THE GRASS RIVER SOIL WATER ASSESSMENT TOOL
A model for predicting sources and sinks of sediment

Final Report

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ABSTRACT

Soil Water Assessment Tool was implemented in the Grass River watershed to determine sources and sinks of sediments. STATSGO soil data and 2006 era land cover extracted from Landsat Thematic Mapper imagery was used to develop the model. Results from the uncalibrated model suggest that Finch Creek is the largest source of sediment in the Grass River, contributing some 401 tons/year over the period between Jan 1, 2006 and December 31, 2010. Cold Creek is the second largest source, contributing 166.8 tons/yr followed by Shanty Creek, contributing 50.0 tons/yr over the same period. Together the three tributaries contribute 363 cubic meters of sediment (equivalent to over 13 dump truck loads) every year to the Grass River. Several stream segments in Finch creek were found to be significant sinks of sediments. Sediments eroded mainly from areas underlain by the Emmet-Montcalm soil series. Urbanized areas in Shanty Creek appear to be significant sources of sediment, however much of this sediment is deposited before it reaches Grass River. Further work will calibrate and validate the model using stage and discharge data being collected at the site by volunteers of the Three Lakes Association and staff of the Tip of the Mitt Watershed Council.

INTRODUCTION

Grass River is a 4.2 kilometer long river that connects Bellaire Lake with Clam Lake. Used originally to transport timber to mills in the south, it is an important transport and recreational waterway. The channel was deepened at the turn of the century to improve the movement of timber. A second southward channel to the west of Grass river was sealed off from Lake Bellaire to increase water flow down the Grass River. Separating the two channels is a large open wetland of Sedge grass. Stakeholders and long term residents have noted that parts of the Grass River are becoming increasingly filled up with sediment. The effect of this is to increase the difficulty of boats to travel in the river. Stake holders have observed that some of this sediment is being deposited at the mouths of Shanty Creek, Cold Creek and Finch Creek. This modeling study was commissioned by The Grand Traverse Bay Watershed Center, Three Lakes Association, Tip of the Mitt Watershed Council and Elk Skegemog Lakes Association to identify sources of sediment in the watershed that may be increasing the load to the river.

METHODOLOGY

The Model

The hydrologic model chosen for this study is Soil Water Assessment Tool (SWAT, Arnold et al, 1998). SWAT is a popular distributed parameter chemical load model for predicting nutrient and sediment fluxes from land use information and has been used successfully in several previous studies of watershed sediments and nutrients (Bingner et al, 1997; Fitzuh and Mackay, 2000; Spruill et al, 2000; Reunsang et al, 2005; Larose et al, 2006; Geza and McCray, 2007; Barlund et al, 2007; Easton et al, 2007; Hu et al, 2007; Tolson and Shoemaker, 2007; Wu and Johnson, 2007; Bosch, 2008; Kliment et al, 2008,). Besides traditional hydrologic paramaterizations for estimating runoff, dissolved and particulate nutrients (soil curve numbers, Green and Ampt equation, and Modified Universal Soil Loss Equation), SWAT also incorporates parameterizations for in-stream nutrient processes, crop modeling, groundwater flow, snow melt and three different evapotranspiration schemes. The model also applies the USGS build up and wash off equations for urban land cover. SWAT also forms the basis of EPA-BASINS, the EPA hydrologic model used in many watershed TMDL and sedimentation studies. While there are other hydrologic models available that can be used to predict sediment fluxes (HSPF, SWMM, GWLF, AGNPS), these other models are either too data intensive (HSPF, SWMM), simplistic (GWLF) or obsolete (AGNPS). SWAT was implemented to predict sediment loads for land use patterns of current day (2006) land use. The model was checked using storm water discharge data collected at Cold Creek by Endicott (2007).

Channel Network Definition

The digital elevation data used to create the model are the USGS 1/3 second topographic elevation data extracted from USGS seemless data server. A hydrography network from Michigan Resource Information System (MIRIS) was used to modify the digital elevation model (DEM), a mathematical representation of the topography, to insure that channel elements of the model closely approximate the observed streams. This hydrography network was edited to remove wetland boundaries and reservoirs (which created triple-line streams). A suite of experiments were run to determine the best channel forming area thresholds. The threshold that best reproduced the observed channel network without creating spurious channels was 100 ha. Stream definition was restricted to an area defined by a dataset (Maskw5) to preserve the actual flow direction of the river. Previous attempts using the basic DEM produced river flow in the wrong direction. The source of the error is believed to be spurious elevation values in the Clam Lake which caused the model to assign the wrong flow direction. Removing the western portion of Clam Lake in the digital elevation model using Maskw5 corrected the result. A road database was used to locate additional outlet sites so that the model will predict flow at all stream/road culverts in the watershed. One point source was added to the Cold Creek to model groundwater inputs from the area around Lake of the Woods which are known to be significant. The upstream end of Grass River, the outlet of Lake Bellaire, was modeled as a watershed inlet. Observed data will be used to quantify flows once the tributaries have been calibrated for water balance. **Table 1** summarizes the contributing area, elevation, channel statistics and reach ids of the outlets.

