# Poplar River, MN (Cook County)
# 2006 Automated, *in situ*, Water Quality Data: Preliminary Analysis

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Richard Axler
Jerry Henneck
Elaine Ruzycki
Norm Will

Center for Water & the Environment
Natural Resources Research Institute
University of Minnesota-Duluth
Duluth, MN 55811

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**Background narrative:**

This report was prepared by Natural Resources Research Institute, University of Minnesota-Duluth (NRRI) staff for use in the Poplar River Turbidity TMDL study by a number of groups that will be analyzing, interpreting, or using NRRI water quality data collected as part of its www.LakeSuperiorStreams.org project, including:

- Minnesota Pollution Control Agency
- Cook County, MN Soil & Water Conservation District
- Poplar River Management Board
- Minnesota's Lake Superior Coastal Program (MN Dept. of Natural Resources)
- U.S. EPA TMDL consultant(s)
- Other interested groups including Lutsen Ski Mountain Resort consultants

The Poplar River was listed as *Impaired for Aquatic Life* due to Turbidity on Minnesota's 303(d) pursuant to Clean Water Act Section 303(d) in 2004 and remained on the List in 2006. Funding was appropriated for the development of a TMDL study in fall 2006. One component of this effort will involve compiling, analyzing and interpreting existing historical data. This report describes various aspects of the automated water quality data set collected by NRRI in collaboration with the MPCA and USGS for the *LakeSuperiorStreams* project, the basis for sampling locations, field and lab methods, and quality assurance protocols. It also describes the rationale used for editing the data set, a summary of the *in situ* sensor turbidity data for 2006 averaged over different time scales in comparison to state regulatory standards, and recommendations for data collection in 2007.

Funding was very limited for this project and could not cover an extensive field component. Grant funds were used to cover the costs and installation of the water quality sensors and sonde, the associated telecommunication instrumentation to enable automated "uploading" of 30 minute data once a day to the *LakeSuperiorStreams.org* website, debugging of the system for display on the website, and development of a customized web section and data utility for animating the data stream from the lower Poplar site. Routine field maintenance, cleaning, sensor calibration, and quality assurance of the data stream for this site in particular, is (and will be in the near-term at least) dependent upon local agency or organization partnerships with the project.

**Site location:**

The decision of where to place the sonde within the stream came down to deciding whether or not the data was to be automatically transmitted in *near* real-time or not – i.e. collected and logged at short (30 minute intervals) but transmitted back to the website server only once a day. We decided that the real-time data transmission was critical as we converted the *DuluthStreams* website and project to the broader geographic scope that was renamed *LakeSuperiorStreams.org*. Funds were only available to enable us to "piggyback" onto the existing stage height/flow gauging station being used by the MPCA. There may have been a more ideal site in the general vicinity to monitor turbidity but funds were not available to set up a second datalogging station that would have required purchasing a second datalogger, solar panel, battery, hard line phone modem, and a costly extension of the phone line. Cellular phone coverage is intermittent in this region and as such is incompatible with consistent data transmission. Therefore, the sonde needed to be deployed in close proximity to the MPCA datalogging station, where the MPCA had installed a hard-wired telephone line (landline). Placing the sonde near the site of the flow measurement also would reduce some of the complications associated with correlating water quality parameters with flow measured at a different location.

**In-situ sonde mount(s):**

Once the general location was decided upon, the exact location and method of securing the sonde in the stream was to be determined. After consulting with Jesse Anderson, MPCA-Duluth and a number of USGS scientists in several states, it became evident that sondes are not generally placed in streams with the high velocity that the Poplar River could experience. The MPCA typically uses a large diameter (~12") heavy wall PVC pipe with fittings on the end and eyebolts for securing with steel cables which they call a "keg" in some of their larger stream monitoring set-ups. After considering a number of alternatives it was decided to put the sonde in a modified "keg". The sonde stays suspended inside the keg and out of the bottom sediment, not really an issue at this location on this stream as the bed consists of primarily bedrock, large boulders and large cobble, some of which moves downstream annually. However, the issues with securing the keg are numerous. The MPCA uses a keg in the larger rivers (such as the Mississippi) typically securing it with one cable attached to an instream bridge abutment which reduces the potential for debris snagging the cables and the abutment itself provides some physical protection to the sonde. Unfortunately, there isn't a bridge abutment on the Poplar to secure the keg. To keep the keg in a relatively stable location on the Poplar we needed to cable the keg perpendicular to the current. The concern with this method was the increased potential for debris flowing downstream to snag the securing cables and the data transmission cable.

The system shown in Figure 1 was put in place in the fall of 2005 and appeared to be a viable anchoring system though no high flows events occurred. The sonde was removed from the river in October but the keg remained in place for the winter season. Sonde data was not logged at Poplar in the fall of 2005 due to technical problems with the datalogger/ program/ sonde/battery. These problems were resolved during the winter by NRRI staff working with MPCA-Brainerd staff that had extensive experience operating this type of system.

The Poplar sonde was redeployed March 28, 2006 prior to major snow melt runoff. An ice free channel of open water down the middle of the stream and some ice chopping allowed us to free the keg and cables. The sonde was connected to the datalogger, communication was established and the system worked well for more than a month. Snow melt proceeded relatively slowly and flows stayed below 700 cfs for much of the snowmelt period in April.

A more *typical* spring results in peak flows of >1000 cfs during the snowmelt/spring rain period (Anderson et al. 2003; J. Anderson, MPCA-Duluth, pers. Comm.). A rain of 1.5” on May 1, 2006 on top of snow and still frozen ground caused a rapid increase in flow and at about 850 cfs we lost contact with the sonde.  It turned out that the sonde was no longer connected to the datalogger because two of the three securing cables broke and the data cable was pulled from the sonde as it was beaten against the rocks. Pieces of the keg and the sonde were recovered several weeks after the incident but the sonde was irreparable.

We contacted a number of researchers, and searched for alternative suggestions for securing the sonde. The USGS Montana staff has extensive experience using in-stream data loggers, and thought that high gradient streams like the Poplar River are seldom monitored because of the difficulty of keeping sondes secure in the streams. They have had some success with a steel pipe secured perpendicular to the stream flow (although they can drive a post in the stream bed) and so after conferring with MPCA-Duluth, Cook County, and Lutsen Mountain staff about the logistical difficulties, cost-risk, and data needs for the TMDL process we decided to try a modification of the  USGS method.  Pipe brackets were custom fashioned after a pattern sent by the USGS and lag bolted to two large boulders. A new sonde was purchased and deployed August 24, 2006.

Flows were very low during late summer and fall and the Poplar watershed was in the drought category according to the National Weather Service (NWS) and Minnesota DNR.  This led to some additional problems although the sonde survived. Several periods of extremely low flow resulted in the conductivity sensor being out of the water and the bridge-mounted (sonar) stage height-flow sensor monitoring the dry shoreline of the stream bed. The sonde was removed November 27th after what appears to be several freezing episodes that affected the quality of the data and could potentially have damaged the sensors and/or sonde.

**Monitoring protocol "explanations" for the Poplar River site in 2006 with recommendations for 2007:**

1. The stream will be monitored continuously (readings recorded every 30 minutes) with a water quality sonde connected to the MPCA datalogger and phone modem during the ice free season.

    a. The water quality sonde will be outfitted at a minimum with temperature, conductivity and turbidity sensors.
    b. The sonde holder was "cabled", i.e. affixed with cables to the stream bottom in 2006 which didn't allow for retrieval and calibration until the flows were low enough to permit physical access to the river. This resulted in extended periods where the sonde calibration could not be maintained due to the high river level and flow.
    c. Being cabled in the stream allowed the sonde to bounce somewhat with the current potentially resulting in erroneous data due to either electronic noise or from turbulent bubbles.
    d. The sonde was lost after 37 days, presumably from debris snagging the cables at what was a moderately high flow (850 cfs). This led to water quality data gap of almost 4 months.
    e. The sonde was replaced in the fall using a method that should allow the sonde to be removed for cleaning and calibration in any flow.
    f. The sonde orientation/rotation within the holder may influence the readings and should be marked so it can be replaced in the same orientation.

