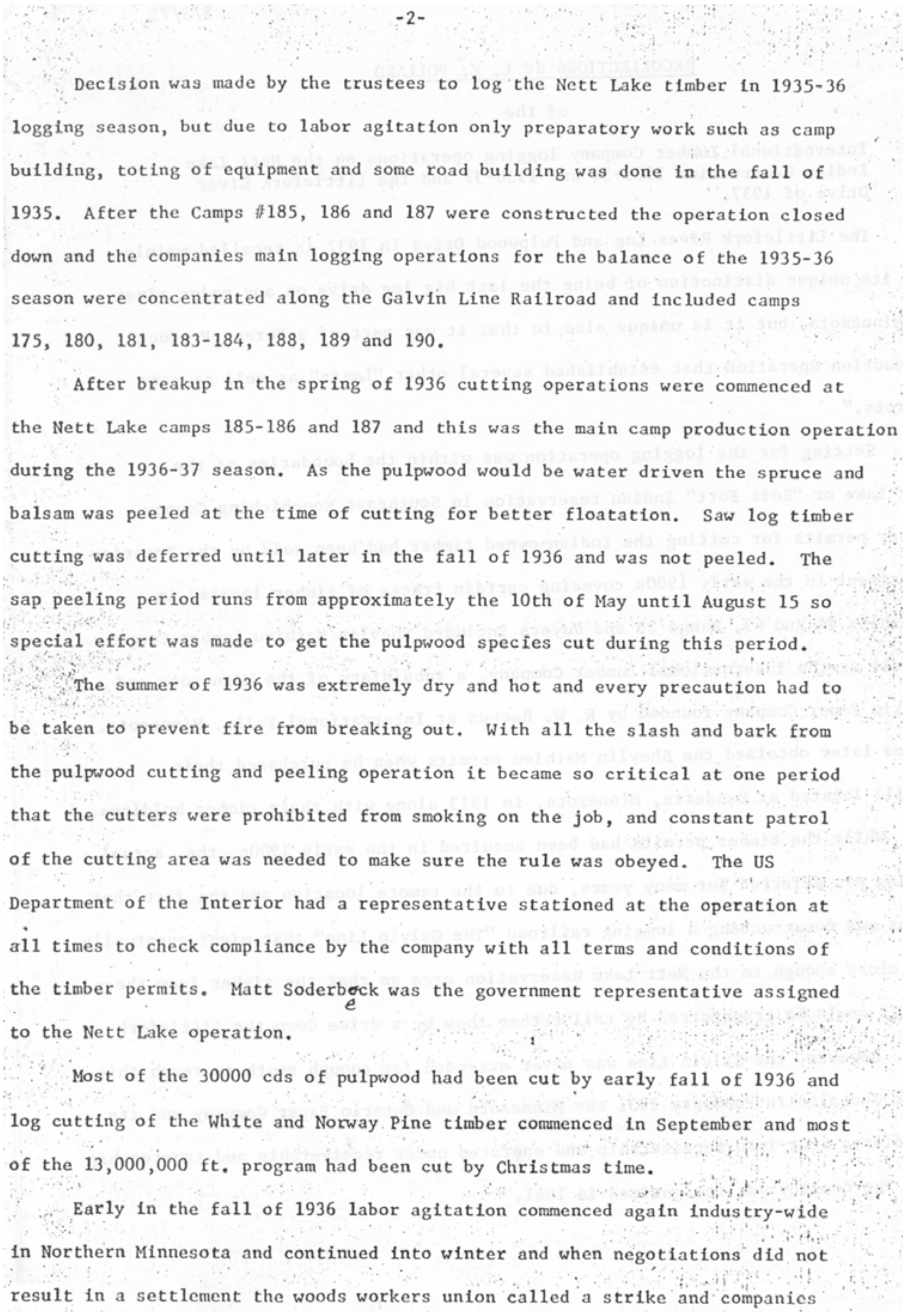
of the

International Lumber Company logging operations on the Nett Lake Indian Reservation 1935-36 and 1936-37 and the Littlefork River Drive of 1937.

