MEMO

(External Correspondence)

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LOW SWCD

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Date: June 25, 2013

Subject: Zippel / Bostic Bays Bathymetry Collection and Zippel Bay Sedimentation Analysis

Introduction

Both Zippel and Bostic Bays, Lake of the Woods (LOW), Minnesota have experienced significant changes over the past hundred years. Data and local management activities have shown that the Bays are experiencing significant sedimentation problems, resulting in regular maintenance (i.e., dredging) of the areas to enable boat navigation and access to businesses upstream of the Bays from LOW.

In an effort to quantify some of the changes in the Bays over the past 100-years and also to inform potential future dredging activities, new bathymetry data was collected in Zippel and Bostic Bays in the spring of 2013. The resultant data was used to compare to historic bathymetry data (from 1913) in Zippel Bay to view trends in sedimentation during this time period. A similar dataset of historic bathymetry data was not available for Bostic Bay and so this component of the analysis was not performed in that area.

The intent of this memorandum is to document the spring 2013 bathymetry surveying that was performed in Zippel and Bostic Bays. In addition, the memorandum summarizes the sedimentation analysis and results for Zippel Bay.

2013 Bathymetry Survey

Acoustic surveys were conducted in the spring of 2013 to develop bathymetry data for Zippel and Bostic Bays, Lake of the Woods, Minnesota. The intent of the data collection was to measure depths and develop bathymetry for the inner parts of the bays, not attempting to gather data around the extreme outer edges of the bays where depths were too shallow or vegetation was too dense for easy boat access. The Lake of the Woods (LOW) Soil and Water Conservation District (SWCD) delineated the priority areas (i.e., upstream and downstream boundaries) for the data collection.

The first survey of the Bays was conducted on May 21-24 with a second visit on June 6-7. Surveys were conducted using a Lowrance HDS-5 depth sounder for lake depths and a Trimble R6 Model 4 RTK GPS Rover Receiver and Trimble R6 Model 1 RTK GPS Base Station Receiver for location. The average water surface elevation at the time of the surveys was 1060.6 feet.

Bay bed elevations were determined using the NAVD 1988 for the Vertical Datum and the NAD83 (2011) MN Department of Transportation (DOT) LOW County Coordinate System (South Zone) for the Horizontal Datum. The raw data was processed using Trimble Business Center v3.1 and the contours were created using AutoCAD Civil 3D 2013 software. Contours and raw survey data were exported to GIS shapefiles for delivery to the LOW SWCD. The contours created from the 2013 survey are shown in **Figure 1** and **Figure 2**.