2. Flow and precipitation will be logged by the MPCA at the datalogger site in conjunction with the sonde data.
    a. Flow is measured by relating the distance to the water surface measured by an ultrasonic sensor to the rating curve for this stream developed by the USGS using measurements of in-stream velocity and cross sectional area.
    b. Precipitation is measured using a tipping bucket rain gauge located on the golf course bridge (MPCA/NRRI datalogger site) and connected to the datalogger except during

freezing weather when the precipitation data from the NWS at the Grand Marais airport is used.

c. This MPCA owned and managed system worked well except for the extremely low flow situations when the river was not flowing beneath the ultrasonic sensor. This low flow can be estimated fairly accurately and constitutes only a very small fraction of the annual flow, and presumably annual pollutant loads as well.

3. The data will continue to be made available to the public on the *www.LakeSuperiorStreams.org* website labeled as *provisional* and updated daily. More frequent updating may be possible if desired and if additional funding is available to cover its costs. We recently updated our QA section on the website to include information regarding the specific Poplar River instrument (http://www.duluthstreams.org/streams/QA_QC.html ) and will soon (Spring 2007) be updating it further to include reference to the new turbidity unit nomenclature base upon the measurement system (sensor/instrument) being adopted by the MPCA as per recent USGS studies (MPCA 2006, USGS 2005).

4. The stream will be sampled for chemical/physical parameters by MPCA-Duluth (Jesse Anderson and Tom Estabrooks have been the lead investigators since 2002) and Cook County staff (presumably Dave Stark, the "new" County Water Plan Coordinator) during the high flow events and follow the MPCA stream monitoring protocol for North Shore streams that emphasizes high flow grab sampling during spring runoff and summer-fall rainstorms (cf. Anderson et al. 2003). NRRI staff (Jerry Henneck and Elaine Ruzycki) will make periodic "as-needed" trips to service the sonde and they will collect grab samples and ancillary data on these trips (temperature, EC25, DO, transparency tube clarity, turbidity, TSS, Cl, and nutrients).

    a. The summer of 2006 was very dry and therefore, fewer samples than expected were collected.
    b. There were also some inadvertent miscommunications between the MPCA, NRRI and Cook County staff that also contributed to reduced summer sampling- a consequence of the typical coordination difficulties that happen in field programs involving multiple organizations with inadequate funding, and a variable sampling schedule dependent on weather events. This can and should be improved in 2007.

5. The QA/QC procedures outlined on the *LakeSuperiorStreams* web page will be followed for the sensor sonde.
    a. The QA/QC protocol was not strictly followed during the 2006 ice free season due to a variety of causes. Having the sonde cabled into the stream did not allow it to be calibrated biweekly as it should have been because of safety risks to field staff. Grab samples were to be taken in coordination with the MPCA north shore stream sampling effort but the communication and coordination issues noted above led to too few samples being collected to resolve some of the QA and data interpretation questions posed below.
    b. We had also assumed that MPCA would be collecting grab samples above the Highway 61 bridge, just downstream from the stage-height and water quality sensors and that the turbidity values from them would provide an additional QA check – essentially an *in situ* Quality Assurance Check Standard (QCCS). In fact, their grab samples were collected about 500 meters downstream of the sensors near the mouth of the creek.
    c. Unfortunately, we were not able to conduct a "planned" variability study in the vicinity of the sonde by taking many different grab samples for turbidity across the stream over a 50 meter reach to estimate short-term spatial variability. We will work with Cook County SWCD to try and accomplish this in 2007 – probably during moderately high flows when turbidity values are relatively high.

**Preliminary data analysis:**

Despite losing the sonde after a month and not getting it replaced until the end of August, 11700 data points were logged at 30 minute intervals. Manual samples were collected on thirteen dates for a ratio of 900 sonde samples per manual sample. The sonde was outfitted with temperature, specific conductivity, and turbidity sensors. The MPCA collected flow and precipitation data throughout the summer at the same location and with the same frequency. The sonde recorded data at the lower golf course bridge (Figure 2) at the same location as the MPCA stage-height and precipitation gauges. The manual samples collected by the MPCA were collected near the mouth of the stream, approximately 0.5 km downstream of the sonde, and downstream of Highway 61. Only two grab samples were collected at the sonde site, both by NRRI.

<u>Turbidity values</u>

A linear regression of the sonde turbidity against the grab sample turbidity yielded a good fit ($r^2 = 0.83$ after the removal of one outlier point) even though the samples were taken at different locations and turbidity was measured with different instruments (Figure 3). The sonde turbidity used for the regression was the average of the three data points closest to the time that the grab sample was taken, and therefore over a one hour interval. Although the sample size was small (n=11) this provides some assurance that the sonde was measuring what would be measured with a grab sample, only at a greater frequency with the sonde. The slope of the line (3.65) is skewed in the direction of the sonde turbidity indicating:

1. turbidity values were uniformly more than 3X higher at the datalogger site (sonde) than downstream (lab turbidimeter), or
2. there was a calibration error for one of the instruments, or
3. the field and laboratory nephelometric turbidimeters were measuring different properties because of different internal sensors and/or different particle size sensitivities (see discussion below and Table 2; see USGS 2005 and MPCA 2006), and/or
4. different locations within the stream (depth and distance from shore) might account for large differences in the *in situ* versus grab samples, and/or
5. the in-stream sensor is responding to turbulent bubbles in addition to actual suspended sediment; and/or
6. other factors are causing the "upstream" sonde to produce higher values.

Figure 4 depicts the relationship between lab measured turbidity and *in situ* values measured with *YSI*6820, *YSI 6920* and *Hydrolab 5A Minisonde* sensor sondes for three trout streams in Duluth (Tischer, Kingsbury and Chester; www.lakesuperiorstreams.org/streams; Axler et al. 2006 during the period 2003-2006, for Amity Creek on the outskirts of Duluth in 2005-2006 and for the Poplar River. The regression coefficients and statistical significance for these regressions are summarized in Table 3. At this point in time we only note that all regressions were highly significant but that the slopes of the sonde *vs* lab turbidimeters regressions for the entire range of data since 2003 ranged from 0.50 for Tischer Creek to 1.30 for Amity Creek in Duluth – much lower than the value of 3.65 for the Poplar River. The MPCA (2006) guidance protocol distinguishes data values <40 "NTU" from those > 40 "NTU". Separating the data set into these two classes, based on the Lab turbidimeters values, improved the correspondence between the two measurements for the lower class (<40 "NTU") with individual stream-regression slopes ranging from 0.83 to 1.25. Note that a value of 1.0 would indicate a 1:1 correspondence between the different measurement systems. There was insufficient data from Poplar in 2006 to warrant partitioning its data.

We have no reason to suspect that field and lab values would differ by a factor of more than three. MPCA grab samples were measured by the MN Department of Health Lab in St. Paul, MN following identical state and federal certified QA/QC procedures, although the turbidimeters could have been different in regard to the USGS categories listed in Table 2. For the present, we will continue to report all turbidity units as NTUs to avoid even more confusion, especially in regard to our websites general audience. However, as per Figure 4, we will attempt to use the new units whenever possible in technical reports and publications.

Therefore, we hypothesize that either:

1. turbidity was in fact higher at the datalogger site than at the mouth of the stream even though the mouth was downstream of the Highway 61 bridge which would typically be assumed to generate additional sediment and turbidity. Assuming that total flow must be at least somewhat higher at the downstream site, this means this "extra" water must have been considerably less turbid at least during lower flows when the samples were all taken (see Figure 5), or
2. there was a systematic measurement error that will have to be addressed, perhaps due to differing measurement systems. In any case it will be important to determine if such systematic errors exist (see Recommendations section below)

The sonde turbidity data is "noisy" in that it has high variability from sample to sample (Figure 5). This is more prevalent in the spring than in the summer/fall period and may be the result of location of the sonde in the spring (Figure 2). The spring was also a period of greater flows and the sonde was placed nearer to the bottom of the river which may have contributed to the greater noise. Entrained air bubbles or heterogeneous particles may also have contributed to the variability, as well as to the higher values noted above. When the sonde was replaced in the summer it was inserted into a pipe bolted to the rocks, which thus far has yielded less noise although the flows were very low due to the drought conditions of Northern MN and never reached the levels seen in the spring.