The Littlefork River Log and Pulpwood Drive in 1937 is recalled mainly for its unique distinction of being the last big log drive on any major river in Minnesota, but it is unique also in that it was part of a Forest Product Production operation that established several other "Lasts" as well as some "Firsts."

Setting for the logging operation was within the boundaries of the Nett Lake or "Bois Fort" Indian reservation in Southeast Koochiching County. Timber permits for cutting the Indian-owned timber had been sold by the Interior Department in the early 1900s covering certain tracts of timber located in Townships 64 and 65, Range 23 and buyers included Shevlin Mathieu Lumber Company as well as the International Lumber Company, a subsidiary of the Minnesota and Ontario Paper Company founded by E. W. Backus at International Falls, Minnesota. Backus later obtained the Shevlin Mathieu permits when he purchased their sawmill located at Baudette, Minnesota, in 1913 along with their timber holdings.

While the timber permits had been acquired in the early 1900s, the actual logging was deferred for many years, due to the remote location and the fact that Backus was constructing a logging railroad "The Galvin Line" that might eventually come close enough to the Nett Lake Reservation area so that the timber from these permits could be transported by rail rather than by a drive down the Littlefork River. However, the Galvin Line was never extended far enough south to reach this timber and also in February 1931 the Minnesota and Ontario Paper Company and its subsidiarys went into receivership and operated under receivership and trusteeship until the company was reorganized in 1941.



Decision was made by the trustees to log the Nett Lake timber in 1935-36 logging season, but due to labor agitation only preparatory work such as camp building, toting of equipment and some road building was done in the fall of 1935. After the Camps #185, 186 and 187 were constructed the operation closed down and the companies main logging operations for the balance of the 1935-36 season were concentrated along the Galvin Line Railroad and included camps 175, 180, 181, 183-184, 188, 189 and 190.

After breakup in the spring of 1936 cutting operations were commenced at the Nett Lake camps 185-186 and 187 and this was the main camp production operation during the 1936-37 season. As the pulpwood would be water driven the spruce and balsam was peeled at the time of cutting for better floatation. Saw log timber cutting was deferred until later in the fall of 1936 and was not peeled. The sap peeling period runs from approximately the 10th of May until August 15 so special effort was made to get the pulpwood species cut during this period.

The summer of 1936 was extremely dry and hot and every precaution had to be taken to prevent fire from breaking out. With all the slash and bark from the pulpwood cutting and peeling operation it became so critical at one period that the cutters were prohibited from smoking on the job, and constant patrol of the cutting area was needed to make sure the rule was obeyed. The US Department of the Interior had a representative stationed at the operation at all times to check compliance by the company with all terms and conditions of the timber permits. Matt Soderb~~o~~eck was the government representative assigned to the Nett Lake operation.

Most of the 30000 cds of pulpwood had been cut by early fall of 1936 and log cutting of the White and Norway Pine timber commenced in September and most of the 13,000,000 ft. program had been cut by Christmas time.

Early in the fall of 1936 labor agitation commenced again industry-wide in Northern Minnesota and continued into winter and when negotiations did not result in a settlement the woods workers union called a strike and companies during the strike period as it involved all logging operations in Northern Minnesota and final negotiations in January were conducted in St.Paul, Minnesota and involved high state officials including Gov. Elmer Benson. The main accomplishment of the strike was the recognition of the woods workers union and the first collective bargaining agreement between the lumber and paper mill companies and ~~the~~ A Woods workers union in Minnesota. The agreement provided for approximately 18% increase in wage rates and some improvement in working conditions and minor changes in camp facilities and food items. One of the food items was for more fresh fruit and when the first grapefruit were put on the tables most of the workers thought they were green sour oranges and there was more "gripping" about that than wages and working conditions.

During the strike period only supervisory employees remained at the camps to guard supplies and equipment. January 1937 was a heavy snowfall month so by the time the crews returned after the January 29 settlement there was almost four feet of snow on the ground and all the logging roads and landings had to be plowed out, also the pulpwood and logs cut along the strip roads were buried under such a depth of snow that the piles of pulpwood and the logs were not discernable and had to be located and "flagged" by men on snowshoes so the workers could shovel them out for the skidding crews.

