Bostic & Zippel Creeks Watershed Assessment

Lake of the Woods County, Minnesota

USDA
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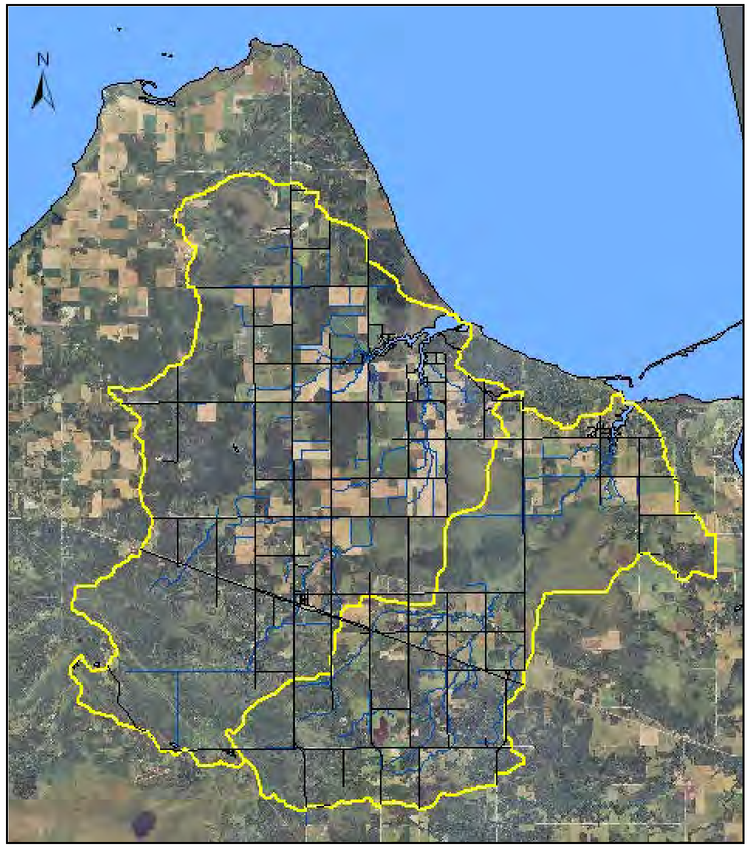

January, 2013

Table of Contents

Figures

Appendices

Appendix A – Sediment Budget Process

Appendix B – RUSLE Sheet and Rill Erosion Analysis

Appendix C – Ephemeral Erosion Analysis

Appendix D – Channel/Ditch Erosion Analysis

Appendix E – Sediment Delivery Ratios

Appendix F – Potential Stream Bank Erosion Analysis

Appendix G – Magnum Pond Sediment Survey

Appendix H – Zippel County Ditch 1 Voiding Analysis

Appendix I – Hydrology/Hydraulics Models

Appendix J- Field Reviews/Meetings

I. Introduction

Erosion within the Bostic and Zippel Watersheds in Lake of the Woods (LOW) County and the resultant sedimentation of bays and channels has been identified as a significant resource concern by local government, natural resources agencies, land owners, and other business interests. In addition to the sedimentation issues, local resource managers also identified flooding, water quality, and wildlife habitat degradation as resource concerns. The purpose of the Bostic and Zippel Watershed Assessment Project was to evaluate the sources and transport of sediments through the hydrologic system from the watershed headwaters downstream to Zippel and Bostic Bays. Current conditions are evaluated along with estimates of past sedimentation rates to provide context. In addition to quantifying the movement of sediments, structural and non-structural sediment reduction alternatives were evaluated.

An initial request for a watershed assessment came to Natural Resources Conservation Service (NRCS) – Water Resources Staff in 2008 from the LOW Soil and Water Conservation District (SWCD). A site visit to tour the watersheds and hear local concerns occurred in November 2008. Members from the LOW SWCD, LOW County Public Works, Minnesota Department of Natural Resources, and the local/state office NRCS Staffs participated in this field review. Following the field review, a detailed plan of work (POW) was developed. In March 2009, NRCS received an official request from the LOW SWCD to perform the assessment. From 2009 through 2011 NRCS personnel made field trips to the watershed to inventory conditions. A sediment budget, which describes the source and fate of eroded sediments on a watershed scale, was developed using a combination of field measurements and GIS. The sediment budget models sediment movement for both present and past conditions as well as "what if" scenarios (impacts of changing land use management or levels of ditch maintenance).

II. Watershed Setting

Size, Topography, and Geologic Setting

Bostic and Zippel watersheds are located in Lake of the Woods County and are 36,380 acres and 63,440 acres in size respectively. See Figure 1. The watersheds are approximately 15 miles northwest of the county seat of Baudette, population 1,106 (2010 census). Both watersheds drain in a northeast direction and outlet into the Lake of the Woods through Four Mile (Bostic) and Zippel Bays. The Canadian Pacific Railroad and Minnesota State Highway 11 run parallel to each other in a northwest to southeast direction across the upper third of both watersheds. Williams, population 191 (2010 census) is the largest city within the study area. It is located on Williams Creek within the Zippel Creek watershed along State Highway 11. The small community of Graceton is located along State Highway 11 near Canfield Creek within the Bostic Creek watershed.

The character of each watershed's topography and soils is largely due to events that occurred during the last glacial period. Approximately 13,000 years ago, much of Manitoba, northwestern Ontario, northern Minnesota, and eastern North Dakota were covered by an immense glacial meltwater lake known as Glacial Lake Agassiz. When the glaciers finally retreated and meltwater drained, it left behind a series of large sandy beach ridges in Lake of the Woods County. The most prominent northwest to southeast beach ridge within the study area is known as Campbell Beach. This beach ridge bisects both Bostic and Zippel watersheds creating a distinct land form separation. State Highway 11 runs approximately 1 mile south and parallel to this beach ridge. The watershed north of the beach ridge is part of the Glacial Lake Agassiz near shore lake bottom with a gentle slope toward the Lake of the Woods. Wave action during the retreat of Glacial Lake Agassiz was responsible for smoothing out the landscape north of the beach ridge. During this period depressions were filled in and knolls leveled leaving much of area with poor natural drainage. Channels in this area were shallow waterways with well defined floodplains.

Figure 1 - Project Map

Figure 2 provides a general topographic perspective of the Zippel Watershed. This shows a profile cut line A-A' from the watershed divide to the Lake of the Woods. Highway 11 and the Campbell Beach ridge are identified. Total relief from top to bottom is approximately 175 feet. In general, the steepest area is found from State Highway 11 northeast to the beach ridge with a fall of approximately 35 ft/mile. The area northeast and southwest of beach ridge has a fall of approximately 12 ft/mile.

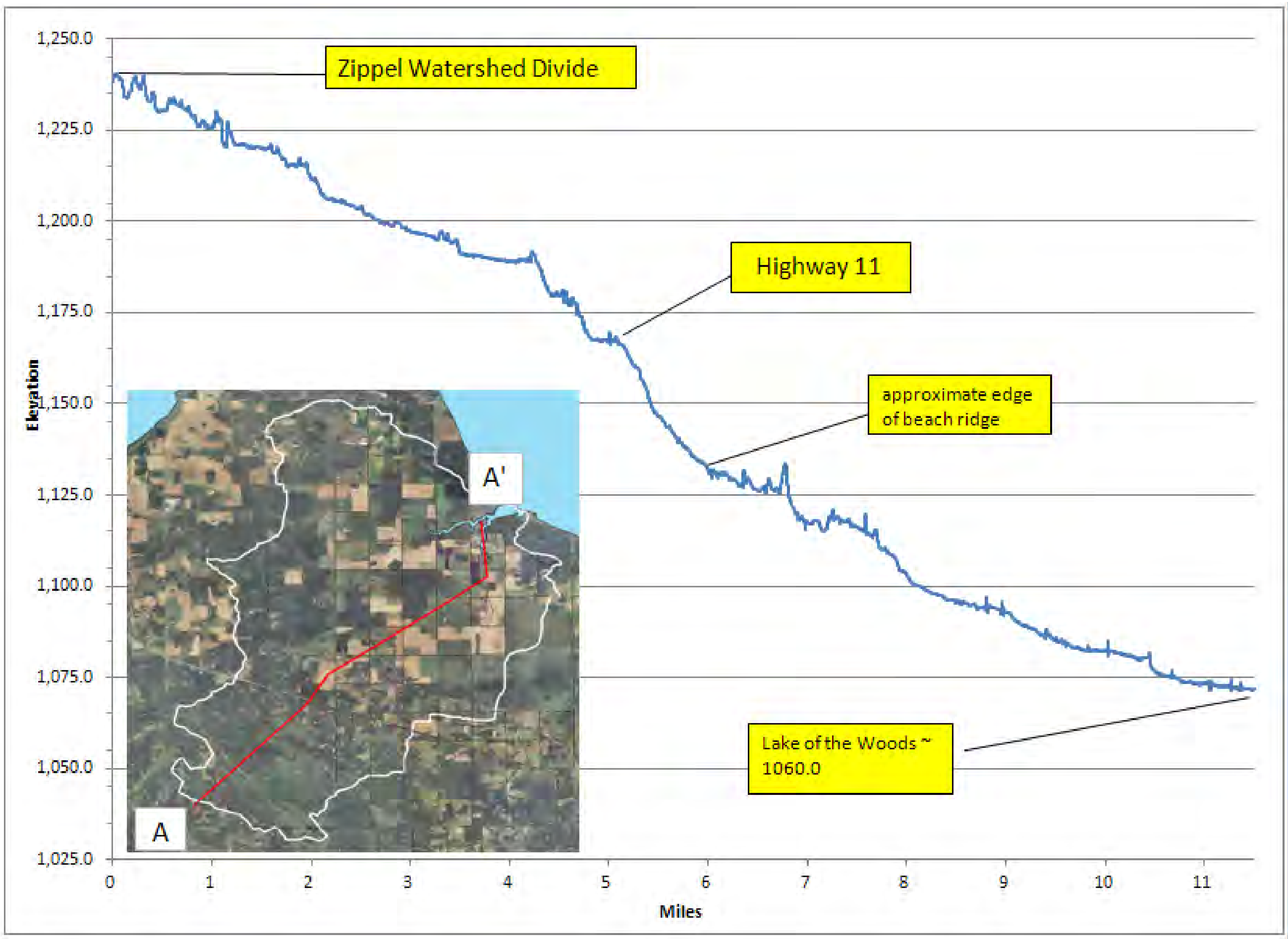

Figure 2 - Southwest to Northeast Elevation Profile Across Zippel Watershed

Climate/Runoff

Lake Of The Woods County has a continental climate with very cold winters and relatively cool summers. During the winter, cold, dry continental polar air dominates while growing seasons experience both hot/dry tropical air masses from the southwest and warm/moist maritime tropical air from the Gulf of Mexico. High intensity thunderstorms are common throughout the summer. Spring and fall seasons are transition periods where air masses from a variety of sources can occur.

Using data from the NOAA Baudette Climate Station, the average annual temperature for the watersheds is 39 degrees F. Annual maximum and minimum temperature extremes occur in July (79.9 degrees F) and January (-7.6 degree F) respectively. On the average, temperatures are above 32 degree F for 121 days (May 21 through September 19).

Average annual precipitation is 22.4 inches. Average total snow fall is about 43.1 inches. Of the 22.4 inches of rainfall, approximately 6 inches leaves the watershed as runoff (Average Annual Runoff 1961-1990 Map – USGS/DNR). The remainder, 16.4 inches, evaporates or is transpired by plants (ET - EvapoTranspiration).

Soils

Soils within both watersheds were derived from lacustrine (lake-laid) deposits, reworked glacial till, and sand beaches left by the retreating Glacial Lake Agassiz, primarily under a forest-type vegetation. The area between the beach ridge and the Lake of the Woods is made up of lake-laid clays and glacial till interspersed with peatlands. The peatlands were formed as the cool, wet, poorly drained conditions inhibited the decomposition of vegetation. Graceton Bog located northeast of Williams in the Bostic Creek watershed is an example of the type of peatlands that developed during this period. In most of these peatlands, the organic layer is shallow (< 2 feet) with clayey lacustrine deposits and loamy glacial till beneath. In some areas, sand is found underneath the peat.

Figure 3 displays the STATSGO General Soils Map for both watersheds. Below are the descriptions of the dominant associations.

- Chilgren-Garnes-Percy Association – Nearly level and gently sloping, poorly drained and moderately well drained soils that formed in loamy till on glacial lake plains and till plains.
- Indus-Taylor-Clearwater Association – Nearly level and gently sloping, poorly drained and moderately well drained soils that formed in clayey glacial lacustrine sediments on glacial lake plains.
- Marquette-Karlstad-Faunce Association – Nearly level to moderately steep, excessively drained to moderately well drained soils that formed in sandy or gravelly sediments or in a loamy or sandy mantle overlying sandy and gravelly outwash on glacial lake beaches, lake plains, or outwash plains.
- Redby-Hiwood-Cormant Association – Nearly level and gently sloping, very poorly drained to moderately well drained soils that formed in sandy sediments on glacial lake beaches, glacial lake plains, and outwash plains.
- Spooner-Baudette Association – Nearly level and gently sloping, poorly drained and moderately well drained soils that formed in silty glacial lacustrine sediments on glacial lake plains.

In general, the beach ridge is comprised of the Chilgren-Garnes-Percy and Marquette-Karlstad-Faunce Associations while bog areas fall within the Redby-Hiwood-Cormant Association.

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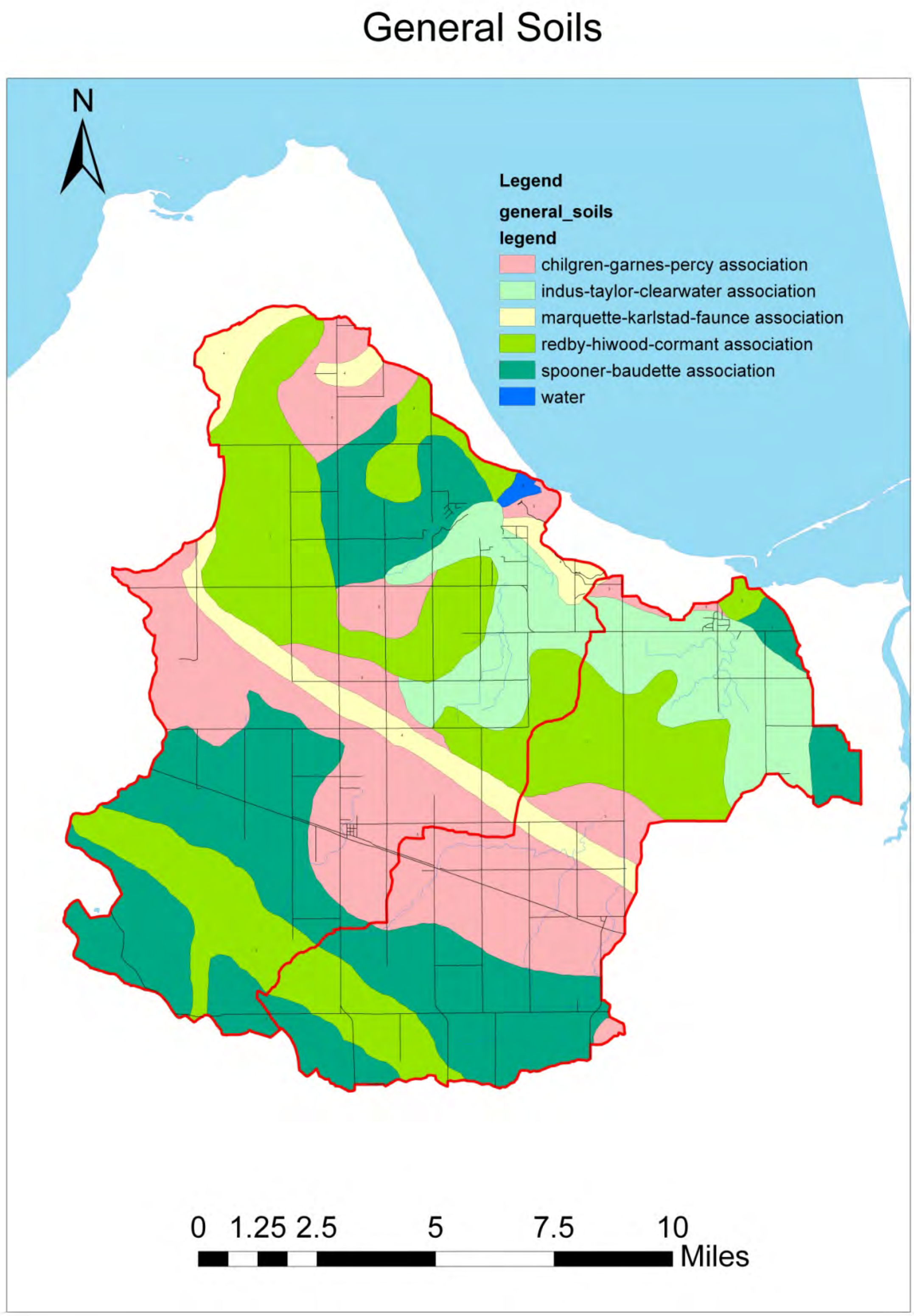

Figure 3 - STATSGO General Soils Data

Land Use

Pre-Settlement/Early Settlement

Figure 4 shows the general pre-settlement land cover of the two watersheds. This information comes from F.J. Marschner's 1930's compilation and interpretation of the State's original land survey notes. These notes were based on observations taken during 1848 - 1907. The figure shows a general pattern of Conifer Bogs and Swamps north and south of the beach ridge with Jack Pine Barrens-Openings and Aspen-Birch along the beach ridge itself. The lower reaches of Zippel and Bostic Creeks have an Aspen-Birch cover.

During the late 1700's through mid 1800's, the region in and around Lake of the Woods was active in the fur trade as a transport link for goods moving from the interior of Canada out through the Great Lakes. Logging followed the fur trade as the major industry with sawmills at Baudette and Spooner. The arrival of the Canadian National Railroad in 1901 was a major factor in accelerating development of the area. Intensive logging during the period from 1900 to 1920 practically exhausted the original timber stands in the county. As is the case in other parts of Minnesota, this naturally made way for agriculturally based settlement. In the fall of 1910, a large forest fire burned over northern Lake of the Woods County. This devastating fire practically destroyed the cities of Baudette and Graceton. One consequence of this fire is that it enhanced land clearing conditions which further accelerated a land use shift towards agricultural use.

Early farming enterprises relied on both livestock and crop systems. In this pre-commercial fertilizer period, crop rotations and manure treatments were important. This livestock and rotation requirement necessitated larger acreages hence an acceleration of clearing and improving land. Areas that were naturally or intentionally burned over were cheaper to convert to cropland. Areas with shallow peat provided the additional benefit of enhanced organic matter compared to mineral upland soils. Deep organics, of course, could not be adapted to agricultural uses due to lack of drainage and an underlying mineral soil to mix with for providing a reasonable structure for supporting crops.

Also during this period in the early 20th century, extensive ditch systems were put in place with the hope of improving conditions for logging access and agricultural production. Within the Bostic and Zippel watersheds, ditching focused on improving drainage within the peat bog areas. Not all attempts at drainage were successful. Traces of abandoned ditches can still be seen in current aerial photos. Drier conditions combined with more fires during the 1930's led to a rapid expansion of the agriculture industry.

The tourism industry got its foothold in the early 1920's as resorts were built along the Rainy River and shores of Lake of the Woods. Several successful resorts still exist today at the outlet bays of the Bostic and Zippel Watersheds.

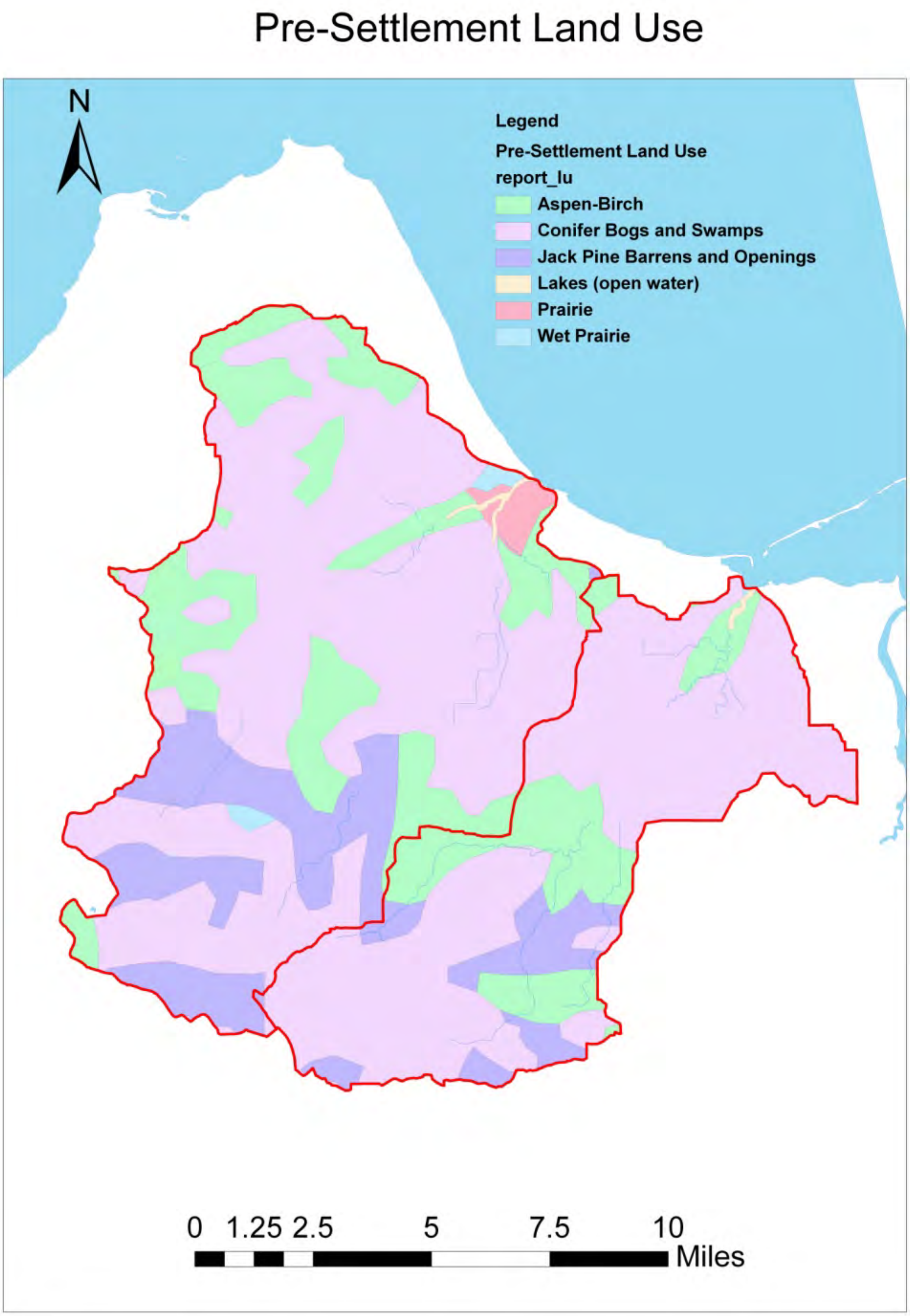

Figure 4 - Pre-Settlement Land Use

1925 Soil Survey Land Use

The 1925 Lake of the Woods Reconnaissance Soil Survey describes principal crops as potatoes, flax, wheat, and cultivated hayseed crops with dairy and poultry products furnishing a large part of farm income. The 1925 agricultural census estimated that 16 percent of the county was in farms. Table 1 summarizes percentages of agricultural land use for the county.

Table 1 - Lake of the Woods County Land Use - 1925

Farm Acreage Use	Percent of Total Farm Acreage
Pasture	20%
Acreage needing Clearing/Drainage	60%-65%
Crop (potatoes, flax, wheat, cultivated hayseed)	15%-20%

Cropping Trends – Agricultural Census 1940-2009

Agricultural Census data for Lake of the Woods County from 1940 through 2009 were analyzed for trends in types of agricultural crops and rotations. Figure 7 and Figure 8 display trends for major crops and livestock numbers within the County. In general, the trend has been from livestock oriented operations with hay/grain for feed in the rotations towards cash cropping. Specific trends to note include:

- Between the 2002 and 2007 census, soybean and small grain acreages have increased significantly.
- Potatoes had a relatively small, but consistent percentage of the total acreage up through 1997. The 2007 census shows an insignificant acreage of potatoes in the county.
- Hay has been trending downward since 1974
- Hogs, Sheep, and Chickens have been down trending since 1959.
- All cattle have been down trending since 1974 (Baudette Creamery went out of business in 1966). Cattle are currently the dominant livestock in the county.

1970's NRCS Planning Records

Watershed specific rotations used in the past were estimated by reviewing NRCS/SCS Conservation Planning folders from the late 1960'/early 1970's. The folders contained information for approximately 20% and 32% of all agricultural land in Bostic and Zippel watershed respectively. Table 2 below summarizes the percentages of various rotations for this period. As with Agricultural Census data, it shows that most cropland was used for small grains and hay with some grass seed.

Table 2 - 1970's Crop Rotations

Rotation	Both Watersheds	Bostic	Zippel
Hay/Grassland	31.5%	18.1%	35.3%
Pasture	24.5%	47.2%	18.2%
General Cropland (no description)	20.6%	14.4%	22.4%
Grass for Seed	8%	0%	10.3%
Sm Grain-Hay-Hay-Hay	6.2%	7.3%	6.0%
Sm Grain-Sm Grain-Clover-Clover-Fallow	5.7%	0%	7.4%
Sm Grain-Sm Grain-Sm Grain-Legume	2.5%	11.6%	0%
Sm Grain	0.8%	1.4%	0.6%

Recent Cropping Trends – CropScape Data 2006-2011

CropScape is an online GIS data source for the USDA National Agricultural Statistics Service Cropland Data Layer (CDL). The CDL is a raster based, geo-referenced, crop-specific land cover data layer and has a ground resolution of 56 meters. The Cropland Data Layer Program uses satellite imagery to provide acreage estimates to the Agricultural Statistics Board and to produce digital, crop-specific, categorized geo-referenced output products.

Figure 5 displays the general agricultural crops trend from 2006 through 2011 using the CropScape data. The plot shows, since 2008, a trend of reducing pasture/hay acreage while increasing soybean acreage. This trend may be explained by the concurrent increase in subsurface drainage installation which allows for more intensive management of cropland.

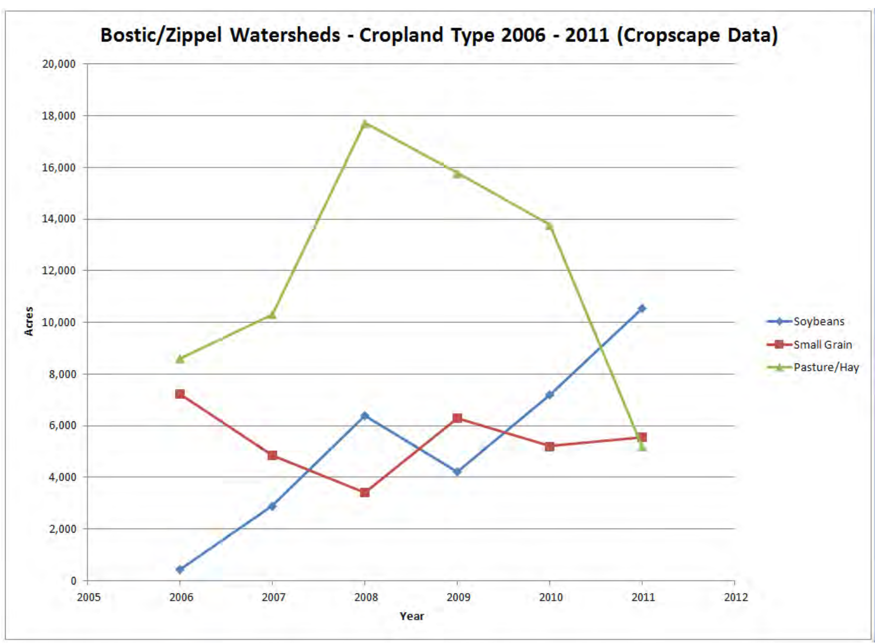

Figure 5 - Agricultural Land Use 2006-2010

Current Watershed Land Use/Land Cover – NRCS/FSA Records and 2006 NLCD GIS Layer

The Bostic/Zippel Watershed Assessment uses a combination of two data sources for "current land use conditions". Non-agricultural land cover areas utilize the 2006 National Land Cover Data (NLCD) while agricultural lands use a detailed analysis of NRCS/FSA field office records. Table 3 summarizes general land cover for both watersheds. Figure 6 displays this same information in map form. Figure 9 and Figure 10 display the same data, by watershed, in pie chart format.

The Zippel Creek watershed has a slightly higher percentage of agricultural land cover than Bostic Creek (27% vs. 21%). Bostic Creek watershed has a significantly larger percentage of wetlands than the Zippel Creek watershed (41% vs. 25%).

Table 3 – 2006 Land Cover Percentages

Land Use	Both Watersheds		Bostic		Zippel	
Forest (includes woody wetlands)	40,825 ac	40.9%	28,449 ac	34.0%	12,365 ac	44.8%
Wetlands	30,861 ac	30.9%	16,034 ac	40.8%	14,830 ac	25.3%
Agricultural Land	25,063 ac	25.1%	17,325 ac	21.3%	7,750 ac	27.3%
Developed	1,710 ac	1.7%	1,008 ac	1.9%	697 ac	1.6%
CRP	949 ac	1.0%	294 ac	1.8%	657 ac	0.5%
Open Water	410 ac	0.4%	330 ac	0.2%	81 ac	0.5%
Total	**99,820 ac**	**100%**	**63,440 ac**	**100%**	**36,322 ac**	**100%**

For the agricultural areas, NRCS and FSA records were used to determine cropping rotations for use in sheet and rill soil loss calculations. This data was gathered by NRCS and SWCD staff in 2010. Table 4 summarizes the percentages of rotations for the watershed while Figure 11 and Figure 12 display this information, by watershed, in pie chart format. General differences between the watersheds are summarized below:

- Bostic Creek watershed has significantly higher percentage of pasture/hay than the Zippel Creek watershed (37% vs. 11%)
- Zippel Creek watershed has significantly more acres of row crops (including small grain) than the Bostic Creek watershed (10,850 acres vs. 3,260 acres)
- Over half of rotations in Zippel Creek watershed have soybeans in the rotation (55%).

Within the past 5 years, many landowners have begun to install extensive subsurface drainage systems allowing for more intensive row cropping rotations such as soybeans. Subsurface drainage usually allows the soil to be worked earlier in the spring and can remove excess water in the soil profile faster than fields with surface drainage only. Changes in cropping systems are occurring rapidly within these watersheds due to subsurface drainage. For example, as of this writing in 2012, many of the bluegrass fields indentified in the 2010 inventory have been converted to row cropping systems.