Table 1 *Model reach characteristics. Note italicized ID in parenthesis are Three Lake Association IDs and are consistent with Grass River & Tributaries Restoration Assessment:2011 Findings Report*

Stream / Road Intersection	Subbasin ID (*ID*)	Area (ha)	Length (m)	Slope (%)	Width (m)	Depth (m)	Elev (m)	Model reach

Shanty Creek at M88	18 (*5*)	485.5	4423.7	2.20	3.33	0.24	188.8	RCH18_OUT
Cold Creek at Tyler Rd	19 (*14*)	1922.1	1825.4	0.41	7.60	0.42	187.2	RCH19_OUT
Unnamed Tributary of Finch at Alden Highway	23	286.4	1647.2	1.71	2.43	0.20	190.6	RCH23_OUT
Cold Creek at Alden Highway	20 (*16*)	1760.6	10161	1.19	7.21	0.41	194.0	RCH20_OUT
Finch Creek at Alden Highway	22 (*18*)	1485.1	1475.7	1.03	6.51	0.38	189.8	RCH22_OUT
Finch Creek at West Elder Rd	21 (*22*)	433.2	1891.8	0.73	3.11	0.23	209.6	RCH21_OUT
Finch Creek South at Finch Creek Rd	16 (*20*)	313.3	1142.1	1.54	2.56	0.21	222.4	RCH16_OUT
Finch Creek at E Bebb Rd	24 (*23*)	247.1	2424.4	2.01	2.22	0.19	240.1	RCH24_OUT
Finch Creek at Finch Creek Rd. (use subbasin 22)	25 (*19*)	1485.1	1475.7	1.03	6.51	0.38	202.0	RCH22_IN*
Cold Creek at Comfort Rd (use subbasin 19)	26 (*13*)	1922.1	1825.4	0.41	7.60	0.42	185.0	RCH19_OUT*

Land Use / Soil / Climate Data

Land cover data from 2006 Landsat satellite imagery was used to develop the model. Much of the watershed is covered with forest and forested wetland (**Figure 1**). Some areas of low density urban development are located on the western part of Shanty Creek and along highway M32. STATSGO soil data, a soils GIS data layer available for the entire Country, was used to extract the soil parameters required for the model. ST-MUID codes were used to link this information (**Figure 2**). Multiple hydrological response units (HRUs) were created for each subbasin using a 5/10% overlap for landuse and soil type respectively. The resulting model has 135 individual hydrological response units spread among 24 subbasins. Daily precipitation and temperature data required to calibrate the model was obtained from the Kalkaska climate station located 14 km south of the Rapid River / Grass River study area. This station has an elevation of 315.3 m and has a COOP-ID of 204257. All other meteorological parameters were obtained from long term statistics of solar radiation, relative humidity, and wind speed of the Fife Lake State Forest climate station located 31 km southwest of the centroid of the watershed.

Field Assessment

A field assessment of road/stream intersections was undertaken to look for evidence of erosion and to collect ancillary discharge data to help calibrate the model. Parameters collected included temperature, electroconductivity, dissolved oxygen, pH and discharge. Culverts were described and measured. Instances of channel bank erosion were noted and photographed.

RESULTS

Tables 2, 3, and 4 provide the sediment yields and loads by subbasin, by outlet, and by tributary predicted by the model for the period spanning Jan 1, 2006 thru Dec 31, 2010. **Figure 3** provides a graphical representation of table 1, which can be used to compare individual subbasins in their propensity for producing sediment loads. Please note, that these values are expressed per unit area, so that a subbasin with a greater yield may not necessarily be contributing more sediment than a subbasin with a lower yield, but which is much larger in size.

Figure 4 graphically represents loads from individual reaches (Table 3) which demonstrates that there are significant sources and sinks of sediment within the stream network. The three creeks (Table 4) introduced a total load of 620 tons of sediment into Grass River every year. If we assume a dry bulk density of 1.7 g/cm3, appropriate for a fine sand, this is equal to 363 cubic meters each year. This is over 13 dump truck loads of sediment being added to the river every year.

Comparison to Observed Data

Much of the study area is covered by forest or forested wetland. Modeled sediment flux rates were compared to observed sediment fluxes from similar landuses (Uris, 1965; Chang et al, 1982). These two studies were conducted using waterquality measurements and Parshall flumes to measure the precise runoff and sediment loads from forested watersheds undergoing different management treatments. SWAT modeled sediment fluxes rates in subbasins 8, 9 and 14, which are dominantly forested are very comparable to the loads observed in managed and unmanaged forested land uses, which range between 1.1 to 22.4 tons/year/km^2 (Table 6). Table 7 compares observed Cold creek discharge from April to September 2006 with the model discharge over the same period. The model underpredicts the observed monthly flow by an average of 26% during the months of April through June. This error increases to 75% during the drier months of July through September. Inspection of the observed flow data shows that Cold Creek discharge is remarkably stable despite the history of precipitation during that period. This is probably due to groundwater inputs. This would explain the discrepancy in the model, the model does not account for groundwater inputs coming from outside the watershed. Our model than probably underpredicts the actual discharge and sediment load. Thus whatever conclusions this study draws on sedimentation, the truth is probably much, much worse. .