An effort was made to determine the best time step to use in the analysis of the data. Data is logged every thirty minutes which provides a short enough time interval to capture most rapid changes but this also increases noise. Averaging the data over a four hour or daily period dampens the noise but may result in missing or minimizing important changes in the stream. Figure 5 overlays *raw* 30 minute values with a running 9 point mean (the same as 4 hour means), and mean daily (based on 24 data points) turbidity. Qualitatively, it appears that the 4 hour running mean *captured* sufficient detail to be useful for visualizing the data – see for example the *events* on Mach 31- April 1, April 12-13, May 1, and November 3, 2006. The 24 hour mean *misses* the higher frequency spikes, although it could be used with mean daily flow to calculate mean daily loading if the turbidity values are well correlated with TSS, TP, etc (not yet analyzed).

Percent exceedances of turbidity (at both the 10 and 25 NTU level) were calculated for the three time steps separated into spring (37 days) and summer/fall (90 days) periods as well as for the complete data set (Table 1). Our initial observations are that nearly all exceedances were during the spring period as there were few rain events and no high flow events in the fall/summer period. Using turbidity as a surrogate for load at the three time steps resulted in a difference of less than 5% between the three time steps for the spring, the summer/fall or the complete data set. This suggests that the time step used in the determination of annual load would have little effect on the annual load for this year.

**Lessons learned and recommendations for next year:**

1. Repositioning and further securing the sonde in August 2006 will hopefully prevent the complete loss of the sonde this season (2007);
2. The new sonde housing will allow for cleaning and calibration on a two week interval consistent with the QA/QC protocol;
3. A surface grab sample will be taken at the time of calibration at both the sonde location and the MPCA location and identical sampling procedures will be used;
4. Better communication and coordination of efforts between the NRRI, MPCA, and Cook county is an essential part of an effective overall QA/QC plan. We suggest that Cook County staff, because of travel constraints for MPCA and NRRI staff, take the lead for the purpose of maintaining and calibrating the *in situ* sonde (with associated grab sampling for turbidity);
5. Increased sampling is needed with an emphasis on sampling at both the sonde/data logger location and at the MPCA sampling location to ensure that the relationship between these two sites can be determined;
6. Consistency in regard to use and reporting of the use of specific lab turbidimeters and *in situ* sensors will be needed as per USGS (2005) and MPCA (2006) recommendations;
7. A joint decision between interested parties must be made as to how to integrate manual (i.e. Lab) and *in situ* sonde turbidity data sets. (underlined for emphasis)
8. The bulk sample grabs should also be checked for specific electrical conductivity (EC25) in the field using a handheld portable conductivity *pen.* NRRI has used these relatively inexpensive ($50-80) instruments since 2002 in Duluth Area streams and shown excellent agreement (Axler et al. 2006; Axler et al. 2004; website *http://lakesuperiorstreams.org/citizen/washburn.html;* Axler, unpubl.)

9. Two or three time-intensive sampling series (10-15 samples) focused on characterizing a storm (or high flow event) are needed. These samples would be part of the comparison study between the two different locations.

**"Exceedances"**

1. There was almost no difference in the % exceedances rate for a 10 NTU criterion between the *raw* (30 minute), 4 hour mean, or 24 hour (daily) mean data. All were >99% during the 37 day period of high flow spring runoff and 4.7-5.5% during summer-fall base flow which was virtually storm-free for our period of record.
2. For a 25 NTU criterion, the 30 minute *raw* data yields a 78% exceedances rate as compared to 86% for 4 hour mean data and 95% for 24 hour mean data. Therefore, smoothing increased the exceedances rate during the high flow period. We have no hypothesis as to the reason for this. Rates were only 1, 4, 1.1, and 2.2%, respectively during base flow and there is no apparent pattern.
3. The limited amount of grab sampling data showed only one "high" value greater than 10 NTU (and also >25 NTU) out of the 14 values generated in 2006, 11 during snowmelt when the high value occurred and three low values during baseflow (Table 1 and Figure 5). Therefore, the snowmelt rates were 7% for both >10 and >25 NTU and 0% for baseflow.

**Appendices**

Nine figures are included showing various views of the 2006 NRRI/MPCA/USGS Poplar River water quality data set as viewed via the ***LakeSuperiorStreams.org*** dataviewer utility.

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Table 1. Poplar River 2006 % turbidity exceedances for criteria of 10 NTU or 25 NTU for different methods of averaging the raw data.

| | 30 minutes (raw) | | 4 hour mean | | 24 hour mean | | Grab sample | |
|---|---|---|---|---|---|---|---|---|
| | # >10 | #>25 | # >10 | #>25 | # >10 | #>25 | # >10 | #>25 |
| Complete data set 2006 | 1897/5967 **32%** | 1306/5967 **22%** | 240/747 **32%** | 191/747 **26%** | 42/127 **33%** | 37/127 **29%** | 1/14 **7%** | 1/14 **7%** |
| | | | | | | | | |
| Spring Mar-May | 849/856 **99%** | 671/856 **78%** | 214/215 **99.5%** | 184/215 **86%** | 37/37 **100%** | 35/37 **95%** | 1/11 **9%** | 1/11 **9%** |
| | | | | | | | | |
| Summer Aug-Nov | 105/2129 **4.9%** | 31/2129 **1.4%** | 25/533 **4.7%** | 6/533 **1.1%** | 5/90 **5.5%** | 2/90 **2.2%** | 0/3 **0%** | 0/3 **0%** |

| Table 2. TURBIDITY PARAMETER AND METHOD CODES Updated 9/19/05 | |
|---|---|
| Instrument Type: | Description: |
| NTU (Nephelometric Turbidity Units) | White or Broadband (400-680 nanometers) Light Source, 90-degree detection angle, one detector. |
| NTRU (Nephelometric Turbidity Ratio Units) | White or Broadband (400-680 nanometers) Light Source, 90-degree detection angle, multiple detectors with ratio compensation. |
| BU (Backscatter Units) | White or Broadband (400-680 nanometers) Light Source, 30- (plus or minus 15) degree detection angle (backscatter). |
| AU (Attenuation Units) | White or Broadband (400-680 nanometers) Light Source, 180-degree detection angle (attenuation). |
| NTMU (Nephelometric Turbidity Multibeam Units) | White or Broadband (400-680 nanometers) Light Source, Multiple light sources. Detectors at 90 degrees and possibly other angles to each beam. |
| FNU (Formazin Nephelometric Units) | Near Infra-Red (780-900 nanometers) or Monochrome light source. 90-degree detection angle, one detector. |
| FNRU (Formazin Nephelometric Ratio Units) | Near Infra-Red (780-900 nanometers) or Monochrome light source. 90-degree detection angle, multiple detectors, ratio compensation. |
| FBU (Formazin Backscatter Units) | Near Infra-Red (780-900 nanometers) or Monochrome light source. 30- (plus of minus 15) degree detection angle (backscatter). |
| FAU (Formazin Attenuation Units) | Near Infra-Red or monochrome Light Source, 180-degree detection angle (attenuation). |
| FNMU (Formazin Nephelometric Multibeam Units) | Near Infra-Red (780-900 nanometers) or Monochrome light source, Multiple light sources. Detectors at 90 degrees and possibly other angles to each beam. |

Table 2. Turbidity units based on measurement instrument as per USGS (2005). Table taken from MPCA. 2006. Turbidity TMDL Protocols and Submittal Requirements. Minnesota Pollution Control Agency, St. Paul MN, December 2006. 100p. *www.pca.state.mn.us/publications/wq-iw1-07.pdf*

