Bohner Lake Inlet Bed Load Study

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For :

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BOHNER LAKE INLET BED LOAD STUDY

INTRODUCTION

The Bohner's Sanitary District No. 1 has had a long concern about sediment building up in the inlet to an unnamed tributary that enters Bohner Lake from the Southwest (Figure 1). The Bohner's Lake Sanitary District has installed a sediment trap on the inlet to the lake to collect sediment before it enters the waterbody. The purpose of the sedimentation basin is outlined in a study titled *Bohners Lake Inlet Watershed Study* prepared by R. A. Smith and Associates, Inc. in 1993. The sediment trap was designed to have a design life of six or more years. The sediment trap and the inlet to the lake were dredged in 2002. 1,800 cubic yards of sediment were removed to create the sediment trap and 800 cubic yards of material were removed from the lake inlet. Within 18 months the sediment trap and inlet channel filled with organic sediment and are now in need of maintenance dredging.

During a field reconnaissance in the spring of 2005 to identify potential sources of sediment that caused the rapid filling in of the lake inlet, staff of Hey and Associates, Inc, and Aron and Associates observed large quantities of bed load material of peat moving downstream from a series of agricultural ditches to the south of the lake. The bed load material had a similar characteristic to the material that filled the dredged areas.

The purpose of the following project is to document the source and quantity of sediment that is entering the inlet area and estimate the typical life expediency of the sediment trap.

The following study will attempt to answer the following questions:

1. What is the characteristics and potential source of the bed load material being transported by the tributary stream?
2. What is the potential annual loading of the bed load material to the lake?
3. What is the characteristics and loading of suspended sediment that is being transported by the tributary?

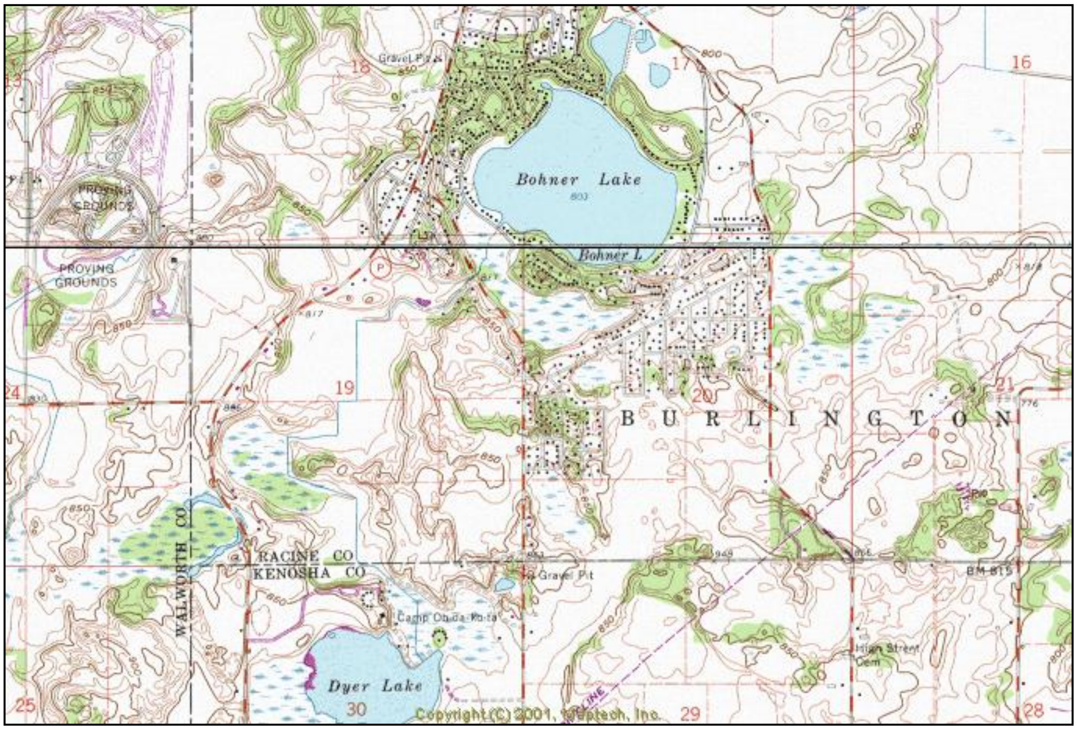

Figure 1

Location of Unnamed Southwest Tributary to Bohner Lake

BOHNER LAKE WATERSHED

Bohner Lake is 135 acre lake located in Southwest Racine County. The lake's total watershed has been estimated to be 1,958 acres, of which 578 acres enters through an unnamed tributary from the Southwest (R. A. Smith and Associates, Inc.,1993). The remaining portions of the watershed drain to the lake predominately through sheet flow from riparian areas of the lake. The headwater of the tributary is at Dyer Lake. The tributary land use is summarized in Table 1.

Table 1

Land Use in Inlet Tributary to Bohner Lake

Land Use	Acres	Percent
Residential	96.3	17
Woodland	186.4	32
Wetland	170.0	29
Agricultural	125.8	22
Total	578.5	100

Source: R. A. Smith and Associates, Inc.,1993

The soils in the tributary watershed are made up of Casco Loam, Fox Loam, and Houghton Muck.