Table 2 *Sediment, Organic Phosphorus (Org P), Organic Nitrogen (Org N), Mineral Phosphorus (Min P), Soluble Phosphorus (Sol P), Total Nitrogen (TN), and Total Phosphorus (TP) yields by subbasin. Sediment is in tons/yr/km^2, all others are in kg/yr/km^2. The table also shows important subbasin input parameters, Subbasin averaged curve number (CN), % slope, and slope-length factor (SL). Bold records indicate those subbasins that are significant sources of sediments. Note that subbasins with high sediment yields are commonly associated with high curve numbers(CN) and % slope.*

Subbasin (id)	Area (km2)	Sediment	Org N	Org P	Sol P	Min P	CN	% slope	SL factor
1	1.1	4.9	43.5	7.5	3.7	0.3	50.3	0.014	122.0
2	0.5	3.9	16.9	3.8	1.6	0.1	37.2	0.012	122.0
3	1.5	**53.7**	**302.4**	**44.7**	**1.5**	**2.8**	**45.5**	**0.052**	**61.0**
4	0.0	0.6	15.4	2.1	0.2	0.1	57.7	0.015	122.0
5	1.7	6.6	45.5	7.0	1.6	0.6	46.2	0.063	61.0
6	0.0	0.8	22.3	3.0	0.2	0.2	60.9	0.022	91.5
7	2.0	1.3	28.5	3.6	0.3	0.2	46.3	0.019	122.0
8	0.8	0.7	16.1	2.0	0.1	0.1	44.2	0.017	122.0
9	0.6	1.4	11.3	1.4	0.7	0.2	49.6	0.037	91.5
10	0.5	4.4	25.8	5.0	1.7	0.2	45.1	0.018	122.0
11	0.2	**16.6**	**43.8**	**5.5**	**1.9**	**1.9**	**57.6**	**0.088**	**61.0**
12	0.2	7.4	27.3	3.5	0.8	0.9	45.4	0.122	24.4

13	1.1	**24.7**	**64.3**	**8.3**	**2.5**	**2.7**	**66.6**	**0.085**	**61.0**
14	0.2	6.3	17.4	2.2	1.7	0.8	**57.2**	**0.077**	**61.0**
15	4.8	**205.7**	**331.3**	**49.6**	**0.8**	**9.3**	**47.9**	**0.07**	**61.0**
16	0.7	**15.9**	**42.6**	**5.5**	**1.9**	**1.8**	**57.2**	**0.079**	**61.0**
17	1.1	**102.5**	**195.6**	**29.1**	**0.9**	**5.5**	**47.8**	**0.067**	**61.0**
18	4.9	35.9	70.2	9.3	1.2	1.3	46.5	0.1	61.0
19	1.6	2.5	57.0	7.0	0.2	0.3	42.9	0.053	61.0
20	17.6	5.2	19.7	2.5	0.8	0.7	44.3	0.077	61.0
21	3.2	**119.7**	**215.8**	**32.2**	**0.8**	**6.1**	**47.7**	**0.065**	**61.0**
22	0.9	**109.1**	**285.8**	**41.9**	**1.5**	**4.8**	**57.3**	**0.064**	**61.0**
23	2.9	**438.5**	**386.8**	**60.7**	**2.2**	**15.3**	**67.8**	**0.064**	**61.0**
24	2.5	**107.8**	**201.1**	**29.8**	**0.8**	**5.7**	**45.4**	**0.066**	**61.0**

Table 3 *Sediment and Nutrient fluxes by outlet. In kg/year (averaged over the simulation period, 1/1/2006-12/31/2010). Note ID's are Three Lake Association IDs and are consistent with Grass River & Tributaries Restoration Assessment:2011 Findings Report*

Culvert location	Subasin ID	Three Lakes ID	Sediment (tons)	Org N (kg)	Org P (kg)	NO3 (kg)	Min P (kg)
Shanty Creek at M88	18	5	51.4	177.9	30.9	2,880	7.7
Cold Creek at Tyler Rd	19	14	95.5	439.0	65.9	13,280	16.1
Unnamed Tributary of Cold Creek at Alden Highway	23		1,256	1,105	214.3	1,390	9.0
Cold Creek at Alden Highway	20	16	92.2	364.8	54.1	10,760	15.7
Finch Creek at Alden Highway	22	18	380.1	3,352	584.2	7,354	21.7
Finch Creek at West Elder Rd	21	22	64.6	900.7	158.0	2,248	5.1
Finch Creek South at Finch Creek Rd	16	20	66.8	521.1	90.8	1,223	4.1
Finch Creek at E Bebb Rd	24	23	266.3	493.0	86.2	886.2	2.8

Table 4 *Sediment fluxes in tons/yr by tributary. Sediment load volume calculated based on a fine sand with a dry bulk density of* $1.7g/cm^3$.

Tributary	Sediment load (tons)	Sediment load (cubic meters)
Shanty Creek	50.0	29.4
Cold Creek	166.8	98.1
Finch Creek	401.0	235.9

Table 5 *Results of stream / road survey. Data collected on July 20 and 22, 2011. Flow measured by a Marsh McBirney Flow meter. Note ID's are Three Lake Association IDs and are consistent with Grass River & Tributaries Restoration Assessment:2011 Findings Report*