Table 4 - 2010 Crop Rotation Acres (Percentage of all Cropland)

Agricultural Use/Rotation	Both Watersheds		Bostic		Zippel	
Small Grain-Soybeans	7,206 ac	28.7%	1,318 ac	17.0%	5,888 ac	34.0%
Wheat-Perennial Rye-Soybeans	3,643 ac	14.5%	0 ac	0%	3,643 ac	21.0%
Bluegrass	3,582 ac	14.3%	120 ac	1.6%	3,462 ac	20.0%
Hay	3,337 ac	13.3%	2,126 ac	27.5%	1,210 ac	7.0%
Timothy X6, Small Grain X3, Fallow	1,482 ac	5.9%	672 ac	8.7%	809 ac	4.7%
Pasture/Hay	1,466 ac	5.8%	715 ac	9.2%	742 ac	4.3%
Wheat-Soybeans-Wheat-Sunflowers	727 ac	2.9%	728 ac	9.4%	0 ac	0%
Oats-HayX5	631 ac	2.5%	331 ac	4.3%	299 ac	1.7%
Small Grain	420 ac	1.7%	208 ac	2.7%	212 ac	1.2%
Potatoes	414 ac	1.7%	35 ac	0.4%	379 ac	2.2%
Unknown Crop	2,160 ac	8.6%	1,484 ac	19.2%	663 ac	3.8%
Total Ag Land	**25,069 ac**	**100%**	**7,738 ac**	**100%**	**17,308 ac**	**100%**

2006 Land Cover

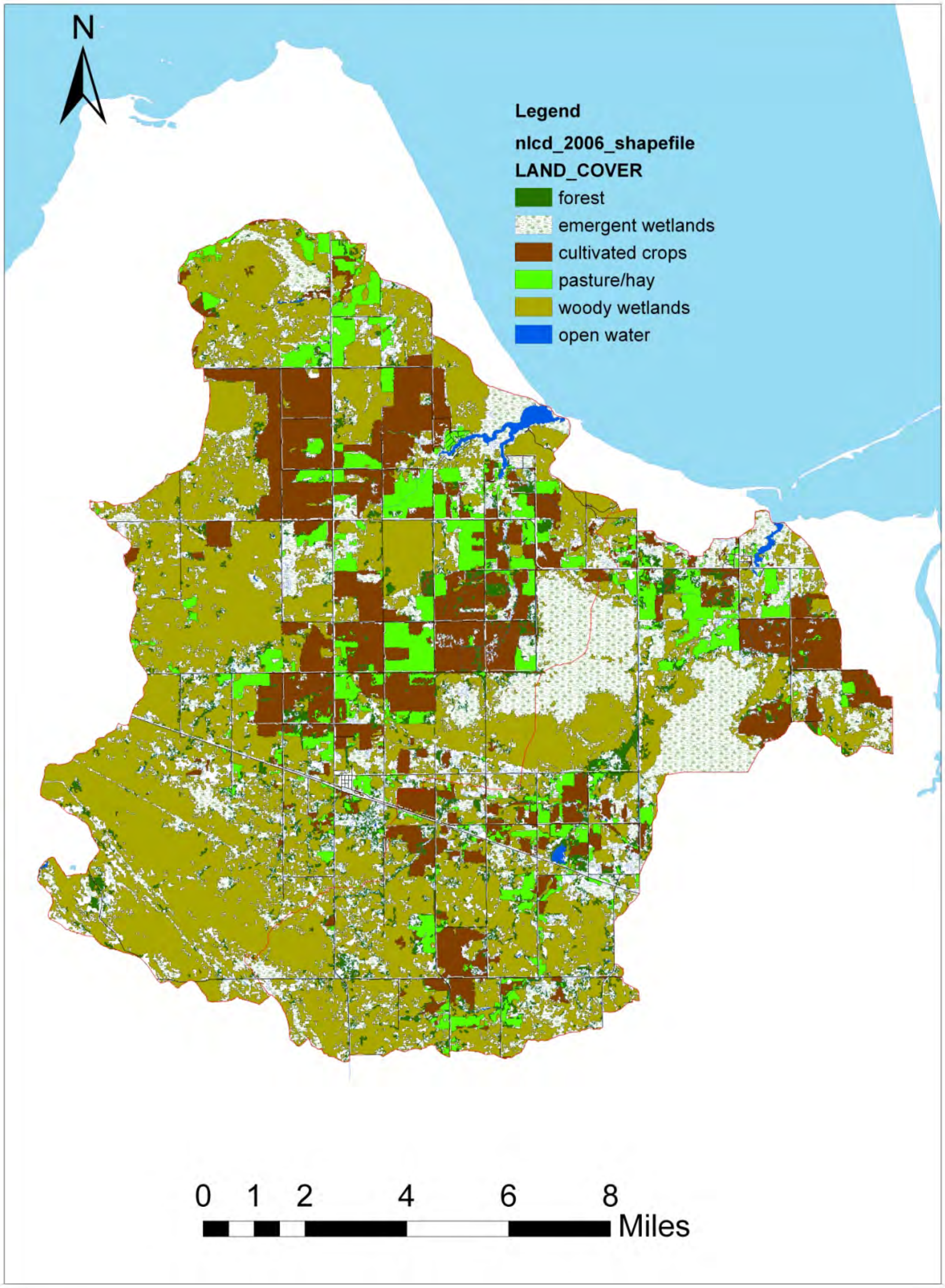

Figure 6 - 2006 Land Cover

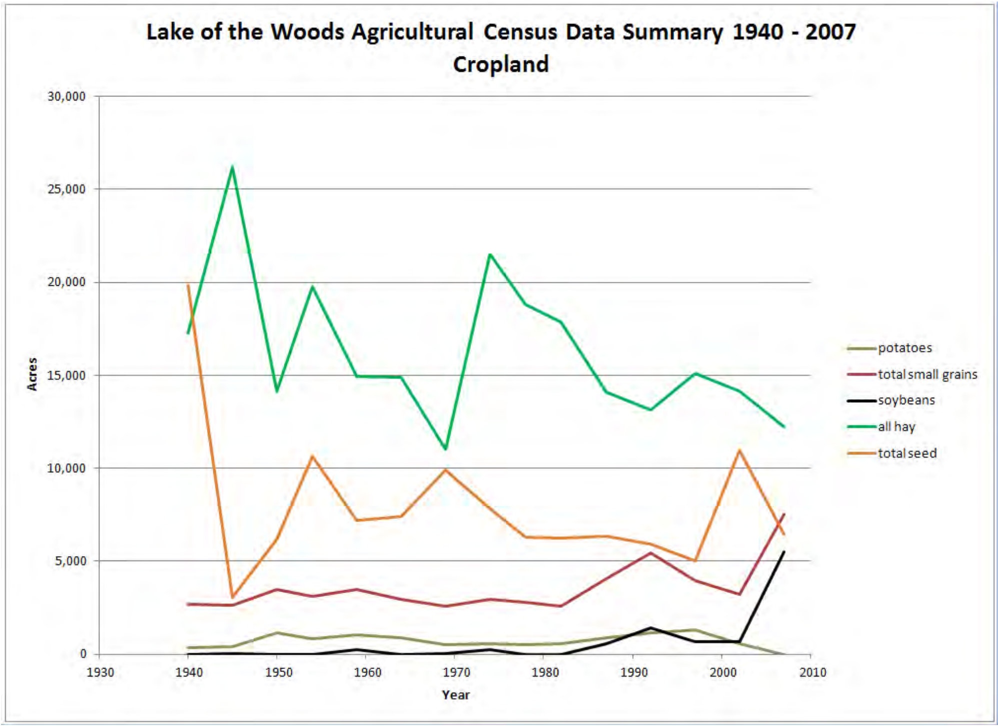

Figure 7 - Lake of the Woods County Ag Census Data 1940 – 2007: Cropland

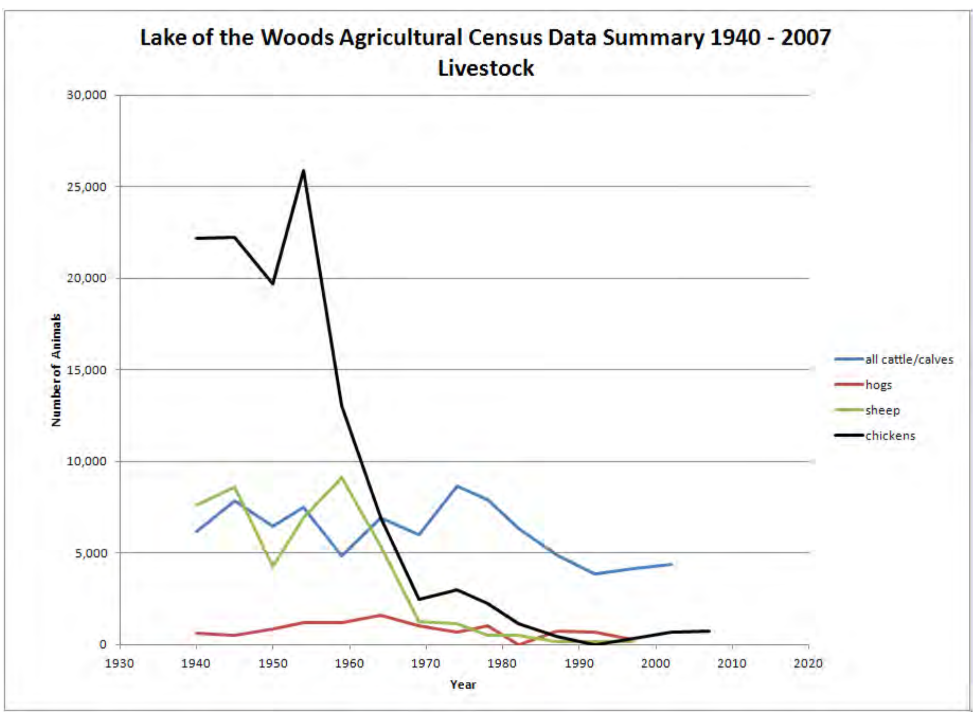

Figure 8 - Lake of the Woods County Ag Census Data 1940-2007: Livestock

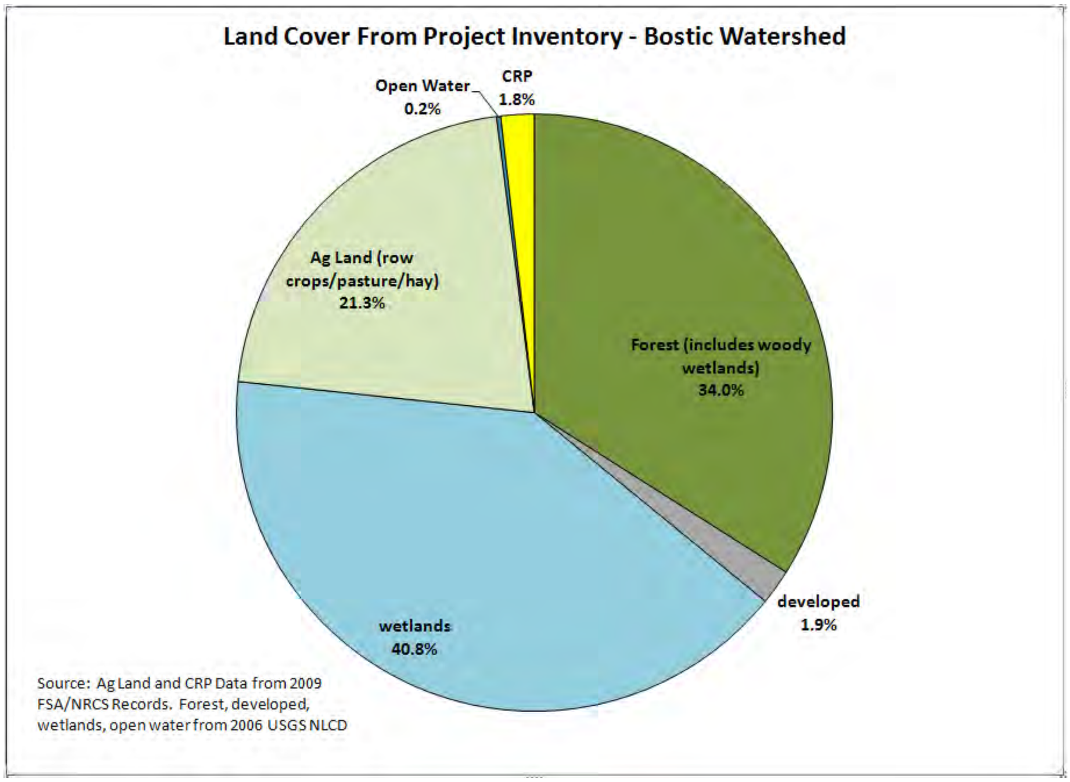

Figure 9 - 2006 Land Cover - Bostic Creek Watershed

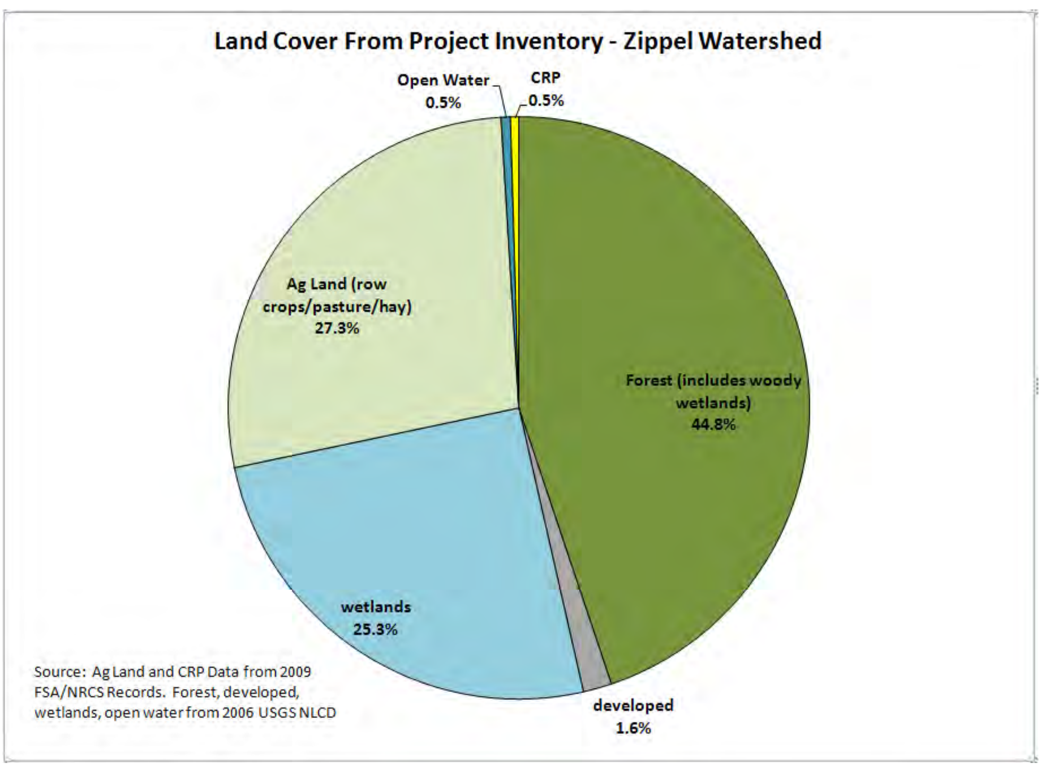

Figure 10 - 2006 Land Cover - Zippel Creek Watershed

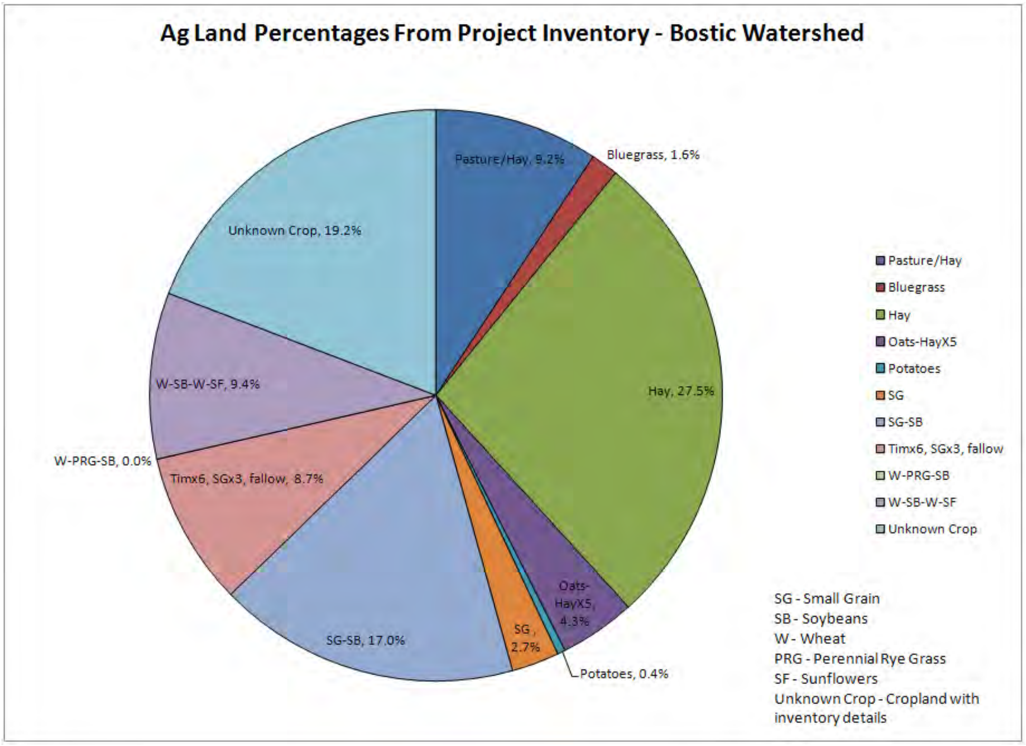

Figure 11 - Detailed Agricultural Land Use - Bostic Watershed

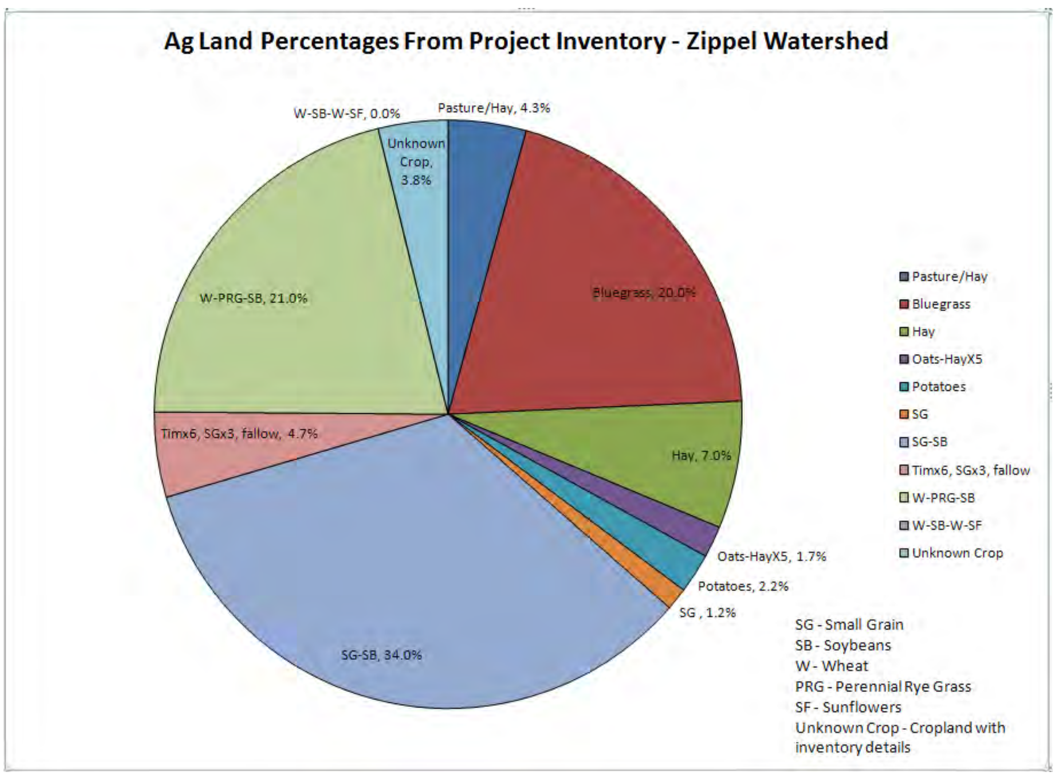

Figure 12 - Detailed Agricultural Land Use - Zippel Creek Watershed

Surface Ditch Systems

With the pre-settlement landscape, runoff would flow out of the upland bog/marsh areas then down through the beach ridge within well defined channel systems (Tomato Creek, Williams Creek, and Canfield Creek). Downstream of the beach ridge, the channels would enter the extensive peat bogs then seep out before exiting into Lake of Woods. Since flow patterns downstream of the beach ridge were not very distinct or direct, this type of landscape would tend to "meter" out the runoff.

The initial drainage efforts of the early 1900's were met with limited success. In the 1930's however, drier conditions, widespread fires on forest land and organic soils, improved dredging equipment, need for improved roads/transportation, and a rapid development of county wide agricultural economy saw the large scale drainage of the watersheds improve. Also, in 1966, an NRCS/SCS PL-566 Watershed Protection Project in the Zippel Creek watershed consisting of over 16 miles of large surface ditches was installed.

Currently, Lake of the Woods County serves as the authority for the ditches within the county and is responsible for repairs and maintenance. Figure 13 displays the current County and Judicial Ditch system for the two watersheds. For perspective, Figure 14 and Figure 15 are on-the-ground photos showing Zippel Creek CD-1 and Bostic Creek JD-16 respectively.

In both watersheds, main ditch and channel grades vary from a very flat, 1.0 to 1.5 ft/mile in the lower 4 to 5 miles of channel to a relatively steep slope of 10 to 12 ft/mile near State Highway 11 crossing. Figure 16 displays the main channel bottom grade from Four Mile and Zippel Bays (elevation 1060) to the headwaters for Bostic Creek and both branches of the Zippel Creek.

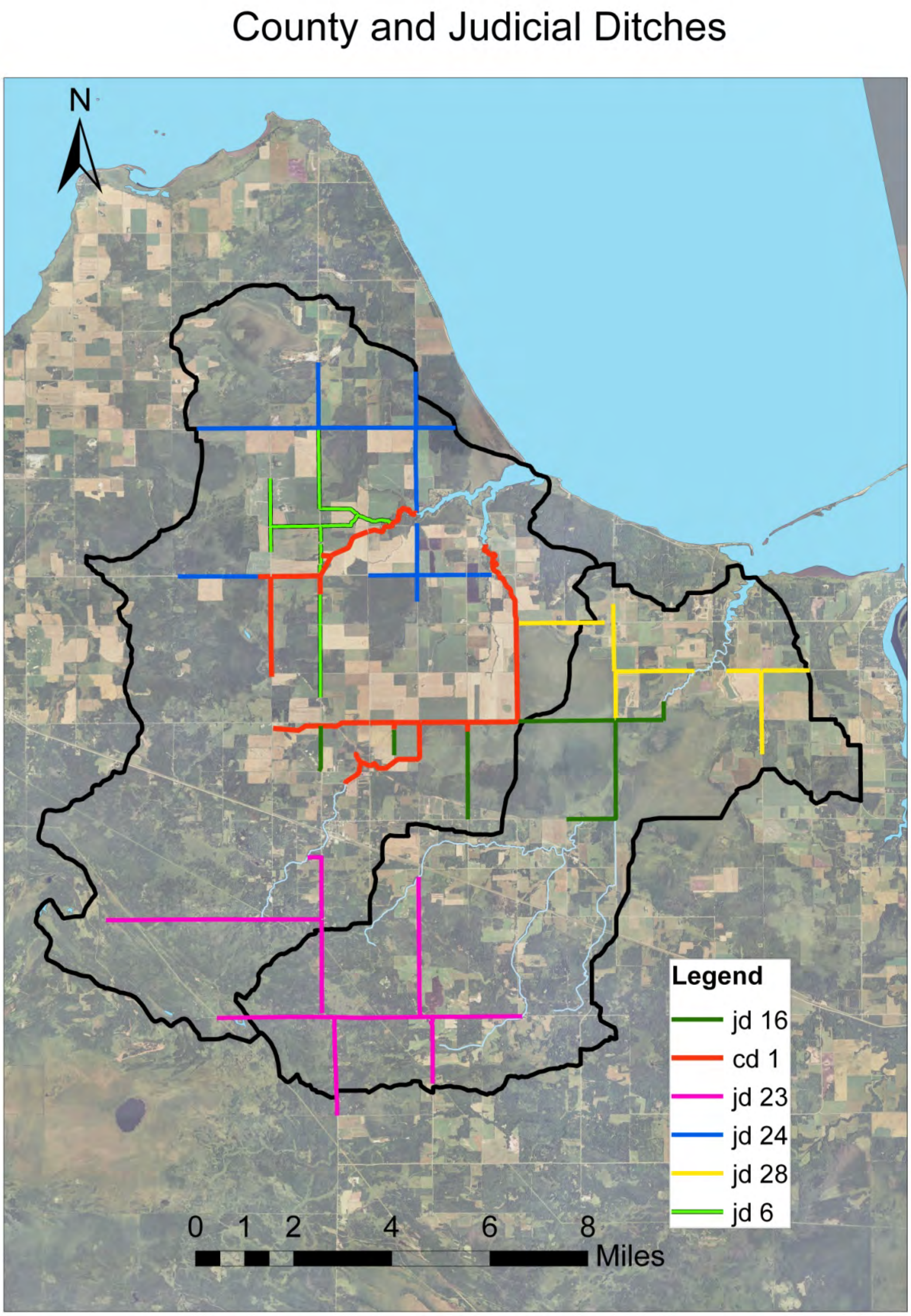

Figure 13 - County and Judicial Ditches within the Bostic/Zippel Creek Watersheds

Figure 14 - Zippel Creek County Ditch 1

Figure 15 - Bostic Creek Judicial Ditch 16

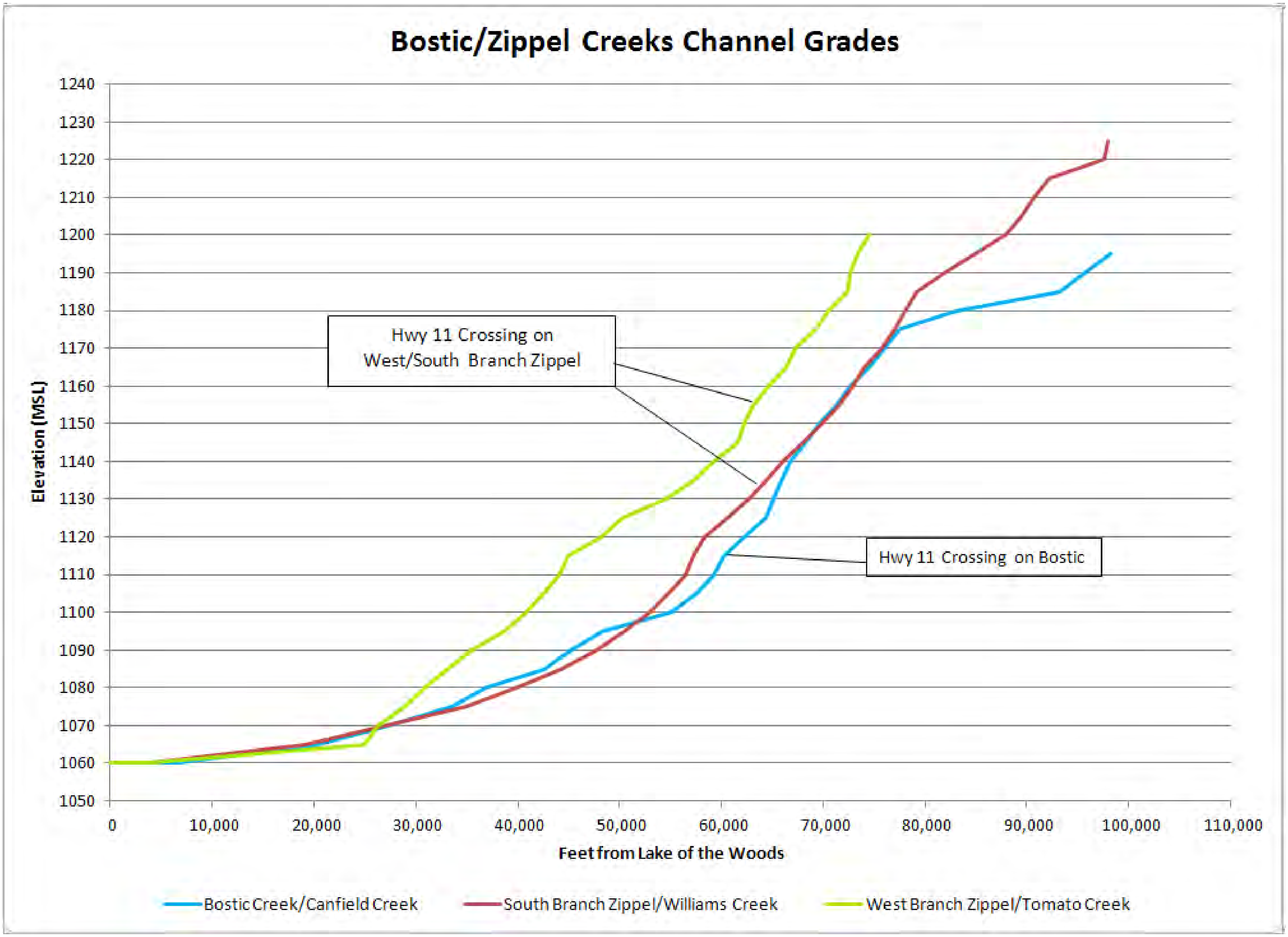

Figure 16 - Main Channel Grades in Bostic and Zippel Watersheds

III. Erosion and Sedimentation Issues

Local resource managers, county public works, private landowners, and other commercial interests within each watershed have expressed concern about turbidity and excessive sedimentation. From the Lake of Woods County perspective, ditch bank and channel bottom erosion and in-channel sedimentation are concerns. In the bays at the outlets of each watershed, resorts owners have navigation issues as sediments accumulate in boating lanes. Within the cropland areas, landowners are faced with providing non-erosive surface drainage from fields to county and judicial ditch systems.

Channel/Ditch Erosion

Maintaining the extensive County and Judicial Ditch system is the responsibility of the Lake of the Woods County Public Works. Ditch instability in the study area is largely a function of:

- runoff water velocities (function of channel shape, grade, vegetation)
- runoff volumes (durations of flows)
- the soil through which the ditch is constructed
- side slope pore water pressures
- channel shape irregularities

Figure 17 is an example of side slope erosion on Judicial Ditch 28 prior to stabilization measures installed by the county.

Figure 17 - Side Slope Erosion - JD28

The potential for channel erosion within the Bostic and Zipple watersheds was assessed with GIS technology using a combination of estimated stream power (function of discharge and channel slope) and the type of soils that channels and ditches run through. See Appendix F for details. Figure 18 summarizes the results of that analysis. The general trend of reaches which have high to very high potential erosion rates roughly correlate with the observations from field investigations (see Figure 22 - Current Average Annual Channel Erosion).

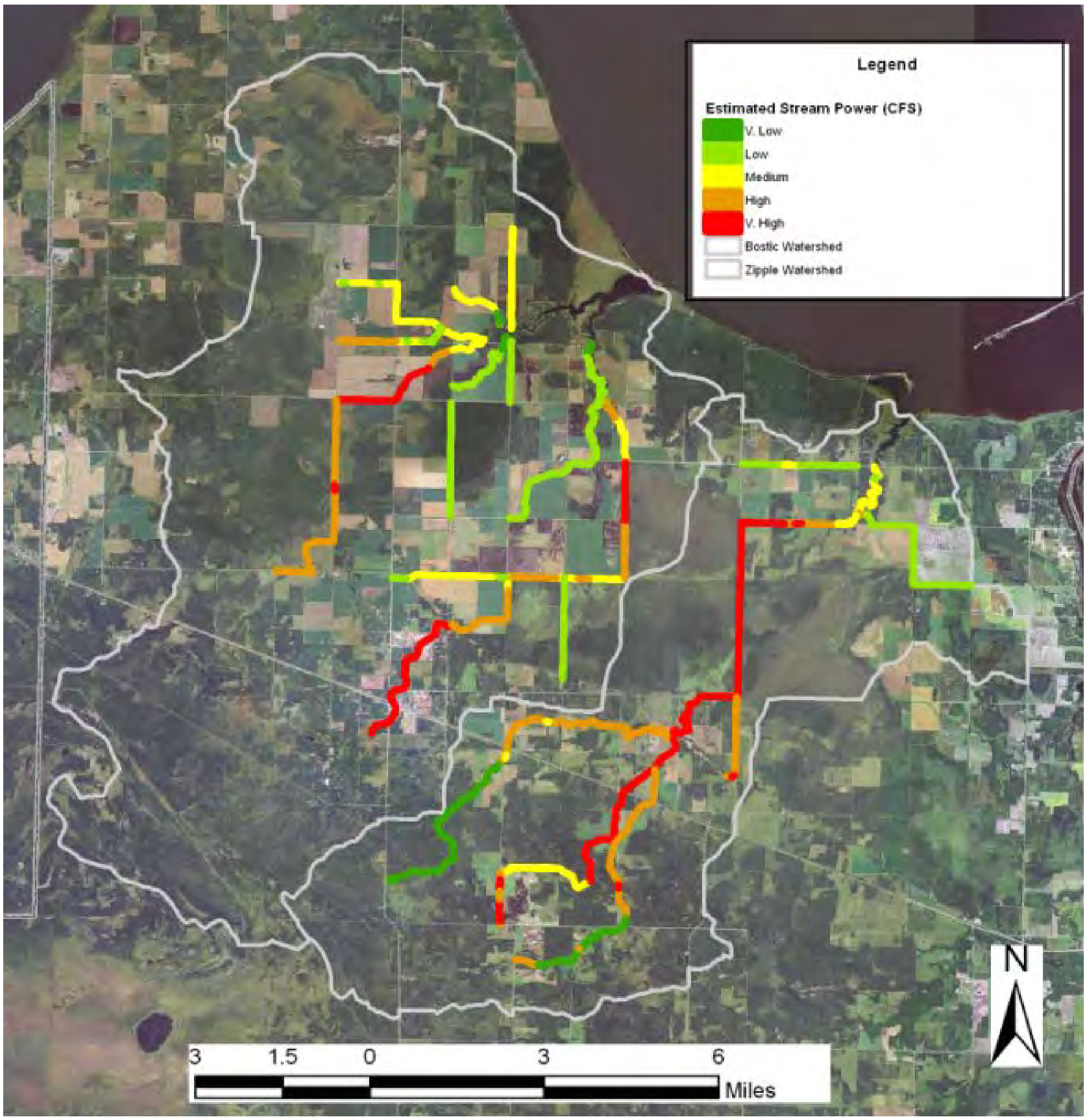

Figure 18 - Potential Channel Erosion Rates Based on Stream Power and Soils

Documented historic accounts of past ditch instability/extensive maintenance issues were difficult to find during this assessment, however, two specific cases were found:

1. 1972 Deficiency Report for the Zippel Creek PL-566 Project – After construction of this project in 1966, resort owners in South Zippel Bay noticed an acceleration of bay infilling. In 1972, the NRCS (Soil Conservation Service at the time), launched an deficiency investigation to determine if the project had resulted in accelerated erosion of the ditch system. The report concluded that the amount of channel erosion within the ditch itself was within an acceptable range however many of the original timber bridges were failing due to inadequate cutoff lengths. Also, the report suggests that much of the loss of open water may be due to Lake of the Woods lower water levels during this period. Below are relevant statements found in the August 1972 Deficiency Inspection Report:

   Channel Stability - "Some degradation of the channel system is evident except the lower of Tomato Creek (West Branch Zippel) ... This system was constructed in 1965 and 1966. It has been evident since 1968 on through 1970 that the system had undergone minor degradation ... The system as a whole has undergone some enlargement, mostly in the early years immediately after construction as is pointed out with respect to degradation of the system. There are some minor slope stability problems at a few isolated points. The condition of the channel does not indicate a design deficiency as the limited changes in grade and cross section are within the realm of expectations."