THE SEDIMENT TRANSPORT PROCESS

Soil erosion by water is the process where material is dislodged from the surface of the land and transported by water to a receiving body such as a stream. Once material is detached it can be transported by the energy of the water. As particle size and weight of the material increases, so too does the velocity needed to transport it. The material transported through the stream is it's stream load. Stream load is composed of dissolved or solution load, suspended load, and bed load.

Dissolved load comes primarily from groundwater seepage into the stream. Ions in solution also come from the solution of materials that line the channel. The most common chemical constituents of dissolved solids are calcium, phosphates, nitrates, sodium, potassium and chloride, which are found in nutrient runoff, general stormwater runoff and runoff from road de-icing salts. The chemicals may be cations, anions, molecules or agglomerations on the order of 1000 or fewer molecules, so long as a soluble micro-granule is formed. The technical definition of dissolved solids is that the solids must be small enough to survive filtration through a sieve size of two micrometers (um).

Suspended load is comprised of sediment suspended in the water and transported through the stream. Turbulent flow suspends clay and silt in the stream. Suspended load comes from material eroded from the surface bordering the channel and deposited in the stream, as well as, erosion of the channel itself.

Bed load, sometimes referred to as traction load, is the material that is transported by sliding, rolling, and saltating (skipping) along the bed of a stream (Figure 2) . Particles comprising bed load can range in size from sand to boulders. The movement of bed load is responsible for bedforms that change in time and space along a stream bed.

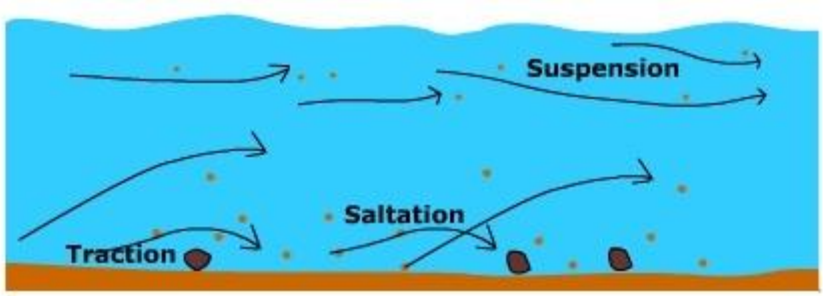

Figure 2
Illustration of Suspended and Bed Load in a Flowing Stream

Particles along a stream bed begin to move when the shear stress exerted by the flowing water exceeds a critical value. The critical shear stress depends on a combination of the particle diameter, the slope of the stream channel, the difference between the density of individual particles and that of water (particle buoyancy), and the degree to which the particles are packed together. As a result, particles of different mineralogical composition and size will have different critical shear stresses. Heavy minerals can be concentrated in stream beds because they are left behind while lighter particles move around them. Likewise, small particles may move while large particles of the same mineral or rock type are left in place. Water density is proportional to the suspended load being carried. Muddy water high in suspended sediment will therefore increase the particle buoyancy and thereby reduce the critical shear stress required to move particles of a given size and composition.

The shear stress exerted by the flowing water, which is proportional to both water depth and stream channel slope, also controls the movement of bed load. Large or heavy particles that have high critical shear stress values may move as bed load when the water is unusually deep during infrequent floods and remain stationary between those times.

Once a particle begins to move, the current above the bed may be strong enough to lift it off the bed and into the flowing water. When the entire weight of a particle is borne by water instead of other particles beneath it, that particle ceases to be part of the bed load and becomes part of the suspended load. Conversely, if the current slows a particle may fall out of suspension and become part of the bed load. The distinction between bed load and suspended load in a stream can therefore change continuously through time.

METHODS

The Bohner Lake Inlet study was broken into four elements:

- Measurement of stream bed load mass
- Measurement of bed load material characteristics
- Measurement of total suspended solids in water column
- Measurement of stream flow

The following section will outline the field and laboratory methods used to acquire the field data used in this analysis.

Bed Load Mass

Bed load mass was measured using a device called a "Helley-Smith Sampler". The Helley-Smith sampler was designed by the United States Geological Survey (USGS) to conduct stream bedload studies. By design, the Helley-Smith sampler it is intended to collect sediment particles that are moving along the bottom, or close to the bottom, by rolling, sliding, or bouncing (actually, those particles moving within 0.25 ft. of the bed). The device consists of a 3 by 3-inch rectangular funnel fitted with a catch bag made of 0.25 mm opening nylon mesh that is attached to the flared end of the sampler (Figure 3). It is placed on the channel bottom for a fixed time period and the amount of sediment collected in the bag is then measured.