Site name	ID	Culvert description	temp	DO	EC	pH	Flow (cfs)	Comments
Shanty at Grass River Rd.	4	4.5 ft round, top 4.0 ft open						Erosion control structure present.
Shanty at M88	5	8 by 2.75 ft beveled	12.6	10.4	378.8	8.4	9.3	Open, no blockage

		cement rectangular						
Cold Creek at Comfort Rd.	13	6 ft round, top 4.5 ft open	12.6	9.9	361.9	8.3		Very steep culvert gradient
Cold Creek at Tyler Rd.	14	8.9 ft round, top 6.4 ft open	12.9	10.0	354.5	8.3	29.8	
Cold Creek at Alden Hwy	16	4 ft round corrigated	12.5	9.6	352.2	8.2	8.8	
Finch Creek at Alden Hwy	18	(2) 4 ft round, top 3.8 and 3.0 ft open	13.5	9.9	350.2	8.5	28.9	Partially blocked by logs and debris
Finch Creek unnamed trib		2 ft round, not open	17.5	9.0	378.3	8.5		Partially blocked by logs and debris
Shanty Creek at old RR bed	2	Bridge					9.4	Open
Unnamed trib at M88		2 ft round						Partially blocked by debris

Table 6 *Observed sediment erosion rates from forested land uses compared with SWAT sediment erosion rates from dominantly forested subbasins.*

Ursis (1965) Land cover	Observed tons/km2	Chang et al (1982) Land cover	Observed tons/km2	Grass River SWAT	Modeled tons/km2
Forest (undisturbed)	4.5	Forest (undisturbed)	1.1	Subbasin 8	0.7
Forest (depleted)	22.3	Forest (thinned)	1.7	Subbasin 9	1.4
Forest (abandoned fields)	29.1	Forest (managed *)	15.6	Subbasin 14	6.3
Pasture	360.9	Forest (clear cut and cultivated)	324.3		
Cultivated row crops	4875				

* Forest managed by removing all marketable-sized trees, leaving undergrowth intact

Table 7 *Modeled versus observed flow in Cold Creek. Data from Endicott (2007)*

Month	Monthly averaged Observed Flow (cfs)	Monthly averaged Modeled Flow (cfs)
April, 2006	29.6	21.9
May, 2006	29.0	20.8
June, 2006	28.1	21.8
July, 2006	28.4	10.4
August, 2006	28.3	6.9
September, 2006	28.5	4.4

DISCUSSION

Despite the model being uncalibrated, the area-averaged sediment fluxes from dominantly-forested subbasins in the model are comparable to observed sediment fluxes from forested watersheds. This suggests that the model is providing reasonable estimates for sediment erosion rates from the landscape. However, the model under predicts the observed flows between 25 to 82% depending on the month. Under prediction is much higher in the late summer. It also appears that the model is more variable than the observed flow which varied very little over the six month time observation period. This is probably because of groundwater inputs into Cold Creek which are excessive throughout the year. So while the model is providing reasonable estimates of sediment load to the stream network, its in-stream water balance needs to be fine-tuned in order to determine how much of this sediment load is transported to the Grass River. Sediment loads predicted by the model should therefore be considered lowball estimates. That the model still predicts significant sediment loads from these tributaries into the Grass River suggests that watershed planners should take action to reduce sedimentation.

SWAT uses the SCS runoff equation to predict surface runoff (SCS, 1986) and the MUSLE equation to predict soil erosion. The equations are applied onto hydrologic response units (HRUs) which are areas of unique combinations of soil and land use. The SCS runoff equation uses a curve number, derived from soil hydrologic group, land cover and management, to predict potential abstraction. Runoff is then predicted from potential abstraction and rainfall. Curve numbers range from 0 to 100 with lower numbers having the greatest values of potential abstraction (and the least amount of runoff). As the curve number increases, runoff will increase. A curve number of 100 has no potential abstraction and is impervious, causing all of the precipitation to runoff . The MUSLE equation uses soil erodibility, raindrop erosivity, slope , slope-length factor and management to estimate the amount of soil that erodes. Since the model assumes a uniform raindrop erosivity throughout the watershed and there are few areas of agriculture where management factor may be less than 1, sediment erosion is controlled mainly by soil type, slope and slope length factor. As soil erodibility, slope and length-slope factor increases, sediment erosion should increase.

Results from the model bear out these relationships. Subbasins with high sediment yields are located in Finch Creek and are associated with the Emmet-Montcalm series (MI107); subbasins 23, 22, 16, 14, 13 and 11. Soil types included within this series have poorer infiltration characteristics (soil hydrological group of B, Emmet, Omena and Charlevoix and A, all others). Area weighted soil erodibility for this series is 0.20. In contrast, the other three soil series (MI117, MI116 MI132) contain soils with hydrologic group of A predominantly and slightly lower soil erodibilities (0.15, 0.17, and 0.12, respectively). This led to higher runoff curve numbers and greater soil erosion, despite the dominantly undeveloped (deciduous forest, rangeland, and evergreen forest, range) land cover. Subbasins 23 and 22 had the highest sediment yield within the Emmet-Montcalm soil series because the former has considerable area of agriculture and because the latter also has a high slope. The urbanized areas located in Shanty Creek (subbasin 18) do appear to have an effect on sedimentation predicted by the model, the load from this subbasin is 50.1 tons/year at the outlet located at M88. The watershed averaged sediment erosion rate is 35.9 tons/yr/km^2 which is above what would be expected from a dominantly forested subbasin (see Table 6). Urbanized HRUs in subbasins 2,5,10 did not seem to have a significant sediment erosion rate (all are 15 tons/yr/km^2 or below), however subbasin 3 did with an average yield of 56.4 tons/yr/km^2.