Table 3 **DRAFT**. Regression coefficients for comparisons of field measured (*in situ* via sondes) and lab measured grab samples. "Values < 40 NTU were based on lab measured values and therefore are actually <40 NTRU using unit nomenclature as defined in Table 2. n= # of values

| Stream-station | slope | intercept | $r^2$ (n) | P | Comments/sonde |
|---|---|---|---|---|---|
| **ALL TURBIDITY DATA** | | | | | |
| Kingsbury –LSS 2003-2006 | 0.54 | 9.1 | 0.85 (87) | <0.001 | YSI 6820 sonde YSI 6136 turbidity wiper removed |
| Tischer –LSS 2003-2006 | 0.50 | 12.3 | 0.70 (70) | <0.001 | YSI 6920 sonde YSI 6136 turbidity wiper removed |
| Chester –LSS 2003-2006 | 0.76 | 3.6 | 0.64 (66) | <0.001 | YSI 6920 sonde YSI 6136 turbidity wiper removed |
| Amity –LSS 2005-2006 | 1.20 | 10.4 | 0.73 (11) | <0.001 | Hydrolab MS5 sonde self cleaning turbidity |
| Amity –LSS 2005-2006 | 1.30 | 2.0 | 0.80 (10) | <0.001 | Omit 1 outlier |
| **Poplar- LSS 2006** | **3.65** | **-1.40** | **0.83 (11)** | **<0.01** | **Omit 1 outlier** |
| All streams pooled (include outliers) | 0.54 | 10.8 | 0.75 (234) | <0.001 | All inclusive |
| **TURBIDITY < 40 NTRU (but calibrated in NTU)** | | | | | |
| Kingsbury –LSS 2003-2006 | 0.90 | 0.40 | 0.60 (29) | <0.001 | YSI 6820 sonde YSI 6136 turbidity wiper removed |
| Tischer –LSS 2003-2006 | 0.83 | 1.71 | 0.43 (31) | <0.001 | YSI 6920 sonde YSI 6136 turbidity wiper removed |
| Chester –LSS 2003-2006 | 0.88 | 1.46 | 0.69 (54) | <0.001 | YSI 6920 sonde YSI 6136 turbidity wiper removed |
| Amity –LSS 2005-2006 | 0.96 | 13.8 | 0.10 (6) | n.s. | Hydrolab MS5 sonde self cleaning turbidity |
| Amity –LSS 2005-2006 | 1.25 | 1.93 | 0.90 (5) | 0.003 | Omit 1 outlier |
| All streams pooled (include outliers) | 0.87 | 2.1 | 0.42 (120) | <0.001 | All inclusive |

Table 4. USGS (2005) categories for lab and field instrumentation used by *LakeSuperiorStreams.org* project since 2002. All sensors were calibrated using identical formazin solutions and shown to be linear over the range of 0-~ 100 NTU's. Samples were not diluted unless > 1000 NTUs.

| NTRU (Nephelometric Turbidity Ratio Units) Instruments--White or Broadband (400-680 nanometers) Light Source, 90-degree detection angle, mutliple detectors with ratio compensation. | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63676 | HACH, sensor model 2100 AN (Ratio ON) | EPA | 180.1 | A | NTRU | Static | Flowthrough accessory provides more dynamic measurement, stable readings |
| 63676 | HACH, sensor model 2100 N (Ratio ON) | EPA | 180.1 | B | NTRU | Static | Flowthrough accessory provides more dynamic measurement, stable readings |
| 63676 | HACH, sensor model 2100 P | EPA | 180.1 | C | NTRU | Static (Portable) | |

| FNU A93) Instruments--Near Infra-Red (780-900 nanometers) or Monochrome light source. 90-degree detection angle, one detector. | | | | | | | |
|---|---|---|---|---|---|---|---|
| 63680 | Hydrolab, sensor model Datasonde 4 and for MS5 (self-cleaning) | ISO | 7027 | N | FNU | Dynamic | Uses Analite NEP9500 Series turbidity probe POPLAR, AMITY |
| 63680 | YSI Environmental, sensor model 6136 | ISO | 7027 | 5 | FNU | Dynamic | KINGSBURY, TISCHER, CHESTER |


**Figure 1. The initial (failed) sonde holder and location. The three cables secured the "keg", one downstream of the big rock, one perpendicular tot he current and the third angled upstream.**