Figure 3
Photograph of "Helley-Smith" Stream Bead Load Sampler

Bed load samples were collected on seven dates at Fishman Road, located just upstream of the sedimentation basin (Figure 4). Samples were collected at the outlet of a 48-inch corrugated metal culvert that drained under the roadway. Typically with bed load sampling several samples are collected across the stream channel using the "equal width increment method" developed by Edwards and Glysson (1988). In this situation since the water was concentrated by the culvert into a narrow section, collection of multiple samples across the cross-section were not possible or necessary. Samples were collected by placing the Helley-Smith sampler on the bed of the outlet of the culvert. Bed load material was then collected for 60-seconds. Material collected in the mesh bag was then transferred into clean glass jars, stored on ice, and shipped to the Wisconsin Laboratory of Hygiene for analysis. At the laboratory total wet mass of material collected was weighted using an analytical balance.

Particle Size Analysis

To determine the characteristics of the bed load material a particle size analysis was conducted on the bed load material collected by the Helley-Smith sampler. The distribution of particle sizes larger than 63 um (retained on the No. 200 sieve) was determined by sieving. The total mass retained on each sieve was measured to determine the percent of the sample larger than the sieve opening. The distribution of particle sizes smaller than 63 um was determined by a sedimentation process, using a hydrometer. A hydrometer is an instrument used for determining the specific gravity of liquids. Table 2 summarizes the particle size class names, particle size in millimeters and sieves used to classify sediments using particle size analysis.

Table 2

Classification of Particles Used in Particle Size Analysis

Class name	Particle size	Sieve Size
Gravel	>2mm	No. 10
Very Coarse Sand	0.85 - 2.0mm	No. 20
Coarse Sand	0.425 – 0.85mm	No. 40
Medium Sand	0.25 - 0.425mm	No. 60
Fine Sand	0.18 - 0.25mm	No. 80
Very Fine Sand	0.15 - 0.18mm	No. 100
Coarse Silt	0.063 - 0.15mm	No. 200
Medium and Fine Silt	0.002 - 0.063mm	(analysis by hydrometer)
Clay	<0.002mm	(analysis by hydrometer)

Percent Organic Matter

To help determine the potential source of the bed material two test were run to determine if the material was organic in nature, such as peat, or was inorganic and made up of soil particles such as silt, sand or clay. The first test was "total residue", also referred to by some as "total solids". Total residue is the measurement of weight of all the bed load material after it has been dried at 103 to 105^{o}C to drive off all of the water in the material. The second test is "non-volatile residue". Non-volatile residue is a measurement of the mass of material that is left behind after the sample is ignited at 550°C in a muffle furnace to drive off any of the organic material present. If we subtract non-volatile residue from total residue we get "volatile residue", which is the measurement of the organic matter in the sample.

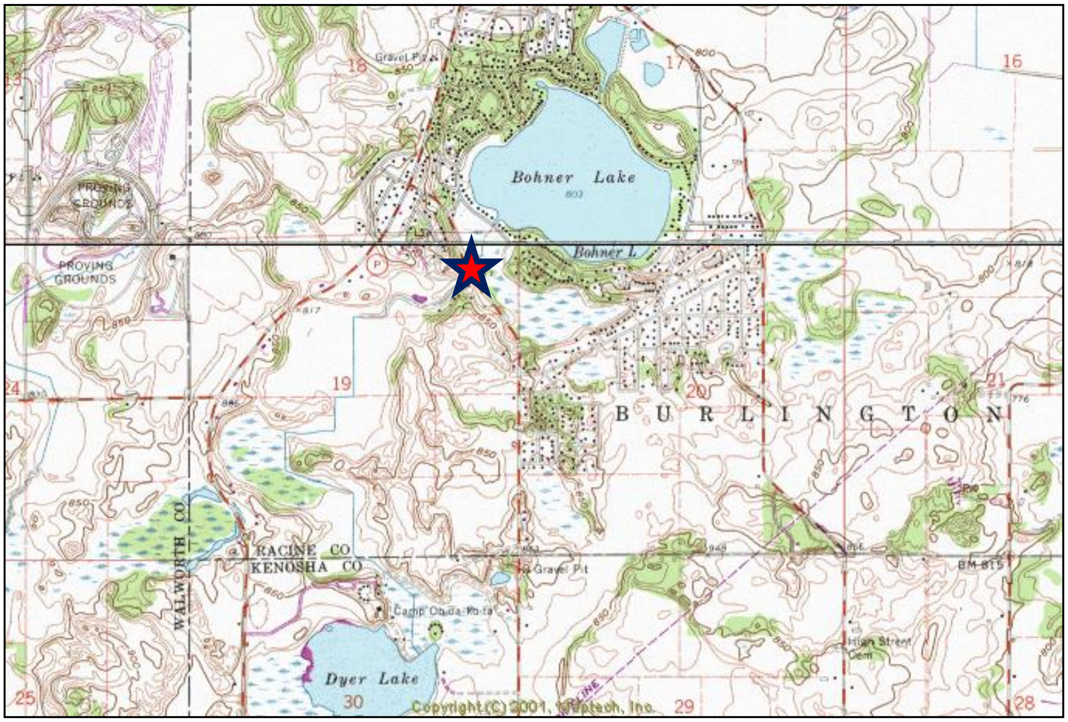

Figure 4

Sampling Location of Unnamed Tributary at Fishman Road

Total Suspended Solids in Water Column

Total suspended solids (TSS) are a measurement of the suspended sediment in the water column. TSS of a water sample is determined by pouring a carefully measured volume of water through a pre-weighed glass-fiber filter of a specified pore size, then weighing the filter again after drying to remove all water. The gain in weight is a dry weight measure of the particulates present in the water sample expressed in milligrams per liter or mg/l. TSS samples were collected on six dates by collecting water from the middle of the water column at the outlet of the culvert at Fishman Road. A one liter sample was collected on each sample date, iced, and forwarded to the Wisconsin Laboratory of Hygiene for analysis.