In plowing out the main logging roads the snow banks along the roadside became so high that the horses used for skidding could not get over the snow bank so tractors with dozers had to be used to open up the entrance to each strip road and even then the horses had difficulty pulling the skidding drays loaded with approximately one cord of peeled pulpwood.

Needless to say, losing the whole month of January production put a tremendous burden on everyone to complete the cutting skidding and sleigh haul before the spring breakup in March. All the men that could be housed in the three camps (approx. 500) were hired and extra tractor equipment was brought in to help with the skidding and sleigh haul operations. The need for snow shovels was so great at all logging operations that the supply carried by Marshall Wells and Kelly How Thompson Co. in Duluth were exhausted almost overnight and extra stocks had to be rushed in.

It is a tribute to the logging staffs and the camp crews that despite the delays and difficulties of additional snow And Cold Weather that all the forest products produced, approximately 30,000 cds. pulpwood and 13,000,000 ft. of pine logs, were delivered to the river ~~loadings~~ Landings by the last week of March 1937.

Most of the pulpwood was delivered directly to the river ice landings while the logs were piled in rollways or decks at right angle to the river bank as the plan was to let the pulpwood ranked on the ice start moving first when the river ice started to move downstream and when the pulpwood was out of the way the log decks would be tripped and the logs would follow behind the pulpwood down the river.

However, nature changed the plan suddenly -- because of the heavy winter snowfall the spring run off of water was tremendous and also around the 15th of April heavy rains commenced and continued for several days causing the river ice to start raising and cracking and then start moving downstream on April 23. As the ice and pulpwood moved downriver it jammed at some of the river bends and with the tremendous runoff of water from the snow melt and heavy rains the river water behind the ice and pulpwood jams rose so fast and so high (over 15 ft.) that the rollways of banked logs spilled into the river also. So the feed-in of timber to the drive was out of control and when the pressure of the high water unplugged the ice jams the entire production of pulpwood and logs started downstream at once. The route of the drive was down the Littlefork River and into Rainy River where the International Lumber Company had sorting and holding booms and a hoisting facility at Loman, Minnesota, where the forest products could be loaded on railroad cars and hauled on the company railroad "The Loman Line" approximately 20 miles back upstream to the sawmill and paper mill at International Falls, Minnesota.

Because of the extremely high water in the Rainy River in the spring of 1937 the boom timbers and piling at the Loman Hoist were under water so if the timber in the Littlefork River drive was permitted to go into the Rainy River There would be nothing to stop it from going all the way to Lake of the Woods.

with little chance of recovery. Therefore immediate action was necessary to try and hold the timber in the Littlefork River and the Nett River Bridge located on Highway #65 About Halfway between the town of Littlefork, Minnesota, and the Nett Lake Reservation was the most logical choice. Hurriedly cables were fastened from the bridge to trees along the river bank and a deliberate jam was caused. There was question for a while if the bridge could stand the strain from the timber pressed against it, but it held, so very little timber got through and went down stream. With 30000 cds of pulpwood and 13,000,000 ft. of sawlogs backed up behind the bridge and completely filling the river approximately 6 miles up stream from the bridge, the water raised behind the jam and the river widened out over its banks allowing the pulpwood and logs to float onto the river flats a considerable distance from the main river channel. When the river water finally dropped back to normal much timber was left stranded on these flats and in some cases was farther from the river than when the trees had been cut on the Nett Lake Reservation. Also, some pulpwood sticks were even lodged in the tree branches as the water had been so high.

While the jam at the Nett River Bridge had saved the timber from being lost in the Rainy River, it actually created a new skidding operation in order to get the timber from the flats flooded by the high water back in the main channel. This was a back breaking job for the river drivers as tractors and horses could not be used, on many sections of the muddy and wet river flats, so peavies and pickeroons were the main tools used. When water levels in the Rainy River dropped enough so the storage booms at the Loman Hoist became operable the jam at the Nett River Bridge was released and timber again started moving down river the first week in May.