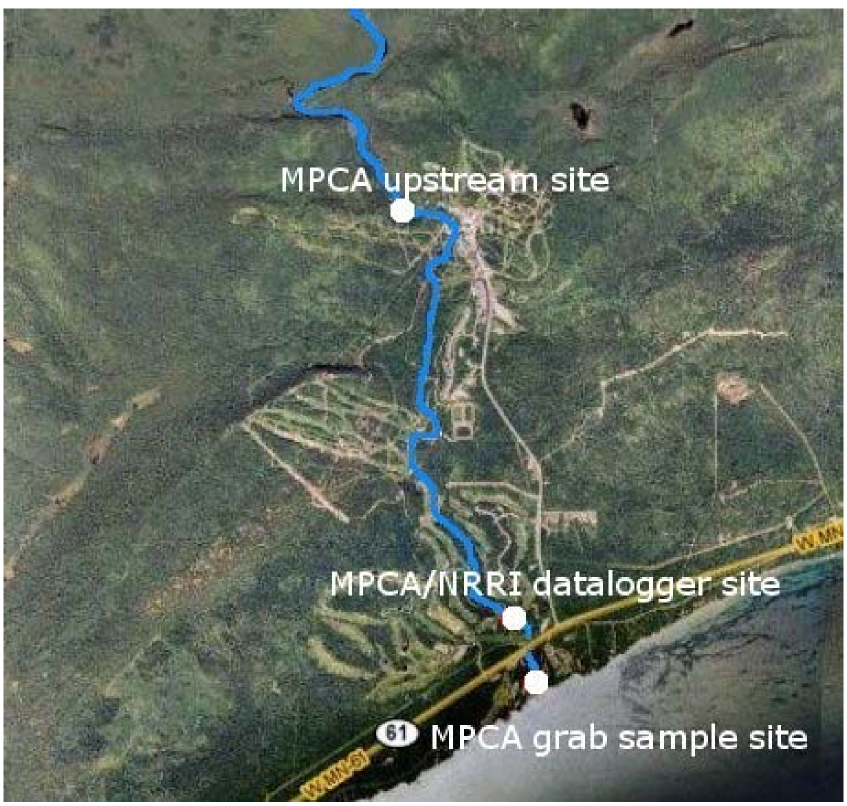


**Figure 2. Poplar River sampling sites also showing the golf course and the ski runs.**

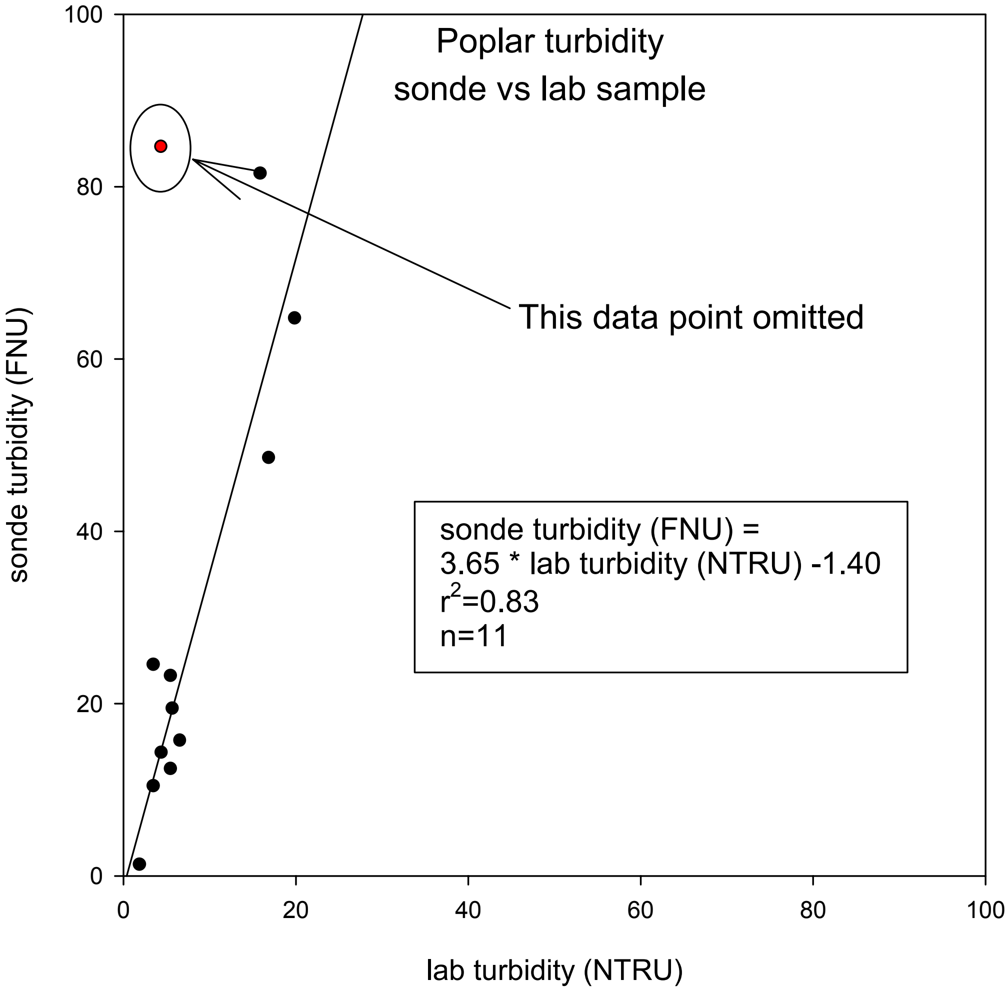


Figure 3. Comparison of the sonde turbidity and the grab sample lab turbidity. Sonde turbidity is the average of three points surrounding the time that the grab sample was taken in order to reduce variability. I really don't have a strong justification for removing this data point. The r2 nearly doubles and the origin comes very close to zero without it. With this point included the r2 is 0.42 and the equation is:

sonde turbidity= 3.07*lab turb + 9.01.

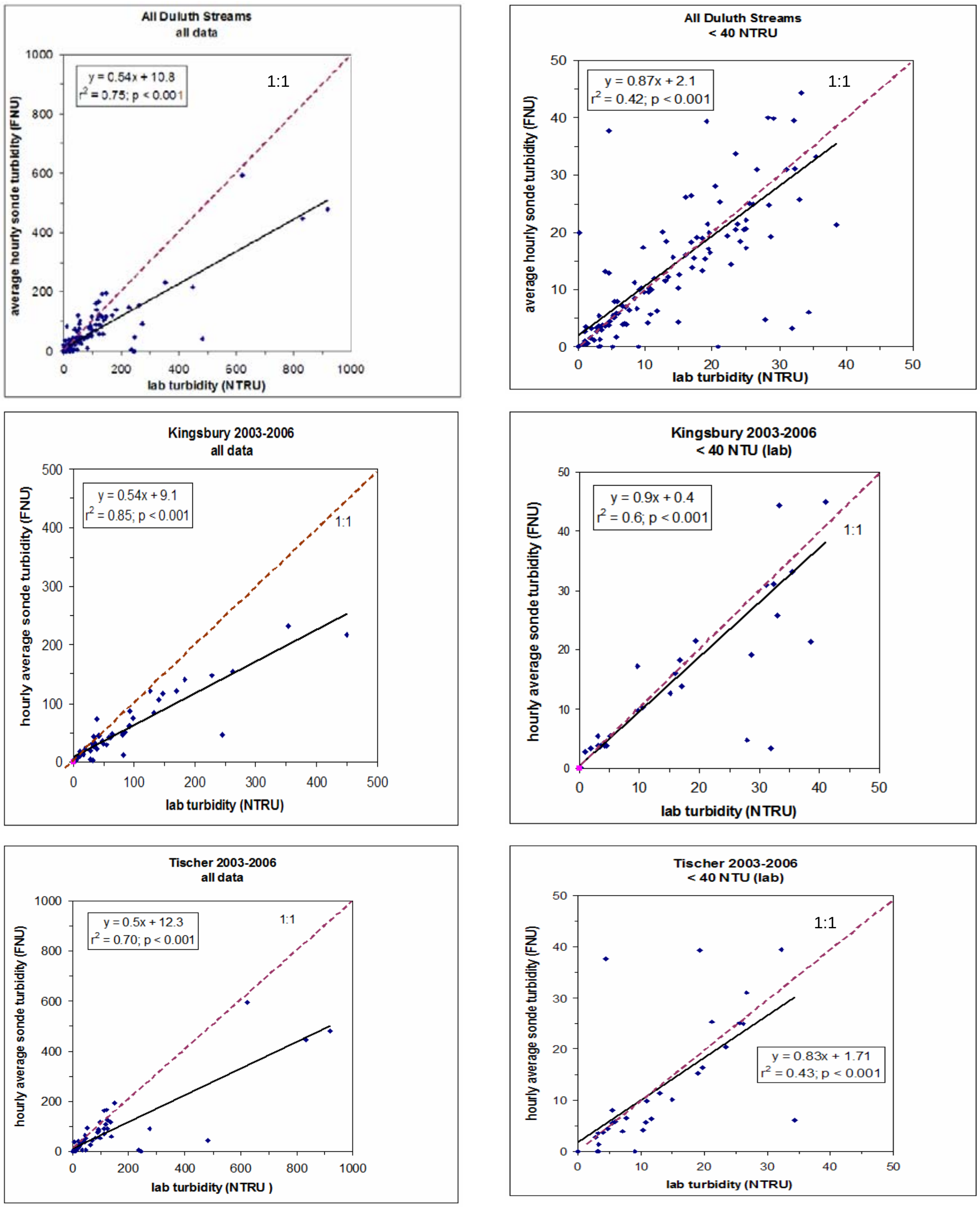


Figure 4. Comparison of turbidity values measured for grab samples analyzed in the Lab versus in-stream values measured with a Hydrolab MS5 *Minisonde* (Poplar & Amity), or YSI 6820/6920 (Kingsbury, Chester,Tischer; details at [www.lakesuperiorstreams.org/streams/QA_QC.html](www.lakesuperiorstreams.org/streams/QA_QC.html)). All instruments calibrated using formazin but units are expressed per current USGS protocols. Data in right-side plots is for values <40 NTU as per USGS (2005) and MPCA (2006) recommendations.