Instantaneous Stream Flow

Instantaneous stream flow was measured on each sampling date by measuring the depth of water flowing in the 48-inch corrugated metal culvert under Fishman Road. In August 2006 the culvert was surveyed to measure the elevation of the inlet and outlet, slope and length of the pipe. Using the Manning's equation, where:

Where:

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}} \sqrt{S} \quad [U.S.]$$

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{\frac{2}{3}} \sqrt{S} \quad [SI]$$

Q = Flow Rate, (ft^3/s)
v = Velocity, (ft/s)
A = Flow Area, (ft^2)
n = Manning's Roughness Coefficient
R = Hydraulic Radius, (ft)
S = Channel Slope, (ft/ft)

the flow in cubic feet per second (ft^3/s or cfs) was calculated.

Annual Flow Record

The annual flow record for the study tributary was estimated using daily stream flow data from available data from the closest USGS stream gauge with similar watershed characteristics. The closest USGS stream gauge to Bohner Lake is the Mukwonago River at Mukwonago. Daily mean flow data for the period of October 1, 2005 through September 30, 2006 was used for the analysis. Daily values measured at the Mukwonago River were linearly transferred by unit drainage area to develop an annual hydrograph for the study tributary.

RESULTS

Annual Flow Record

Using data from the USGS stream gauge at the Mukwonago River at Mukwonago the annual flow hydrograph for the study tributary was developed and is illustrated in Figure 5. For the water period of October 1, 2005 through September 30, 2006 it is estimated that 429-acre-feet (140 million gallons) (8.913-inches) of water entered Bohner Lake from the study tributary.