   Bridges – "The prime concern of the total system is with respect to the present bridge damage. The condition of the bridges has gotten to a critical point. They are fabricated timber box culvert structures ... We feel the problem with respect to the bridges is undermining of the structures" (needed deeper cutoffs ... design was not adequate to cope with ice damage). These timber bridges have since been replaced with concrete box and arch pipes.

   Influence of Lake of the Woods water levels – "This committee further feels that the problem mentioned in your letter is primarily due to a lowering of the water level in Zippel Bay of approximately 1 ½ feet since July 1969.

2. Zippel Creek County Ditch 1 Voiding Analaysis – As-built cross section surveys of the above mentioned PL-566 project were compared to cross sections surveyed in 2009 for West Branch and South Branch Zippel Creek. Differences in area were calculated to estimate volume of soil removed during the period 1967 to 2009. Consideration was given to extensive re-grading of ditch side slopes done by the county in 2001-2004. See Appendix H for details. Figure 19 shows the reaches where the comparison was made.

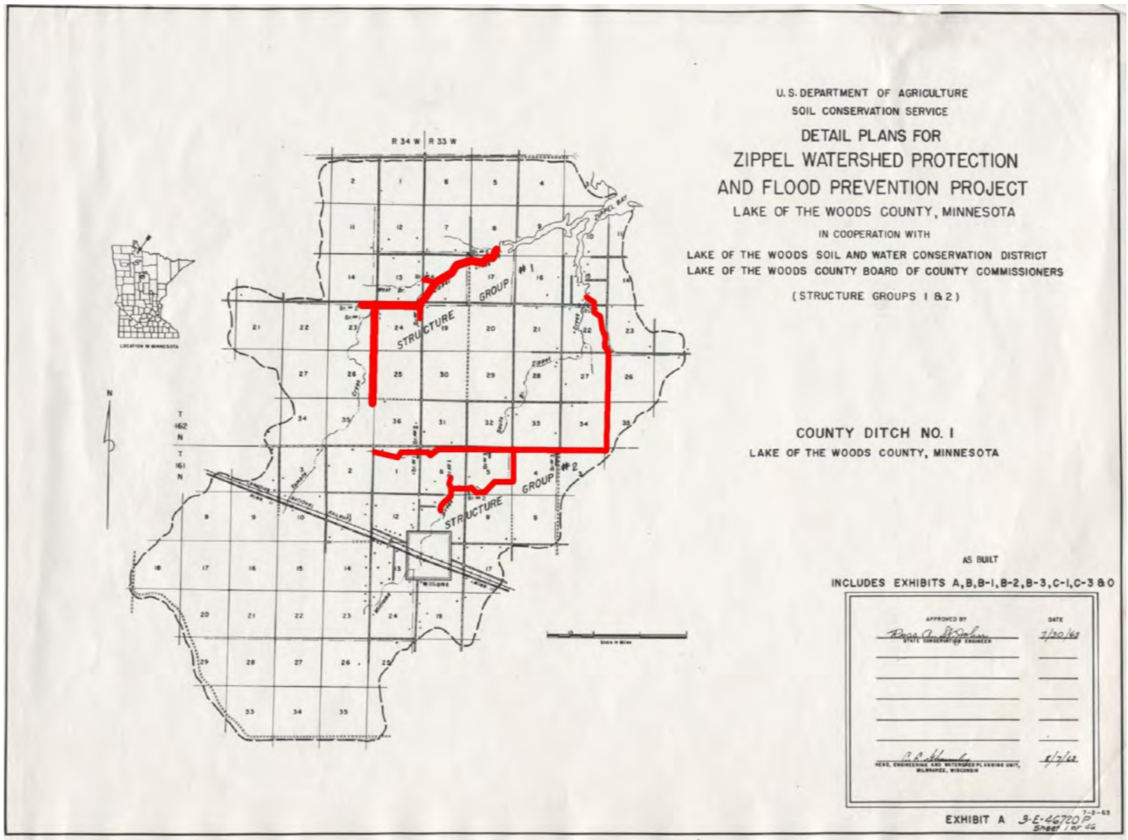

Figure 19 - Zippel Creek Cross Section Comparison Reaches

Figure 20 shows a comparison between the 1967 as-built channel slope (magenta line) and the 2009 condition (black line). From this plot, it can be seen that the upper 2/3 of this reach has degraded (down cut) while at the lower end, where the bottom grade flattens as it approaches the bays, the channel bottom has aggraded (filled in). Figure 21 shows a cross section that down cut approximately 3 feet and widened. Accumulating the differences in end areas, the amount of voided material was estimated. Table 5 summarizes the amount of the material voided in South and West Branch Zippel Creek between the period 1967 and 2009 (42 years).

Table 5 - Estimated Channel Voiding 1967 - 2009

Reach	Cubic Yards Voided	Tons Voided
West Branch Zippel	17,380	24,510
South Branch Zippel	52,020	73,350

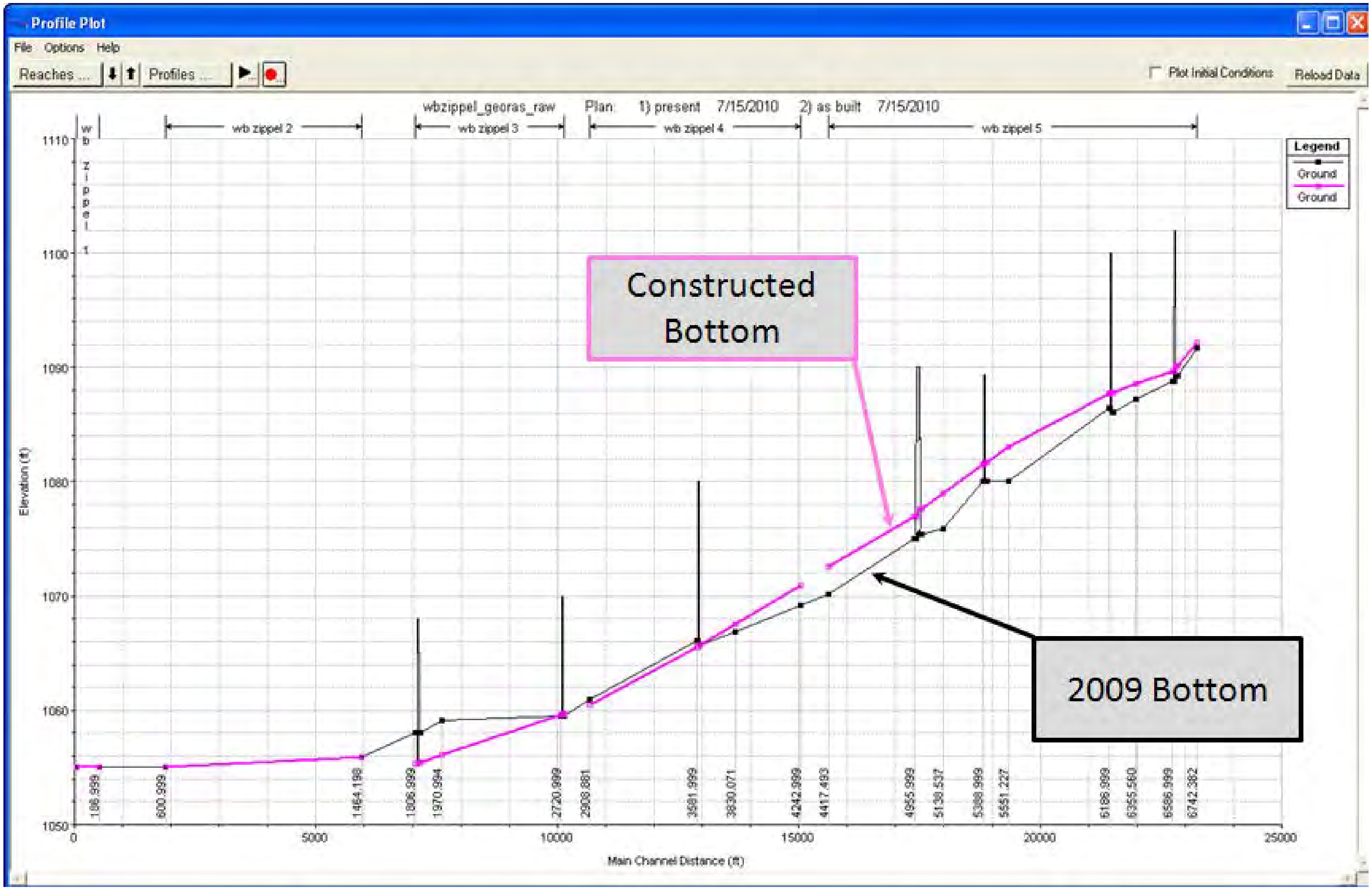

Figure 20 - West Branch Zippel Ditch Slope Profile

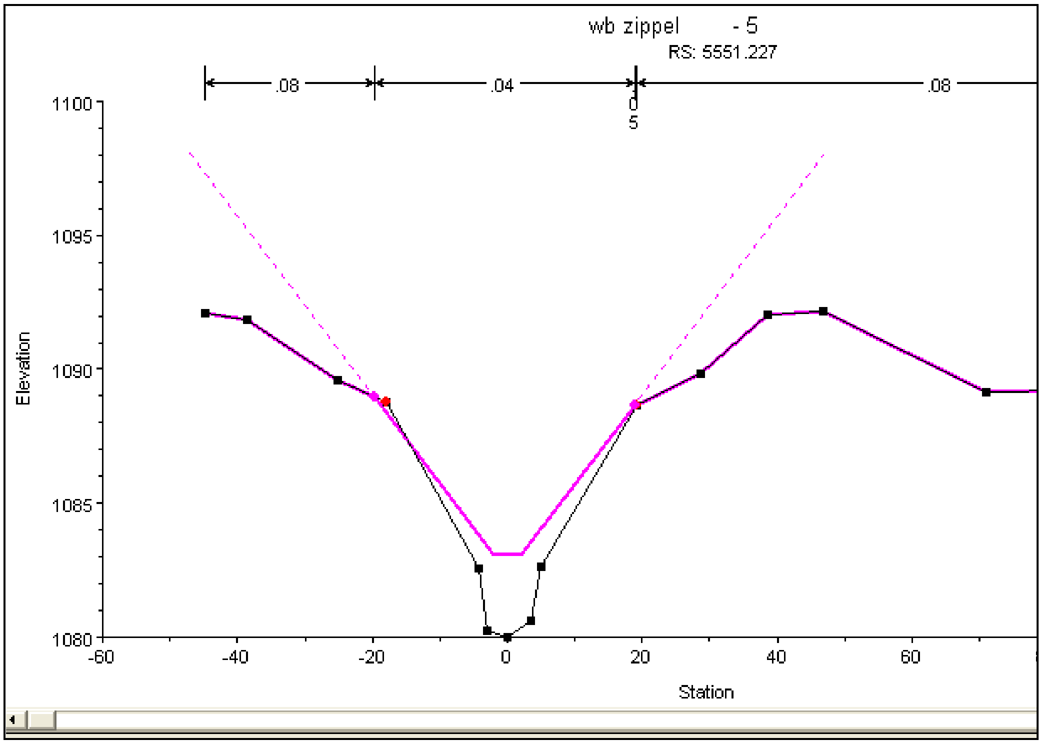

Figure 21 - Comparison of 1966 and 2009 Channel Shape - West Branch Zippel

During this project's watershed assessment, the ditch systems were generally stable with few areas of active erosion. However, this should be viewed in light of fact that there have not been any major rainfall events in these watersheds since 2002 (personal communication Dan Crompton – LOW Public Works) and that the County has a fairly aggressive operation and maintenance system in place for addressing erosion issues. It is estimated that approximately 2,060 and 2,225 tons per year of channel erosion currently occurs within Bostic Creek and Zippel Creek Watersheds respectively. Details of this sediment source and percentage reaching the creeks' outlet bays are discussed in the Sediment Budget Section.

The County has undertaken several stabilization projects over the past several years including rip rap toe protection, rock check dams, sloping back unstable side slopes, and installation of 4,800 ft of two-staged ditch design (JD 28). Most of the stabilization efforts over the years focus on flattening side slopes and replacement of old timber box bridges with concrete pipe crossings. Most of the stability problems noted during the project investigation involved side slope seepage from wetland/bog areas adjacent to the ditches and mass slumping where the ditches go through unstable sandy silt soils. Many of the ditches exhibit a bare earth low flow channel with fairly stable grassed side slopes. In some areas, there appears to be a meander pattern forming in the bottom sediments of the larger ditches. See Figure 23 for an example of this on County Ditch 1 in the Zippel Creek Watershed. Although these sediments are becoming vegetated, the long term stability of this configuration is uncertain as there have not been significant rainfall events since 2002. The longer the vegetation is permitted to establish itself however the more likely it can withstand future high flows.

Stream and ditch bank erosion were estimated as part of this assessment. Representative reaches were walked, erosion sites measured, and voided volumes calculated. Reaches that were not specifically walked and measured were assessed as to which inventoried reaches they were most similar to in terms of soil and bottom slope. Reaches identified with 0 erosion rates indicate depositional areas and are basically located in areas affected by Lake of the Woods backwater. Sediments that have accumulated in these reaches are susceptible to movement into the bays during large runoff events (water volumes and velocities are sufficient to mobilize previously deposited particles). Actual amounts stored in these reaches were not surveyed as part of this assessment however observations made while walking within these particular reaches verified significant amounts of "stored" sediment.

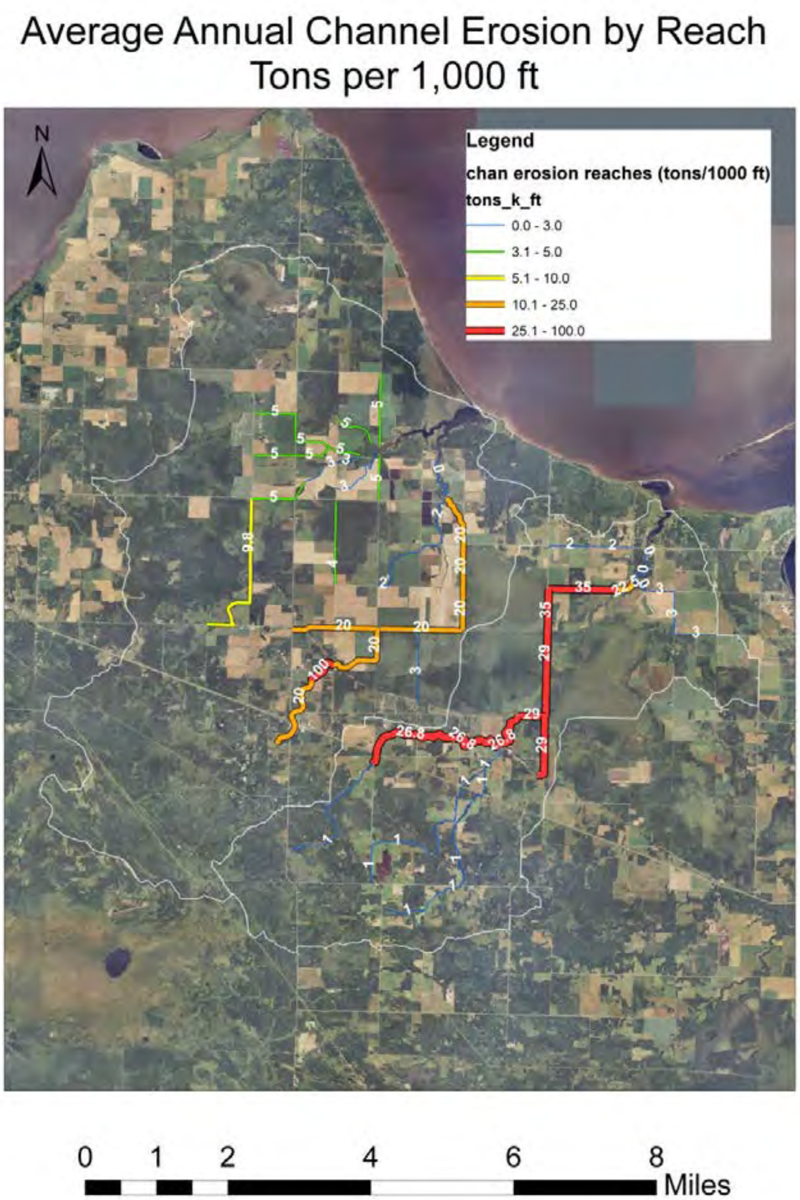

Figure 22 - Current Average Annual Channel Erosion Rates (tons/1,000 ft)

Figure 23 - Meandered Low Flow Channel in CD-1 West Branch Zippel Creek

Sheet and Rill Erosion

Sheet and Rill Erosion is defined as the soil removed from the land surface in a uniform thin layer (sheet) and very small concentrated flow paths (rills). Sheet and rill erosion can occur on all types of land cover however, the amount that occurs on cropland is substantially higher than non-cropland (i.e. row crops will erode at rate 75 – 100 times greater than woodland).

Sheet and rill erosion within these two watersheds is relatively low due to flat slopes and the types of crops and rotations used on cropland. Table 6 below summarizes the range of slopes found on cropland (includes CRP/Idle/Hay ground).

Table 6 - Slopes on Cropland (based on LiDAR slope analysis)

Slope Range	Percent of Watersheds
0 – 1 percent	59%
1 – 3 percent	33%
3 – 5 percent	5%
5 - 7.5 percent	2%
> 7.5 percent	1%

Average annual soil loss for various land uses/rotations on one of the predominant soils found in both watersheds (Clearwater Clay – 1% slope), is displayed in Figure 24. As can be seen in the figure, there are significant differences in soil loss depending on land use. For perspective, a few scenarios are summarized below:

- A field with a small grain/soy bean rotation has half the soil loss as a field with potatoes
- Converting a blue grass field to a small grain/soy bean rotation can quadruple soil loss
- Placing a small grain field into CRP can reduce soil loss by a factor of 15

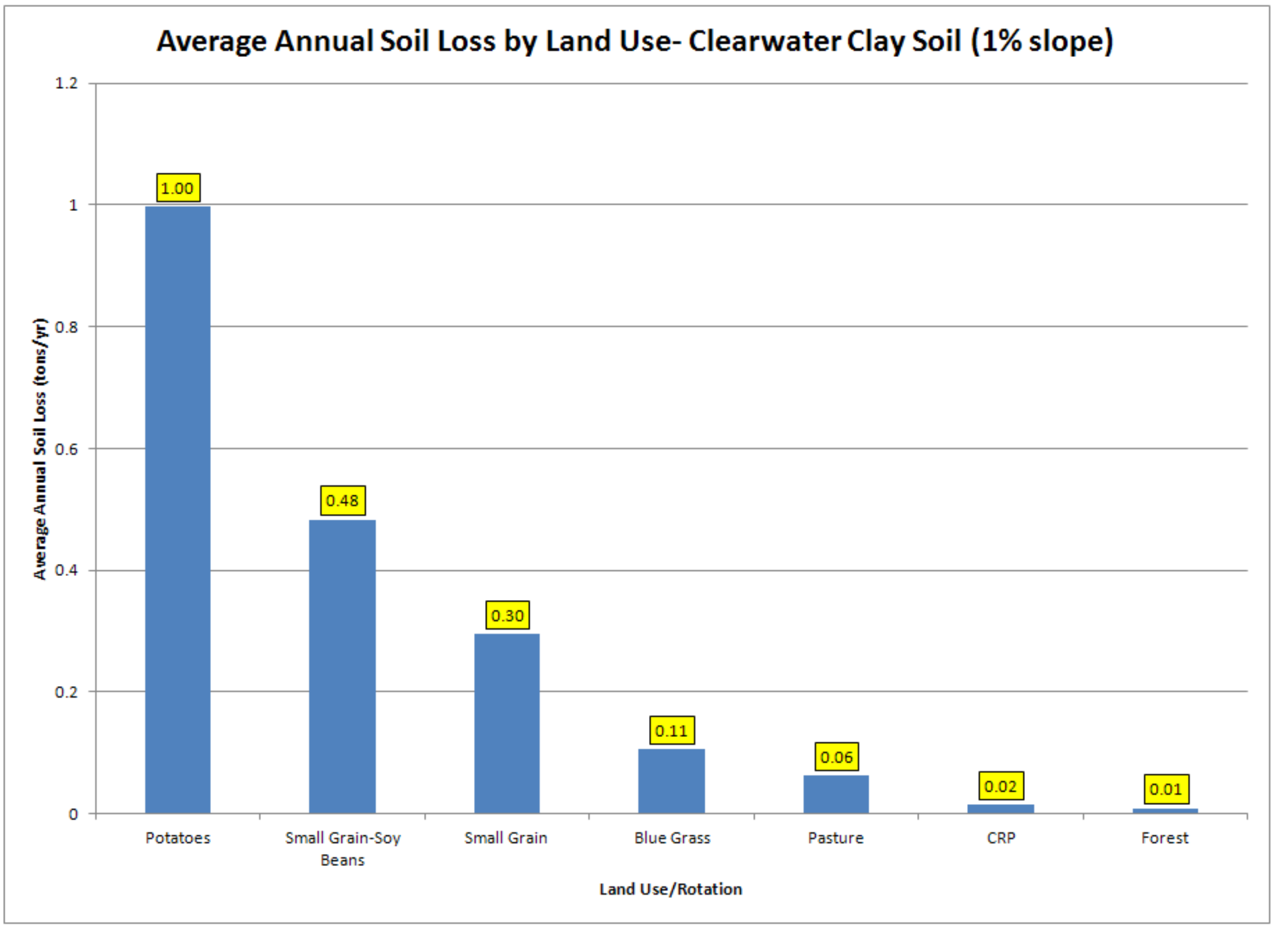

Figure 24 - Average Annual Soil Loss on Clearwater Clay Soil for Various Land Uses/Rotations

Mean sheet and rill soil loss on cropland was calculated to be 0.11 and 0.23 tons/acre for the Bostic Creek and Zippel Creek watersheds respectively. The maximum soil loss rates for both watersheds were found to be 1.7 tons/acre (a wheat/ryegrass/soybean rotation on a Taylor Loam soil). Tolerable erosion rates for all soils within the watersheds range between 3 and 5 tons per acre. Figure 25 displays the sheet and rill erosion rates assuming the 2010 land use/crop rotations.

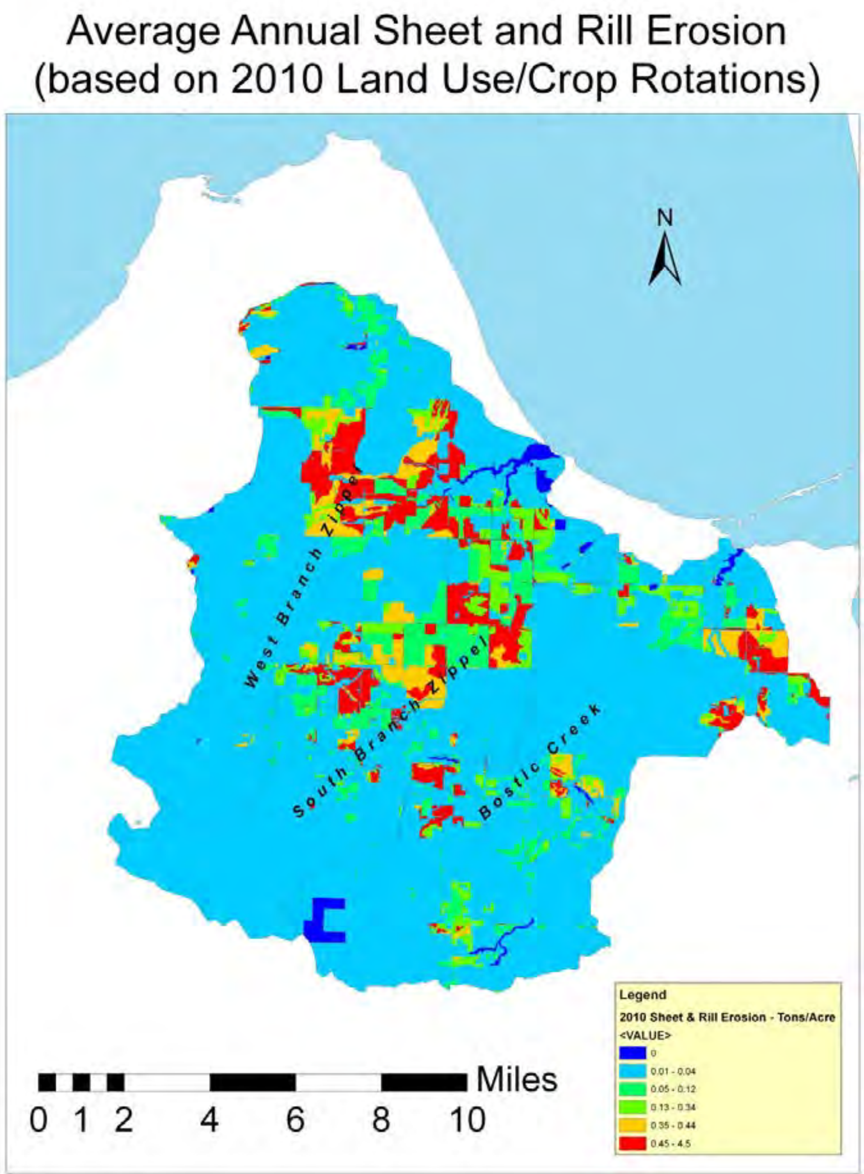

Figure 25 - Average Annual Sheet and Rill Erosion

Total sheet and rill erosion, including minimal amounts from non-cropland, for Bostic Creek is 1,873 tons per year while Zippel Creek is 5,479 tons. Not all of this is transported down to the bays due to depositional processes along the way (within the field, within small depressions and wetlands, within the ditch system, etc.). The percentage of these total on-site erosion figures that is actually transported down to the bays is discussed in the Sediment Budget section.

Ephemeral Erosion on Cropland

Field investigations and aerial photography interpretation show that ephemeral erosion may be a significant contributor to overall sediment load in these watersheds. Ephemeral erosion is defined as erosion resulting from large concentrated flow paths within a field's main drainage way. This type of erosion is usually obliterated by tillage operations after harvest and during seedbed preparation. Figure 26 shows traces of ephemeral erosion sites within the Zippel Watershed. These sites show up as a lighter color due to less vigorous vegetation within the eroded flow path. Figure 27 and Figure 28 show an on-the-ground example of an ephemeral erosion site before and after spring tillage. The severity of erosion from each individual site is usually a function of the contributing drainage area and relative difference between the average field elevation and the elevation of the adjacent drainage ditch (if present).

Measures that can be used to reduce this type of erosion include cover crops or grassed waterways along the main drainage paths, drop structures to take water off the fields and into the ditch in a non-erosive manner, and combining several drop locations into one by means of edge of field diversions.

Approximately, 30 miles and 104 miles of ephemeral erosion length were identified in Bostic and Zippel Creek watersheds respectively. Tonnage and percentage of overall sediment load are discussed in the Sediment Budget section of this report.

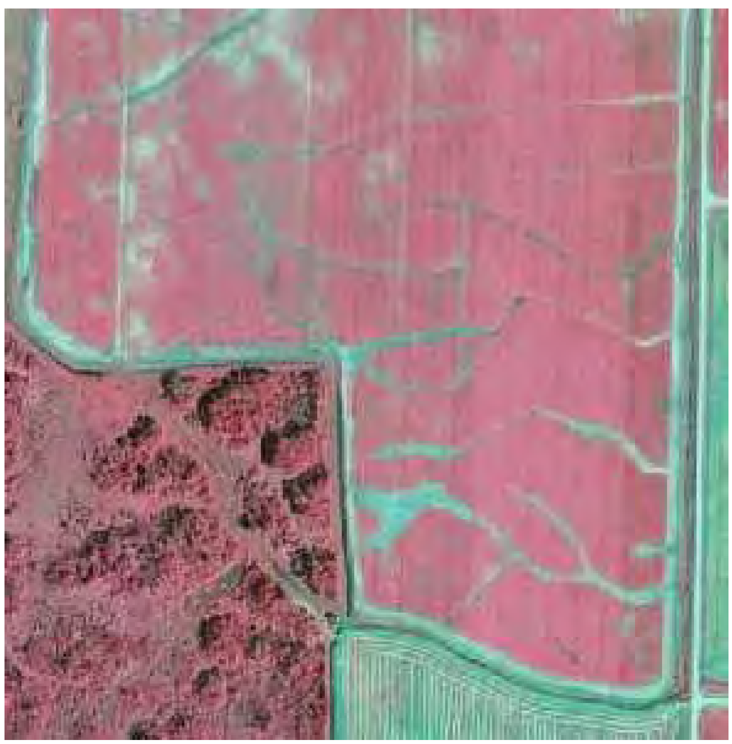

Figure 26 - Ephemeral Erosion Sites on IR Photo

Figure 27 - Ephemeral Erosion Before Tillage

Figure 28 - Ephemeral Erosion After Tillage

IV. Sediment Accumulation in Zippel/Four Mile Bays

At the lower ends of Bostic and Zippel Creeks, the channels enter Four Mile and Zippel Bays respectively. Due to the low relief between the lower watershed floodplains and the bays, water velocities in the main ditches slow down dramatically as they near the bays (see Figure 16 for channel grade near each creek's outlet relative to the upstream channel slopes) allowing for sediments to settle out. During field investigations for this assessment, it was noted that approximately the first 2 miles of channel leading to the bays was in a "depositional" condition in that channel velocities were insufficient to move sediments during normal flow conditions. The sediment in these reaches accumulates until a significant runoff event can generate enough velocity to move that sediment downstream.

Influence of Lake of the Woods Water Levels

Lake of the Woods water levels also have a significant impact on the area of open water in Zippel and Bostic Bays. Besides the obvious relationship between lower Lake of the Woods levels and exposing shallow areas in the adjoining bays, there is the potential for more vigorous stands of emergent wetland vegetation. Thicker vegetation in the adjoining shallow floodplains can lead to more trapping of sediments. Over time, a singular channel shape evolves having a width and depth adapted to moving suspended sediments downstream.

A treaty exists between Canada and the United States stating that Lake of the Woods outlet flow rates cannot be altered as long as water levels are between 1056 feet and 1061 feet. It should be noted that this 5 foot normal variation in lake level can cause the amount of open water in the bays to appear to vary dramatically from one period of years to another regardless of any sediment accumulation.

Bay Dredging

A report by the U.S. Army Corps of Engineers ("Lake of the Woods, MN: Small Harbor Economic Analysis – December 2005") makes reference to sedimentation issues in the main Zippel Bay. It states that a 3,000 foot navigation channel was constructed in 1914. This navigation channel required dredging in 1991 (1,950 cubic yards) and 1995 (unknown yardage). The report suggests the extensive ditching that occurred between 1964 and 1966 (probably reference to the Zippel Watershed PL-566 Project) was a significant contributor to Zippel Bay's sedimentation problems.