The resolution of the original land cover data (30 by 30 meters) means that many of the roads will not be assigned as developed land cover. This will be exacerbated by the assumed percentage of landcover and soil type, used to develop hydrological response units. The values used were 5 and 10% respectively. Only subbasins where urban development contributes more than 5% of the subbasin area will contain a HRU unit that is assigned as urban landcover in the model. In this watershed, subbasins 1,2,3, 5, 10 and 18 all had HRUs with urban landcover. The question is to what extent is runoff and sediment from roads not being captured by the model. It should be noted that curve numbers for undeveloped land use classes have been assigned values that assume 3% of the area is impervious (to incorporate the effects of roads).

The field assessment identified many sites where runoff from unpaved roads could be introduced into the stream network (see Table 5 and **Figure 5**). There were also undersized culverts with erosion associated with them. Previous studies by Reid and Dunne (1984) and Madej (2001) suggest that unpaved forest roads can be major sources of sediment. This is especially true for dirt roads that undergo high vehicular travel rates. The former study determined that a dirt road undergoing heavy traffic can produce 130 times the sediment from the same road with no traffic. Many of the roads in this watershed are unpaved and experience traffic all year round from people that live in the watershed. Recreational use of these roads probably increases dramatically in the summertime. Road stream intersections should be managed better. Increases in road density or the recreational use of roads could cause an increase in sediment erosion over time.

FURTHER WORK

The next step in this study is to calibrate the model for water balance and to validate it using our field observations. The following are known weaknesses of the model which ought to be addressed.

1) The land cover used is coarse resolution (30 by 30 meter pixel) and does not pick up even large highways such as M88. Aerial photography should be used to produce a new landcover that reflects all anthropogenic imperviousness in the watershed. Bear in mind the resolution of the DEM (10 by 10 meters) puts a limit to how accurate we can be. One advantage of doing this is that the model will use the USGS build up and wash off algorithms for predicting sediment loading over a larger portion of the watershed. However if the areas of development are small relative to the subbasin it may not matter.

2) Urban areas at the western end of Shanty Creek were suspected by stakeholders to be a significant source of sediment. The reason for this are field observations taken by volunteers of the Three Lakes Association along the creek, the presence of a golf course and condominium developments without storm water infrastructure. Volunteers noted visual evidence of channel bank erosion that were believed to be caused by storm runoff originating from the development. Model sediment yields were above what would be expected from a forested watershed (see figures 3 and 4). Continued sampling and flow monitoring of this site is essential to determine the true impact that this development has on Shanty Creek.

3) Volunteers of the Three Lakes Association identified two dams in Shanty creek. The question is should these be explicitly parameterized in the model. A considerable amount of

work would be required to parameterize these features. The question is, is it justified if these features have low reservoir storage values and will probably not cause hydrograph attenuation. Putting these reservoirs in the model will cause more deposition to take place in the stream network and will likely reduce the sediment load reaching Grass River predicted by the model.

3) Course resolution STATSGO soil data was used to developed hydrologic response units in this study. At this resolution, there are only four soil mapping units in the watershed. SSURGO soil data would greatly increase the number of soil mapping units and HRUs as well as the spatial variability of curve number, soil erodibility and other soil-related variables used by the model. This increase in spatial variability comes with a significant increase in time and resources required to calibrate the model.

5) The model results agree with the discharge data collected by the Three lakes Association (Endicott, 2007), which suggests that the creeks in descending order of importance are Finch, followed by Cold Creek followed by Shanty Creek. Field observations of flow and sediment at the three outlets should be continued to verify this. Much of the sampling that has taken place has been in the low flow period of June through September. We need more sampling during the winter and spring as these seasons tend to have greater sediment loads.

CONCLUSIONS

A hydrologic model developed for the three major tributaries of the Grass River suggest that all contribute significant volumes of sediment to the river. Finch Creek was most important, contributing on average 401 tons of sediment per year. This occurs near the outlet of the Grass River at the eastern end of Clam Lake. Cold Creek is next important, contributing 166.8 tons of sediment per year. Shanty Creek contributes 50.1 tons of sediment per year, not far upstream from where Cold Creek empties into Grass River. It is likely that all three of these tributaries are partly responsible for the sedimentation issues seen by stakeholders in the Grass River. Together, these tributaries introduce 363 cubic meters of sediment every year to the river. This is equivalent to over 13 dump truck volumes of sediment. Actual sediment loads from these tributaries are probably higher, as the model does not account for groundwater inputs which were observed in the field. Including groundwater inputs into the model, not possible now due to the paucity of field data, will increase sediment loads. Further work should collect additional field data in order to parameterize the model to account for groundwater inputs and fully calibrate the model for water balance and sediment. Field assessments of stream road intersections in the watersheds associated with these tributaries suggest that there is erosion occurring around culverts, and that erosion from unpaved roads may be occurring. These are sites of concern which should be addressed watershed planners in order to reduce the sediment loads coming from these tributaries.