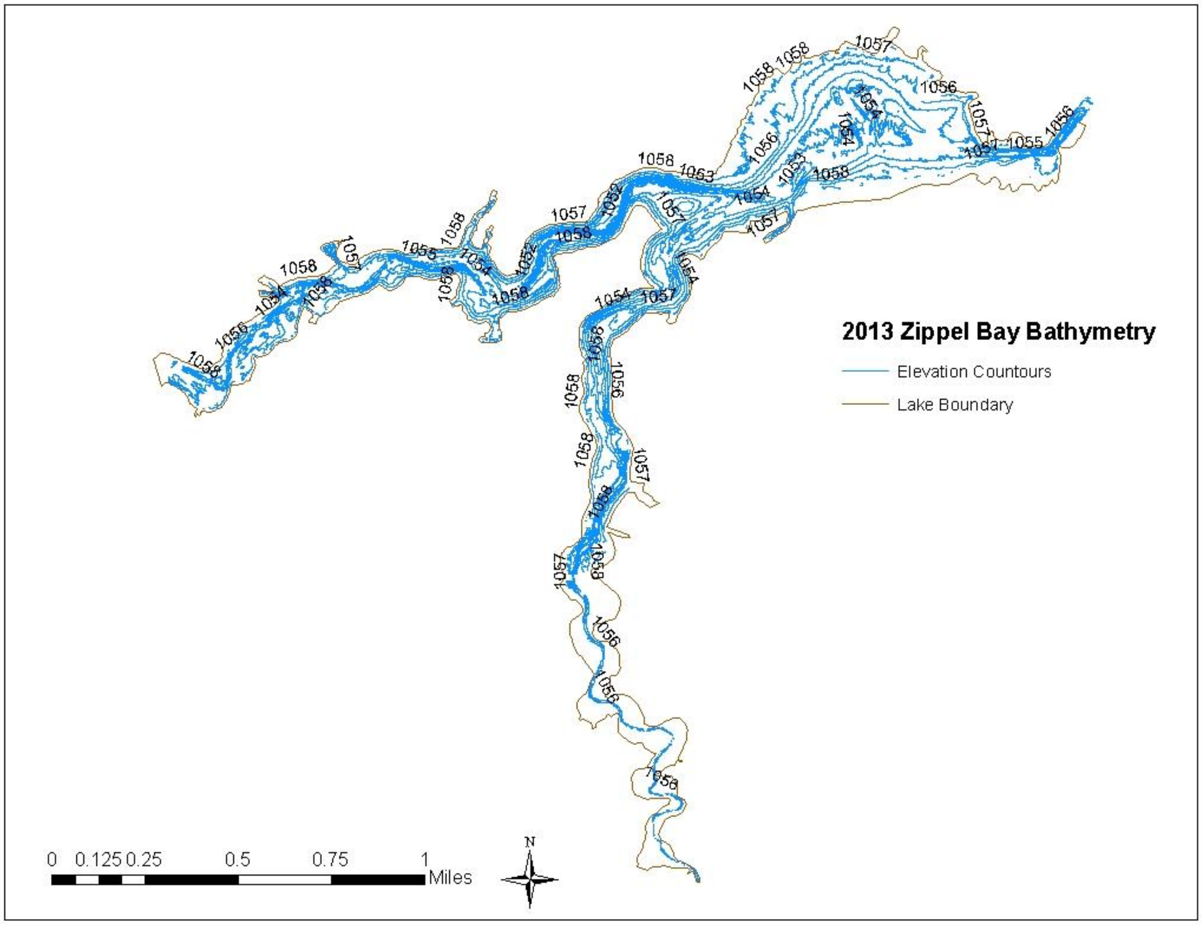

Figure 1: 2013 Bathymetry Contours for Zippel Bay, LOW, Minnesota from Acoustic Survey.