Zippel Bay Resort owners on South Zippel Bay report that the area in front of the resort's docks requires dredging most years to maintain an access channel out to the main channel. Recent estimates put this dredging at approximately 300 cubic yards per year. Lake of the Woods County Public Works personnel recall that Randell's and Walleye Retreat Resorts on Bostic Bay required maintenance dredging in 2008. Reports of reduced open water in South Zippel Bay due to sedimentation can also be found as far back as 1972 when residents stated that areas in the bay where they once water skied cannot even be accessed by boats. The newspaper reporting on this (Northern Lights Newspaper July 20, 1972) displayed ground photos showing a significant change in open water location within a 2-year period (1969 to 1971) and attributed this change to " ... silt and weed growth" and low water levels in Lake of the Woods.

Aerial Photography Comparison

Photographs taken of Bostic Bay between 1983 and 2009 from County Road 8 clearly show a smaller open water area in the vicinity of crossing (see Figure 29 and Figure 30). Aerial photos were also used to establish patterns of open water sedimentation. Figure 31 and Figure 32 display South Zippel Bay and Bostic Bay, respectively during 1941, 1979, and 2009.

- For South Zippel Bay, it appears that the start of open water begins near the center of section 15. In 1979, the open water has moved to within 1,000 ft of north section 15 line. In the 2009 aerial photo, the open water has moved another 1,000 – 1,500 feet north. It should be noted that Lake of the Woods lake level during 1941 was approximately 1 foot lower than those in the 1979 and 2009 photos further emphasizing the loss of open water area over these time periods.

- For Bostic Bay, the open water extends upstream of County Road 8 approximately 1,000 feet. In the 1979 photo, the open water is only about 250 feet upstream County Road 8 (which had been re-aligned sometime between 1941 and 1979). By 2009, open water is approximately 1,500 downstream of County Road 8.

PL-566 Watershed Plan Reference

Other evidence of past bay infilling is found in the Zippel Creek PL-566 Watershed Plan written in 1962. In this report it states: "Williams Creek and Tomato Creek outlet into estuaries of Lake of the Woods. These estuaries apparently have been silting up at a slow rate. The sediment that has settled out in these inlets has come principally from channel scour and bank erosion of the drainage system and from organic debris."

Zippel Bay Sediment Coring

In 2005, a sediment coring study was conducted for the main Zippel Bay in addition the south and west arms of the main bay ("Multi-Core Investigation of a Lotic Bay of Lake of the Woods Impacted by Cultural Development" – E.D. Reavie, N.G. Baratono 2007). This study, done in support of South East Lake of the Woods TMDL Evaluation, involved isotope analysis of sediment cores to estimate long-term trends in sedimentation rates in the bays. The cores themselves were taken in January 2005 and were 1.5 – 2 meters in depth. Excess ^{210}Pb was used to determine sediment accumulation rates. Figure 33 shows a graphical summary of that study[1]. Specific conclusions stated in the report include:

- In the main bay, peak sediment accumulation occurred in the 1960's. The rate during this period was estimated to be 15 times pre-settlement rates.
- From the 1970's through the 1990's, sedimentation has been decreasing in the main bay back to pre-1950's rates. This decrease is attributed to less new ditching during this period.
- The renewed increase in main bay sedimentation from the 1990's to 2000 may be from movement of accumulated sediments in the south bay (rates for the south bay have been

[1] The results in that report are expressed as grams of sediment accumulated per square centimeter per year. This was converted to inches per year assuming a submerged sediment density of 1,300 lbs/yd^3.

steadily increasing from the 1970's). The decrease in main bay accumulation rates from 2003 correspond to decreases in the south bay during this same period.

- The west bay accumulation rates are much less and do not display the same year-to-year variability compared to the main bay and south bay.

Based on these figures, since 1900, the depths at the sampling sites have filled in 22 inches, 20 inches, and 11 inches for the main bay, south bay, and west bay respectively. One factor to keep in mind is that the rate of accumulation is likely much higher further upstream in the bays where the incoming channel slopes begin to flatten. The aerial photo sequences shown in Figure 31 and Figure 32 show this clearly – loss of surface area in an upstream to downstream sequence with the lower end remaining relatively the same.

Figure 29 - Bostic Creek Looking Upstream from Co Rd 8 - 1983 and 2009

Figure 30 - Bostic Creek Looking Downstream at Bostic Bay from Co Rd 8 - 1983 and 2009

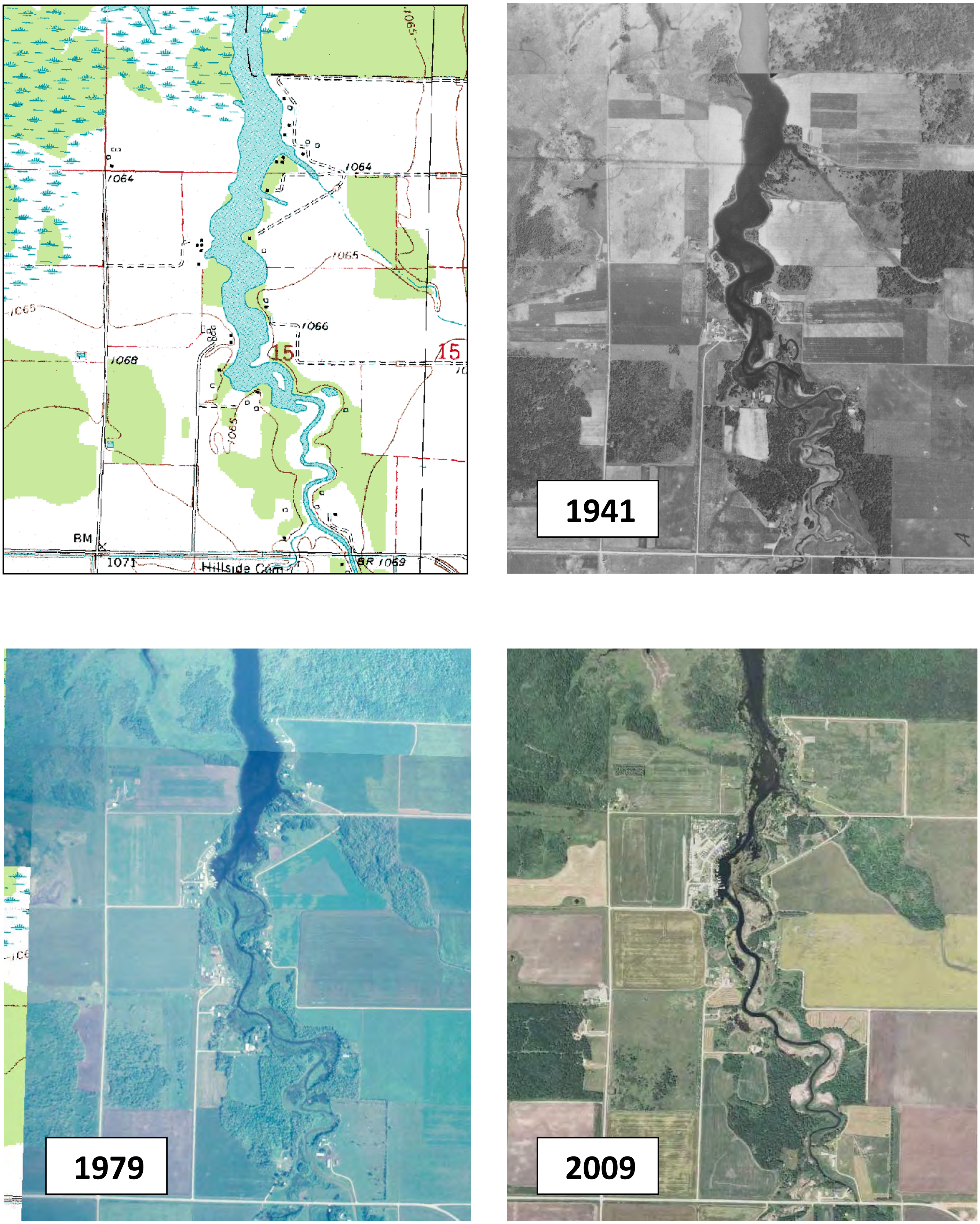

Figure 31 - South Zippel Bay 1941 - 2009

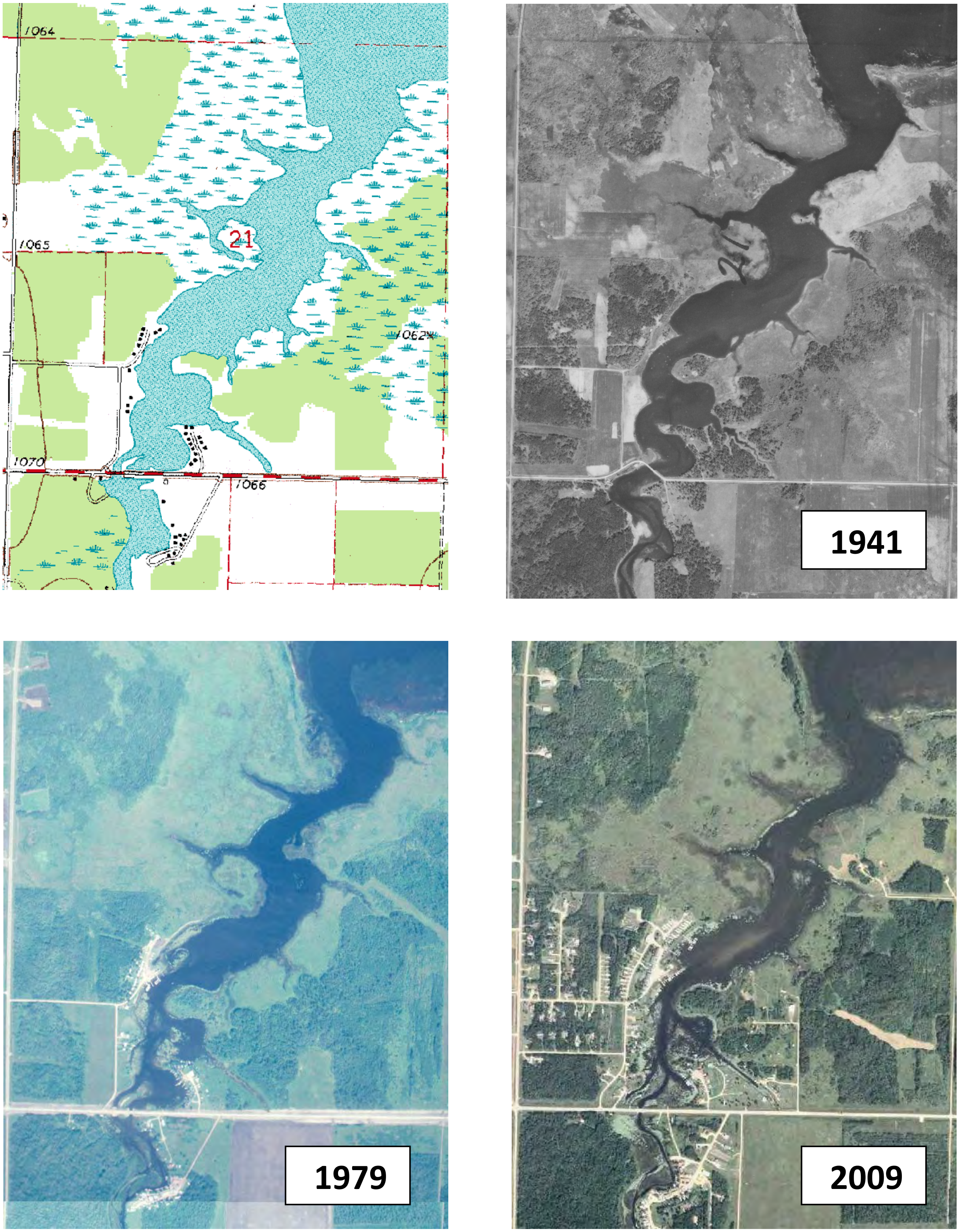

Figure 32 - Bostic Bay 1941 - 2009

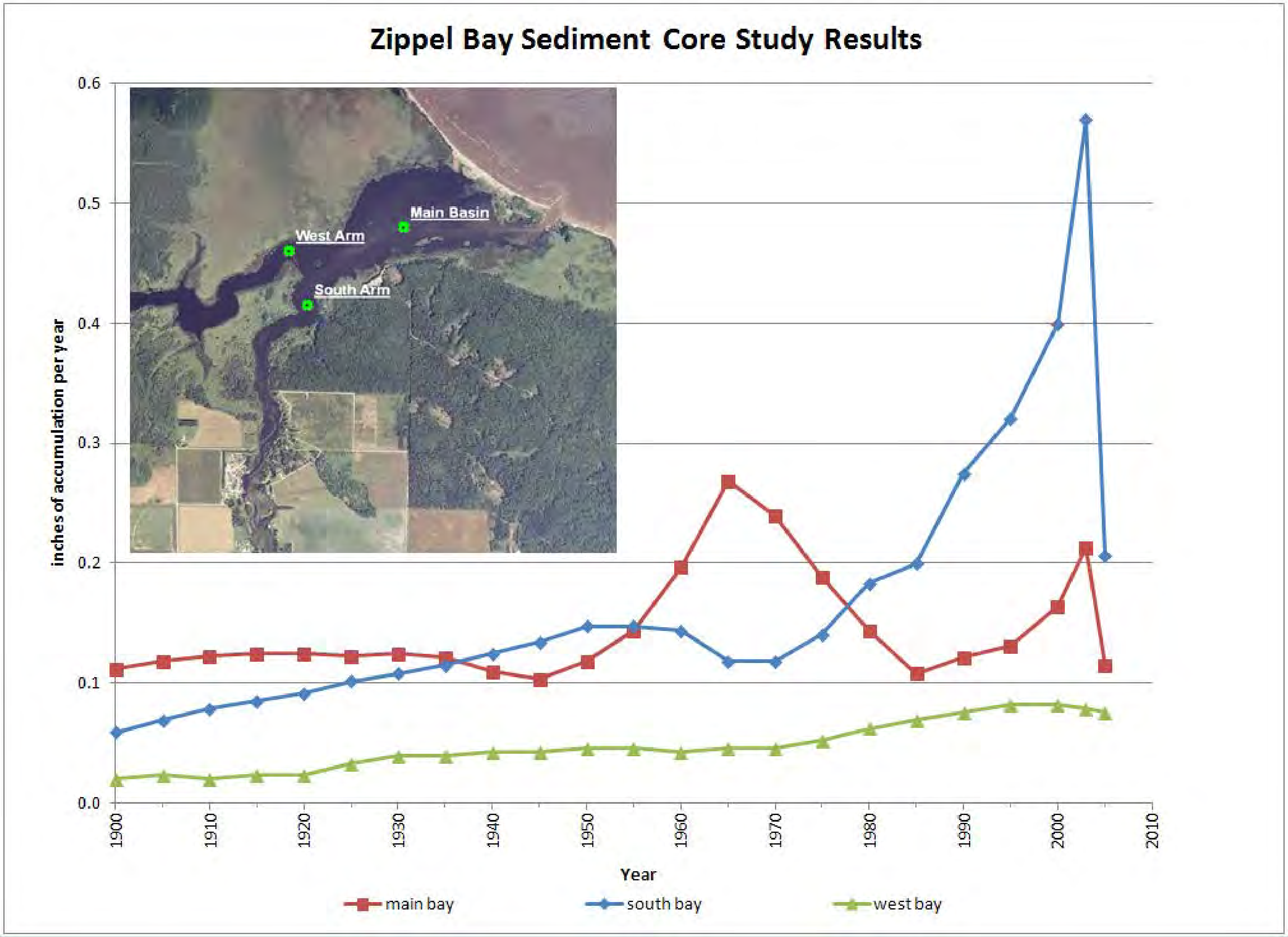

Figure 33 - Zippel Bay Sediment Core Study

V. Sediment Budget

Introduction

The following paragraph provides the definition of a sediment budget and its application[2]:

> "Developing a sediment budget is a technique used to identify and quantify all the soil erosion, sediment deposition, and yield processes that occur within the drainage area. Many types of erosion occur, including sheet and rill, wind, classic gully, ditchbank, and streambank erosion; likewise, the deposition processes vary widely within the drainage area. The development of a sediment budget is an essential first step in planning for the reduction of sediment yields. With a sediment budget, impacts on sediment yield from possible changes in soil erosion or sediment delivery can be easily predicted. Numerical values can be changed to reflect, for example, a particular treatment scenario and produce a new sediment yield value."

For this assessment, sheet and rill, ephemeral, and channel/ditch erosion were estimated as part of the sediment budget. The total of each type of erosion that occurs at its source is referred to as "Gross" erosion. For example, all of the sheet and rill erosion that occurs within a watershed, without accounting for movement or deposition, would be termed "Gross Sheet and Rill Erosion". Of course all sediments that erode do not travel the entire distance to a watershed outlet. Deposition occurs along the way within the field, wetlands, channel bottoms, etc. Factors called "sediment delivery ratios" or SDR's are applied to gross erosion amounts to arrive at the "net" amount of sediment reaching the outlet. "Net Sheet and Rill Erosion" would reflect the amount of sheet and rill erosion coming from a watershed that makes it to the watershed outlet without being deposited along the way.

Sediment Budget Results

The sediment budget takes all three major types of erosion occurring in the watershed (sheet and rill, ephemeral, and stream bank erosion), then models the routing of those sediments through the hydrologic system to the bays. Along the way, the deposition of sediments in fields, depressions, wetlands, and channels is estimated using SDRs. The end product is the total amount of sediment entering Bostic, West Zippel, and South Zippel Bays. Table **7** displays the gross erosion amounts by watershed. These figures represent soil particles moved by water erosion from their original position on the landscape (field or ditch bottom/side slopes). Table 8 summarizes the total sediment yield to each of the three bays within the assessment area. These figures represent the soil particles that move within the runoff all the way through the hydrologic system without deposition. As can be seen in the far right column of Table 8, the percentage of gross erosion that moves all the way through the hydrologic system to the bays varies by watershed. This variation is due to potential sediment trapping areas between fields and ditches, distance traveled efficiency of the ditch system (ditch density, roughness, and slope), etc. Figure 34 displays the same information in bar chart form.

[2] From "Erosion Sedimentation Sediment Yield Report – Thief and Red Lake Rivers Basin, Minesota" – USDA-NRCS 1996

Figure 35 through Figure 37 are schematic representations of the Bostic, South Branch Zippel, and West Branch Zippel Creeks sediment budgets. These figures are intended to provide a visual "tracking" of sediment from the sources down to the sediment reaching the bays. The width of the bar arrows are scaled to represent the relative amount of sediment within each source and "sink" (deposition area). As can be seen from these figures, source and sink amounts are quite large compared to what exits the watershed to the bays.

Table 7 - Gross Erosion Amounts by Watershed

Watershed	Sheet & Rill Erosion (tons)	Ephemeral Erosion (tons)	Streambank/Ditch Erosion (tons)	**Total (tons)**	**Average Tons per Acre**
Bostic Creek	1,873	406	2,060	**4,339**	**0.12**
South Branch Zippel Creek	2,367	497	1,644	**4,509**	**0.17**
West Branch Zippel Creek	3,111	1,273	581	**4,965**	**0.14**

Table 8 - Sediment Yield to Bays by Source

Bay	Sheet & Rill Erosion (tons)	Ephemeral Erosion (tons)	Streambank/Ditch Erosion (tons)	**Total Sediment Yield (tons)**	**Percent of Gross Erosion Reaching Bays**
Bostic Bay	163	136	744	**1,043**	**24%**
South Zippel Bay	268	248	843	**1,359**	**30%**
West Zippel Bay	600	1,101	518	**2,219**	**45%**

Figure 34 - Gross Average Annual Erosion and Sediment Yield to Bays

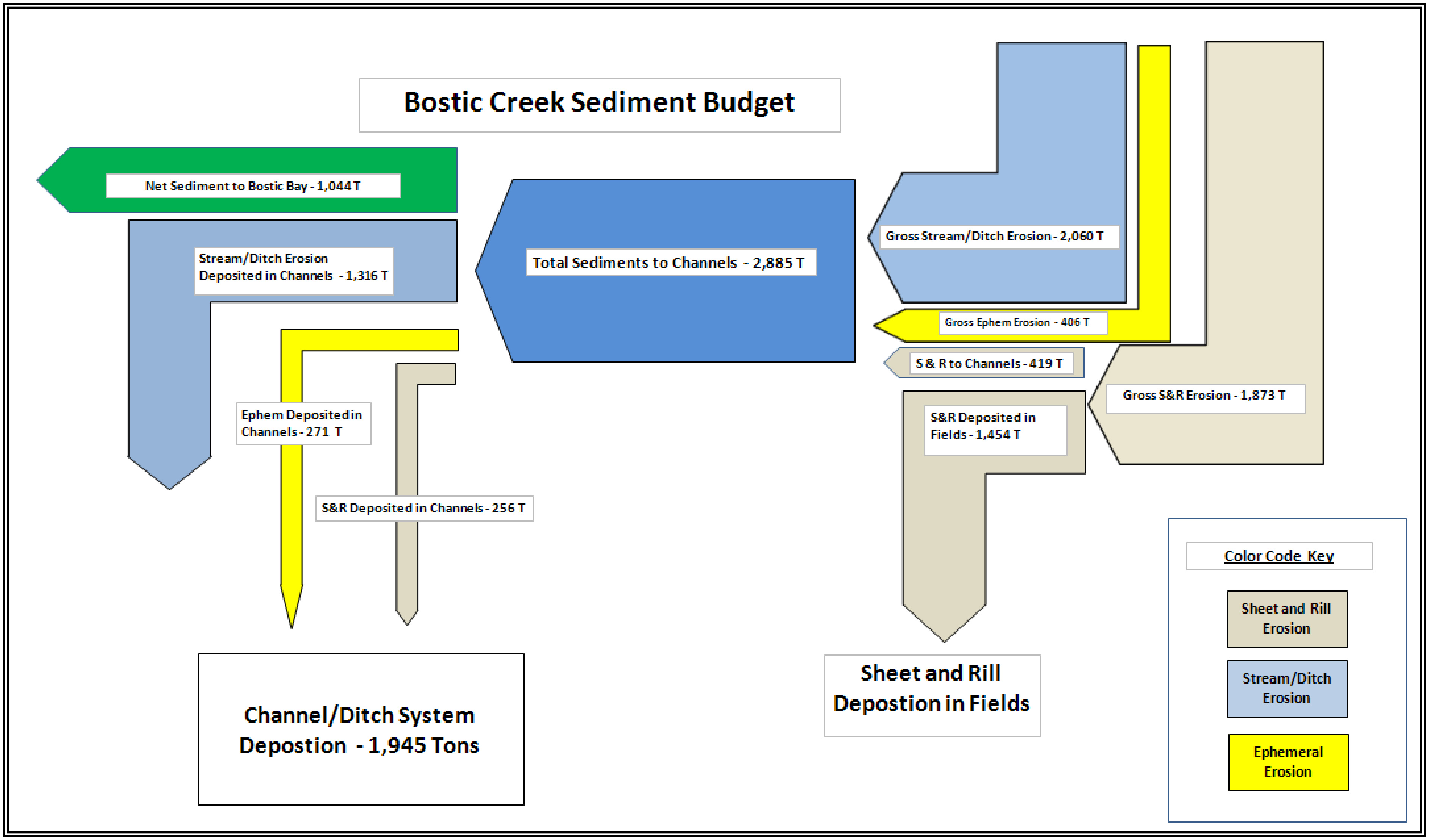

Figure 35 - Bostic Creek Sediment Budget Schematic

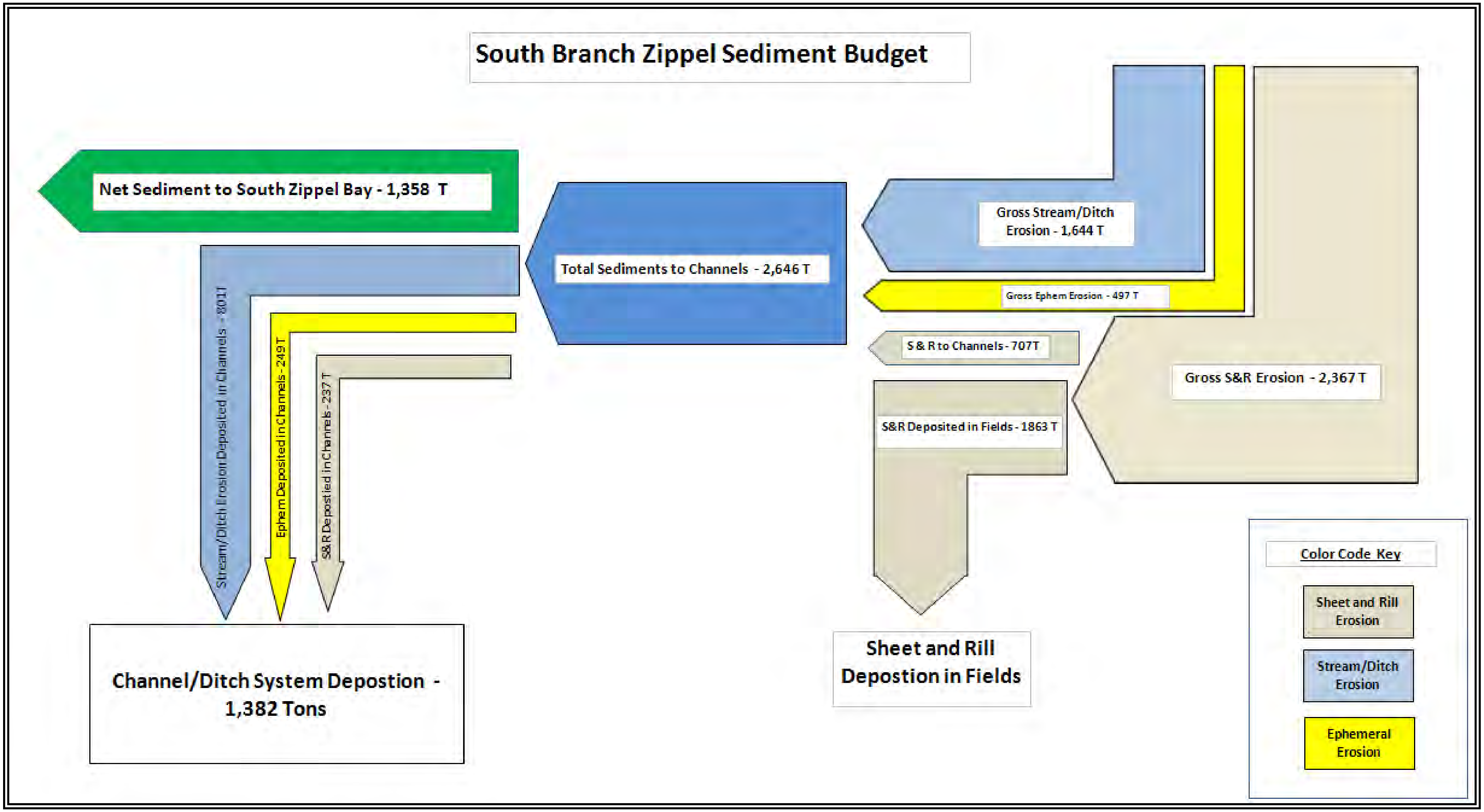

Figure 36 - South Branch Zippel Sediment Budget Schematic

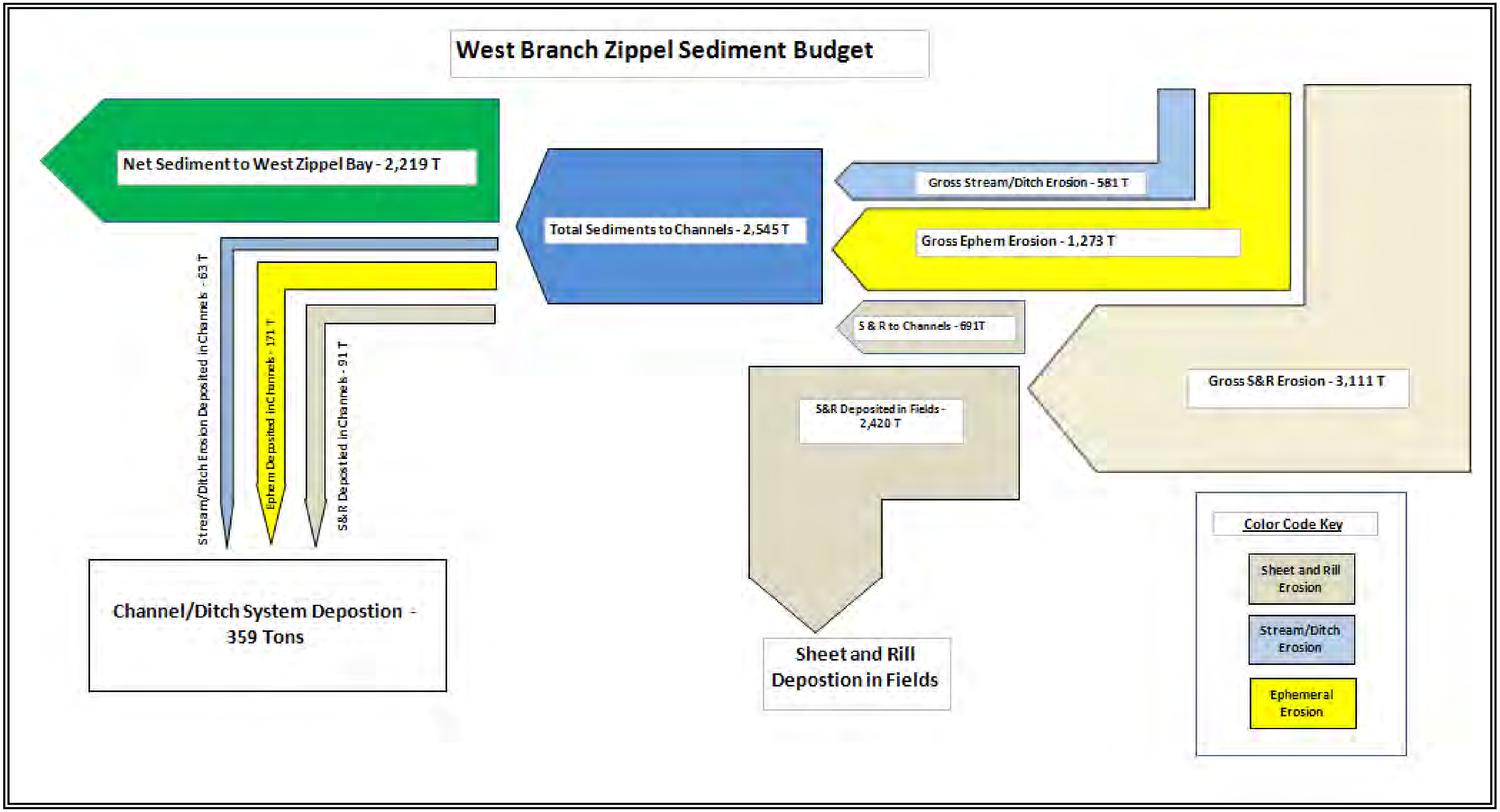

Figure 37 - West Branch Zippel Sediment Budget Schematic

To summarize this data:

- Total sediment yield to Zippel Bay is 3,578 tons (South Branch + West Branch), about 3.4 times the amount of sediment entering Bostic Bay (1,044 tons)
- A significant proportion of the sediment reaching West Zippel Bay is from ephemeral erosion (50%)
- Over 60% of the sediment reaching South Zippel Bay is from channel/ditch erosion
- The proportion of sediments from cropland (sheet and rill + ephemeral erosion) to channel/ditch is 29%, 38%, and 77% for Bostic, South Branch Zippel, and West Branch Zippel respectively
- The Bostic Creek watershed has the smallest overall sediment delivery ratio (SDR - gross erosion/watershed sediment yield) at 24%. West Branch Zippel Creek watershed SDR is 45% while the South Branch Zippel Creek watershed SDR is 30%.

Not all of the sediment entering the bays will accumulate since most of the fine material will remain in suspension and flow out into Lake of the Woods. Using NRCS sediment deposition techniques for reservoirs, approximately 44 percent of the average annual incoming sediment would deposit in the bays[3]. Table 9 summarizes sediment deposition within the Bays. Although the volume of sediment deposited is small relative to each bay's capacity, it should be noted that the distribution of the deposition is in an upstream to downstream direction with the upper bays filling first. Average annual deposition rates in inches for the Zippel Bays appear reasonable when compared to the coring study values.