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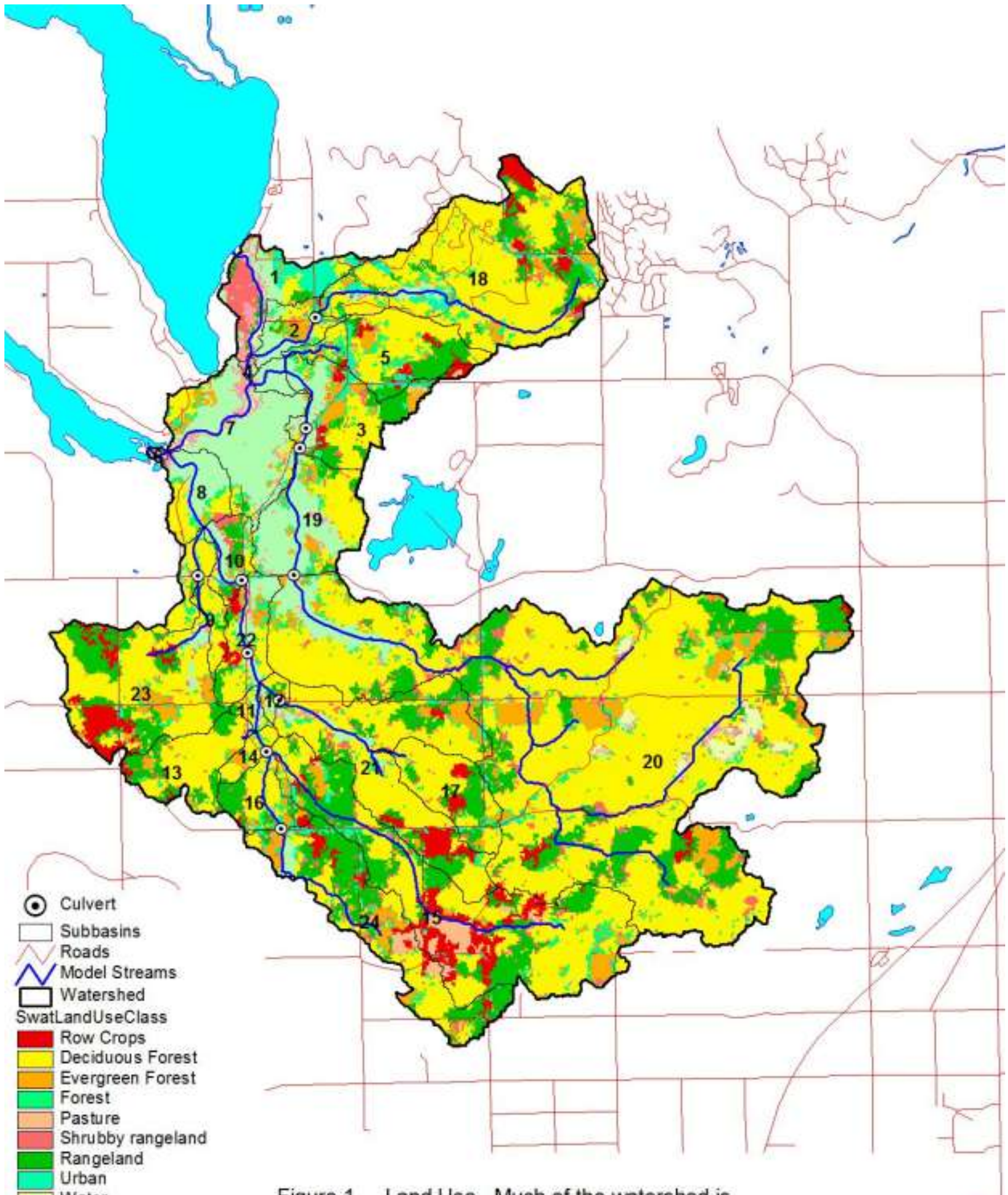

Figure 1 Land Use. Much of the watershed is covered by forest, wetland and forected wetland.