However The Work of "Bringing Down the Rear", the stranded pulpwood and logs left on the river flats all the way from the Nett Lake Reservation area continued until early June when the rear drive crews joined up with the crews releasing the big jam and watering the stranded logs and pulpwood at the Nett River Bridge area. There had been approximately 150 men employed in both driver crews and after joining up they were consolidated in one crew of 40-50 men to continue on down river and water any timber that was left high and dry when the water dropped. This part of the drive was completed about July 15 when the last of the Littlefork River drive reached the Rainy River in time to be hoisted at Loman and rail hauled to the sawmill and paper mill at International Falls before fall freezeup.

The upper drive crew used two regular wanagans - one for cooking facilities and one for sleeping quarters - and also one large raft with a tent for housing the men. The Nett River Bridge crew used several large rafts with tents for both housing and cooking quarters.

In summary it can be said that if the Littlefork River Drive of 1937 has the unique honor of being the "last" great river drive in Minnesota it put on a great show. In fact the entire operation in connection with producing the logs and pulpwood for this drive included some additional "lasts" as well as some "firsts."

The "firsts" include --

The operation was planned and commenced in 1935-36 but labor agitation forced postponment until 1936-37 -- "first" time woods workers had such influence on logging plans.

The strike of January 1937 resulted in the "first" collective bargaining agreement between lumber and paper mill companies and a union representing the woods workers in Minnesota.

The river drive workers also worked under a labor agreement negotiated at the last minute before the drive was to start so they also joined the "firsts" as the first union labor river drivers in Minnesota. The rate was .60 per hour plus board and lodging.

The "lasts" include in addition to the river drive --

The "last" company operated camp logging operation - after the 1936-37 season the company obtained their requirements of forest products from independent logging contractors and open market purchases.

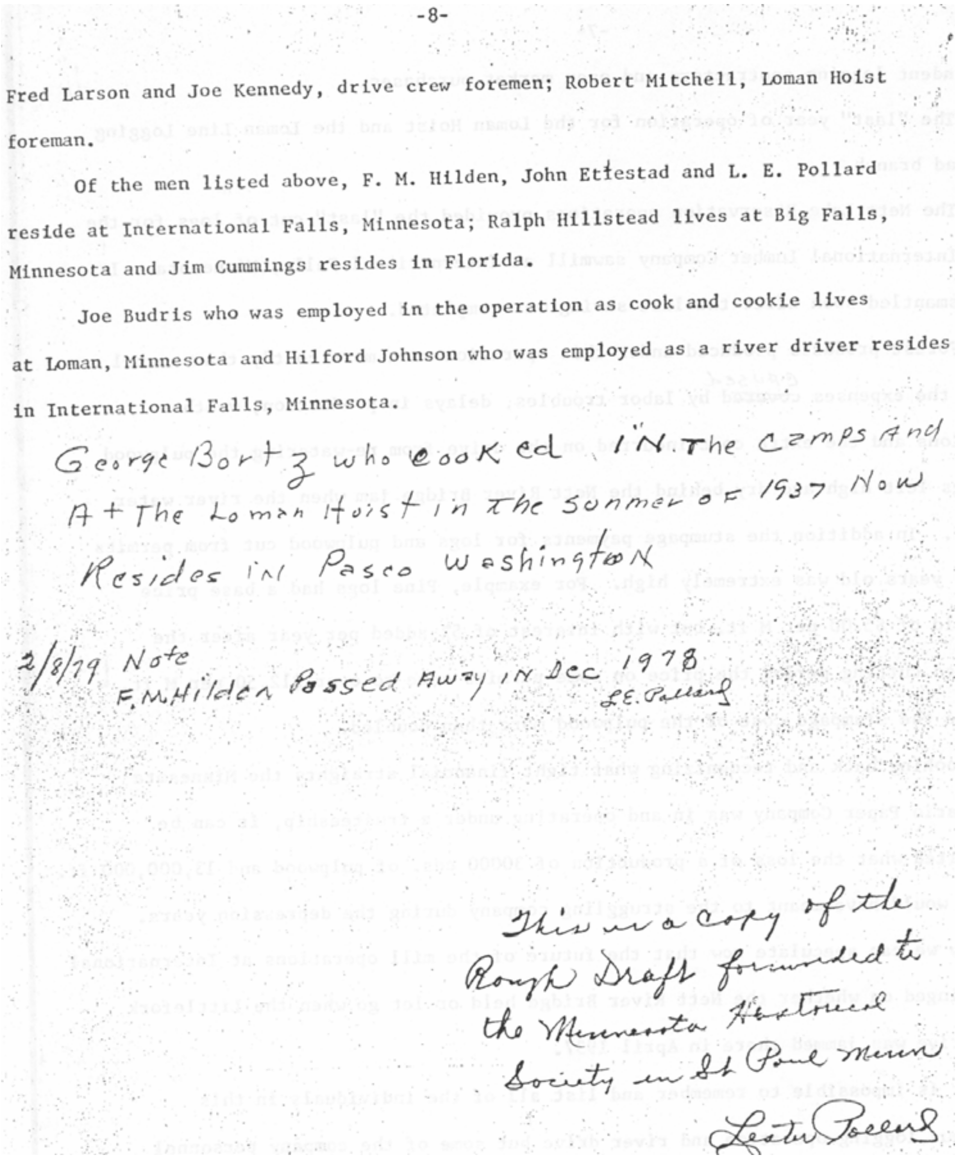
The "last" year of operation for the Loman Hoist and the Loman Line Logging Railroad branch.