Table 9 - Average Annual Sediment Deposition Estimates

Bay	Cubic Yards of Sediment Deposited per Year	Acre Feet of Sediment Deposited per Year	Average Annual Depostion Depth (inches)	Acre Feet Capacity of Bay (normal LOW Water Levels/assume avg 4 ft depth)
Bostic Bay	707	0.44	0.1	252
South Zippel Bay	921	0.57	0.2	208
West Zippel Bay	1,537	0.95	0.2	260

To put estimated sediment yield from these two watersheds in perspective, a comparison was made with other watersheds in the state. Sediment data from the report "Suspended Sediment in Minnesota Streams" (USGS WRI 85-4312 – 1986) were compared with the Bostic and Zippel Creek data. See Figure 38. Sediment yields from Bostic and Zippel Creek watersheds are not significant when compared to some of the more intensely farmed watersheds (Whitewater River, Root River, and Redwood River). In general, the Bostic and Zippel watersheds would fall into an average to low sediment yield. This comparison, however, should be viewed in light of the watersheds' percent cultivated (shown next to the graph's x-axis watershed name). Bostic and Zippel watersheds are not nearly as intensively farmed as most of the higher sediment yielding watersheds.

[3] Calculated using NRCS NEH Section 3 – Sedimentation/Chapter 8 Sediment Storage Design Criteria procedures. Assumes average bay depth of 4 feet, surface areas of 63 acres (Bostic Bay), 43 acres (South Bay Zippel), and 65 acres (West Bay Zippel), an average annual runoff of 7 watershed inches, and a median sediment curve.

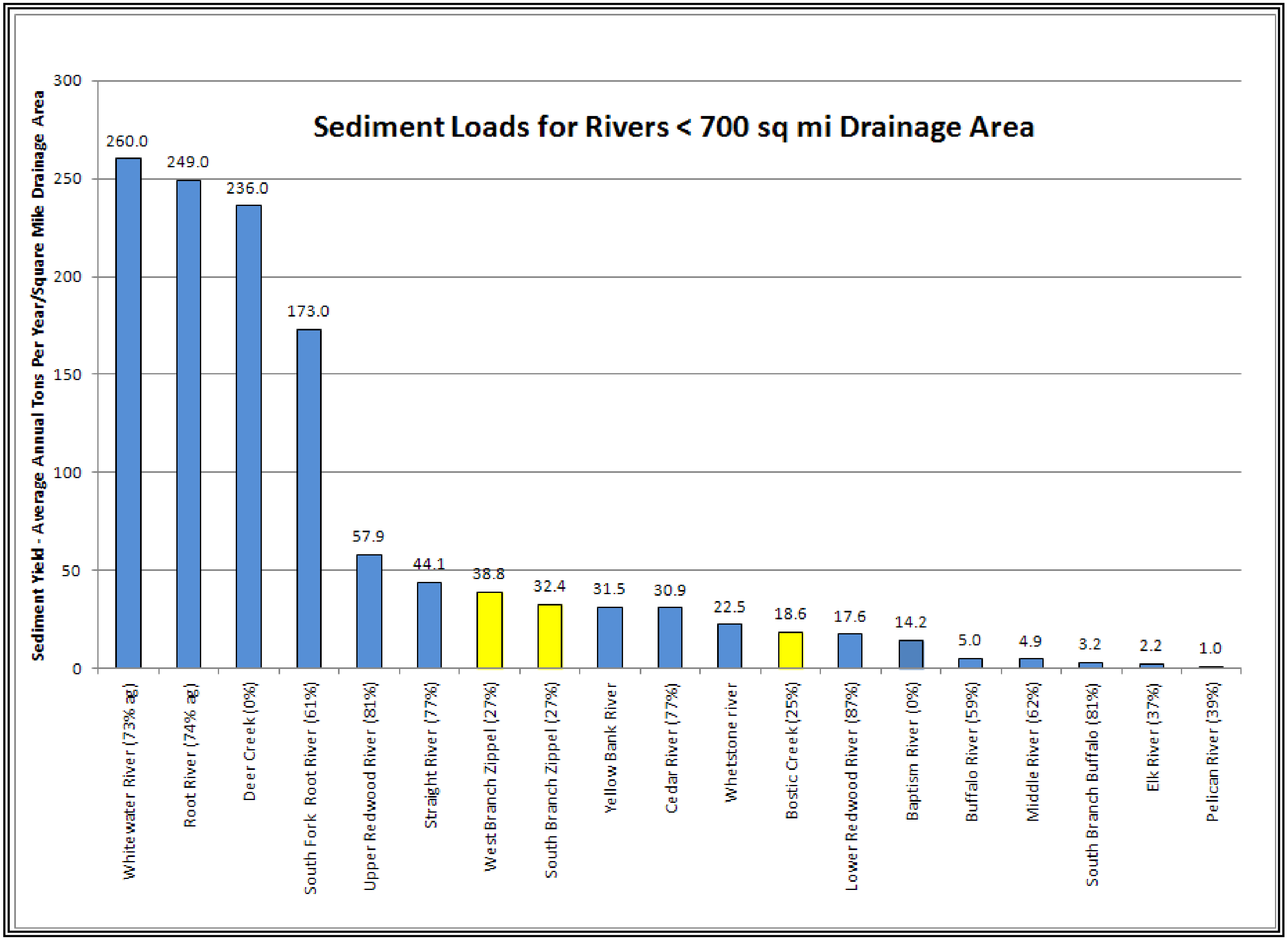

Figure 38 - Sediment Yield Comparison (% cropland shown next to watershed name)

VI. Impacts of Alternative Scenarios on Sediment Budget

A sediment budget can be used to assess "what if" types of scenarios to show sensitivity of watershed sediment yield to change. For example, what would be the impact on sediment load to the bays if more row crops were grown or if high channel erosion rates were reduced. For this assessment, 4 separate scenarios were analyzed:

1. All existing CRP + 50% Continuous Hay + 50% Oats – 5 yr Hay rotations are converted to Small Grain – Soybean rotations. This is 1,885 acres in Bostic Creek and 1,049 acres in Zippel Creek.
2. All row crops (potatoes, small grain, soybeans) are converted to continuous hay. This is 3,564 acres in Bostic Creek and 10,573 acres in Zippel Creek.
3. Control all channel/ditch erosion to a 5 tons/1,000 feet level.
4. Limiting erosion potential to a level equivalent to small grain (C factor < = 0.1) and reducing ephemeral erosion amount by 50% (cover crops + grade control structures).

For scenarios 1, 2, and 4, all three types of erosion (sheet and rill, ephemeral, and channel erosion) are impacted[4]. For scenario 3, sheet and rill erosion was assumed to remain unchanged from current conditions. Figure 39 through Figure 41 summarize this analysis in bar chart form. The vertical scale of these three charts is the same to emphasize the relative sediment loads and impacts between watersheds.

- For all three watersheds, switching all current CRP and half of the existing hay ground to small grain/soybeans rotation has a minimal effect on sediment yields. This is largely due to the relatively small percentage of land use that is being changed within these watersheds (5% and 2% of total watershed area within Bostic and Zippel Creek watersheds respectively).
- Conversion of all row crops to some form of continuous cover has a significant impact on sediment yield within the Zippel watersheds. Although this scenario is impractical, it does point out the Zippel Creek watersheds' higher sensitivity to this type of change. Impacts are greatest in West Branch Zippel due in part to the amount of ephemeral erosion that would be reduced in addition to the sheet and rill erosion reductions. Also, channel/ditch erosion is minimally impacted – the change in runoff volumes and resultant stream stresses are not significant enough to produce large changes in channel erosion.
- Limiting channel/ditch erosion to 5 tons per 1,000 feet can reduce watershed sediment yields by 49% and 43% for the Bostic Creek and South Branch Zippel Creek watersheds. On the West Branch Zippel Creek watershed, where channel/ditch conditions are more stable, this scenario has a much smaller impact.
- Limiting erosion to levels associated with small grain rotations (max C factor = 0.1) and reducing ephemeral erosion by 50% with cover crops and drop structures is an alternative within the realm of possibility. This alternative would have the most impact in the West Branch Zippel Creek by reducing sediments to West Zippel Bay by 36%. Smaller reductions would be realized in the Bostic (13%) and South Branch Zippel (18%) watershed sediment loads.

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[4] Ephemeral erosion varies by type of crop within a field and ditch erosion is impacted by upland runoff volume changes and runoff travel times ("flashiness").

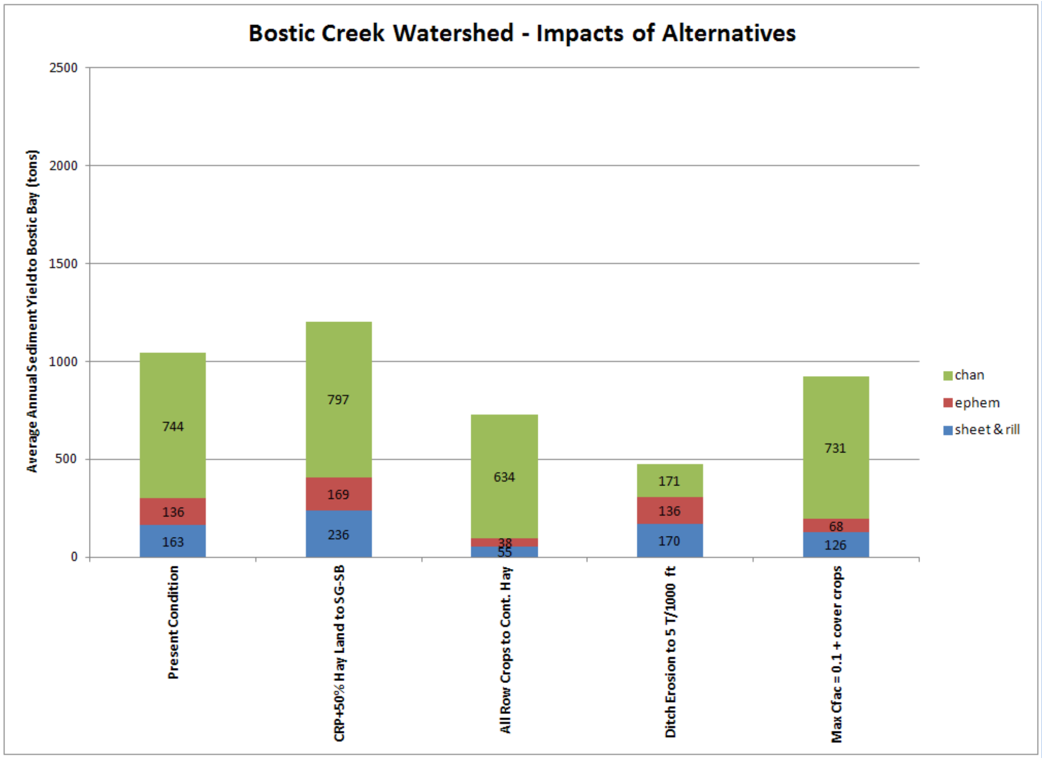

Figure 39 - Impacts of Change on Bostic Creek Sediment Yield

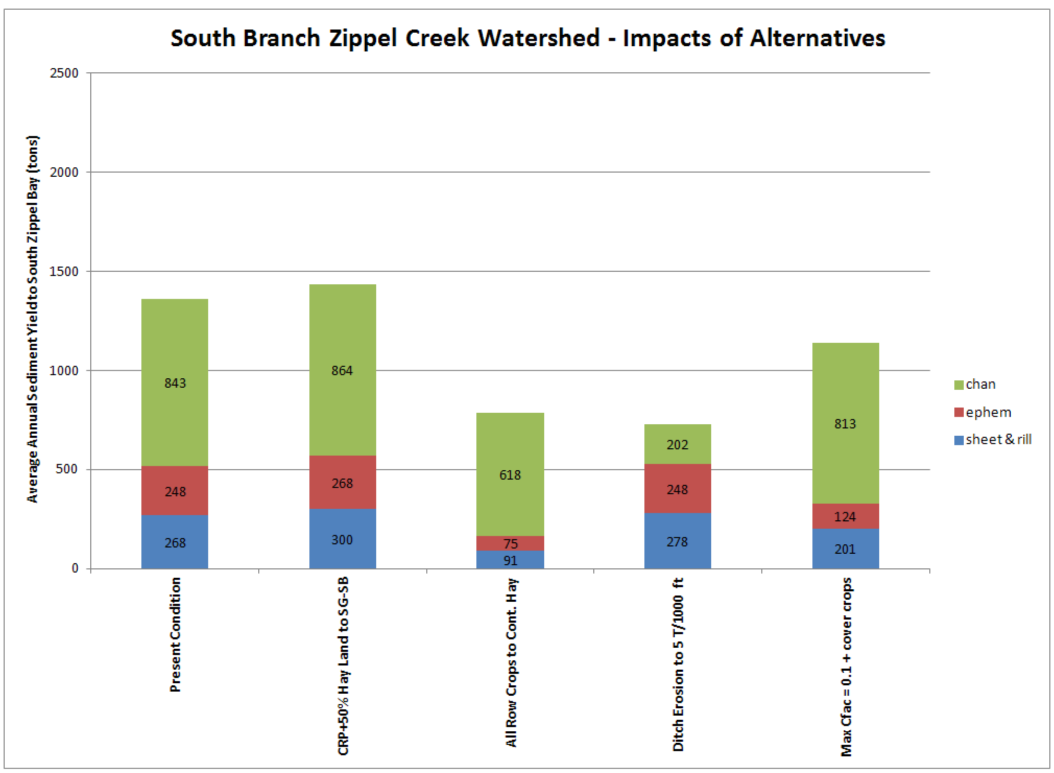

Figure 40 - Impacts of Change on South Branch Zippel Creek Sediment Yield

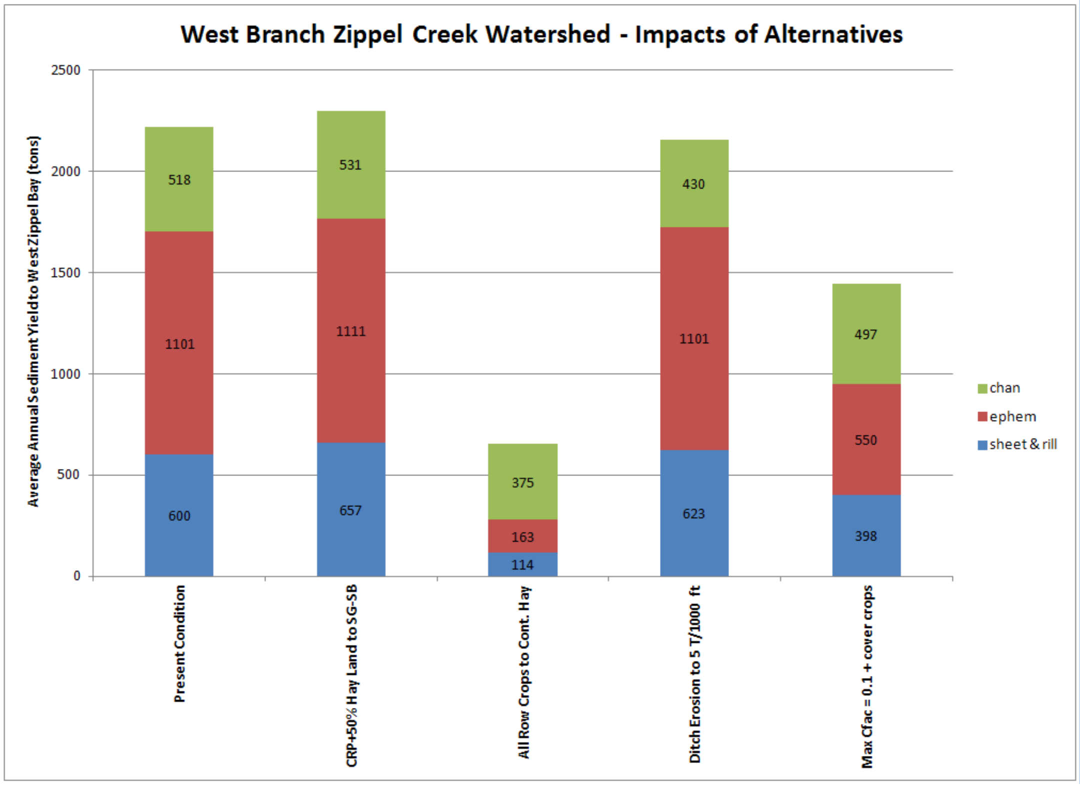

Figure 41 - Impacts of Change on West Branch Zippel Creek Sediment Yield

VII. Summary and Conclusions

Presently, both the Bostic and Zippel watersheds are relatively stable from a sediment yield perspective. Watershed average annual sheet and rill erosion rates on cropland are 0.11 and 0.23 tons/acre for Bostic and Zippel watersheds respectively. These rates are well below the average tolerable soil loss levels from an onsite soil productivity perspective. When non-cropland sheet and rill, ephemeral, and channel/ditch erosion are considered, along with sediment delivery factors, total yields from these watersheds are 0.03 and 0.06 tons/acre for Bostic and Zippel watershed respectively. When compared to sediment loads from other watersheds within Minnesota, rates are low to moderate in terms of yield per square mile. However, when one considers the relatively low percentage of cultivated land within these watersheds, Bostic and Zippel watersheds' sediment yield is considerable.

Estimates of sedimentation rates within Bostic and Zippel Bays are on the order of 0.1 – 0.2 inches per year. This number however, is an average over the entire bay and the actual bay sedimentation occurs unevenly with the lower stream reaches/upper bay reaches filling in first. Although it was not surveyed as part of this assessment, the rates where the lower channels first reach the bays is likely much higher, perhaps on the order of several inches a year[5]. The open water areas within the upper bays fill with

[5] On South Zippel Bay, a channel like shape has been advancing northward (downstream) over the years as evidenced by aerial photos. Since approximately 1980, the channel/bay confluence is in the vicinity of the dock areas of Zippel Bay Resort. According to the resort, dredging is required here almost every year to maintain open passage from the docks to the navigation channel.

sediment to the point where a channel is formed. If the sedimentation is gradual enough, the channels that form in these areas evolve into a shape and size that can transport sediments through. This process then continues downstream as a channel with low/emergent wetland vegetative floodplains continues to form.

It should be noted that channel and ditch erosion estimates made as part of this project are based on observations and measurements taken during a relatively low runoff period (from SWCD monitoring records - personal communication with Mike Hirst LOW SWCD – 2012). When runoff rates return to normal levels, sediments stored in the lower channels and unstable side slopes will likely be remobilized increasing this component of the sediment budget even more.

Sediment reduction alternatives were analyzed. Alternatives included upland land use changes and channel/ditch erosion treatments. As expected, the most effective alternatives were those that focused on the largest sediment component for that particular watershed. In Bostic Creek, where channel erosion is a significant sediment source, reducing this form of erosion to 5 tons/1,000 feet can reduce watershed sediment yield by 54%. Conversely, in West Branch Zippel where channel erosion is a much smaller component of the total sediment load, yield is only reduced by 3% when channel erosion is reduced to 5 tons/1,000 feet. Since upland erosion sources are a much larger component of the total yield in West Branch Zippel, treatment of these sources is a more efficient way to reduce sediment yields at the outlet. For West Branch Zippel, reducing sheet and rill erosion and ephemeral erosion[6] results in a 35% reduction in sediment yield at the outlet (11% and 16% reduction for Bostic and South Branch Zippel respectively for this same alternative).

At this time, the ditch system does not appear to have any extensive chronic erosion or stability problems. There is evidence that there may have been a significant amount of ditch erosion in the past following the initial construction or alterations of the ditch systems. It is suspected that new ditching, enlarging of existing ditches, and extensive repair/maintenance projects since the 1950's may have resulted in stability problems due to:

- problems establishing good vegetative cover within a reasonable time following construction
- too steep of side slopes given the soil types encountered
- saturated side slopes in ditches adjacent to wetland areas resulting in excessive pore pressures leading to slumping
- channel headcutting that results when culverts are replaced and inverts are set below existing grades

Down cutting in County Ditch 1 in the Zippel watershed has been an issue in the past as evidenced by comparison of 1966 and 2009 surveys. Portions of this ditch show down cutting up to 2 feet lower than preconstruction conditions. Fortunately, down cutting appears not to be excessive at this time. Field investigations as part of this project revealed that channel down cutting may have slowed as the ditch

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[6] This alternative was simulated by:

- Limiting sheet and rill RUSLE C factor to 0.1 throughout the watershed (amount that could be expected from a small grain field).
- Reducing ephemeral erosion rates by 50%. This would be estimated reduction to be expected by using cover crops plus grade control structures at the larger sites

begins to move towards a quasi-equilibrium following past disturbance events. This may be due to a combination of:

- the channel bed eroding down to a resistant layer of dense, high clay content glacial lake sediments
- self armoring from the erosion of fine materials leaving larger cobbles, gravel, and large clay aggregates (sorting)
- the channel bottom slope has eroded down to the a grade that is controlled by culvert crossing inverts (fixed hard points)

Over the years, a significant effort has been put forth by the County to repair and modify the ditch system to reduce erosion. Measures include reducing side slopes, installing toe rip rap, replacing failing timber bridges with concrete pipe, armoring inlets/outlets of culvert crossings, and installing small grade control drops on steeper grades or areas with unstable soils. These efforts, combined with the natural channel shaping processes over time, have created a channel system that is in a reasonable equilibrium with its sediment load. Of course, there are some reaches (north-south section of JD16 in Bostic Creek watershed and upper end of south branch Zippel CD-1 through the beach ridge) that are unstable, however, these appear to be manageable and are trending toward stability. Again, many of the recent observations come during a period of relatively low runoff. What appears stable today may be mobilized when runoff rates return to normal.

Due to the large proportion of wetlands and forest in these watersheds, the hydrology is reasonably "buffered" against land use/land management change. The proportion of the runoff currently from these natural land covers is relatively high compared to the managed cropland (21% and 27% agricultural land for Bostic and Zippel Creek watersheds respectively). Also, the amount of land that is used for cropland should remain relatively stable due to USDA swampbuster/sodbuster provisions along with the basic impracticality of converting these wetlands and forest to cropland. It should be noted however that there has been a sharp increase (>50%) in the proportion of agricultural land that has been converted to soybeans and small grains since 2002.

The recent increase of drainage tile installations, which allows for more intensive management of cropland, does not appear to significantly impact sediment yield on a watershed scale basis due to the low percentage of total agricultural land compared to natural covers (21% and 27% agricultural land for Bostic and Zippel Creek watersheds respectively). Water quality (increase in nitrates entering the ditches) and wetland impacts, however, are likely to be more of a concern with increased tile drainage. Also, some of these tile installations require extensions of existing ditch system for outlet purposes which in turn can increase channel/ditch erosion potential. Increased tile drainage can also increase average base flows which in turn reduces the amount of vegetation within the lower toe slopes of the channel. In the ditches running through erosive soils, this can result in increased erosion through side sloughing and head cutting up-channel.

VIII. Recommendations

With exception of a few focus areas outlined below, erosion and sedimentation rates within these two watersheds are not exceptionally high. However, since there are potential adverse changes to the watersheds' future condition, a preservation type of management is recommended. These adverse potential changes include: 1) a return to normal runoff rates, 2) potential remobilization of stored sediments from lower downstream channel sinks into the bays, and 3) increases in percentages of more erosive crop rotations. Local SWCD/NRCS and Lake of the Woods County Public Works should continue to aggressively track and treat erosion problems as they come up. Continued coordination between the two groups on soil erosion and sedimentation issues will be critical to maintaining stable watershed conditions into the future.

Recommendations are broken down into two sections: 1) Implementation Items - those treatments or actions that could be utilized in the short term to reduce sedimentation and 2) Data Enhancement – information that would be needed to improve the effectiveness of future long term treatment options.

Implementation Recommendations

1. <u>Judicial Ditch 16/Judicial Ditch 28</u> – This ditch drains the vast majority of the Bostic Creek watershed. The reach in question here is the north-south JD 16 (east of Co Rd 4) and east-west portion of JD 28. This channel essentially takes runoff from the uplands and routes it though Graceton Bog then east to the natural Bostic Creek channel. Field reviews and discussions with LOW County personnel confirm this to be one of most unstable reaches. The general impression is that soils, high runoff event volumes, high base flow volumes, and steepening channel grades contribute to this reach's instability. Recently, a 4,800 feet reach has been reshaped into a two-staged channel to reduce erosive velocities and the county has installed several rip rap grade control structures. These projects have been mostly effective however there are still instabilities (lack of meandering in two-stage channel limits velocity reductions/flows tend to flank around riprap grade control structures). Cross section surveys were taken several years ago and a general hydraulic model was developed however the wide spacing of the cross sections did not provide enough detail for a stability analysis.

    - It is recommended that a detailed survey of this reach along with a soil investigation be made. This type of hydrologic and geotechnical study should dovetail well with the recommended geomorphology study in the Data Enhancement Recommendation section. With this information, a comprehensive design for channel stabilization would be developed. Such a design would likely include grade control structures and side slope drainage treatments.

2. <u>Enhancing Vegetative Cover Establishment on Future Projects</u> – To give vegetative cover more time to become established, it is recommended future repairs and modifications be performed earlier in the summer rather than in the fall. The vegetation not only buffers bank materials from erosive flows, its root mass also helps bind those materials together and through the growth process removes some of the excess moisture that promotes instability. Obviously construction during the fall makes such operations easier, but having an established vegetative cover in place for heavy spring flows dramatically increases the chances improvements will not unravel and that they will function as desired.

3. Ephemeral Erosion Treatment - Ephemeral erosion, especially in the West Branch Zippel watershed, is probably the most visible and potentially treatable forms of erosion in these watersheds. Since most of these erode directly into main ditches (without upland deposition potential), treatment of these can be very efficient at impacting watershed sediment load. Many of these are currently "controlled" by landowners placing field stone into the existing gullies.

    - It is recommended that the local SWCD/NRCS work with landowners to encourage use of cover crops and installation of grade control structures at field drainage junctions with the main ditches. In many situations it would be practical to combine several small surface drainage swales with edge of field diversions to bring to one structure. For small drops between fields and ditches (1-2 feet), installations of simple buffers can prevent head cutting up into fields.

4. Enhance Filtering Capacity of Buffers - In flat watersheds such as Bostic and Zippel Creek, buffers can be very effective at filtering sediments leaving a field. The ability of a buffer to filter is reduced when the buffer is too narrow or not level enough to encourage sheet flow as opposed to channelized flow. Also, permanent woody vegetation such as trees or shrubs within a buffer can increase filtering capacity and reduce the tendency to form channels through the buffer.

    - It is recommended that buffer widths of 75-100 feet be encouraged along with inclusion of woody plants where compatible with field operations and soils.

5. Upstream Storage – Reducing peak discharges and storage of runoff can be an effective way to reduce downstream channel erosion. A preliminary study of storage in Canfield Creek showed that peak flows could be reduced by 25% by controlling the upper 8.7 mi^2 of the 26.5 mi^2 watershed. This reduction in peak flows would reduce stream bank erosion by approximately 12% (based on shear stress/erosion model developed for this project). In other parts of the state, downsizing road culverts has also been shown to reduce peak discharges. Care must be taken when selecting these so as not impact upstream interests. With the current availability of LiDAR data, the reliability of such assessment will be greatly enhanced.

    - It is recommended that runoff reduction practices such as ponds and wetlands be encouraged in the areas of the watersheds upstream of the beach ridge where topography is better suited and loss of cropland would be minimal. Road retention utilizing downsized culverts should be investigated in cooperation with the LOW Public Works Department.

6. Drainage Water Management – With the increase of subsurface drainage installations, an opportunity exists to promote water retention utilizing drainage water management (DWM) practices. DWM reduces runoff during the non-growing season through the use of small gated structures within the subsurface system. Prior to seed bed preparation and throughout the growing season, gates are open and fields drain normally. In late fall through early spring, gates are closed, effectively storing water in the soil profile. This effectively takes the spring soil water and delays its release until after the main ditches have peaked. In addition to the water storage benefits, DWM systems can be used to keep water tables elevated in the crop root zone

during times of drought. The flat topography of cropland in these watersheds makes this a feasible practice.

- Since this is newer type of water conservation practice, it is recommended that DWM be tested on trial basis with a few cooperators. If successful, the practice could be encouraged on a larger scale.

Data Enhancement Recommendations

1. Geomorphologic Analysis - Both of these watersheds have been extensively ditched within the lake plain south of the Glacial Lake Agassiz beach ridge. These deep ditch systems, without adequate floodplains to reduce velocities, can experience high bed/bank shear stresses resulting in increased erosion. Lack of a floodplain within the ditches also increases sediment transport efficiency (very little of the sediment within streamflows can deposit prior to exiting into Bostic and Zippel bays). It is recognized that reverting to pre-settlement hydrology and natural channel systems is impractical. However, opportunities exist in some areas for channel reconfiguration. In order to properly design channels, consideration must be given to the geomorphic characteristics of that particular reach.

   - In anticipation of potential channel restoration in the future it is recommended that a geomorphic stream study be conducted. Such a study would consider information such as sediment inflows, runoff volumes, peak discharges, base soils, etc. in the design of channels. As NRCS no longer has enough staff available to conduct such a study, an outside entity would have to be contracted to do so. Unfortunately, such an analysis could take considerable time and be fairly costly. Therefore, it is recommended SWCD/NRCS and Lake of the Woods County Public Works select areas they view as most critical and study only those areas initially. Suggested reaches would include Judicial Ditch 16/Judicial Ditch 28 (see below) and the lower reaches of Bostic, South Branch Zippel, West Branch Zippel Creeks where sediments have begun to accumulate upstream of the bays.

2. Sediment Transport in Lower Reaches – During field investigations, it became obvious that significant volumes of sediment is stored within the channel reaches just upstream of Co Rd 8 for Bostic and South Branch Zippel watersheds and downstream of County Road 61 (T162N, R33W, Sec 17-18 Crossing) in West Branch Zippel watershed. Much of this sediment is historic in nature (deposited over a period of decades). These sediments have the potential to move during large events. Quantifying these sediments and potential for movement were not included in this assessment. Knowing the volume of these sediments, rate and susceptibility of movement would be useful for future downstream bay sedimentation analysis.

   - It is recommended that a sediment coring and bathymetric survey be made of these lower reaches to determine volume of sediments and rate of filling. As part of this analysis, a correlation should be made between movement of these sediments and incoming upland runoff and flow velocities. If there is potential for significant volumes of these sediments to move into the upper bays, treatments to prevent movement should be investigated such as planting of mature woody wetland plants, re-shaping of channel to a stable shape, and direct removal of sediments.

3. Ditch Maintenance/Dredging Costs Records - Several of the recommendations listed above require significant resources in terms of time and money. To justify these resources, through grant applications or SWCD/NRCS time prioritization, some actual economics data relating resource degradation to monetary costs is needed.

    - It is recommended that the SWCD coordinate with the Lake of the Woods County to develop a ditch repair and maintenance costs database for these two watersheds. In addition to the County's ditch repair records, the costs, dates, and amount of dredging being done by the resorts in Bostic, South Zippel, and West Zippel Bays should be included.

4. Stream Flow Monitoring - Much of the data used to develop the sediment budget for this study comes from modeling. Monitoring actual flow and sediments is necessary to get a true picture of watershed condition. The LOW SWCD in cooperation with the MPCA currently maintains several monitoring stations in the Bostic and Zippel watersheds however much of the data is limited to suspended sediment. Suspended sediment data is useful for establishing general trends in relative turbidity between different channels but it cannot provide loading (actual amount or volume of sediment over time). The monitoring program could be improved upon by including collection of discharge data.

    - It is recommended that the SWCD/MPCA consider purchasing equipment to improve actual stream flow rate measurements. Accurate flow rates would be used to translate TSS measurements into actual sediment loading (tons of sediment passing a station).

5. Upstream Sediment Erosion and Down Cutting Studies – It would be useful to add inexpensive channel sediment monitoring equipment such as bank pins and scour chains in a few locations. This would help quantify and verify current rates of channel erosion made by walking the stream. This would greatly improve the understanding of the instream sediment transport system in these watersheds.

    - It is recommended that sediment monitoring equipment be installed within channels/ditches at locations which have been estimated to have a high erosion rate in addition to some lower erosion rate areas for data control purposes. NRCS Geologist assistance is available for site selection technical assistance.