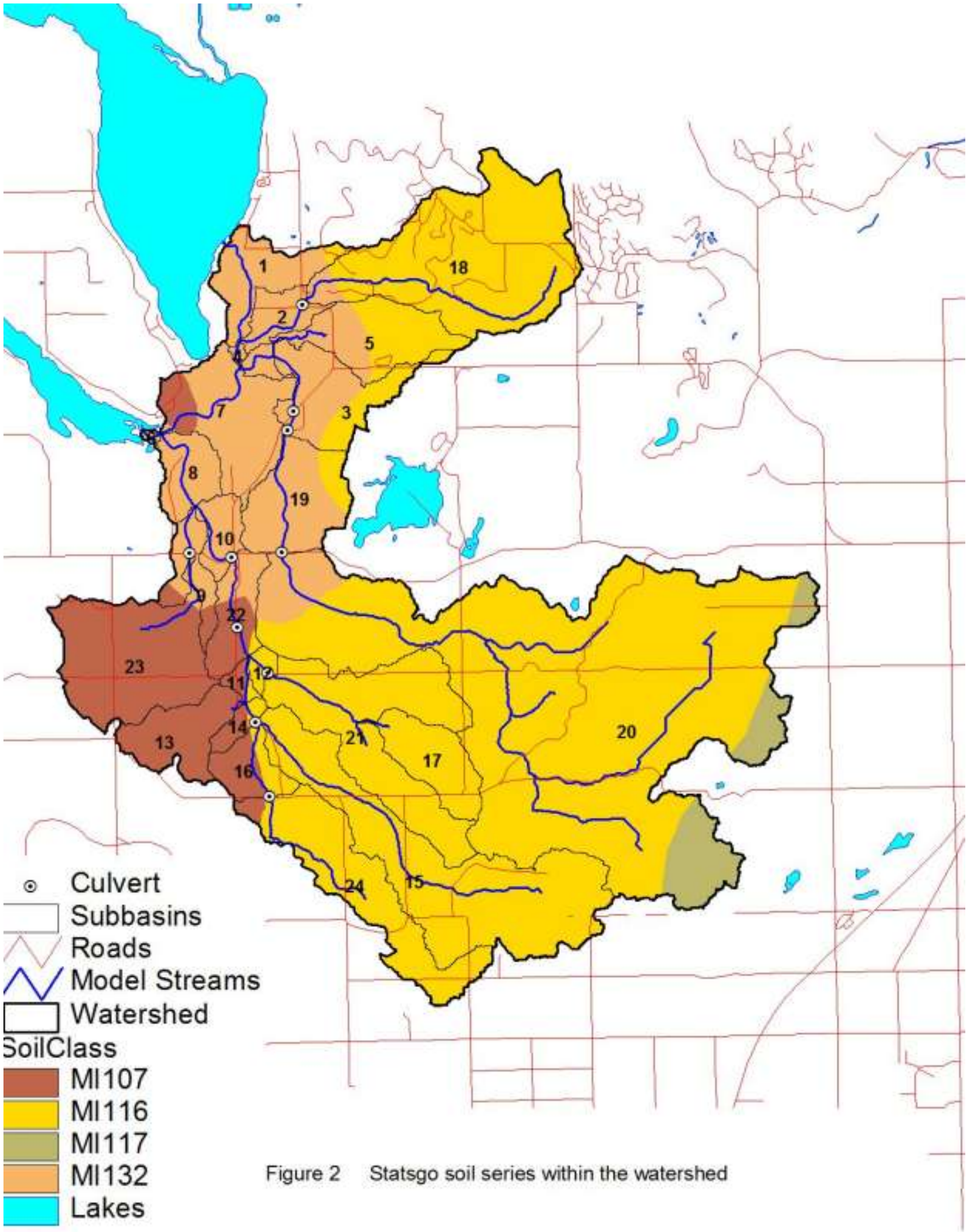

Figure 2 Statsgo soil series within the watershed

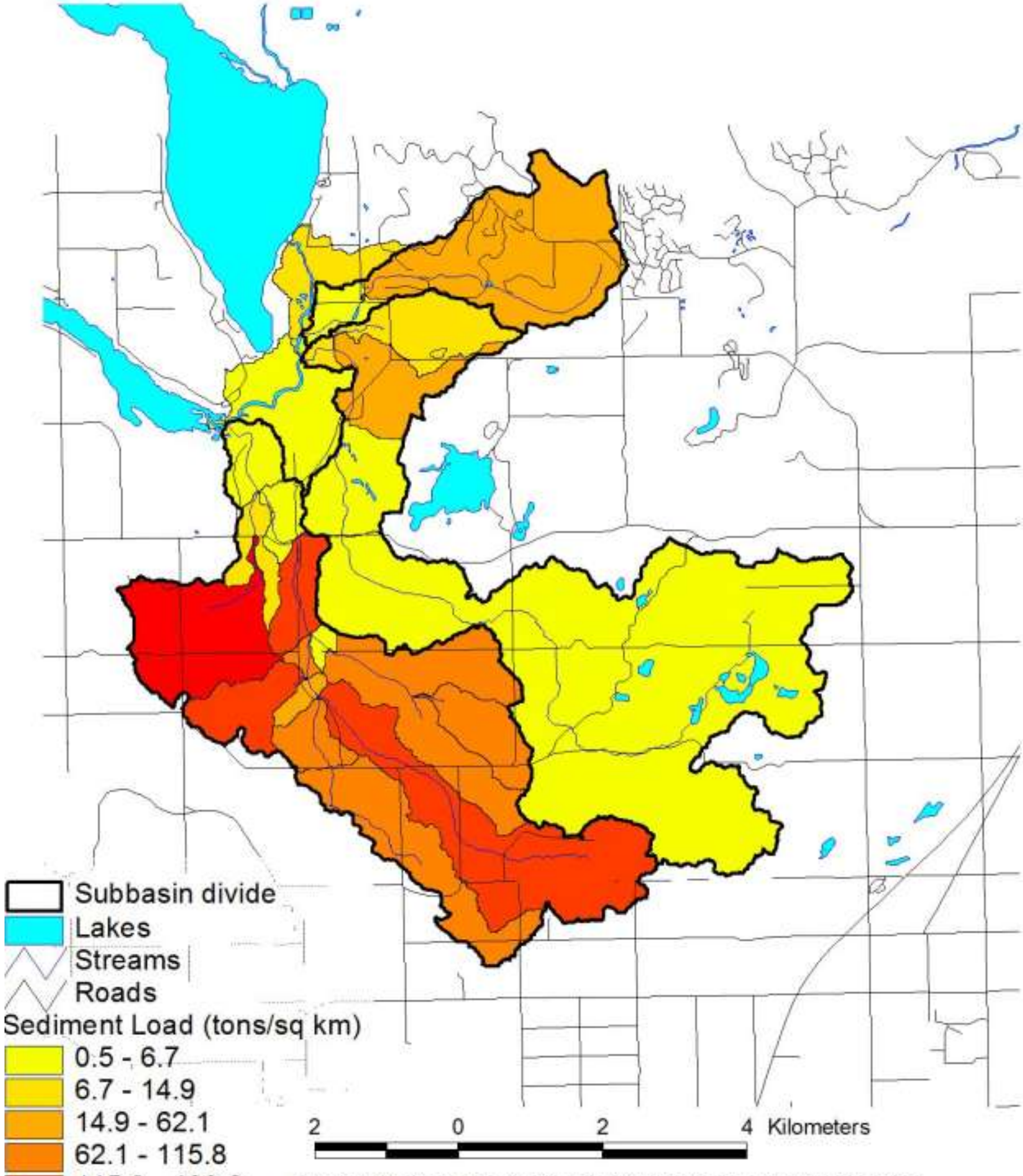

Figure 3 Sediment load per unit watershed area computed by the model for subbasins. The results indicate that subbasins associated with Finch Creek are areas of concern.

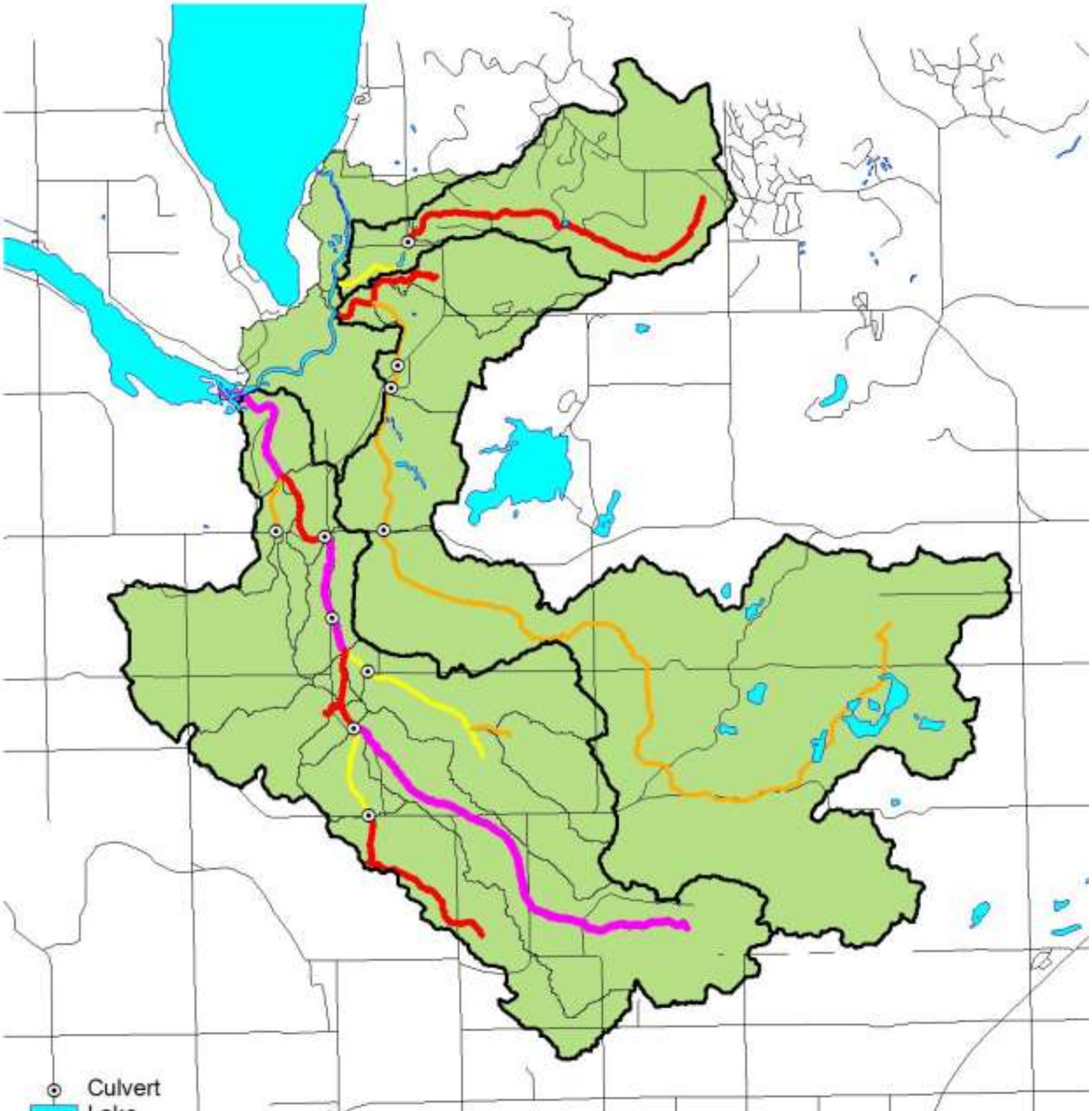

Figure 4 Sediment loads in individual stream reaches. Note there are stream reaches where deposition is taking place.

Figure 5 1: Erosion control structure in Shanty Creek. 2: Shanty Creek at M88. 3: Cold Creek at Tyler Rd. 4: Finch Creek tributary 5: Erosion gully leading from unpaved rd to Finch Creek Tributary. 6: Steep, unvegetated slope adjacent to unpaved road (Finch Creek). Many stream road intersections in the watershed offer little protection from sediment washed off directly from unpaved roads.