The Nett Lake Reservation operations provided the "last" cut of logs for the large International Lumber Company sawmill at International Falls, Minnesota. It was dismantled soon after the last sawing was completed.

Forest products produced under this operation were more costly than normal due to the expenses ~~covered~~ caused by labor troubles, delays in production, weather conditions and the extra cost incurred on the drive from re-watering the pulpwood and logs left high and dry behind the Nett River Bridge jam when the river water receded. In addition the stumpage payments for logs and pulpwood cut from permits over 25 years old was extremely high. For example, Pine logs had a base price when sold of $5.00 per M ft. but with interest of 5% added per year after the specified cutting period the price on some permits came to over $12.50 per M ft. likewise the stumpage cost of the pulpwood more than doubled.

Looking back and recognizing what tight financial straights the Minnesota and Ontario Paper Company was in and operating under a trusteeship, it can be appreciated what the loss of a production of 30000 cds. of pulpwood and 13,000,000 ft. of logs would have meant to the struggling company during the depression years. Possibly we can speculate now that the future of the mill operations at International Falls hinged on whether the Nett River Bridge held or let go when the Littlefork River drive was jammed there in April 1937.

It is impossible to remember and list all of the individuals in this tremendous logging operation and river drive but some of the company personnel directly involved include: F.rank L. Bussmann, Supt. of Logging, and in direct charge of entire operation; L.ester E. Pollard, Asst. to Bussmann; F.red M. Hilden, timber buyer; O. W. Ferguson, woods supt.; John M. Nelson, head cruiser; Oscar Naes, head checker; John Etlestad and Swan Frieberg, woods checkers; Chas. Johnson, W.illiam J. "Beaver" Dwyer, Frank Hogan and Joe Poquette, camp foremen; John Osborn, Jim Cummings and Ralph Hillstead, camp checks; Allen M. Hanson, tractor equip. supervisor;



Fred Larson and Joe Kennedy, drive crew foremen; Robert Mitchell, Loman Hoist foreman.

Of the men listed above, F. M. Hilden, John Ettestad and L. E. Pollard reside at International Falls, Minnesota; Ralph Hillstead lives at Big Falls, Minnesota and Jim Cummings resides in Florida.

Joe Budris who was employed in the operation as cook and cookie lives at Loman, Minnesota and Hilford Johnson who was employed as a river driver resides in International Falls, Minnesota.