Appendix A – Sediment Budget Process

The sediment budget used for this project involves these basic steps:

1. An HEC-HMS hydrologic model was developed for the two watersheds (see Appendix I). The watersheds were broken down into 43 (Bostic) and 47 (Zippel) subareas for Bostic and Zippel respectively. Connecting these subwatersheds are 26 (Bostic) and 25 (Zippel) reaches that represent the various ditches and natural stream channels. See Appendix I for Bostic and Zippel HEC-HMS routing schematics.
2. Sheet and rill erosion is calculated using RUSLE on a 3m x 3m grid basis for all land uses and is then aggregated up to the HMS subwatershed level (see Appendix B)
3. Ephemeral erosion is calculated for each identifiable ephemeral trace on aerial photos then accumulated on an HMS subwatershed level (see Appendix C)
4. Channel erosion is calculated for each HMS reach (see Appendix D)
5. Sheet and rill, ephemeral, and channel erosion sediment amounts are then routed through the watersheds' hydrologic system along the HEC-HMS reach pathways
6. Reductions in sediment load due to settlement along transport pathways are accounted for by using Sediment Delivery Ratios (SDR's). Two types of SDR's are used (see Appendix E for details on how these SDR's were derived):
    - An <u>Upland SDR</u> is applied to sheet and rill erosion yields to account for deposition within the individual fields and surface hydrology system within each HMS subwatershed. The upland SDR is a function of HEC-HMS subwatershed size.
    - A <u>Channel SDR</u> is applied to all erosion sources (Sheet and Rill, Ephemeral, and Channel erosion) as sediments make their way through the watersheds' hydrologic network (HMS reaches). Sediments from far up in the watershed will be reduced more than sediment close to the watershed outlet since it must travel through more HMS reaches. See Figure A-3 shows the reaches used to route sediments through the watersheds.

Figure A-1 is an excerpt from the sediment budget spreadsheet showing how sediments from an HMS watershed and channel reach are routed through the hydrologic system down to the outlet into West Zippel Bay.

West Branch Zippel

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
2									q2 velocity	1.79	2.62	2.64	1.10	1.27	0.80	1.69	1.31	1.35	1.42	1.59	1.36	1.33	1.04					
3							average reach L:	7515	base sdr	0.92	0.97	0.98	0.82	0.85	0.72	0.91	0.86	0.87	0.88	0.91	0.87	0.87	0.81					
4									length	21455	7701	5002	10311	9472	2966	5191	4683	5176	7749	4336	9101	5597	5874					
5									final sdr	0.77	0.97	0.98	0.75	0.82	0.89	0.94	0.91	0.91	0.88	0.95	0.84	0.90	0.85					
6	type	watershed/reach	da (sq mi)	10-yr discharge	gross upland erosion	sheet and rill sdr	net upland erosion	upland ephemeral	channel erosion	r-043	r-045	r-049-w	r-083	r-087-w	r-049-e	r-057	r-061	r-067	r-069	r-071	r-075-079	r-087-e	r-075	sdr	upland erosion net	ephemeral net	streambank net	
7	w	41	9.46	328	37.1	0.165	6.1	3.5		1	1	1			1									0.66	4.0	2.3		
8	r	r-043	9.46	328					210.3		1	1			1									0.85			179.3	
9	w	43	9.05	331	105.0	0.166	17.5	14.8			1	1			1									0.85	14.9	12.6		
10	w	45	2.69	108	142.7	0.197	28.0	50.8				1			1									0.88	24.5	44.5		
11	r	r-045	21.20	760					38.5			1			1									0.88			33.7	
12	w	47																										
13	w	59																										
14	r	r-049-w																									13.3	
15	w	81																										
16	r	r-083																									29.9	
17	w	83																										
18	w	86																										
19	r	r-087-w																									25.3	
20	w	49																										
21	r	r-049-e																									8.9	
22	w	51																										
23	w	55																										
24	w	53																										
25	r	r-057																									22.4	
26	w	57																										
27	r	r-061																									22.1	
28	w	63																										
29	w	65	0.63	14	114.6	0.239	27.3	97.8										1	1	1				0.76	20.7	74.1		
30	r	r-067	2.16	95					25.9										1	1				0.83			21.5	
31	w	67	1.33	50	319.4	0.215	68.6	188.3											1	1				0.83	57.1	156.8		
32	r	r-069	3.49	144					38.7											1				0.95			36.6	
33	w	69	0.77	33	162.6	0.232	37.7	84.2												1				0.95	35.7	79.7		
34	w	61	0.14	5	13.4	0.397	5.3	1.6												1				0.95	5.0	1.5		
35	r	r-071	8.30	333					21.7															1.00			21.7	
36	w	71	0.22	11	44.2	0.350	15.5	8.9																1.00	15.5	8.9		
37	j	nc_r049e-r07	34.93	1281																				1.00				
38	w	77	11.31	353	282.4	0.161	45.5	24.6													1			0.84	38.5	20.8		
39	w	79	0.68	21	112.6	0.236	26.6	94.6													1			0.84	22.5	79.9		
40	r	r-075-079	11.99	370					45.5															1.00			45.5	
41	w	85	2.15	105	57.6	0.201	11.5	5.7														1		0.90	10.4	5.1		
42	r	r-087-e	2.15	105					28.0															1.00			28.0	
43	w	73	1.42	86	1.5	0.213	0.3	0.0															1	0.85	0.3	0.0		
44	r	r-075	1.42	86					29.4															1.00			29.4	
45	w	91	3.13	227	108.8	0.193	21.0	55.1																1.00	21.0	55.1		
46	w	89	1.23	80	78.9	0.217	17.1	10.0																1.00	17.1	10.0		
47	w	75	1.19	52	231.3	0.217	50.3	66.8																1.00	50.3	66.8		
48	w	87	1.16	74	247.9	0.218	54.0	97.8																1.00	54.0	97.8		
49	j	west bay	57.20	2124	3111.3		690.5	1272.6	581															1.00	600.0	1100.8	517.7	2218.51
50					Upland Erosion			Ephemeral Erosion	Channel Erosion																and rill contributio	ephemeral	streambank	grand total (tons)
51																									0.3	0.5	0.2	
52																			deposited in channels						90.5	171.8	63.1	325.5

Channel Sediment Delivery Ratios - function of Q2 channel velocity (in row above) and chennel length

Sediment Routing Example:

For watershed #41 (cell B5), field sheet and rill is 37.1 tons/ac (gross upland erosion). Upland SDR is 16.5% so 37.1*0.165 = 6.1 tons makes it to the channel system (net upland erosion). Also, 3.5 tons of ephemeral erosion makes it directly to the channel system. Sediment from watershed 43 is then routed through four downstream reaches (noted with a "1" in columns J-W) to the watershed outlet (West Zippel Bay). Channel SDR for each individual reach is shown row 5 directly above (i.e. for reach R-043, 77% of sediment moves through). The accumulated SDR for the four reaches that the sediment must move through is shown in column X (0.66=0.77*0.97*0.98*0.89). Total sediment from watershed 43 that makes it to the basin outlet is 4.0 + 2.3 = 6.3 tons.

For reach-043 (column B), total channel erosion is 210.3 tons. Sediment from this reach is routed through three downstream reaches to the watershed outlet (West Zippel Bay). The accumulated SDR for the three reaches that the sediment must move through is shown in column X (0.85=0.97*0.98*0.89). Total sediment from reach-043 that makes it to the basin outlet is 210.3*0.85 = 179 tons.

Process continues for each watershed and reach and then summed Total net sediment entering West Zippel Bay = 2,219 tons.

Figure A-1 - Sediment Budget Routing Spreadsheet Example

Appendix B – RUSLE Sheet and Rill Erosion Analysis

RUSLE (Revised Universal Soil Loss Equation) was used to estimate average annual sheet and rill losses within the watershed. RUSLE uses the following equation to make this estimate:

$$\text{Average Annual Soil Loss (tons/acre/year)} = R*C*K*LS$$

where: R = rainfall factor (72)

C = cover and management factor – function of crop rotation/land use

K = soil erodibility factor – function of soil type

LS = length/slope factor – function of soil type and slope

C factors were assigned to each crop rotation and land use found in the watershed. The table below summarizes the various C factors used in this study. Ordered highest to lowest based on C factor.

Land Cover/Rotation	Acres	C factor
Potatoes	414	0.33
Cultivated Crop (default for cropland not identified with a specific rotation)	2,160	0.16
Small Grain - Soybeans	7,206	0.16
Wheat-Perennial Rye-Soybeans	3,642	0.16
Wheat-Soybeans-Wheat-Sunflower	727	0.13
Small Grain	420	0.098
Timothy (6 yrs)-Small Grain (3 yrs)-Fallow	1,481	0.081
Bluegrass	3,582	0.035
Oats-Hay (5 yrs)	631	0.035
Pasture/Hay	1,466	0.021
Continuous Hay	3,337	0.015
Barren Land	34	0.005
Emergent Wetlands	17,187	0.005
Grassland	1,858	0.005
Shrub	459	0.005
CRP	949	0.005
Idle	11,330	0.005
Forest	2,390	0.003
Woody Wetlands	38,443	0.003
Developed	1,710	0.0001
Open Water	411	0.0

ARCMAP GIS was used to make the calculations. Basically, two 3 meter x 3 meter resolution grids were created:

1) RKLS grid (created using SSURGO data)

2) C factor grid

A RUSLE average annual soil loss grid was then created by multiplying the two grids together using Spatial Analyst – Raster Calculator. Zonal statistics was then used to determine the total average annual soil loss on an HMS watershed basis (the sediment budget's routing scale size). The RUSLE sheet and rill erosion amounts for each HMS watershed were then used as input to the sediment budget routing model (see Appendix A). The sediment budget routing model simulates the movement of these sediments through the hydrologic system downstream, accounting for deposition within the field and the downstream channels.

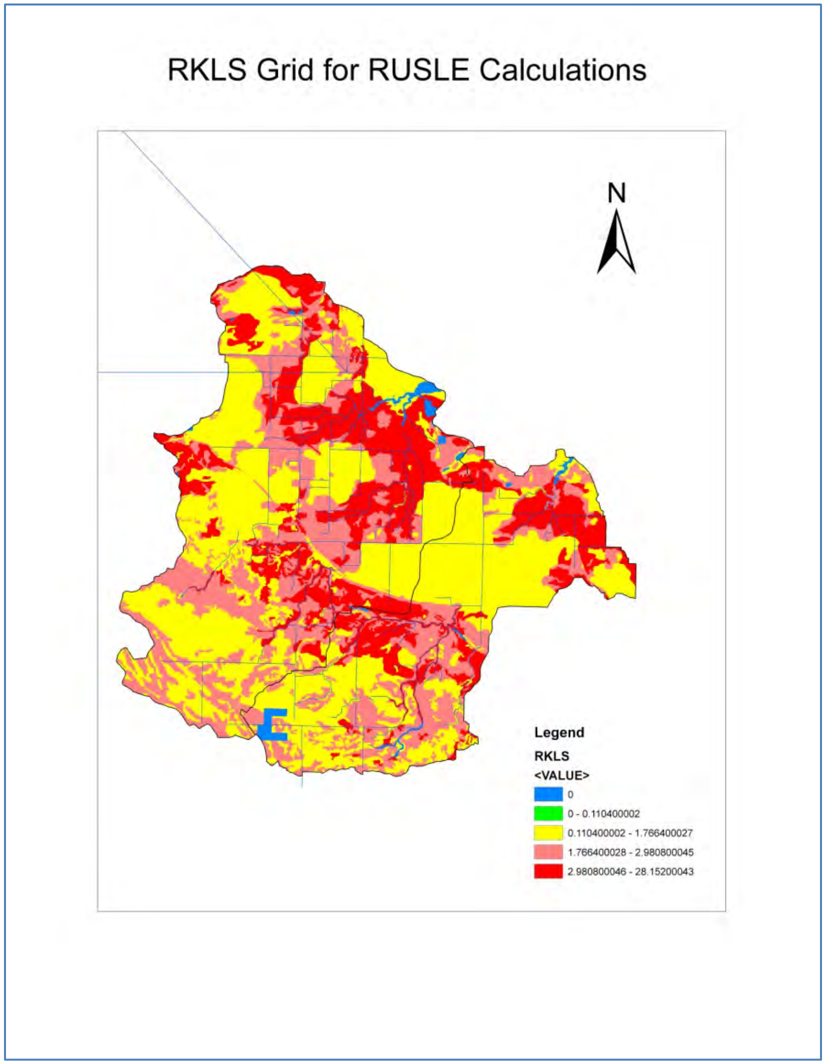

Figure B-1 - RKLS Map of Watersheds

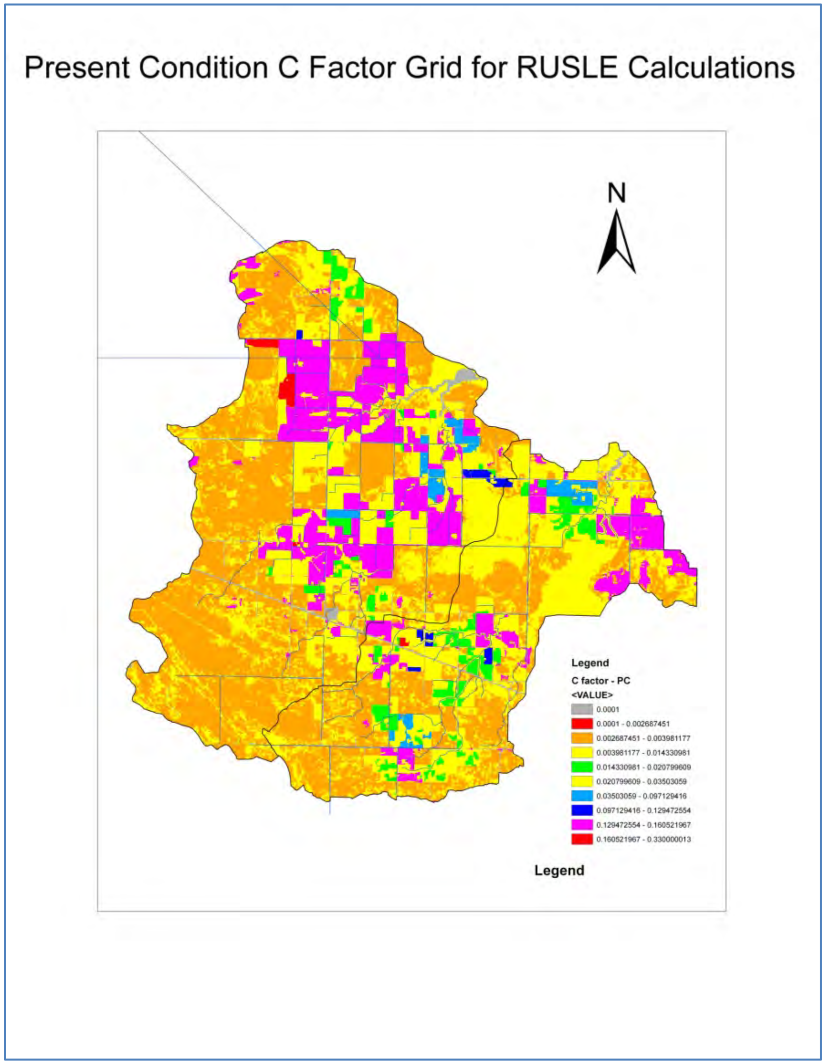

Figure B-2 - C Factor Map of Watersheds

Appendix C – Ephemeral Erosion Analysis

Ephemeral erosion within the two watersheds was estimated using a combination of field sampling and GIS analysis. Basically the procedure was as follows:

1. Using GIS, a random set of 23 ephemeral sites (based on erodible signatures visible on IR photography) was provided to the SWCD office. In the field, SWCD personnel measured width, depth, and length of erosion.

2. Total volume of eroded material per foot of length was calculated.

3. A relationship between erosion length and cubic yards was estimated. See Figure C-1.

4. Using GIS with 2009 aerial imagery, all obvious ephemeral erosion sites were traced and lengths were calculated. A total of 710 sites were identified (135 miles total length).

5. Assuming 1.4 tons/yd^3, the total tonnage of ephemeral erosion within each HMS watershed (the sediment budget's routing scale size) was calculated.

6. When calculating ephemeral erosion on less intensively managed fields, a factor was used to reduce the total ephemeral tonnage leaving those fields. The adjustment factor was also used in the alternatives analysis to estimate ephemeral erosion rates associated with a change in management.

7. These ephemeral erosion amounts for each HMS watershed were then used as input to the sediment budget routing model (see Appendix A). The sediment budget routing model simulates the movement of these sediments through the hydrologic system downstream, accounting for deposition within the channels.

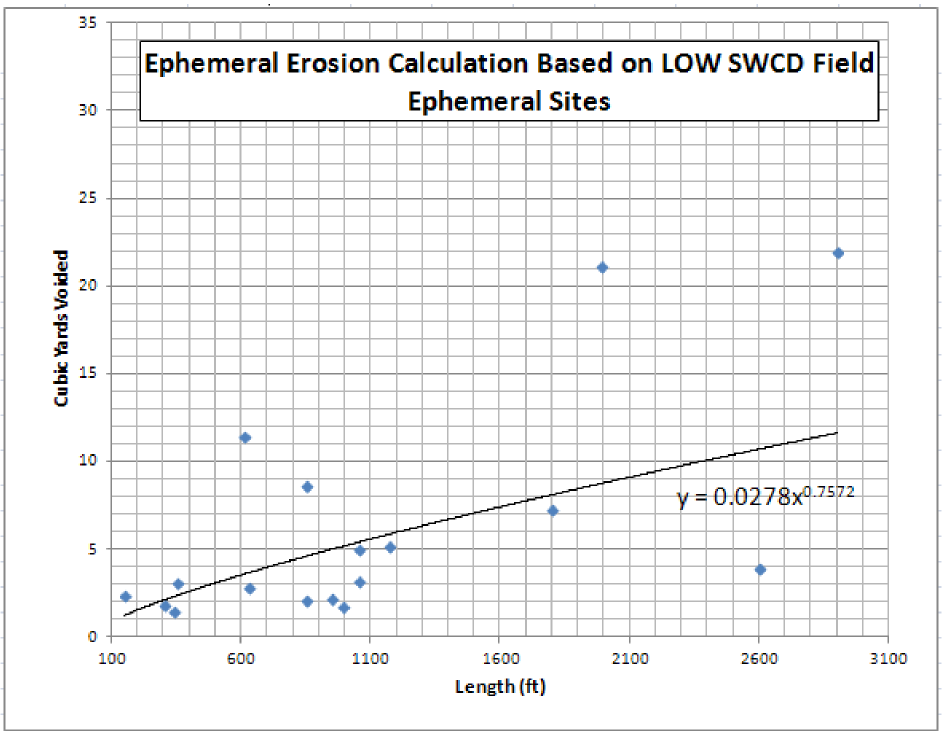

Figure C-1 SWCD Ephemeral Sample Sites Length/Eroded Volume Relationship

Table C-1 - Ephemeral Erosion Factor for Various Crops

Rotation within the Field	Ephemeral Multiplier
Potatoes	1.00
Small Grain-Soybeans	0.60
Wheat-Perennial Rye-Soybeans	0.60
Wheat-Soybeans-Wheat-Sunflower	0.51
Small Grain	0.40
Timothy (6yrs)-Small Grain (3yrs)-Fallow	0.33
Oats-Hay (5yrs)	0.15
Bluegrass	0.15
Continuous Hay	0.07
CRP	0.02
Idle	0.02

Appendix D – Channel/Ditch Erosion Analysis

Channel and ditch erosion amounts were estimated using the following procedure:

1. Reference reaches were selected for making in-the-field detailed measurements of existing streambank erosion. These reference reaches included channels with varying soil types, slopes, and adjacent land uses. See Figure D-2.
2. The reaches were walked and individual erosion sites' length, width, and depth were measured. An estimated total 6.8 miles of channel were walked. See Figure D-1 for a sample of measurements made within a reach.
3. Erosion measurements were converted to tons of bank/side slope material eroded per 1,000 feet of channel.
4. Some channel erosion yields were adjusted to account for temporary conditions (recent construction activities, infrequent slumping, etc.).
5. Field measured channel erosion estimates were transferred to un-sampled areas assuming similar erosion rates for similar channel soils, slope, maintenance, and upstream hydrology.
6. Final adjustments were made following consultation among NRCS, SWCD, and LOW County personnel.
7. These channel erosion amounts for each HMS watershed were then used as input to the sediment budget routing model (see Appendix A). The sediment budget routing model simulates the movement of these sediments through the hydrologic system downstream, accounting for deposition within the channels.

Reach	#4 - Cty Ditch 1			
Length	Height	Depth		Volume
30	3	2		180
20	3	2		120
30	3	3		270
10	2	3		60
30	2	2		120
40	2	3		240
30	2	2		120
20	2	2		80
25	2	2		100
150	3	4		1800
				3090
		Total:	114.4444	or 115 yds^3
Average density of materials from Braun Intertec Study (2001) 77.5 lbs/ft3				
27ft3/yd3 @ 77.5lbs./ft3 or 2092.5 lbs/yd3 = 1.05 tons/yd3				
Reach Tonnage = 120.75 - 121 tons				
Reach Length -		4300		
tons/1000' = 35 tons				

Figure D-1 Example Channel Erosion Field Measurements

Figure D-2 - Channel Erosion Field Measurement Reaches

Appendix E – Sediment Delivery Ratios

Sediment delivery ratios (SDR's) are adjustments made to "gross" erosion estimates to account for deposition of sediments between the origin of the sediments and the point where a total sediment yield is desired. RUSLE sheet and rill estimates reflect the amount of soil eroded on site. Deposition of this soil can occur further down slope from the point of origin – in the field itself, in wetlands, grassed waterways, ditches, etc. The same process occurs with ephemeral and stream bank erosion except that the deposition occurs within the downstream channel network (all ephemeral erosion sites were assumed to outlet to the channel system). For this assessment, two SDR's are used: 1) Upland SDR and 2) Channel SDR.

Upland SDR

The upland SDR was developed using a combination of data from the Magnum Pond Sediment Survey (see Appendix G) and data from the Upper Mississippi River Comprehensive Basin Study (1970)[7]. The Magnum Pond Sediment Survey provided data that was used to establish the relationship between upland sheet and rill erosion (250 acres) and sediment deposited within the pond. The Magnum Pond Sediment Survey data showed that 26% of the sheet and rill erosion estimate was accounted for in the pond sediment survey (the other 74% would be assumed deposited in the upland fields and surface ditches).

The overall relationship between drainage area and SDR for these watersheds was created as follows:

1. Use the Magnum Pond Survey drainage area/SDR relationship as an "anchor point": 26% delivery at 250 acres (0.39 sq miles)
2. For drainage areas less than 250 acres, assume a log-log relationship from 100% delivery at 0.01 square miles to the Magnum Pond anchor point
3. For drainage areas greater than 250 acres, assume a log-log relationship from the Magnum Pond anchor point forward using the MLRA 88 SDR/drainage area slope relationship

Figure E-1 is a graphical representation of the upland SDR applied to sheet and rill erosion amounts within each HMS watershed (the sediment budget's routing scale size). For comparison, the SDR relationships for the 1) Upper Mississippi River Comprehensive Basin Study MLRA 88 and 2) NRCS Chapter 11 (Ponds) MN Sedimentation Supplement are shown.

[7] Part of the Upper Mississippi River Comprehensive Basin Study addresses Fluvial Sediment Yields by Major Land Resource Areas (MLRA). The Bostic and Zippel watersheds lie within the MLRA 88 – Northern Minnesota Glacial Lake Basins which is common to both the Upper Mississippi River Basin and the Souris-Red-Rainy Basin to the north.

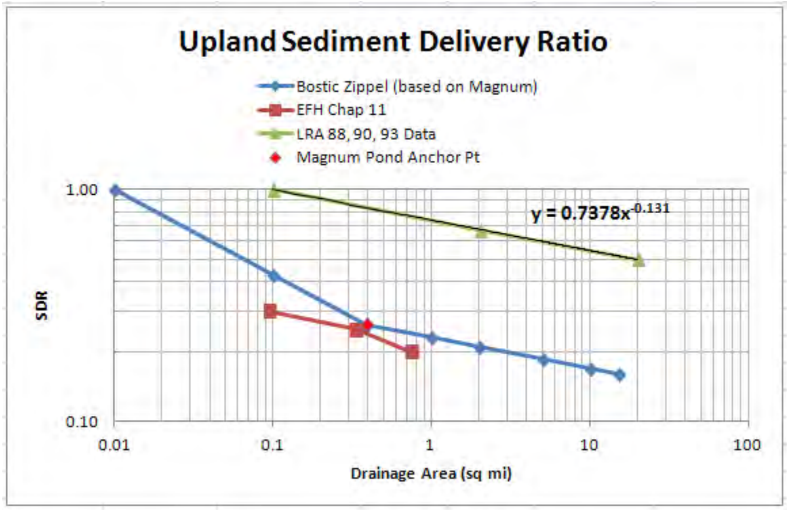

Figure E-1 - Bostic and Zippel Watersheds Upland Sediment Delivery Ratio

<u>Channel SDR</u>

The channel SDR relationship was based on estimated channel velocities for the 2-year event peak discharge[8] and adjusted for routing reach length. The channel sediment routing reaches were the same as those used in the HEC-HMS hydrology model and varied from 2,000 to 21,000 feet. See Figure E-2. Channel velocities for 2-year discharge were calculated using Manning's equation and channel slope, shape, and roughness. A Base SDR based on the relationship between velocity and SDR was estimated. Table E-1 below shows the adopted relationship between velocity and Base SDR.

Table E-1 - Channel Sediment Delivery Ratios (SDR)

Reach Q2 Channel Velocity (fps)	Base SDR (% of upstream sediment delivered through reach)
0.1	0.4
0.25	0.5
0.5	0.6
0.75	0.7
1.0	0.8
1.5	0.9
3.0	1.0

This base SDR was assumed to apply to the average sediment routing reach length (7,500 feet). The adjustment in SDR for different reach lengths was based on the equation:

$$\text{Reach}_X \text{ SDR} = 1 - (\text{Length of Reach}_X * (1\text{-Base SDR})/7{,}500)$$

[8] From HEC-HMS hydrology model – see Appendix I

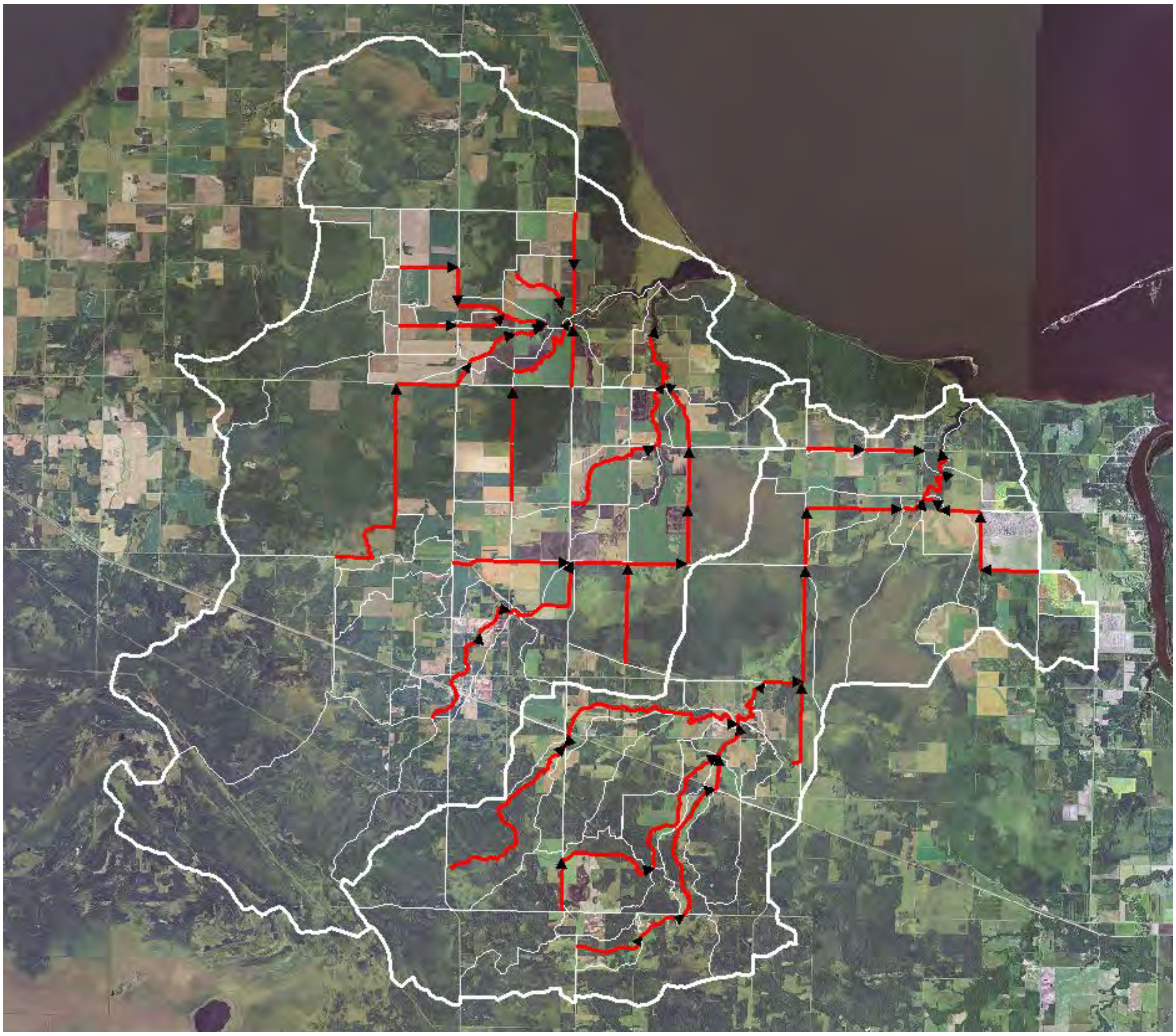

Figure E-2 - Channel Routing Reaches

Appendix F – Potential Stream Bank Erosion

Potential channel erosion within the Bostic / Zipple watersheds was assessed using GIS technology and a combination of estimated stream power and ditch bank soil erosion potential layers. The soil erosion potential was estimated by identifying the soils within 10 feet of the ditch and assigning each soil type a different erosivity and relative erosivity group based on the engineering properties of the soil. Table F-1 shows the estimated relative erosivity properties of soil types found on the stream banks within the watershed. Based on this analysis five groups were identified: Very High, High, Medium, Low and Very Low. The table below summarizes the soil types that were placed in each group. These were estimated by assigning a relative erosivity value based on Unified Soil Classification Symbol (USCS) groups found in the soils layer. The soil erosivity was then applied to all soil types that were found within 10 feet of the ditch bank. Figure F-1 shows a map of the relative erosivity values created for the streambanks within the Bostic / Zipple watersheds. As seen on the figure, there are only a few locations in the Bostic / Zipple watersheds, where the soil erosivity is considered high or very high and a majority of the ditch area has soil in the medium to very low range.

Stream Power for each of the reaches was calculated using the following equation:

$$\Omega = \rho g Q S$$

Where:

Ω = stream power
ρ= density of water 64.2 lb/ft^3
g = acceleration due to gravity (32.2 ft/sec^2)
Q = discharge (cfs)
S = hydraulic slope (ft/ft)

Density of water and gravity are constant across all reaches, so they were not used in the calculation. As a result, a relative stream power index for a given reach was calculated by simply multiplying the stream discharge (Q) times the average channel slope (S). For this analysis, a 10-year return period peak discharge was used (generated using the HMS model – see Appendix I) and the average channel slope of the reach. The resulting relative stream power values varied from 0 to 2.0 and are summarized in Figure F-2. When visually comparing Figures F-1 and F-2, it becomes apparent that there are more high to very high values associated with stream power than what was seen with the soil erosivity. This indicates that soils in these watersheds are relatively erosion resistant and much of the bank erosion may be associated with high stream power in those areas.