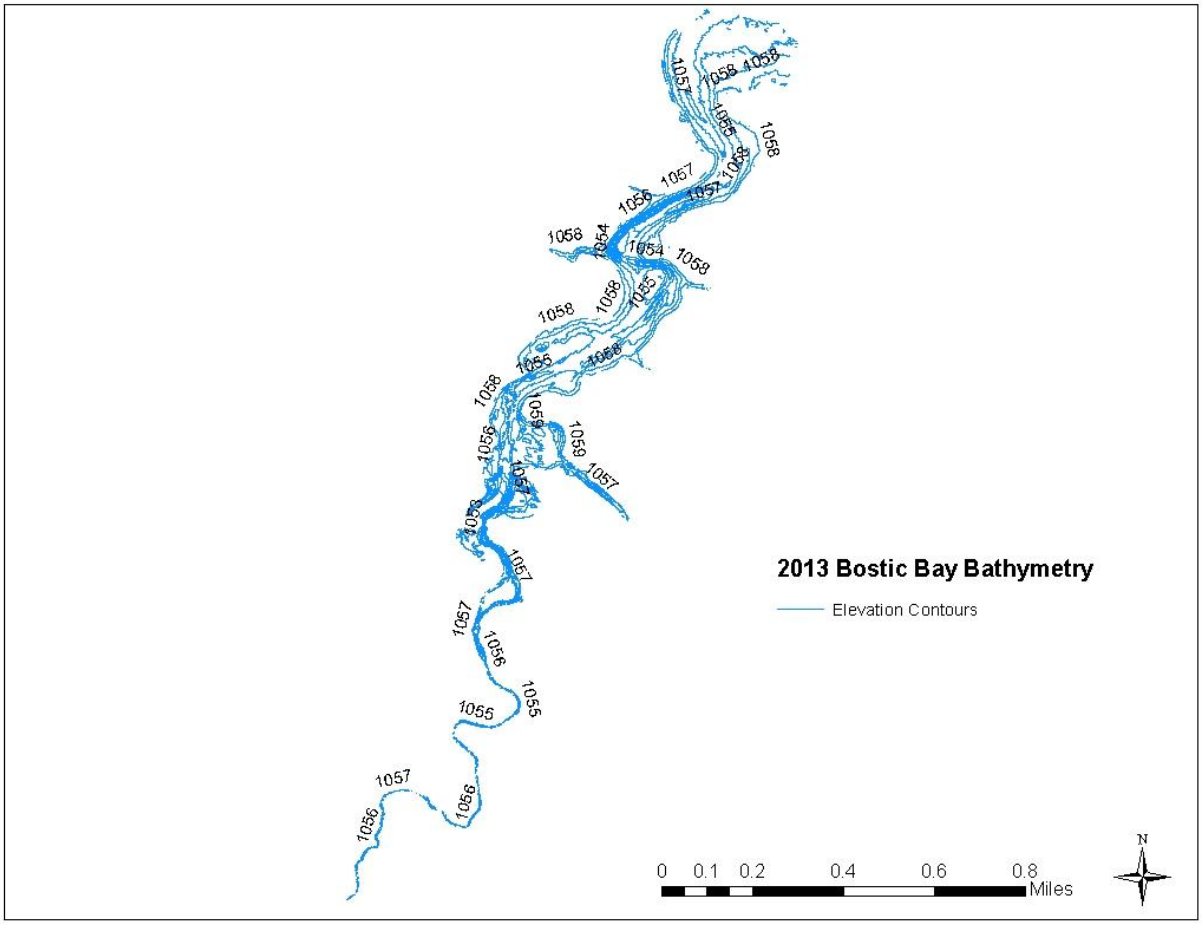

Figure 2: 2013 Bathymetry Contours for Bostic Bay, LOW, Minnesota from Acoustic Survey.

1913 Bathymetry Data

The LOW SWCD provided the 1913 “Southern Shore, Lake of the Woods from Northwest Angle Inlet to Big Grassy River, 1913-1914” bathymetry map of Zippel Bay for using in comparing current to historic conditions. The map was provided as an image, which was then georeferenced and used to digitize elevation contour lines and point elevations in ArcGIS. The average lake surface elevation at the time of the mapping (according to the map) was 1060 feet. The vertical datum of the 1913 bathymetry data is U.S.C. and G.S., 1912 adjustments. Datum conversions were needed to adjust the 1912 datum to 1988 datum for comparing the two bathymetry datasets. Through conversations with local officials, it was concluded that a conversion of -0.58 feet is needed to transform the 1912 datum to the NAVD 1929 datum in this area; a 1.342 foot conversion was then used to convert NAVD 1929 to the 1988 datum. As such, a total of 0.762 feet was added to the 1913 Bay bed elevations to move from the 1912 to the current 1988 datum.

In addition to the datum change, elevation contours were interpolated for elevations below 1054 feet (adjusted elevation of 1054.76 feet) in the middle of the Bay to account for the point depth measurements on the map and allow for a better representation of the Bay bed while performing analysis in ArcGIS. To construct the interpolated contours, additional point elevations were added between points of the same elevation and a topographic surface was constructed using the “TOPO to raster” tool in ArcGIS. The additional points were needed to apply more weight to point elevations during interpolation in ArcGIS. Once the interpolated topographic raster was constructed, contour lines were generated and contours below (adjusted elevation) 1054.5 feet were extracted. These contours are represented in **Figure 3** as “Interpolated Contours” and were used in construction of the 1913 Triangulated Irregular Network (TIN) surface. The digitized 1913 Bay bed elevation contours with datum adjustment and interpolated contours are shown in **Figure 3**.