George Bortz who cooked IN The camps And At The Loman Hoist in the sonmer of 1937 Now Resides in Pasco Washington

2/8/79 Note
F.M.Hilden Passed Away IN Dec 1978
L.E. Pollard

This is a copy of the
Rough Draft forwarded to
the Minnesota Historical
Society in St Paul Minn
Lester Pollard


International
Logging Operations
1936-37 Season
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RAINY LAKE
FT. FRANCIS
RANIER
INTL FALLS
RAT ROOT L.
ERICSBURG
KABETOGAMA
LITTLE FORK
ST. LOUIS COUNTY
Nett River
Bridge Area
NETT L.
PELICAN
LAKE
LITTLE
FORK
RIVER
CP-167
CP-185
HOLSTROM SPUR
15 MILES
NETT LAKE
15 MILES
32 MILES
DEER L.
THISTLEDEW
STURGEON
ITASCA COUNTY
Location
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Appendix 2. Quality Assurance Plan

Little Fork River Turbidity and Sediment Study 2004
Quality Assurance Plan

Project Name:	Little Fork River Turbidity and Sediment Study
Project Manager:	Nolan Baratono, MPCA Rainy River Basin Coordinator
Other Participants:	Jesse Anderson, MPCA Research Scientist Nathan Schroeder, MPCA Student Worker
Project Dates:	April 2004 – September 2004
Watershed:	Little Fork River
HUC:	09030005

Problem Definition and Background:

The Milestone Site for the Little Fork has had approximately a 20% exceedance of Minnesota Rule 7050 for Turbidity. Initial goals of the Turbidity/Sediment Study will be to build on Alan Anderson’s 2001 Rainy River Characterization and Minnesota Milestone Data (LF -0.5) to answer the following questions to determine the severity and extent of the turbidity and sediment exceedances.

Project/Task Description:

Scope the severity and extent of the turbidity and sediment problems for a potential TMDL as follows:

1. Document turbidity (NTUs) and sediment (TSS) concentrations of the mainstem from the Rainy River confluence to the headwaters,
2. Determine potential sources of sediment loading to the mainstem by recording turbidity and sediment concentrations (and, if possible, loads using the Littlefork gage, USGS # 05131500) from the Rainy River confluence to the headwaters,
    - Determine tributary sources of the turbidity and sediment,
    - Determine mainstem sources of turbidity and sediment,
3. Provide information needed to determine scope of likely TMDL study, including geographic extent (part or all of mainstem, tributaries, etc.), potential causes of erosion (land use, channel destabilization, etc.)
4. Preliminary Study Overview:
    - Sites (Criteria: 1) road access, 2) tributary flow identification/isolation):
        - LF-157 - St. Lewis CSAH 420 crossing (mile 157; N47°50.656’/ W92°32.859’; bridge elevation 1334’) – field measurements only

    - LF-142 - Highway 53 at Cook (mile 142.4; N47°51.260’ / W92°41.934’; bridge elevation 1324’) – field measurements and lab analysis
    - LF-128 - Highway 73 at Linden Grove (mile 127.6; N47°51.492’ / W92°52.199’; bridge elevation 1291’) – field measurements only
    - LF-101 - Highway 65 at Silverdale (mile 100.7; N47°58.570’ / W93°08.634’; bridge elevation 1219’) – field measurements and lab analysis
    - LF-59 - Highway 65 at crossing south of Koochiching CSAH 31 (mile 59.2; N48°12.528’ / W93°29.792’; bridge elevation 1176’) – field measurements and lab analysis
    - LF-21 - Highway 217 at Littlefork (mile 21.3; N48°23.613’ / W93°33.706’; bridge elevation 1129’) – field measurements and lab analysis
    - LF-0.5 - Highway 11 crossing at Pelland (Milestone Site LF-0.5; N48°31.268 / W93°35.212’; bridge elevation 1109’) – field measurements and lab analysis
- Parameters:
    - Record field measurements (NTUs [Hach 2100P Turbidimeter], DO, temp, conductivity [YSI 650 Multiprobe], transparency [T-Tube] stage [tape-down measurements]) at each sample site,
    - Collect samples for laboratory analysis of nutrients (NTUs, TSS, TP and Total Orthophosphorus).