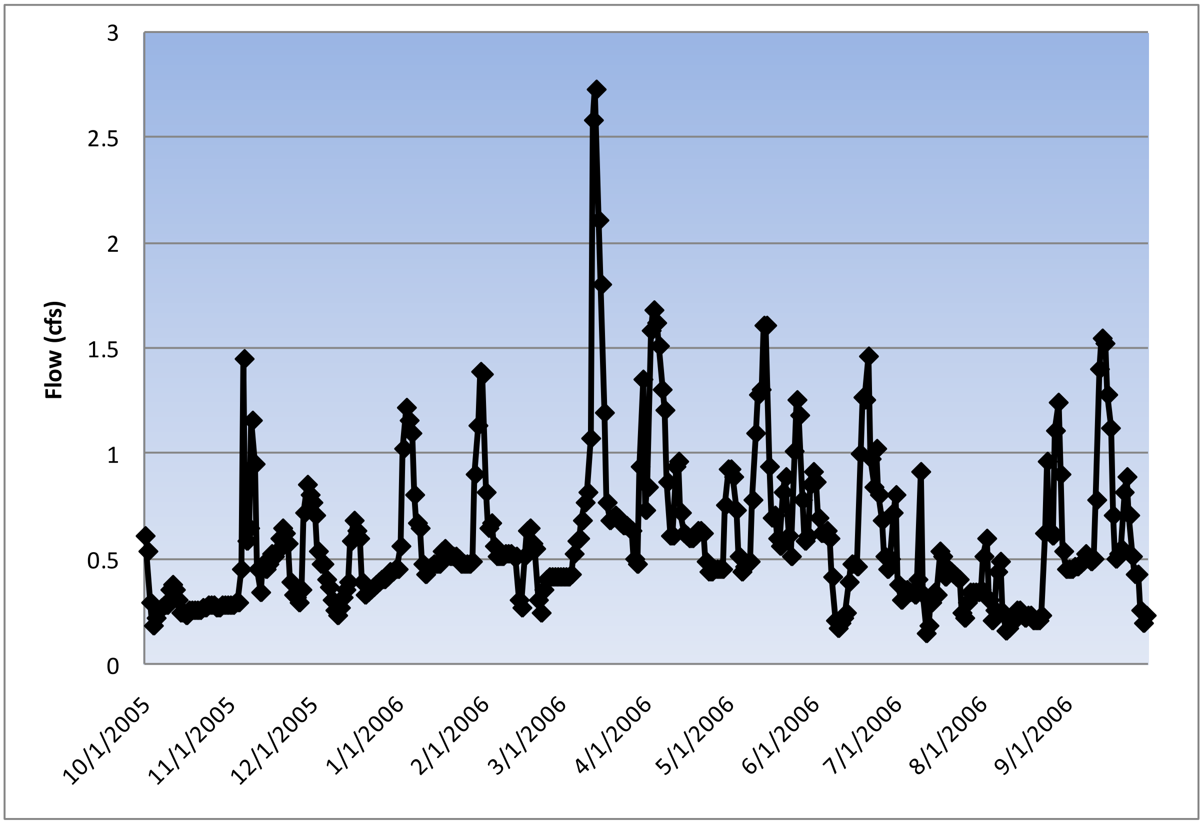

Figure 5

Estimated Annual Flow Hydrograph for Study Tributary

Characteristics of Bed Load Material

To determine the characteristics of the bed load material entering Bohner Lake the material collected by the Helley-Smith sampler was analyzed for percent organic matter and particle size distribution. Percent organic matter was calculated by measuring the total residue and total volatile residue. The total volatile residue represents the fraction of the sample that is organic matter. Table 3 summarizes the results of the two samples for organic matter in the bed load material. The results show that more than 77 percent of the bed load material is organic in nature.

Table 3

Results of Total and Volatile Residue Sampling of Bed Load Material

Date	Total Residue (mg/l)	Total Volatile Residue (mg/l)	Percent Organic Matter (%)
5/15/2006	9400	7400	78.72
6/18/2006	3010	2320	77.08

Figure 6 illustrates the particle size analysis run on the bed load sample collected on May 15, 2006. From the distribution we see that 70 percent of the sample is made up of particles greater than 500 um (0.5mm) in size, 25 percent is sand (125 to 500 um), 4.4 percent is silt (5 to 125 um) and 0.1 percent is clay (< 2um).

The high percent of large particles (>500 um) combined with the high percentage of organic matter in the samples confirms the original hypothesis that the material moving as bed load down the study tributary is likely peat in nature. The likely source is erosion of the Houghton Muck soils located in the valley floor of the drainage area which are peat in nature. Much of the Houghton soils have been historically used as muck farms to grow cash crops.

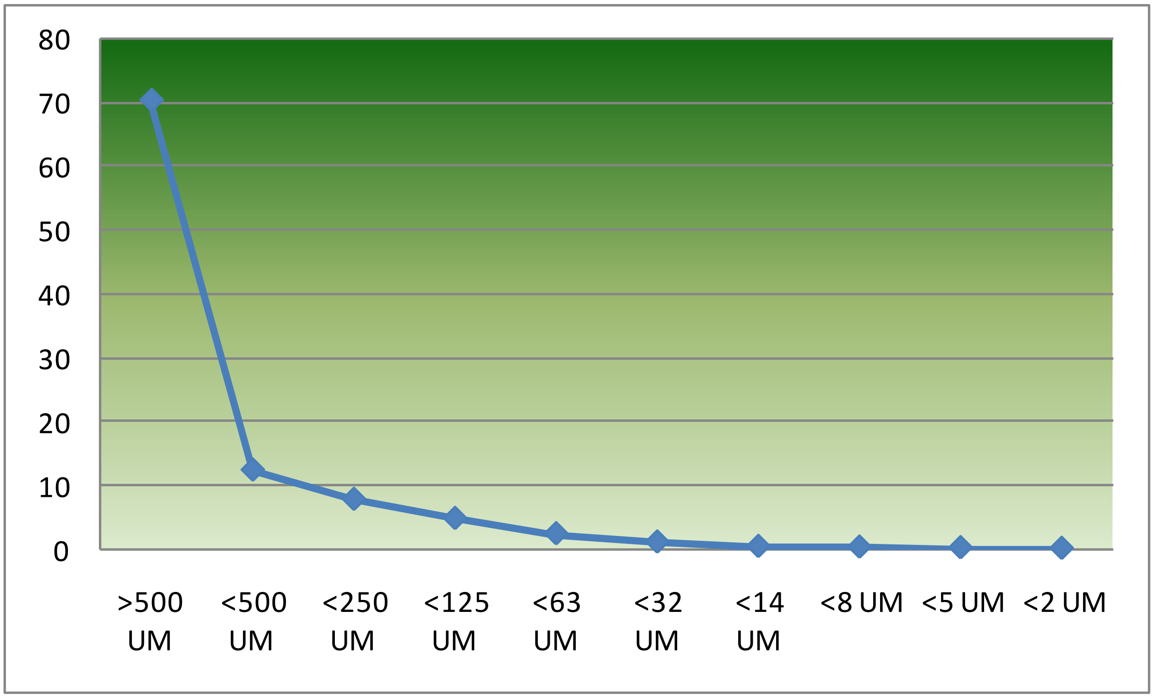

Figure 6

Particle Size Distribution for Bed Load Sample on May 15, 2006

Bed Load Mass and Annual Loading

The results of the total mass measurements for the bed load sampling for seven sample dates is summarized in Table 4. The total mass of wet material collected during the one minute sampling with the Helley-Smith sampler ranged from 763 to 1,834 grams (1.68 to 4.04 pounds). The water depths measured on the sampling dates, along with calculated flows, velocities and specific energy are summarized in Table 5. To determine if there is a relationship between bed load and stream flow, a plot of bed load mass per minute versus stream flow was prepared (Figure 7).