Table F-1 Comparison of soil type and relative erosivity values

---		Erosivity	Relative Erosivity
SM or SP or SP-SM	Sand, low or no plasticity	5	V. High
SM or SP-SM			
SP or SP-SM			
ML	Peat and Silt, low PI to no plasticity	4	High
PT			
CL	Clay, Moderate plasticity	3	Medium
CL-ML or ML			
CL or CL-ML			
CL or CL-ML or ML			
CL or CL-ML or ML or SC-SM			
CL or CL-ML or SC or SC-SM			
CL or ML or SC or SM			
CH	Clay, High plasticity	2	Low
CH or CL			
GP or GP-GM	Large Gravel	1	V. Low

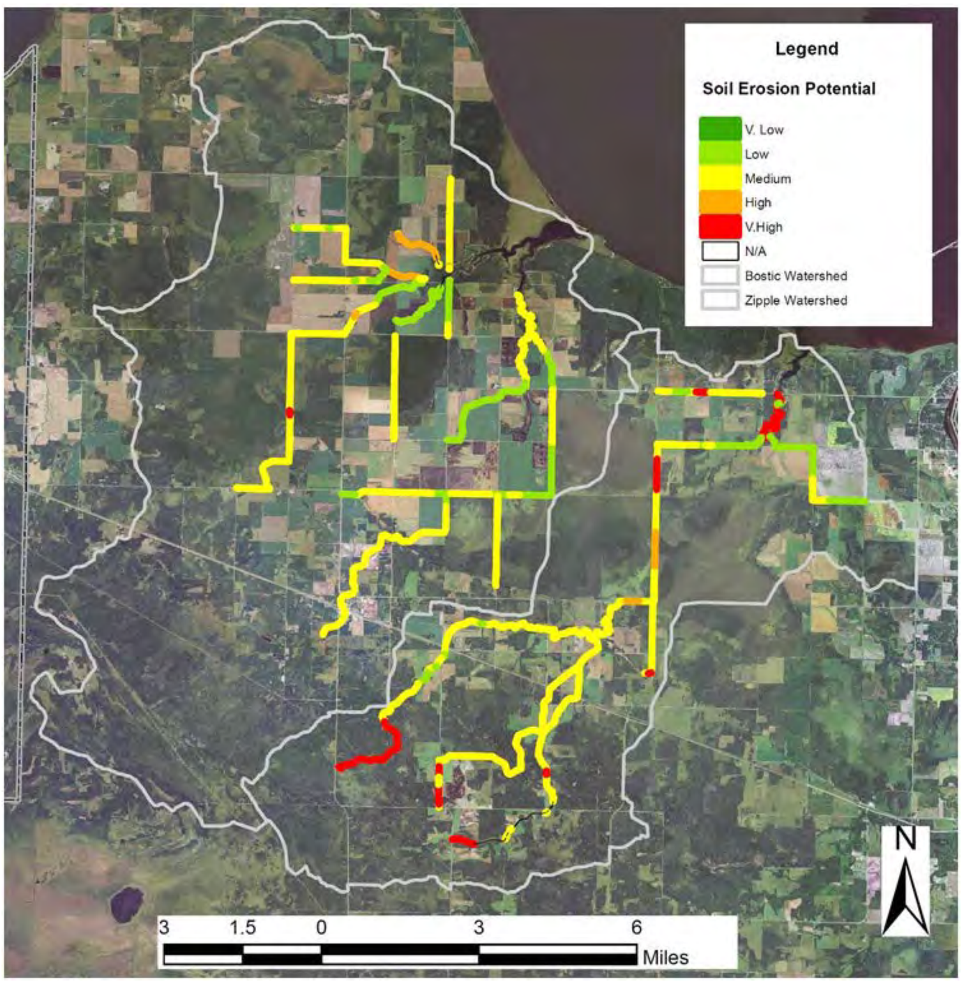

Figure F- 1 Relative soil erosivity for the ditch channels within the Bostic/Zipple system

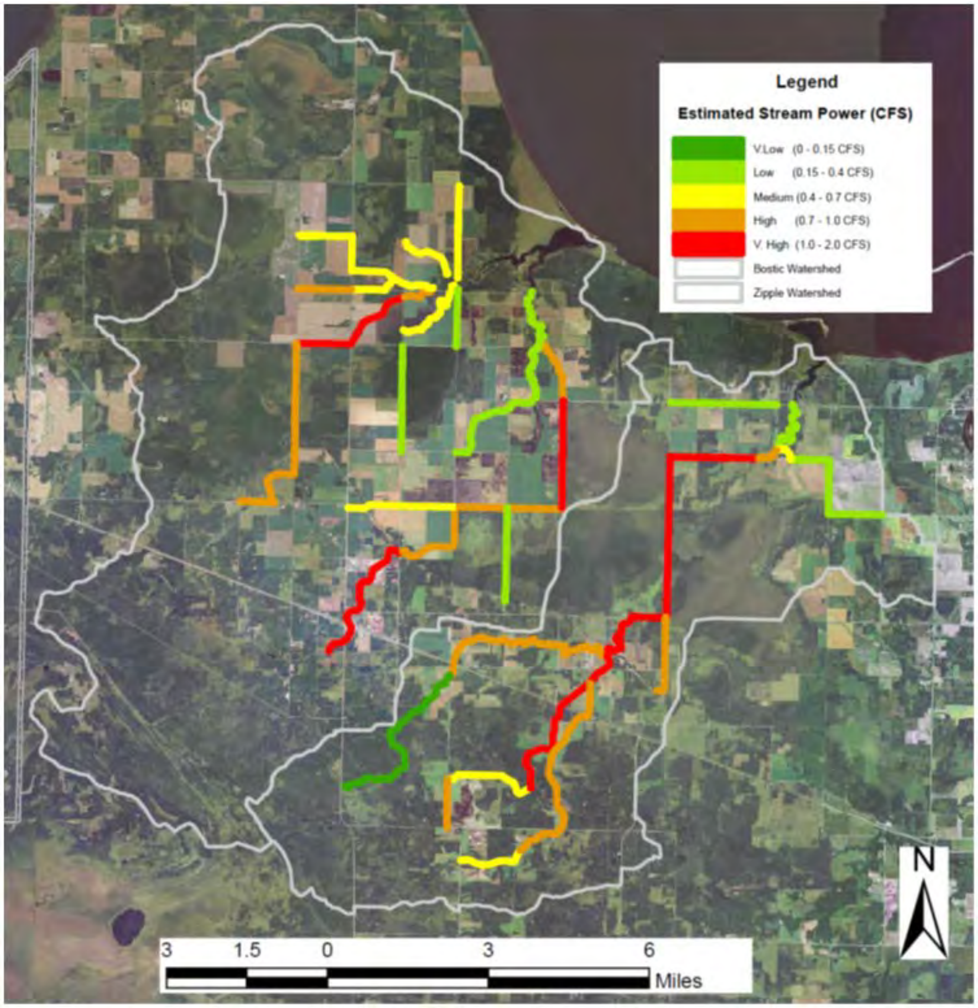

Figure F- 2 Estimated relative stream power in the Bostic / Zipple watersheds

Geographic Information Systems (GIS) was used to merge the potential soil erosivity data with the relative stream power data. The merging of these two variables (soils and relative stream power) was considered an indicator of potential channel erosion. Figure F-3 summarizes the resulting potential stream erosion rates. Approximately half of the ditch system is projected to have a very low to medium erosion potential and the other half is high to very high.

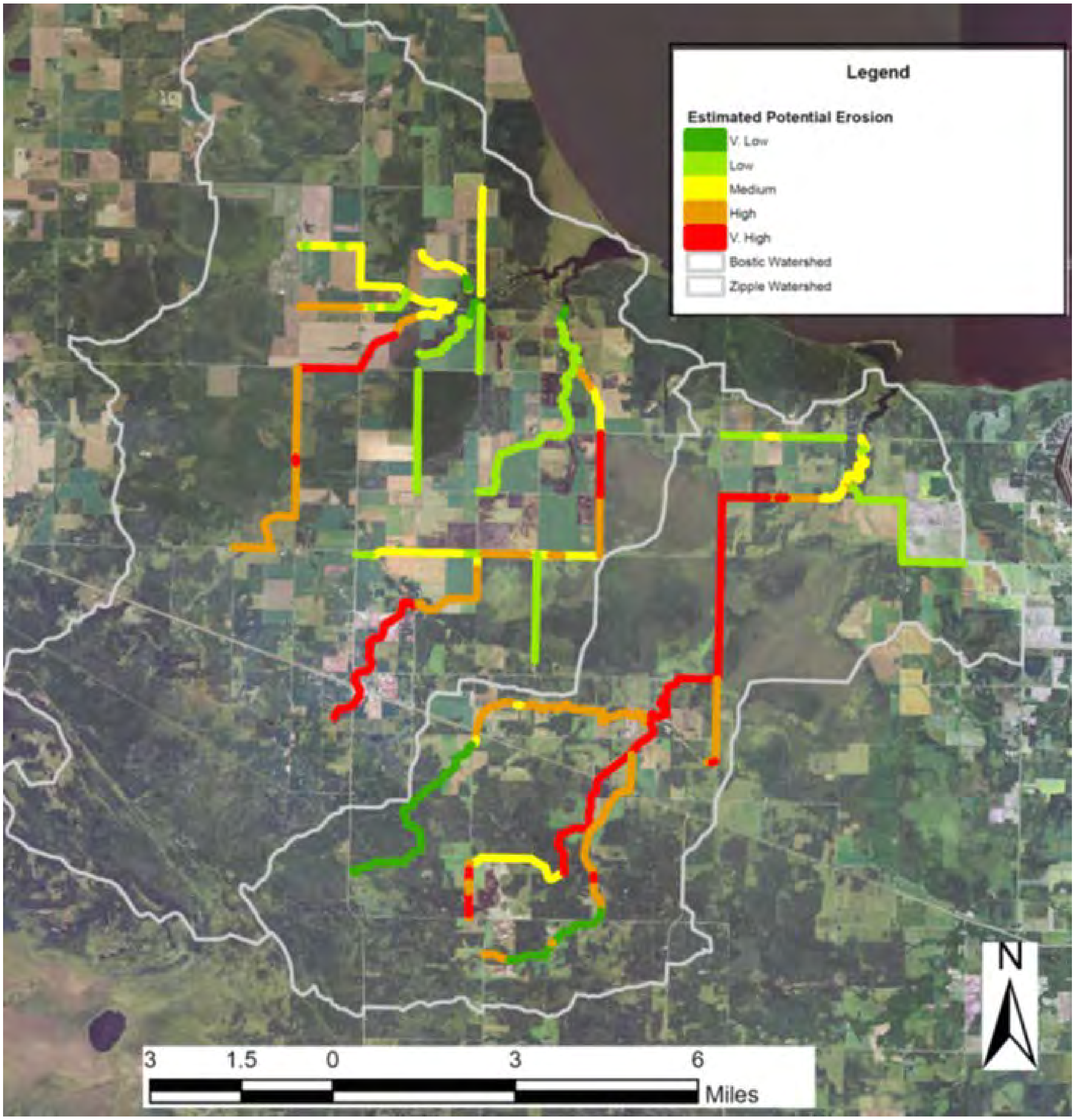

Figure F- 3 - Estimated Potential Erosion Rates Derived From Combination of Stream Power and Soil Erosivity Layers

The general trend of reaches which have high to very high potential erosion rates seems to be roughly similar to those estimates made from field work assessments (see Appendix D). With that being said, the relative distribution of high erosion does not match perfectly between the two data sets. It is hard to determine exactly what is causing these differences but it is likely that they are being caused by other factors that were not used in this analysis such as differences in management and vegetation. Despite the variations in the estimated potential versus actual erosion rate, the potential erosion map can serve as a guide to show reaches that would be considered to be relatively prone to erosion and may require extra repair and/or maintenance focus.

Appendix G – Magnum Pond Sediment Survey

Introduction

One of the biggest challenges in developing a watershed sediment budget is estimating a sediment delivery ratio (SDR). A SDR is an estimate of the percentage of on-site erosion that is transported to the watershed's outlet without depositing along the way in depressions, ponds, channels, etc. Appendix E provides details related to development of the SDR/drainage area relationship. A key piece of information used in developing that relationship was a sediment survey of a small (250 acre drainage area) NRCS designed pond project built on the Gene Magnum property in the 1960's (Figure 1). This pond is located approximately 7.5 mile east of the Bostic watershed.

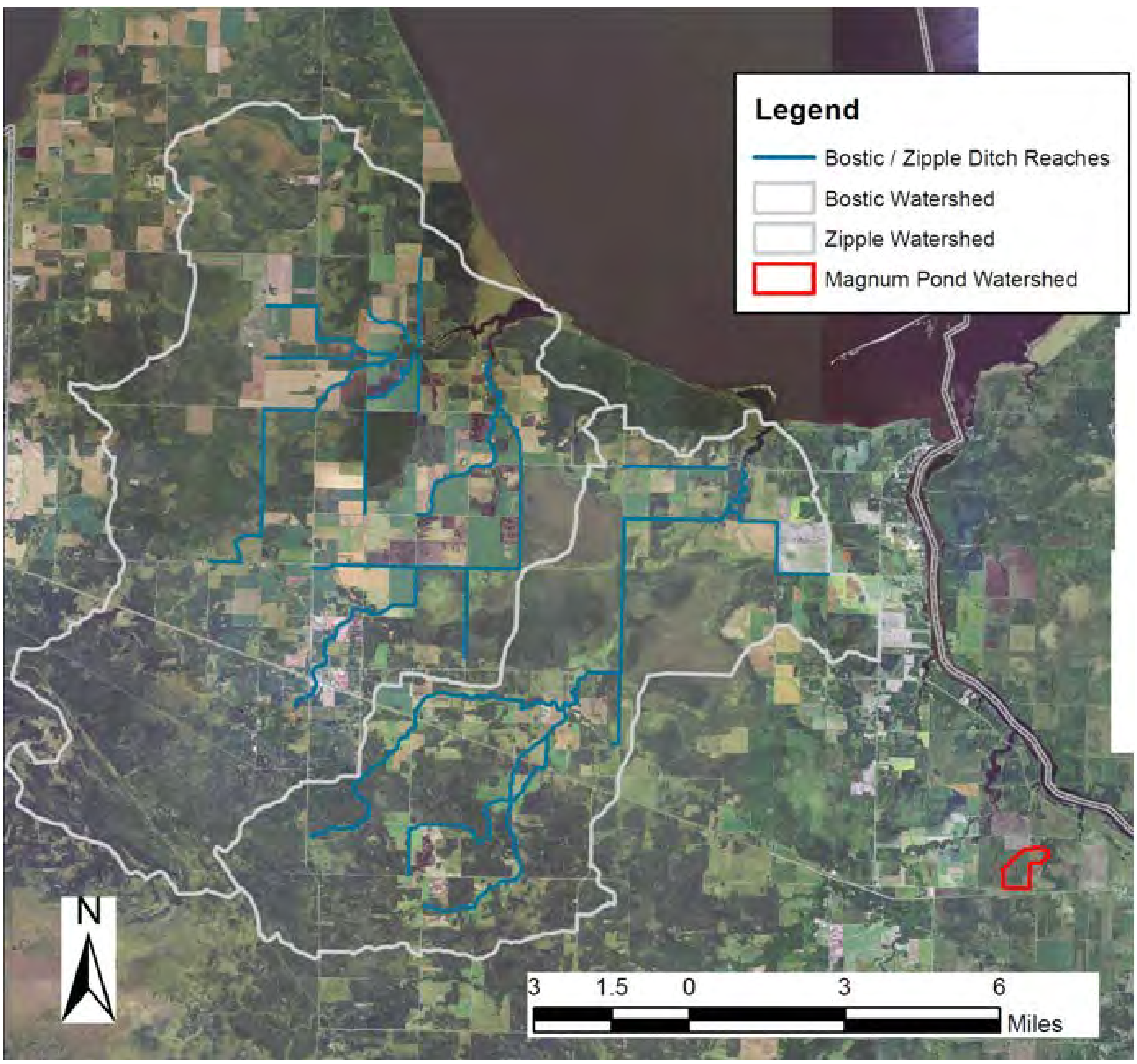

Figure G- 1 Location of Magnum Pond Watershed (in red) Relative to the Bostic/Zippel Watersheds

The land use (Figure 2 & 3) in the magnum pond watershed (average c factor of 0.033) is similar to what you would find in portions of the larger Bostic / Zipple watersheds (Table 3 from main report). The main difference between the two was that the Magnum watershed had more agricultural land (37.1%) than the Bostic / Zipple watersheds (25.1 %). Since there are no large channels or ditches within this small watershed, the SDR calculated from this survey would apply to sheet and rill along with ephemeral gully type erosion.

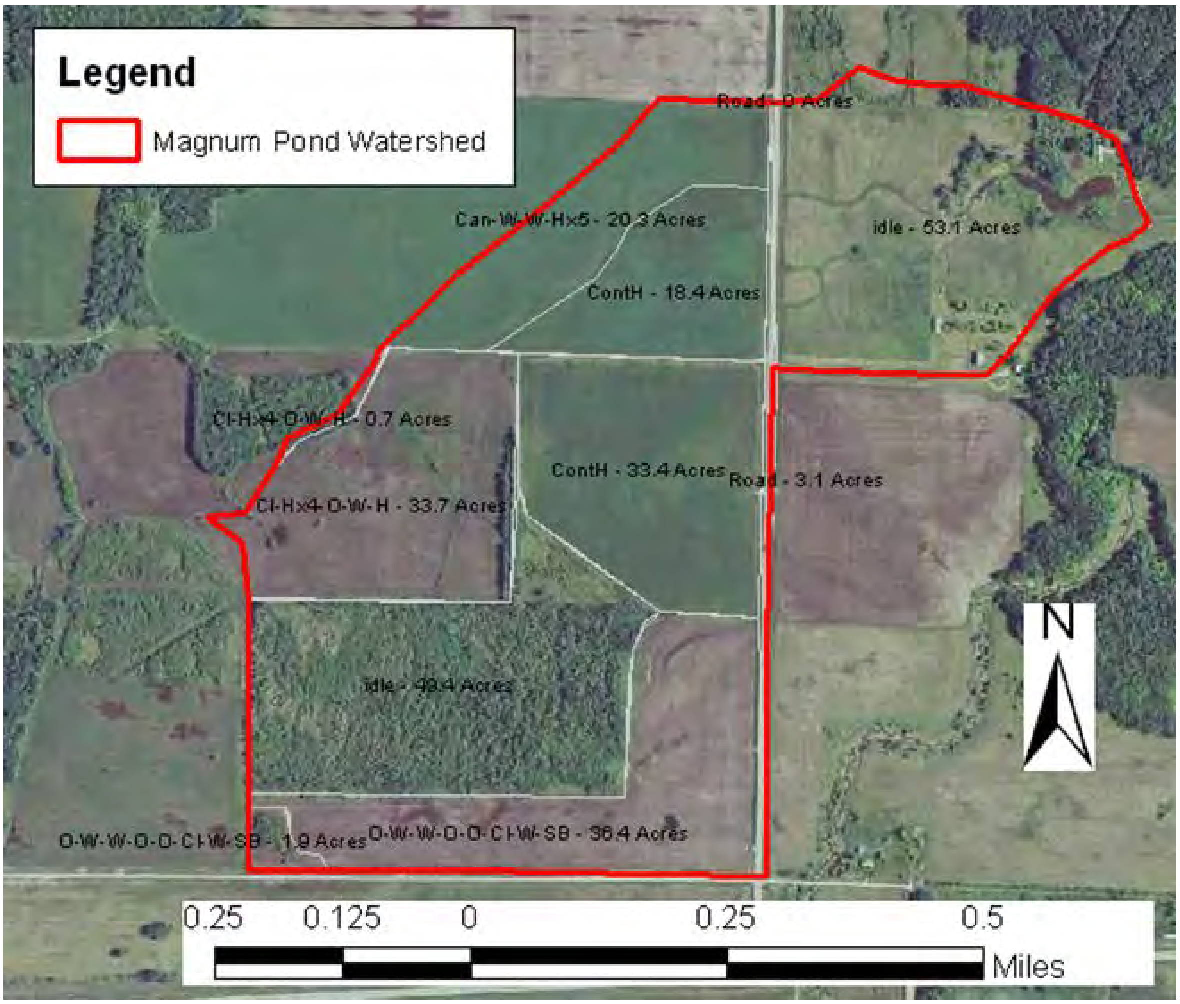

Figure G- 2 Areal View of Magnum Pond Watershed with Land Uses

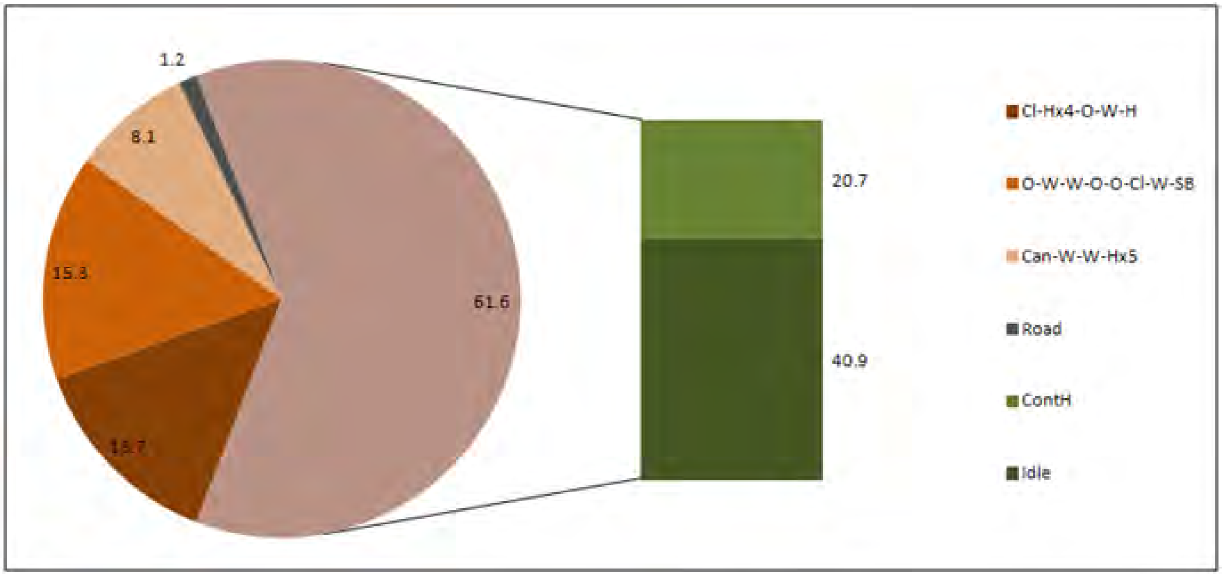

Figure G- 3 - Magnum Pond Watershed Land Use Distribution Displayed in Percent of the Total 250 Acres Drainage Area

Methods and Results

The Magnum pond site watershed was analyzed in the same manner as the Bostic / Zipple watersheds. (Revised Universal Soil Loss Equation (RUSLE) was used for sheet and rill erosion calculations and a length/soil loss relationship was used for ephemeral erosion) The amount of sediment collected in the pond pool area divided by the calculated sheet, rill, and ephemeral erosion amounts was used to estimate the percentage of the sediment that is actually reaching the outlet of the system. The amount of sediment collected in the pond was estimated using two methods:

1. Use the engineering drawings produced during the initial design of the project (figure 4) to estimate the designed storage then survey the current pond storage and subtract the two to get the amount of sediment deposited since construction
2. Manually estimate sedimentation by conducting soil borings and using a "push pole" to estimate the amount of soft deposited sediment in various locations within the pool area.

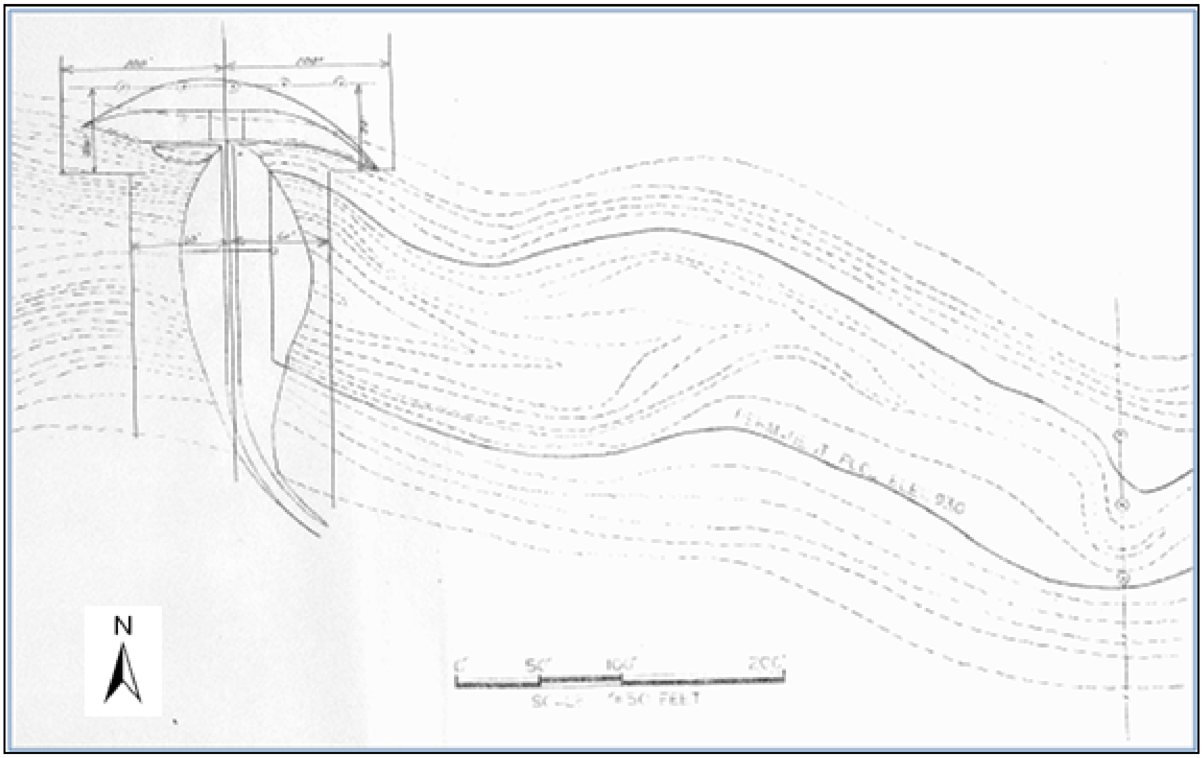

Figure G- 4 - Map of Magnum Pond Showing Proposed Pool Storage Area

The survey used to estimate the current pond storage for method one used Trimble survey grade GPS, a Total station, and a boat with an attached sonar device that was connected to the survey grade GPS unit and calculated water depths. The survey points were brought into Autocad and a TIN elevation model was created by interpolating between the points. The TIN was used to calculate the current storage volume and this number was subtracted from the original in order to determine the amount of sediment deposited within the pool area. The value calculated from this method was unrealistically high and we ended up disregarding this calculation because the initial storage area was surveyed and calculated by a less accurate method and was assumed to be incomparable.

Method two used a Trimble GeoXT GPS unit to obtain UTM coordinates of hand boring and push pole locations. Hand borings were used in the dry locations of the pool area (areas higher in elevation above the existing pond water surface). The geologist made an in-the-field call on the depth to natural ground on each boring (tile probes were used in the immediate vicinity of the hand borings to confirm or adjust the geologist's feel for the natural ground) Using a boat, push poles were used within the pool area to estimate the depth to pre-pond construction natural ground The resulting depth measurements were brought into a Geographic Information System layer file and used to interpolate across the area in order to create a layer containing the approximate depth of sediment within and above the pool area. This sediment depth was then multiplied by the estimated density of the sediment to arrive at the tons of sediment deposited within the pool area of the pond since its construction. Appendix G table 1 is a summary of the data calculated for the Magnum sediment survey. As seen in table 1, the sediment delivery ratio for the pond is 0.26.

Magnum Pond Survey	
ount of Sediment Accumulated in Pond	Estimated Erosion from the Watershed
261.9 **Tons over 36 years**	9.6 Ephemeral Erosion per year (T) 26.5 RUSLE Soil Loss per year (T) **36.1 Total RUSLE + Ephem per year (T)** **1,300 Total Upland Erosion over 36 years**

Total Upland Erosion * SDR = Sediment Stored in Pond + Sediment Passing Through Pond[9]

1,300 * SDR = 262 + 78.2

SDR = (262+78.2)/1,300 = **0.26**

[9] Sediment passing through pond was estimating using procedures outlined in NRCS NEH-3 Sedimentation Chapter 8. The procedure uses average annual runoff and storage volume to estimate a pond's trapping efficiency. For this site, a trapping efficiency of 0.77 was calculated. For every ton of sediment that enters the pond, 0.77 tons are deposited - .23 tons stays in suspension and continues downstream. Total incoming sediment to pond = 261.9/0.77 = 340 tons. Total passing in suspension = 340 * (1 – 0.77) = 78.2 tons.

Appendix H – Zippel County Ditch 1 Before/After Cross Section Analysis

A comparison of cross section surveys made in 1967 and 2009 on County Ditch 1 was made within the Zippel Creek watershed. As-built surveys of the NRCS (SCS at that time) PL-566 project in 1967 were available to compare with a 2009 survey taken at coincident cross sections. See Figure H-1 for the reaches involved in the 16.2 mile channel work project installed under the PL-566 program.

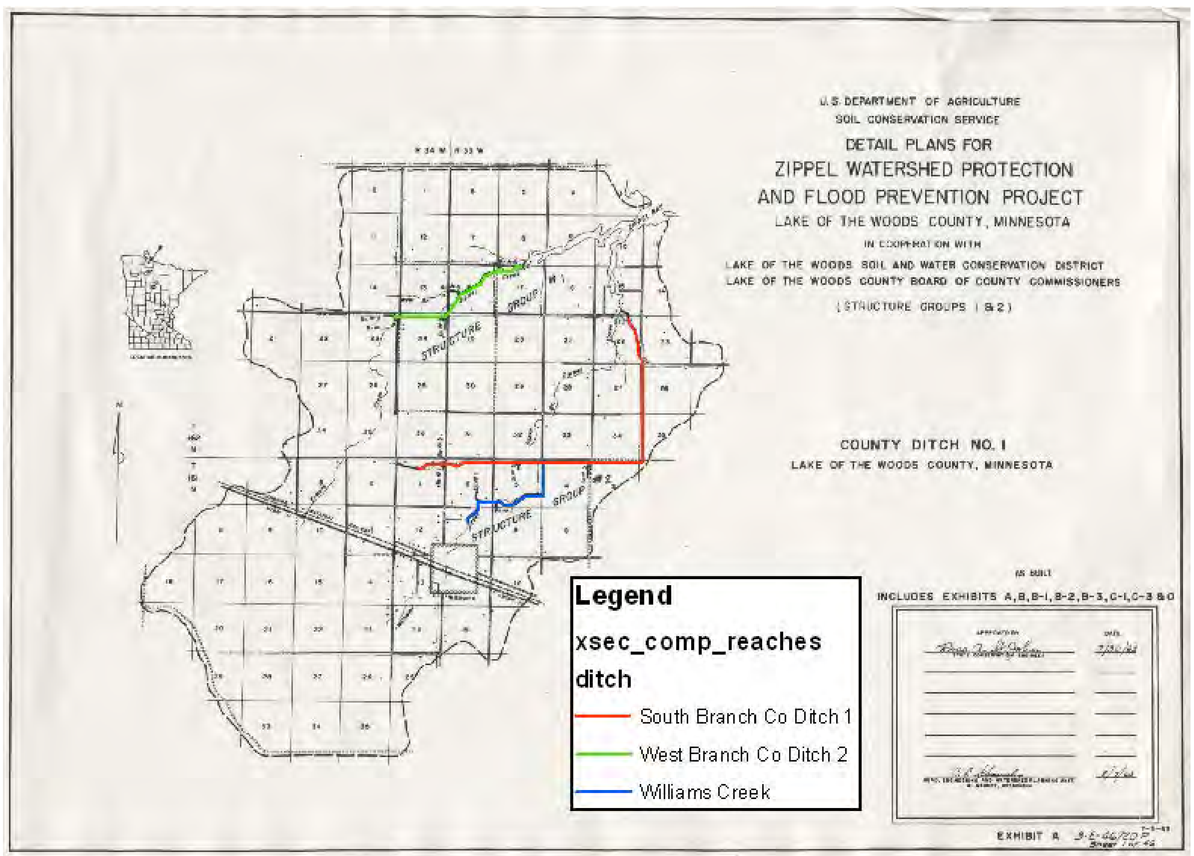

Figure H- 1 – Zippel Watershed County Ditch 1 PL-566 Project Reaches

Volume of material voided (and volume accumulated for some sections near the bays) was calculated by comparing differences in the cross sectional area of the surveyed sections. Adjustments were made to the calculations to account for repairs and other alterations that the LOW County had made to these reaches over the years. Figures H-2 and H-3 are examples of cross sections that show voiding and accumulation respectively. Figures H-4 and H-5 show 1967 and 2009 channel bottom profiles for the South and West Branches of County Ditch 1 respectively (vertical lines on these plots represent road culvert crossings). In general, there has been an obvious 1 to 2 feet of downcutting in the reaches upstream of Zippel Bay's tailwater influence. As the channels approach the Bay downcutting is less and, in the West Branch, sediment accumulation is apparent.