Quality Criteria:

- Field Equipment:
    - Hach 2100P Turbidimeter
        1. Full bench calibration every 30 days following Hach instructions with the use of NTU calibration standards
        2. Check and record calibration with NTU standards prior to each sampling trip. If Turbidimeter reading deviate from standards by 10% or more, recalibrate the unit
    - YSI 650 Multiprobe
        1. Full bench calibration every 30 days following YSI instructions with the use of conductivity and pH calibration standards
        2. Calibrate barometric pressure and oxygen prior to each sampling trip
- Sample Type:
    - Representative grab samples collected at approximate middle depth of water column without disturbing streambed materials
    - Complete mixing of samples via a churn splitter
- Sample handling:
    - Nutrient samples stabilized with H_2SO_4

    - Nutrient, turbidity and TSS sample bottles kept on ice and shipped the same day to MDH Laboratory in Minneapolis
  - Sample Frequency:
    - April (ice break-up) through June 30 – 2 / month
    - July through October – 1 / month
    - Storm events – minimum 5 (=> 0.5” precipitation)
  - Lab Precision and Accuracy
    - All samples are sent to the Minnesota Department of Health Laboratory in Minneapolis for certified analysis (MDH 2004 Laboratory Handbook)
    - Sampling protocol includes 10% duplicate samples

Little Fork River Turbidity and Sediment Study Sampling Methodology

Equipment

- ☐ YSI 650 Multiprobe w/ 1 meter increments marked and weighted down
- ☐ Hach 2100P Turbidimeter
- ☐ Turbidity Tubes (60 and 100 cm)
- ☐ Weighted Sampling Bucket
- ☐ Weighted tape measure
- ☐ Topographic Maps w/sites marked
- ☐ Stream sampling sheets & Clipboard
- ☐ Digital Camera

Dissolved Oxygen, pH and conductivity Profiles

- Calibrate multiprobe
- The first reading should be taken just under the surface.
- Take reading by jiggling the probe just below the surface, record results once reading best stabilizes.
- For deeper streams, lower the probe to 1 meter and repeat. Readings should be taken at 1-meter increments all the way down to the bottom.
- Record all parameters on a database (DO, pH, conductivity and temperature).
- Graph results with D.O. and temperature on the x-axis and depth on the y-axis (numbering the y-axis “depth”, you will start with 0 on the top and number down).

Nutrients (Total Phosphorus, Nitrite-Nitrate-N, and Total Kjeldahl Nitrogen)

- Samples are collected in 250-ml bottles supplied by MDH Lab. Grab samples are taken at middle depth in the water column without disturbing streambed materials or collecting floating materials or constituents from the water surface. Samples should be collected along the stream cross-section, or at a point that the sampler judges most likely to reflect the total instantaneous flow at the cross section. Multiple cross-section samples are emptied into a 2 Liter bottle or churn-splitter and mixed completely to ensure a representative sample. The 250-ml bottle is filled from the 2 Liter bottle. Nutrient samples are immediately preserved with sulfuric acid (H_2SO_4) supplied by MDH Lab.

- All nutrient samples are kept on ice and shipped the same day so that they can be analyzed at the MDH laboratory.

Total Suspended Solids (TSS) and Turbidity (NTUs)

- Samples are collected in 1 Liter bottles supplied by MDH Lab. The procedure for collecting the sample is the same as described for the nutrient sample except that the sample is then transferred to the 1 Liter bottle.
- Samples are kept on ice and shipped to MDH Lab the same day they are taken for analysis.

Minnesota Pollution Control Agency Profile and Field Data Sheets are completed for each site including sampler's name, date, time, stream i.d., wind conditions, color of water, physical condition (algae), recreation suitability, uses observed, zooplankton, stage or flow and turbidity or transparency tube.

Appendix 3. 2004 Water Quality Data