Table 4

Results of Bed Load Sampling

Date	Total Mass Bed Load (grams/min)	Total Mass Bed Load (pounds/min)
5/15/2006	1,834	4.04
6/18/2006	845	1.86
2/22/2006	835	1.84
6/24/2006	763	1.68
8/24/2006	802	1.77
10/3/2006	844	1.86
10/4/2006	856	1.89
Mean	968	2.14
Geometric Mean	923	2.04
Standard Deviation	383	0.84

Table 5

Water Depth and Flow Calculations for Sample Dates

Date	Water Depth (inches)	Flow (cfs)	Velocity (fps)	Specific Energy (ft)
5/15/2006	6.00	2.32	2.56	0.60
6/18/2006	4.50	1.27	2.13	0.45
2/22/2006	3.25	0.64	1.73	0.32
6/24/2006	3.50	0.75	1.82	0.34
8/24/2006	7.25	4.43	2.87	0.73
10/3/2006	9.50	5.97	3.38	0.97
10/4/2006	5.50	1.93	2.42	0.55
Mean	5.64	2.47	2.42	0.57
Geometric Mean	5.29	1.84	2.36	0.53
Standard Deviation	2.21	2.01	0.59	0.23

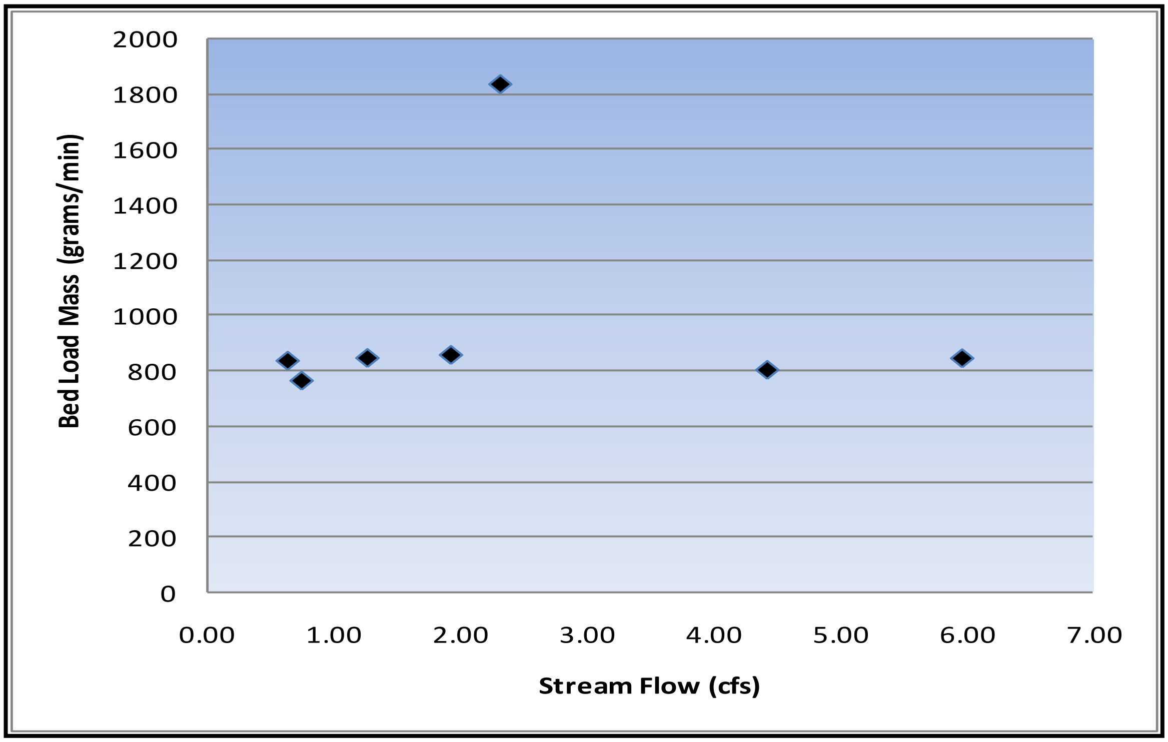

Figure 7

Bed Load Mass per Unit Time versus Stream Flow

As we see in Figure 7, based on the available samples, there is no relationship between stream flow and mass of bed load being carried by the tributary. Most values lie around a mean of 824 grams per minute. The one value of 1,834 grams per minute on May 15, 2006 is over two standard deviations from the mean value. When we average all of the values to calculate a mean we give equal weight to each value. In this case one outlier can dramatically influence the mean. In these situations it is better to use the geometric mean, which is the average of the logarithmic values of a data set, converted back to a base 10 number. The geometric mean puts less weight on the outlier values. For calculation of annual loading of bed load material the geometric mean value will be used.