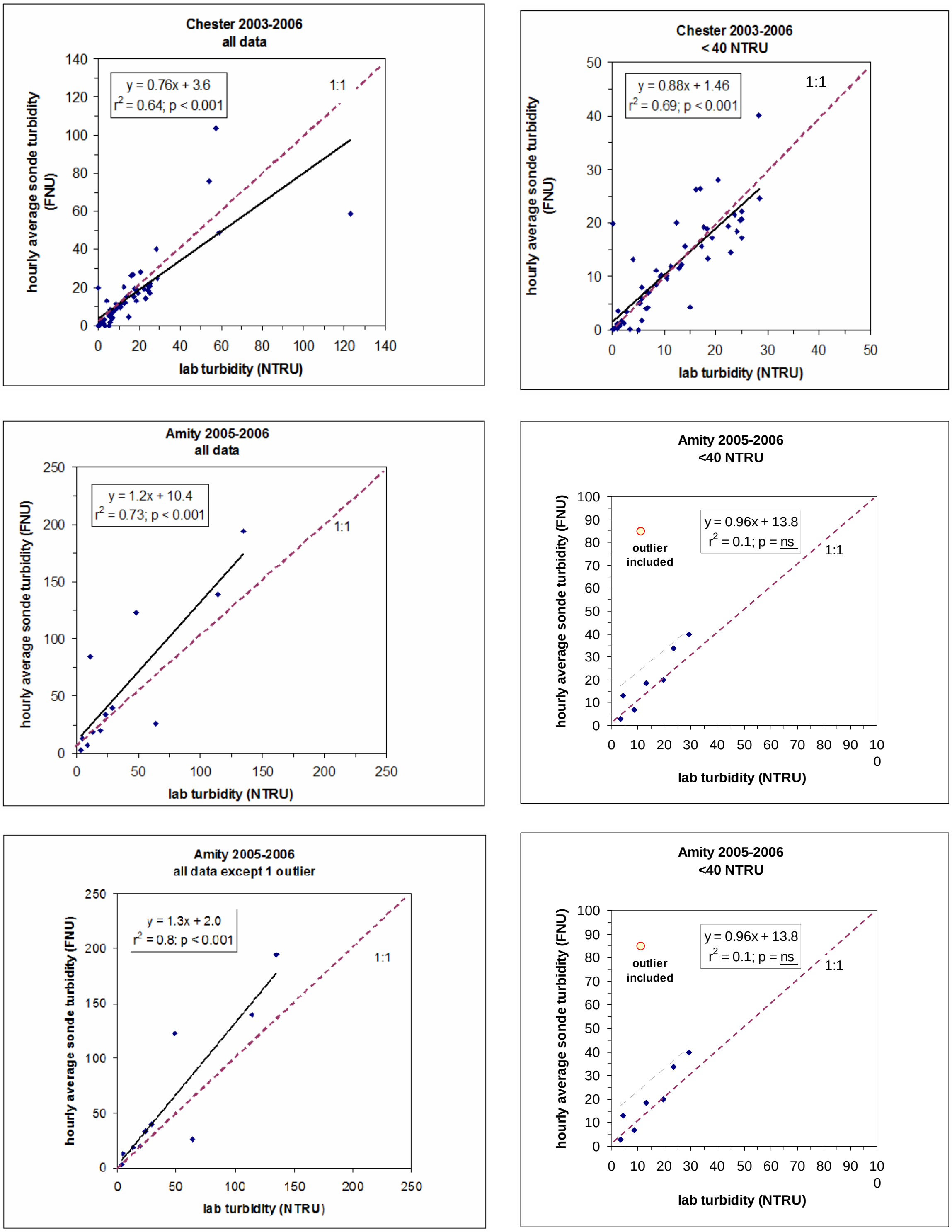


Figure 4 (continued). Comparison of turbidity values measured for grab samples analyzed in the Lab versus in-stream values measured with a Hydrolab MS5 *Minisonde* (Poplar & Amity), or YSI 6820/6920 (Kingsbury, Chester,Tischer Creeks).

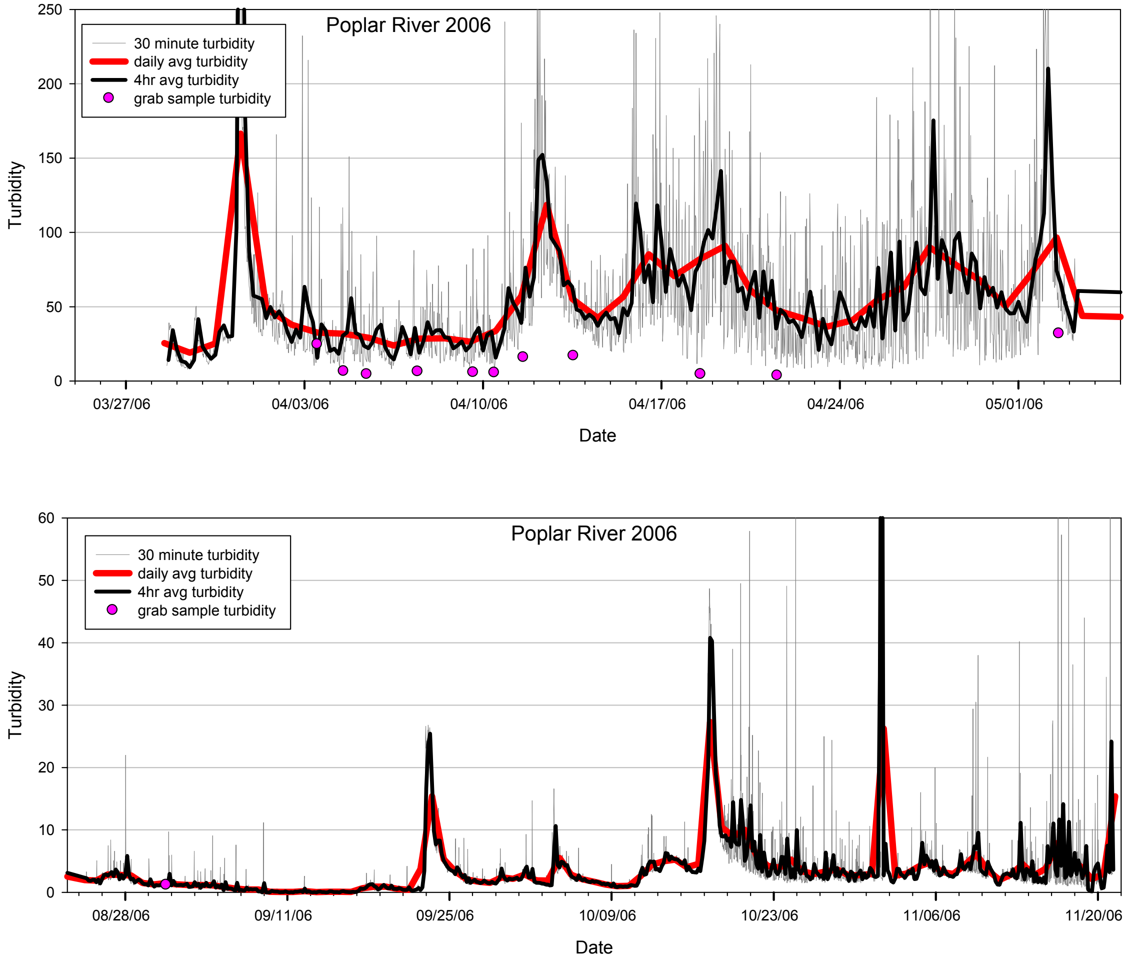


Figure 5. Time plots of turbidity showing raw (30 minute), and 4 and 24 hour mean values, showing the spring runoff and summer-fall baseflow periods. The plots illustrate the different degrees of "noise" smoothing and also show the grab sample turbidity values in relation to the sonde turbidity values.

Appendix: Poplar River real-time data access and dataviewer (animation) via ***www.lakesuperiorstreams.org***


1. Data viewer: ***http://duluthstreams.org/streams/data/Java/index.html***

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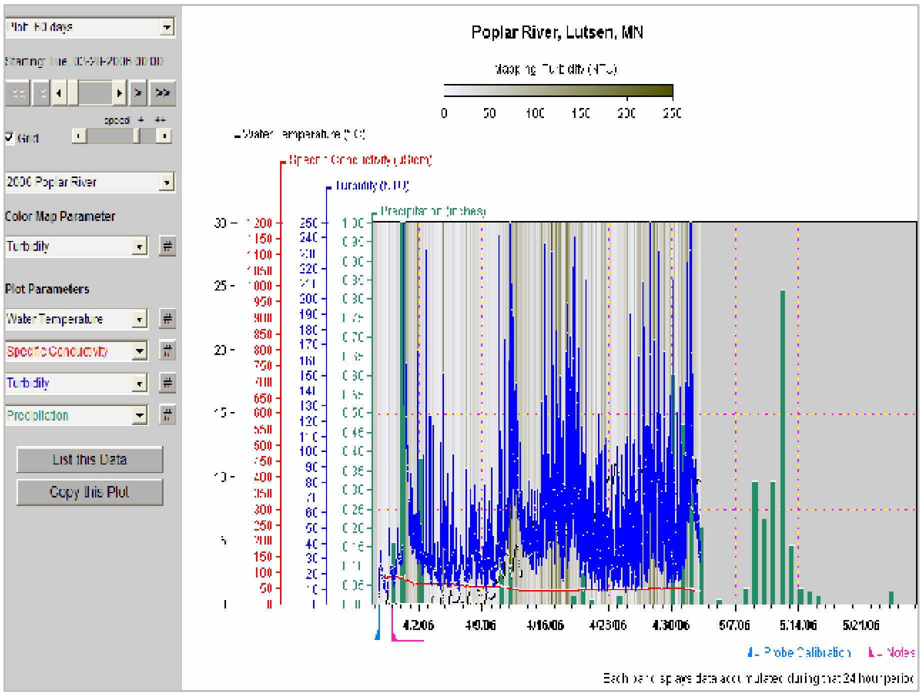
2. Weekly data summaries and QA/QC information
***http://duluthstreams.org/northshore/data/poplar/weekly/html/index.html***