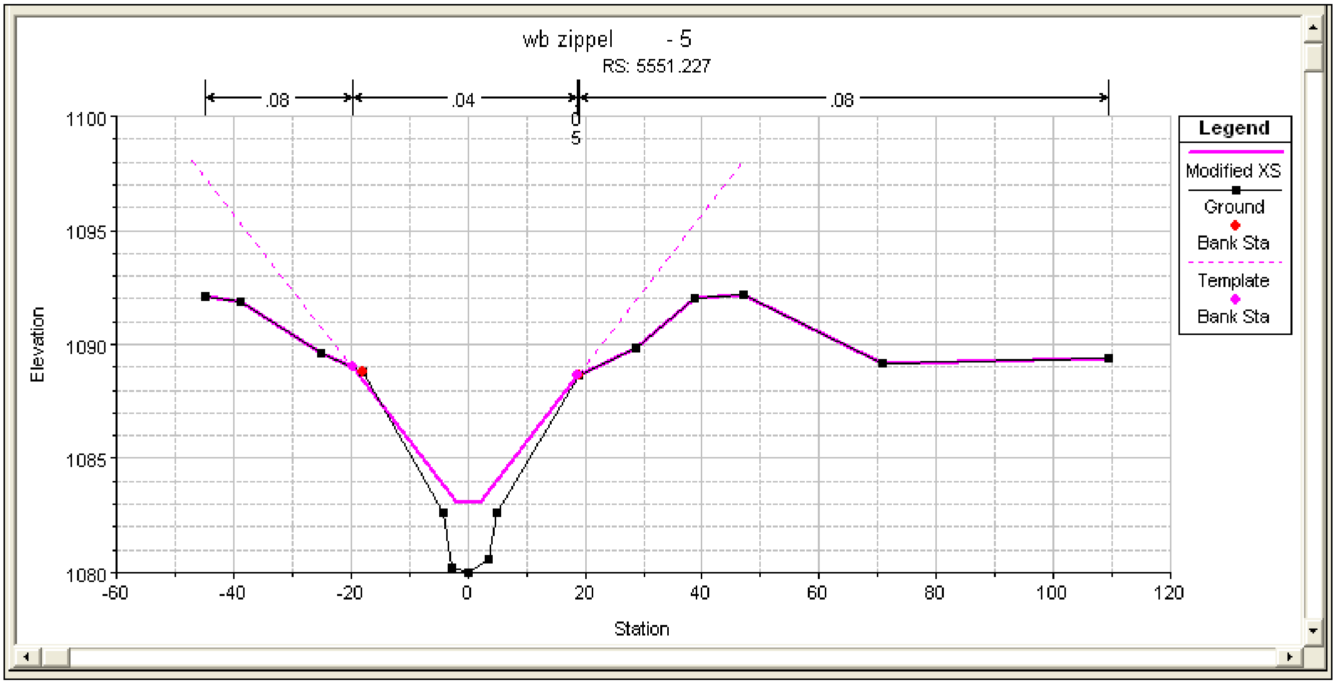

Figure H- 2 Cross Section Comparison Showing Downcutting and Widening (Upper West Branch) - 1967 (red) and 2009 (black)

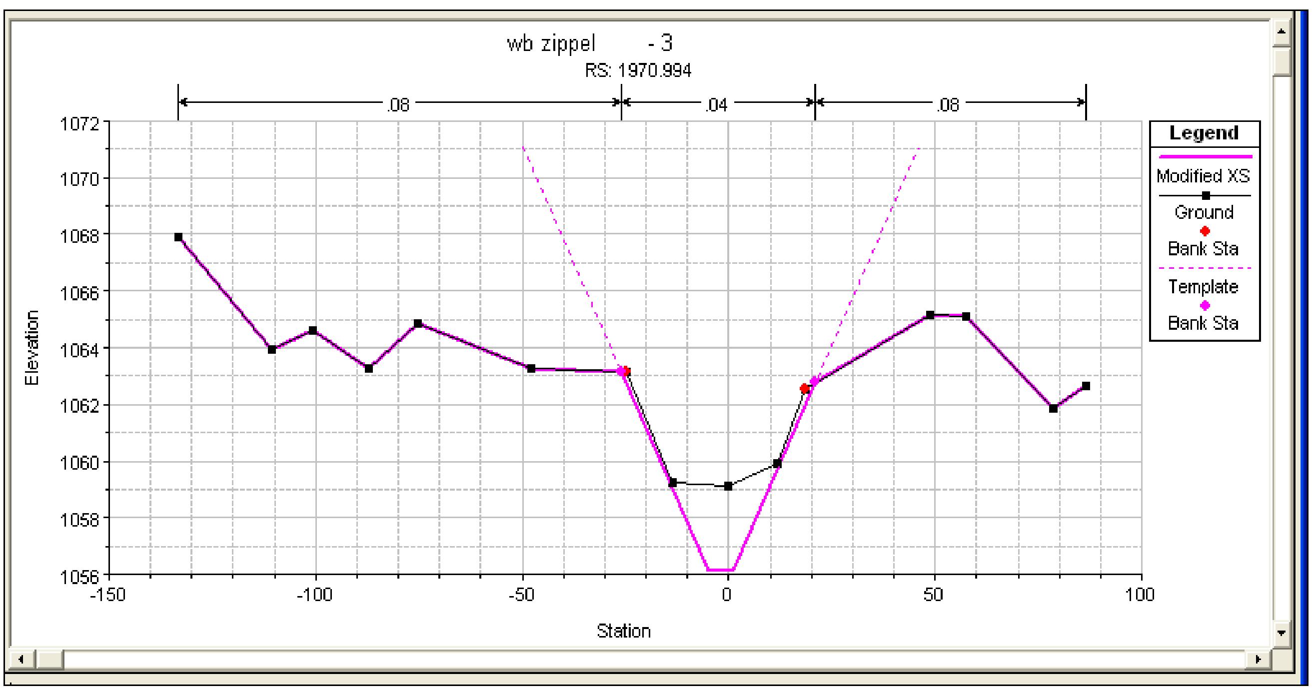

Figure H- 3 - Cross Section Comparison Showing Sediment Accumulation (lower end of West Branch)

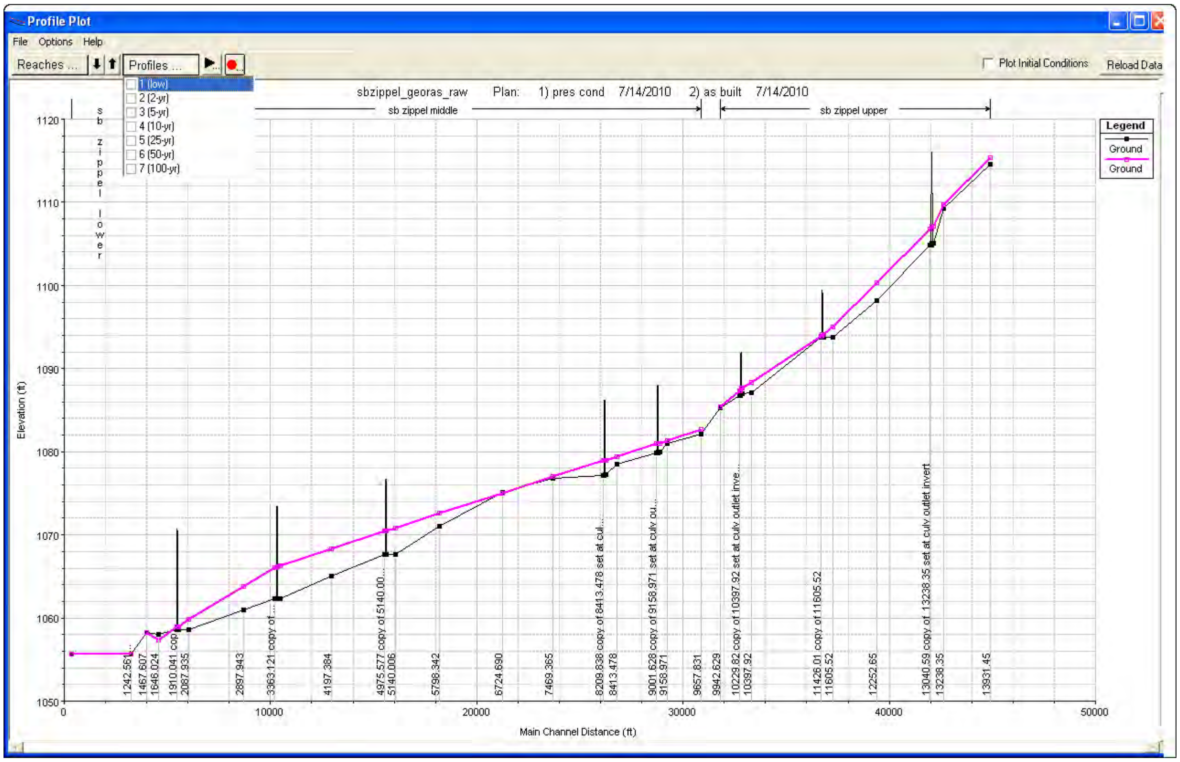

Figure H- 4 South Branch County Ditch 1 Channel Bottom Profile

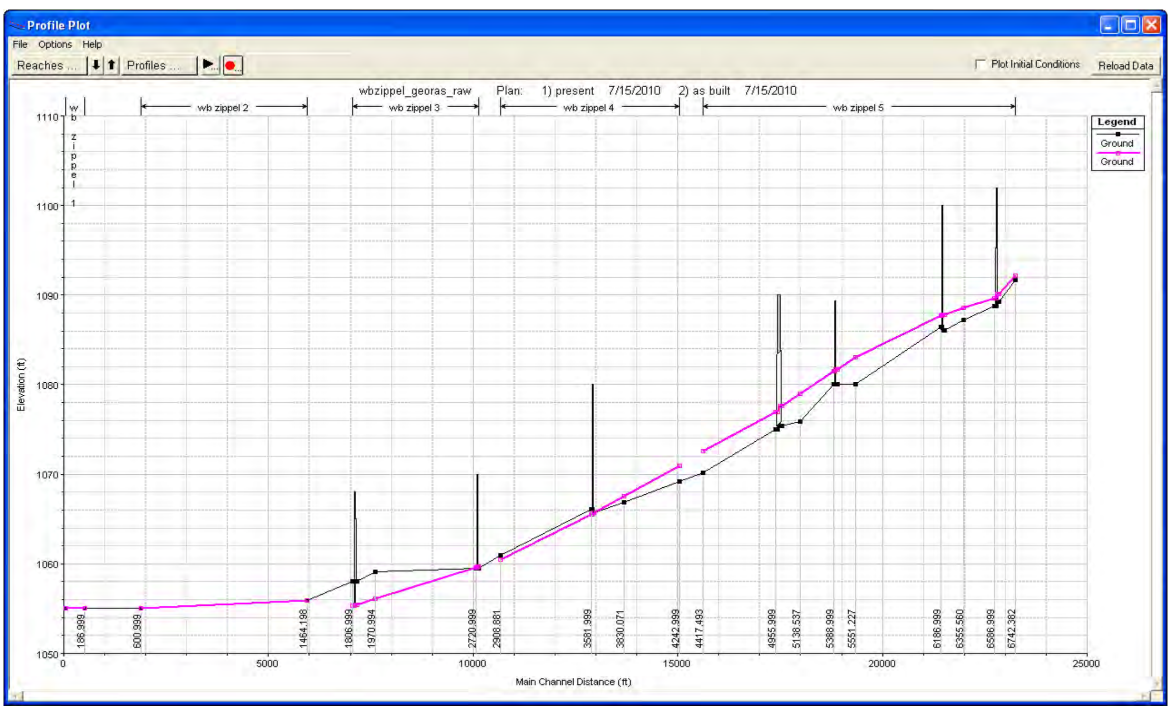

Figure H- 5 West Branch County Ditch 1 Channel Bottom Profile

Figures H-6 through H-8 are plots showing the cumulative loss of channel bank material through downcutting and widening for the South Branch, West Branch, and Williams Creek respectively. Steep portions of these curves would represent areas where channel erosion is highest. In the West Branch at the lower end, the curve reverses direction indicating an accumulation of material as the channel nears West Zippel Bay.

Total amount of material voided is summarized below in Table H-1.

Branch	# of cross sections surveyed	Material Voided 1967-2009
West Branch	9	17,380 Yd^3 (11 Ac Feet)
South Branch + Williams Creek	21	52,019 Yd^3 (33 Ac Feet)

The data does not provide answers as to when or how these changes took place – did these changes take place gradually over time or did they occur over a few years of large runoff events? It is known that the NRCS (SCS at the time) had filed a Deficiency Report in 1972 responding to concerns from local land owners over channel degradation issues. That report concluded that channel degradation was within “realm of expectations” however the floors of the original timber bridges that were installed were undermined due to short cutoff walls. Over time, these bridges have been replaced with concrete arch pipes by the county. Comparing the 2009 culvert inverts to the 1967 crossings shows most of them to be 1 to 2 foot lower than 1967 inverts. Since culverts usually act as stable hard points in a channel system, it is possible that some of the downcutting is simply the result of the channel grade adjusting to recessed culvert invert elevations.

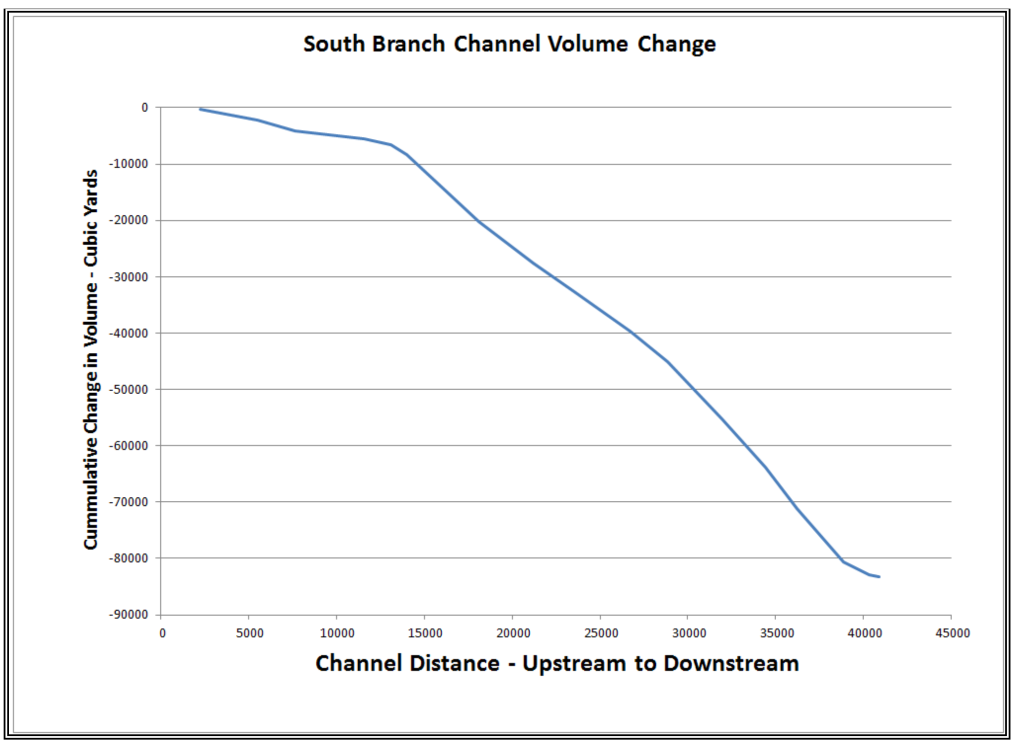

Figure H- 6 South Branch Co Ditch 1 Cumulative Change in Volume (1967 - 2009)

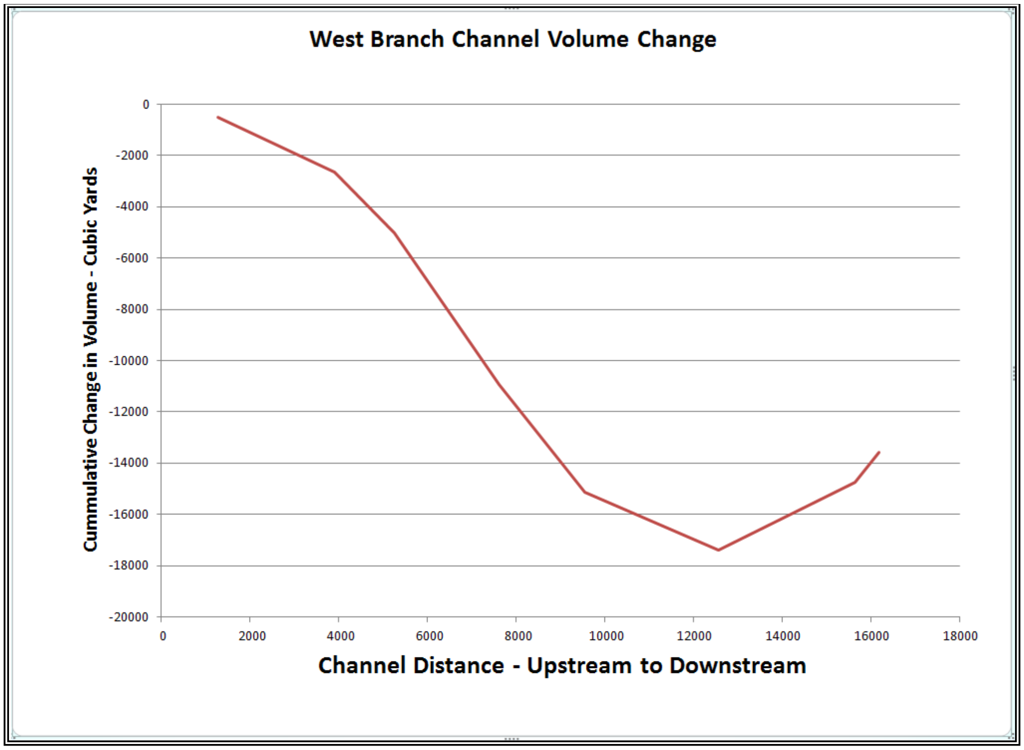

Figure H- 7 West Branch Co Ditch 1 Cumulative Change in Volume (1967-2009)

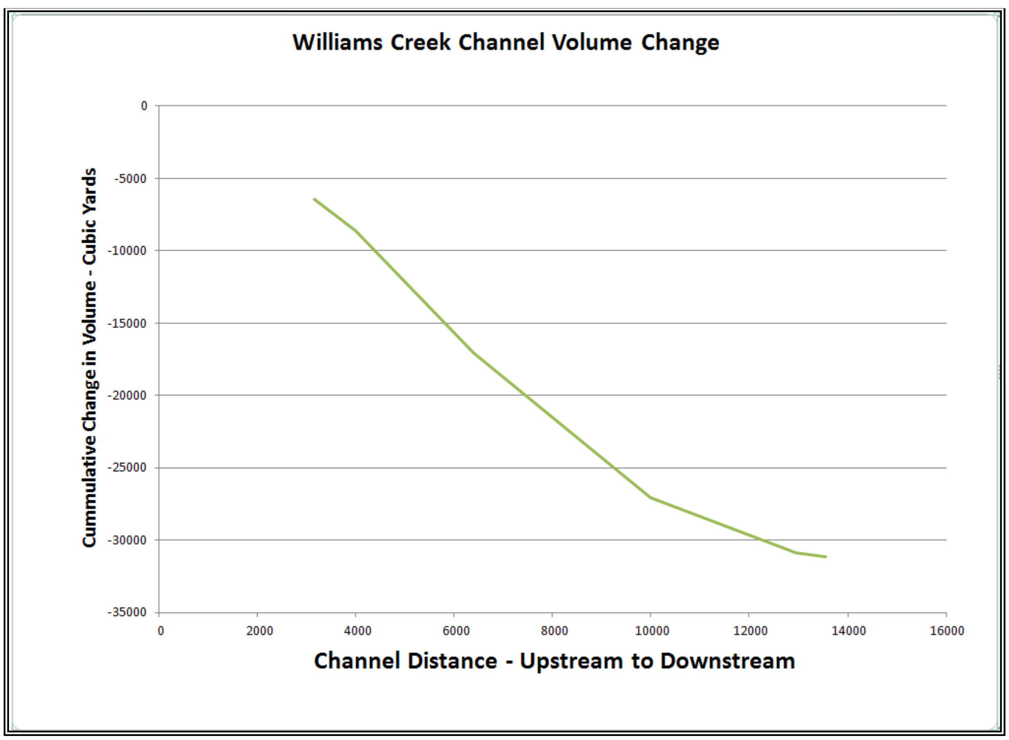

Figure H- 8 Williams Creek Cumulative Change in Volume (1967-2009)

Appendix I – Hydrology/Hydraulics Models

Hydrology models were developed for both watersheds to estimate peak discharges and runoff volumes by frequency. The Corps of Engineers' Hydrologic Modeling System (HMS) was used. This model works by estimating rainfall/runoff response for "subbasins" (subdivided areas of the overall watershed based on similar soils and land cover) and routing them downstream through "reaches" (lengths of existing ditches or natural channels). 43 and 47 subareas were delineated for the Bostic and Zippel Creek watershed models respectively utilizing LiDAR, County Ditch Maps, and aerial photography. 26 and 25 routing reaches were used for the Bostic and Zippel watershed models respectively to represent each watershed's hydrologic channel system. See Figures I-1 and I-2 for HMS routing schematics showing the connectively between subbasins and reaches.

For each subbasin, runoff curve number and lag time were calculated. Runoff curve numbers were based on 2006 NLCD land use layer and 2009 SSURGO soils, both rasterized to a 5m resolution. Subbasin lag times were estimated by digitizing the longest flow path then using the Folmar & Miller equation[10]. Reach routing was modeled using the Muskingum Cunge routing method which uses length, slope, roughness, and channel shape.

The models were calibrated by comparing modeling results with USGS StreamStats and PL566 project discharges (calculated in 1967 using Meyers Drainage Curves) for a 10-year event. See Figure I-3 for a plot of modeling results for drainage area vs. Q10 discharge for Zippel Creek watershed. The original HMS results, using the GIS derived RCN and lag parameters, were much higher than the StreamStats and PL566 values. A target that was approximately halfway between the StreamStats and PL566 appeared reasonable. The 1st calibration attempt using only a reduced runoff curve number (95% of original) was still too high. The 2nd and final adopted calibration attempt used a reduced runoff curve number (90% of original) and increased lag (double the original lag) which provided a reasonable fit to the target calibration.

The calibrated HMS models were used as a routing template for the Sediment Budget (sediment budget uses the same routing sequence as the HMS model). The HMS model was also used to determine the 2-year peak discharge used in the sediment budget channel SDR equation.

The HMS model developed for this sediment analysis project would also be useful for other projects requiring flow/frequency information. Contact the Lake of the Woods County NRCS Office for further information.

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[10] Folmar & Miller equation is $Tc(hrs) = (LHL^{0.65})/108.3$. To convert to HMS lag time assumes $Lag (min) = 0.6 * Tc(hrs) * 60$

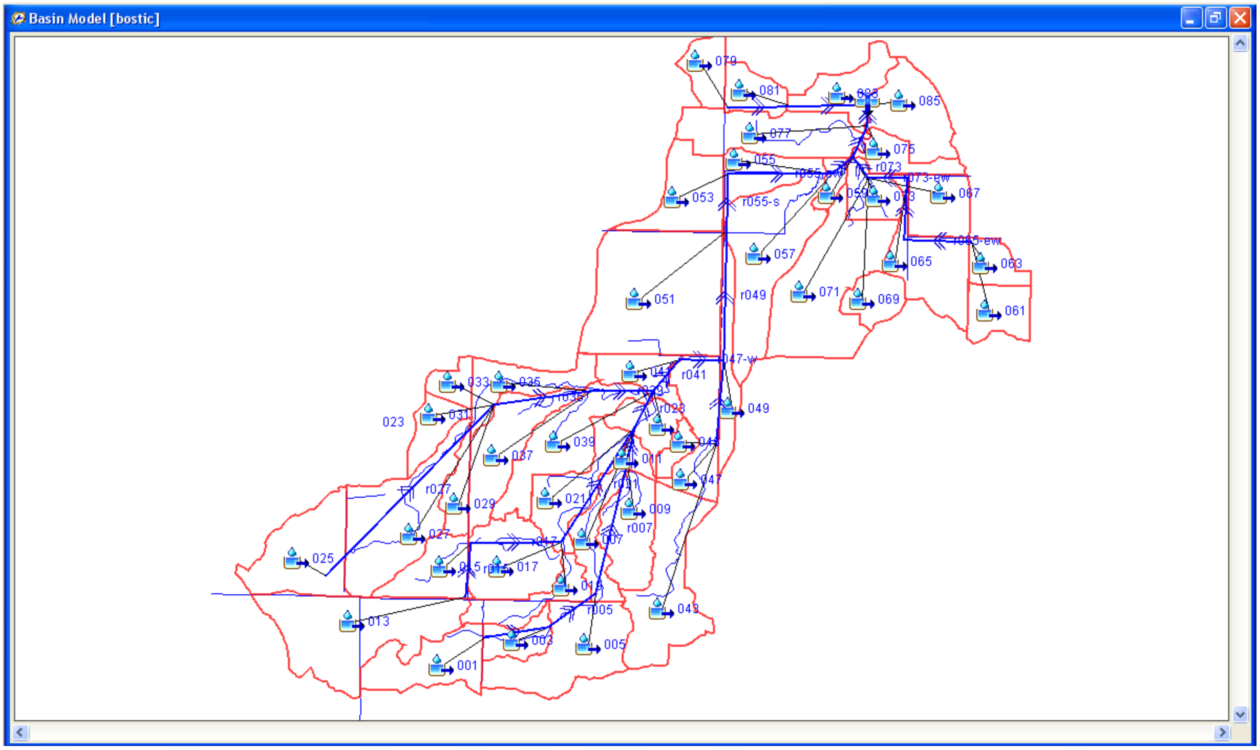

Figure I- 1 - Bostic Watershed HMS Routing Schematic

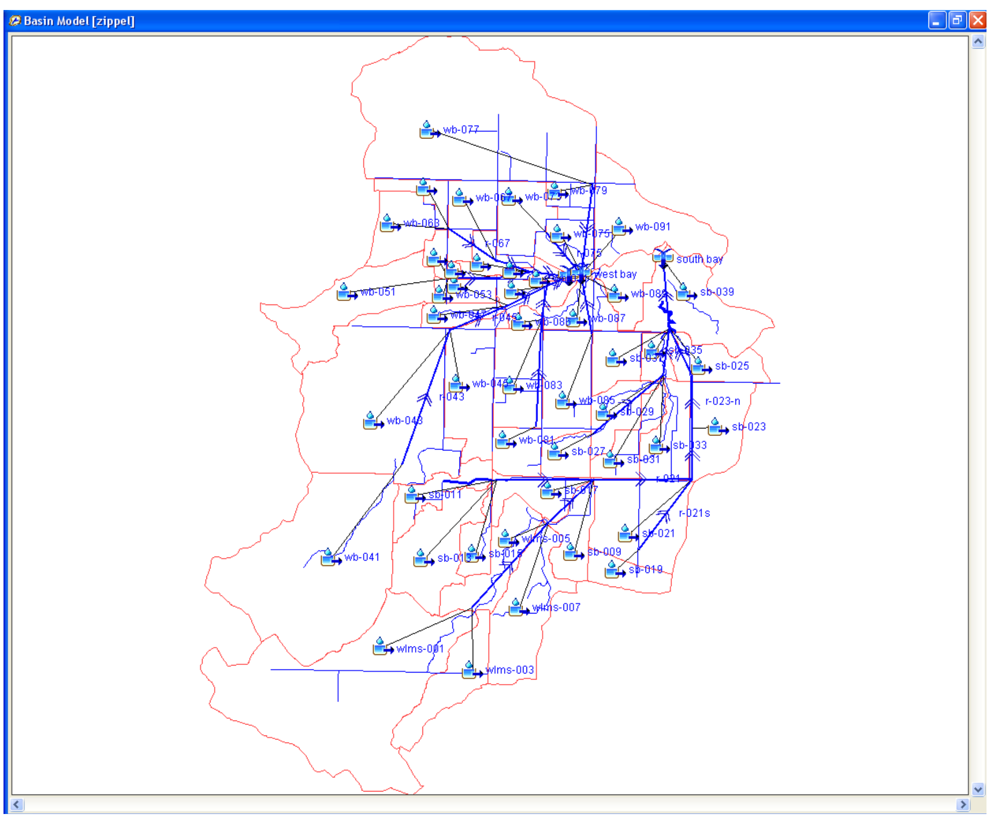

Figure I- 2 - Zippel Watershed HMS Routing Schematic

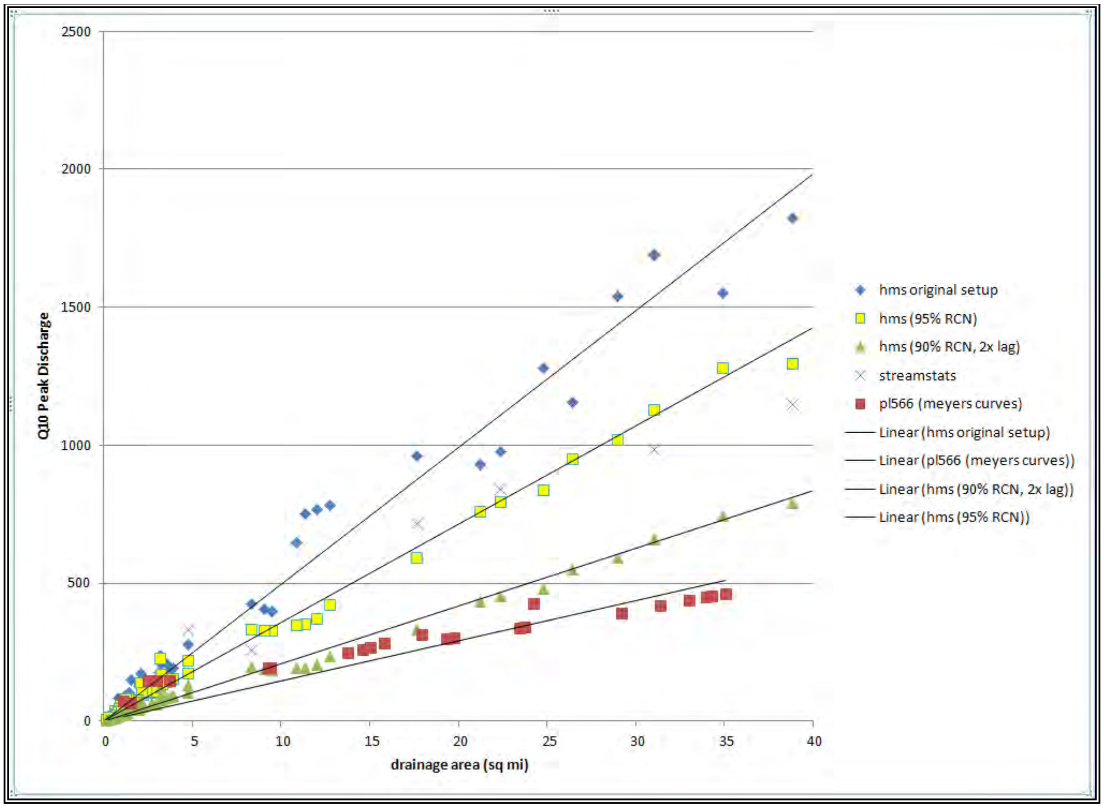

Figure I- 3 - HEC-HMS Calbration Results

HEC-RAS hydraulic models were also developed for Bostic, West Branch, and South Branch Zippel Creeks. These hydraulic models use data from 2007 and 2009 surveys of cross sections and culverts. See Figure I-4 for a plan view showing locations of cross section surveys. These models are very basic in nature and were used to make visual comparisons in channel shape changes from 1967 to today (see Appendix H). These HEC-RAS models are <u>not</u> of sufficient detail to accurately describe stage/discharge relationships along the ditch systems.

Figure I- 4 - Locations of Surveyed Cross Sections in Bostic and Zippel Creeks (in red)

Appendix J – Field Reviews/Meetings

Several working field trips and local meetings took place as part of this effort. Below is a summary list of these activities:

- Initial Meeting and Watershed Tour with LOW County/DNR/SWCD/NRCS - Nov 2008
- Geology/Hydrology Field Work (walking channels, land use inventory, review of county ditch records, etc.)
  - Nov 2008
  - July 2009
  - Sept 2009
  - June 2010
  - May 2011
- Public Meeting - July 2009
- Cross section surveys – Nov 2009
- Pond Sediment Survey – May 2011
- SWCD Ephemeral Gully Erosion Survey – April 2011
- Presentations to SWCD Board – May 2011, April 2012
- Meeting with LOW County Staff to Review Preliminary Results – April 2012

Meeting minutes and field trip reports are available. Contact the Lake of the Woods NRCS office for further information.