The loading of material entering a water body is the measurement of mass or volume over a given time period. Figure 5 illustrates that generally bed load is uniform on most dates and is independent of stream flow. Therefore, the annual mass loading of bed load material can be calculated by multiplying the geometric mean of mass per unit time by the time in one year:

Total Load = 2.036 (lbs/min) * 525,600 (min/year) = **1,070,121.6 (lbs/year)**

We can convert this mass load in pounds to a volume by using literature values of weight per volume (density). The SIMetric.co.uk webpage provides density data for a variety of bulk materials including wet peat. Wet peat has a bulk density of 3232.5 pounds per cubic yard (1121 kg/m^3). Based on this wet peat density we have the following volume of bed load material moving down the study tributary:

Total Wet Volume Bed Load = 1,070,121.6 (lbs/year) / 3232.5 (lbs/cu-yd) = **331.05 (cu-yds)**

As material enters the sedimentation basin and lake it will begin to settle under the force of gravity. As sediment moves through the water column towards the bottom it traps water between the particles resulting in a mass that is partially solids and partially water. R. A. Smith and Associates in their work in 1992 measured the solid/water content of the material in the sedimentation basin and lake and found the material to be approximately 18 percent solids and 82 percent water. If we add the water to the wet solids measured entering the lake we get the following total volume of material settling in the lake inlet area:

Total Wet Volume Sediment = 331.05 (cu-yds) / 0.18 = **1,839 cu-yds**

We see that the total volume of estimated annual bed load input from the tributary is approximately equal to the volume of material originally dredged in 2002.

Total Suspended Solids

Total suspended solids (TSS) is a measurement of the suspended sediment in the water column. On six dates TSS samples were collected at the culvert at Fishman Road. The results of the sampling and calculated instantaneous loading of material in pounds per day are presented in Table 6. The results show a range of TSS concentrations ranging from 14 mg/l to 260 mg/l. TSS concentrations above 40 mg/l cause cloudy water conditions and levels above 100 mg/l can damage aquatic life.

To determine if there was a relationship between flow rate and TSS concentration, the two parameters were plotted and the results are illustrated in Figure 8. The results, similar to base load, do not show a good relationship between flow rate and TSS concentration based on the limited sampling.

Table 6

Results of Total Suspended Solids Sampling

Date	Flow (cfs)	TSS (mg/l)	Loading (lbs/day)
5/15/2006	2.32	-	-
6/18/2006	1.27	77	526.86
2/22/2006	0.64	260	896.50
6/24/2006	0.75	194	783.90
8/24/2006	4.43	37	883.09
10/3/2006	5.97	155	4985.45
10/4/2006	1.93	14	145.57
Mean	2.50	122.83	1370.23
GEOMEAN	1.77	82.35	786.83
STDEV	2.20	96.15	1793.68

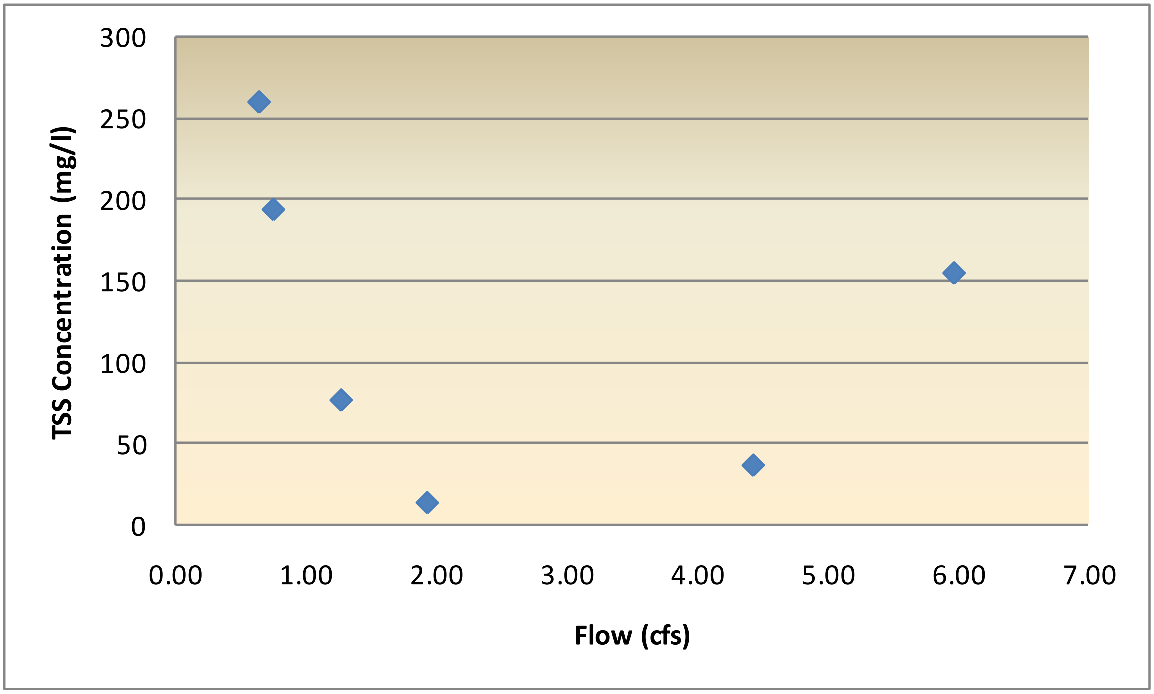

Figure 8

Total Suspended Solids Concentration versus Flow Rate

To see if there was a seasonal relationship of TSS concentration that may be related to cropping practices and degree of vegetative cover, TSS concentrations were plotted by date (Figure 9). From the limited sampling we do not see any good seasonal relationships.