3. Water chemistry summary (MPCA collected data since 2002)




4. Spring 2007: 60 day period. Sensors destroyed by flood on May 3, 2007. Green bars denote 24-hr precipitation

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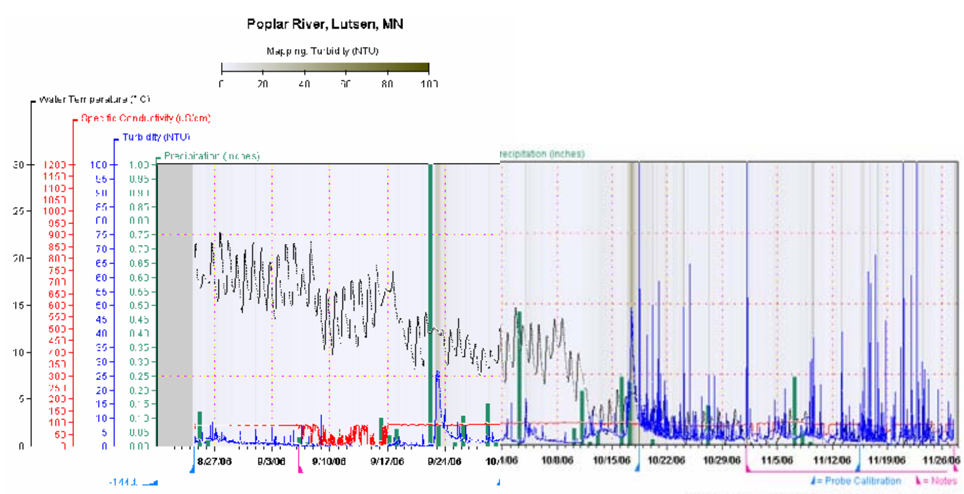
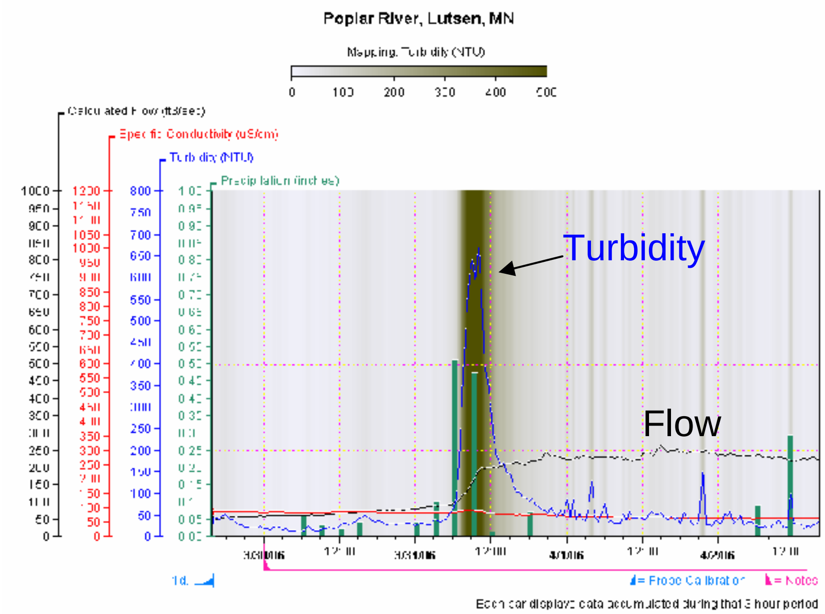



5. Fall 2007: ~93 day period. Sensors removed for the winter in late November. Note turbidity scale change from full-scale 250 NTU-FNU) to 100 NTU-FNU relative to spring data (above).




6. Detail of first recorded rain-on-snow event, Spring 2006. **Green bars** show two 3-hr precipitation events of ~ 0.5 inches each. Line plot Turbidity scale = 800 NTU-FNU with peak levels >650; color map set to 500 NTU-FNU full scale

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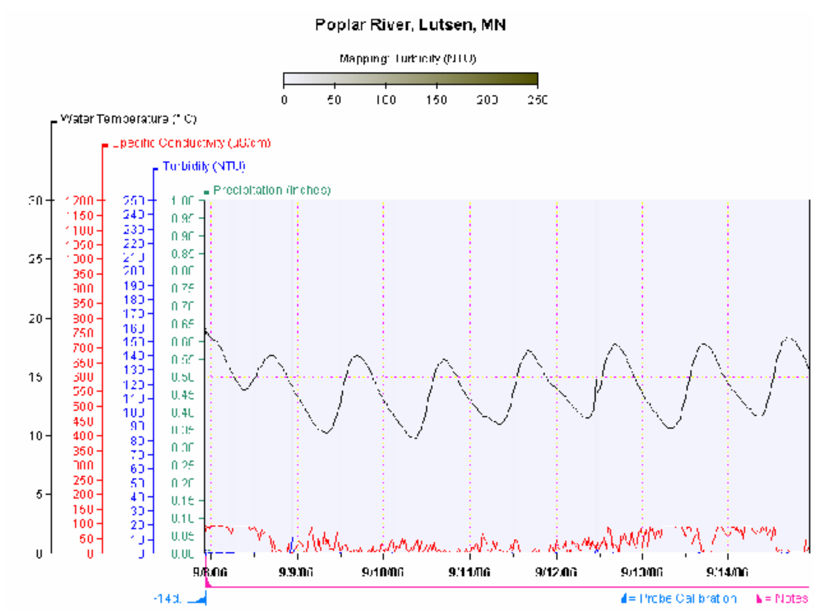
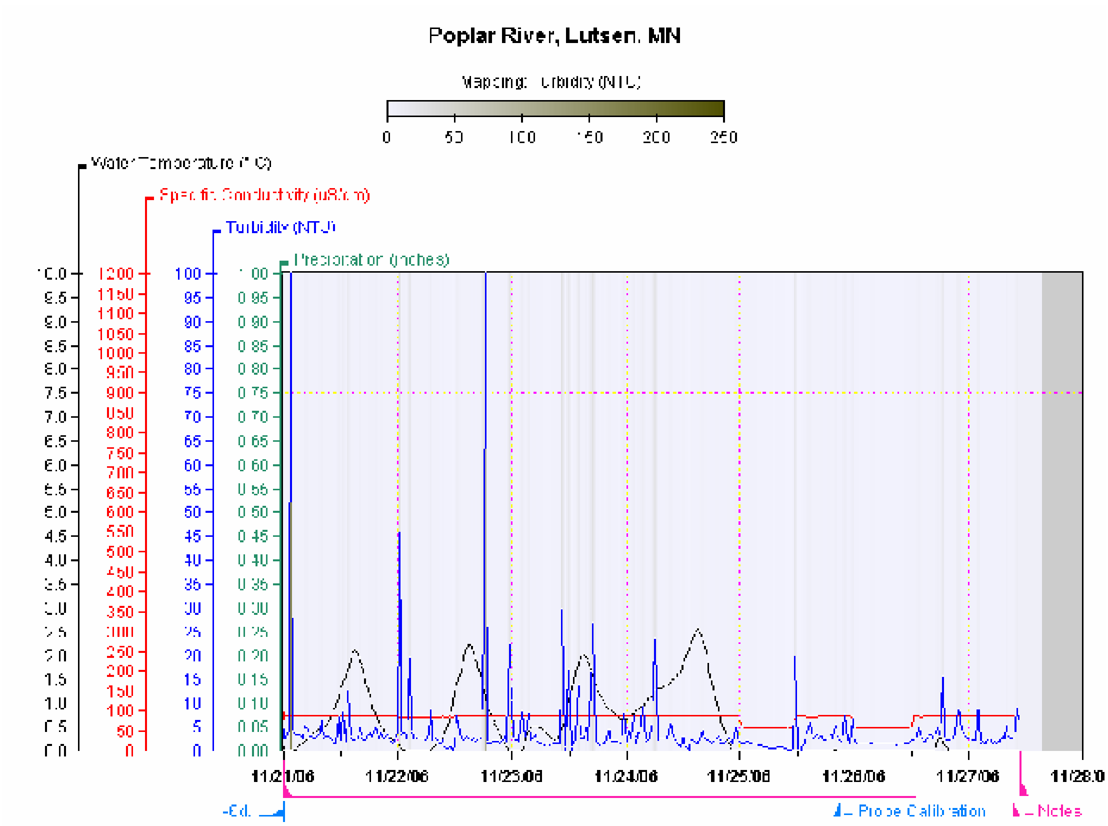
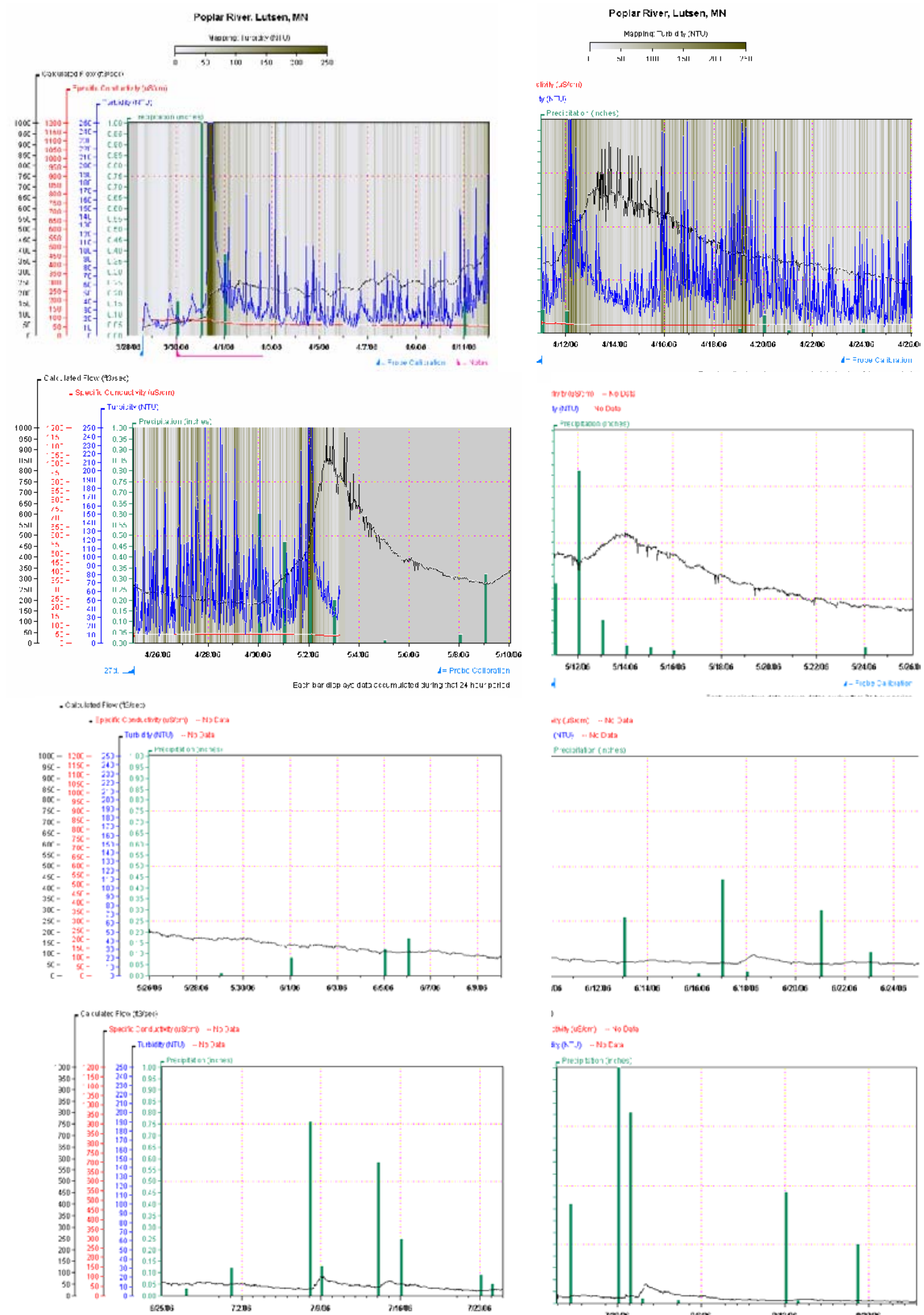


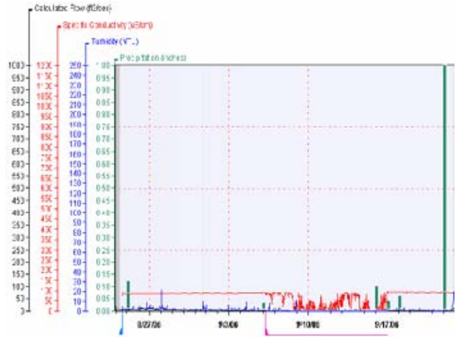

7. One week detail of base-flow period in Fall 2006 when water quality sensors are presumed to be no longer completely underwater. Note that turbidity sensor reads zero most of the time and conductivity sensor is "chattering" with many zeros. Temperature likely accurate based on examining diel patterns before and after this "dry" period.

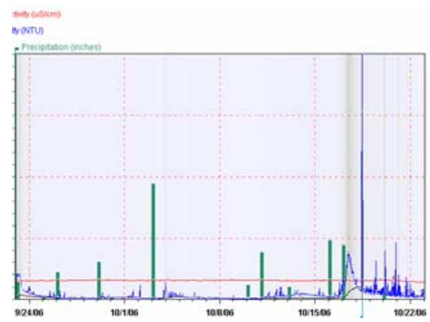
8. Final week of 2006 data set showing presumed sensor freezing episodes where EC25 decreases (ice is a poorer electrical conductor than water) and temperature decreases to zero. Turbidity values apparently also decrease to 0-1 NTU-FNU when the sensor ices up.

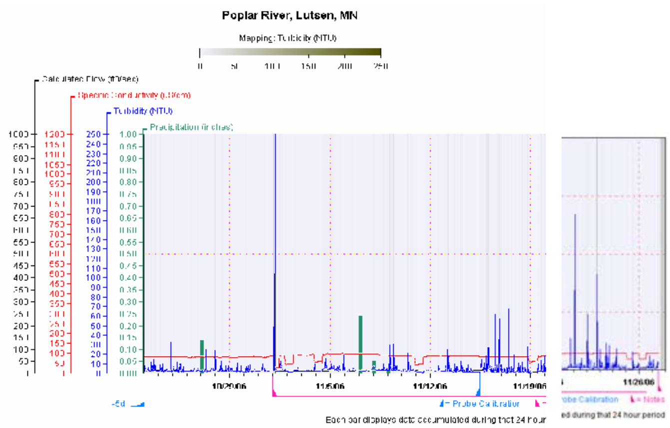


9. Fifteen (15) day plots of Poplar R. intensive data for Spring and 30 day plots for Summer-Fall 2007. May-Aug data set is missing water quality data due to lost sensors but there is continuous flow data from MPCA sensor that records water level ultrasonically from a bridge. **Green bars** show precipitation events for 24 hr periods; all water quality scales set identically.




Precipitation (inches)
9/3/06
9/10/06
9/17/06


Precipitation (inches)
9/24/06
10/1/06
10/8/06
10/15/06
10/22/06


Poplar River, Lutsen, MN
Mapping: Turbidity (NTU)
Calculated Flow (ft3/sec)
Turbidity (NTU)
Precipitation (inches)
10/29/06
11/5/06
11/12/06
11/19/06
11/26/06
= Probe Calibration
= Notes
Each bar displays data accumulated during that 24 hour period