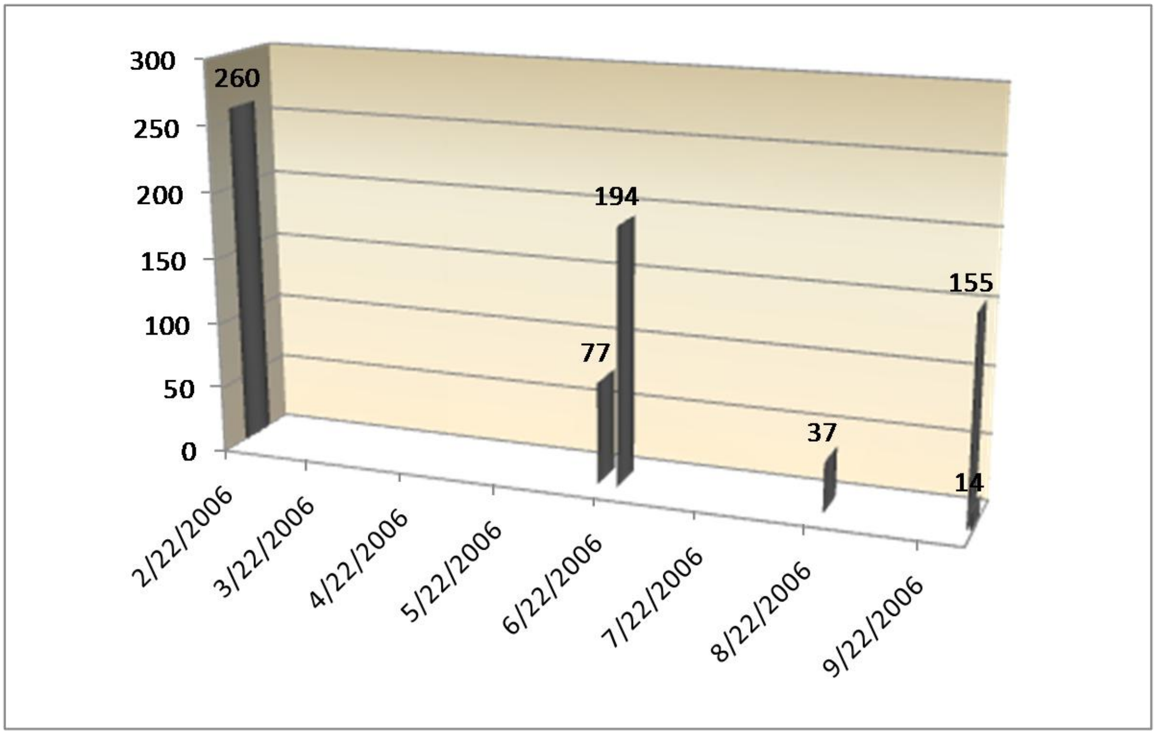

Figure 9

Total Suspended Solid Concentrations by Date

TSS concentrations can be highly variable and are influenced by vegetative cover, soil moisture, and rain intensity. The limited data does not all the calculation of annual loads to the sedimentation basin or lake. Due to the fine nature of suspended solids, most likely move through the sedimentation basin and lake inlet and deposit in the open water areas of the lake.

CONCLUSIONS

Based on the available sampling in 2006 it is estimated that the Southwest tributary to Bohner Lake inputs approximately 1,839 cubic yards of bed load material to the lake inlet on an annual basis. The bed load material is over 77 percent organic in nature and has more than 70 percent of its particles larger than 500 um, indicating that the material is likely peat that is being eroded off of areas of Houghton Muck soils. The rapid filling in of the sedimentation basin upstream of the lake and the lake inlet following dredging in 2002 is likely due to the high amount of bed load material that is moving along the tributary bed.

The rate of material movement appears to be relatively uniform from sample date to sample date and is not related to flow rates. The tributary channel carries a relatively uniform base flow, feed by springs in the glacial valley. A likely source of the bed load material is erosion of the banks of the agricultural ditches that were installed to facilitate farming of the wetland valley between Dyer Lake and Bohner Lake. To determine the exact locations of the soil erosion would require a field survey of the drainage ditches.

RECOMMENDATIONS FOR FUTURE ACTION

Prior to re-dredging of the sediment basin and lake inlet, a survey should be conducted on the drainage system in the Southwest tributary to determine if the sources of the bed load material can be controlled. The survey should begin with a field reconnaissance to see if oblivious sources of the erosion can be identified. Due to the wet nature of the soil and many riparian wetlands along the drainage system the reconnaissance would best be conducted in the winter on frozen ground. Based on the reconnaissance survey a strategy for the development of a management plan should be put together. Based on the above work, dredging of the sedimentation basin and lake inlet without some control of the source material will result in the need to re-dredge on an annual or bi-annual basis.

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