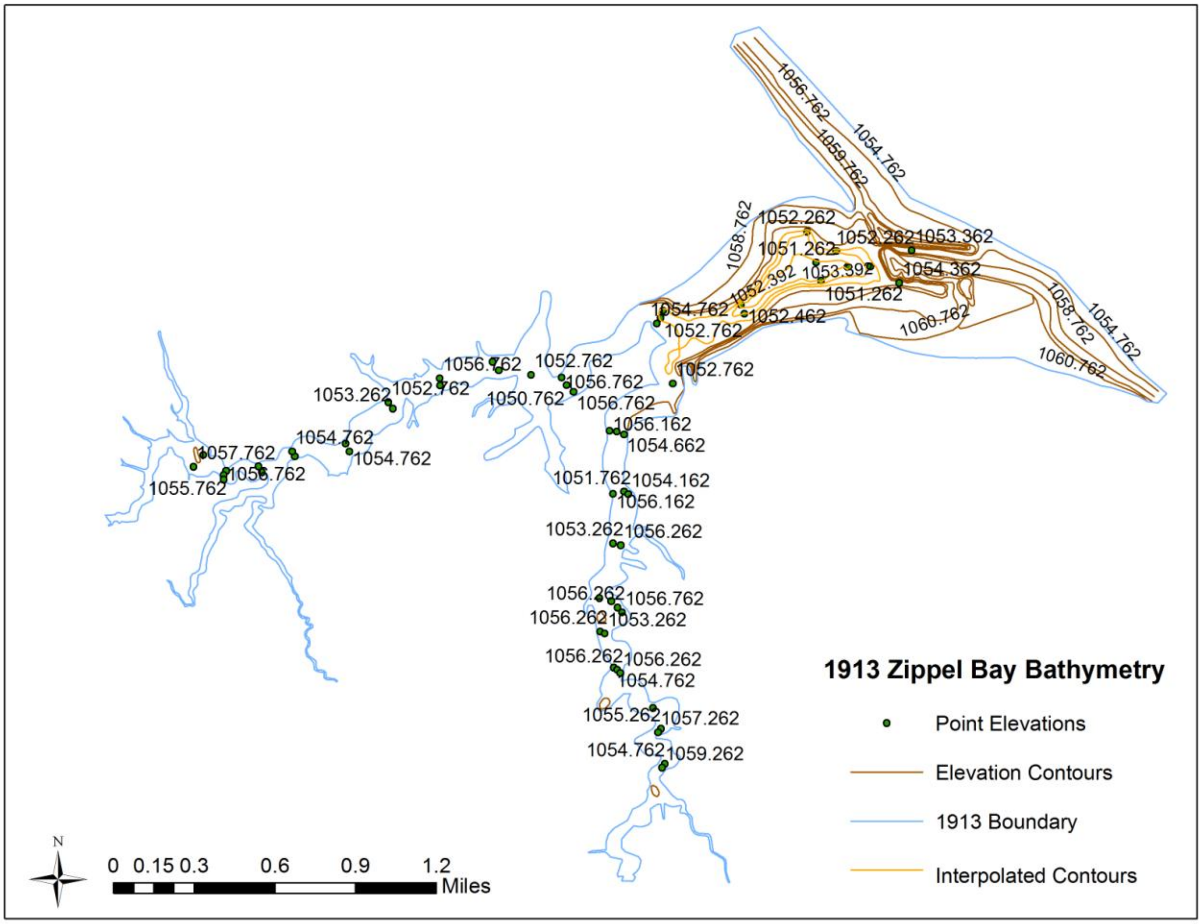

Figure 3: 1913 Bathymetry Contours for Zippel Bay, LOW, Minnesota Digitized from 1913 Map.

3-D Analysis

The 2013 and 1913 bathymetry contours were converted to TIN surfaces using ArcGIS software. The TIN surfaces provide a digital representation of the lake bed surface, made up of irregularly-distributed nodes derived from the contour lines and point measurements with three-dimensional coordinates (x, y, z) that are arranged into a network of non-overlapping triangles.

The command "Create TIN" in the 3D Analysis Tools toolbox in ArcGIS was used to create the TINs. In addition to the contour lines and point measurements, a boundary of the bathymetry data was used to restrict the extent of the interpolated TIN surface. For the 2013 TIN, the water surface boundary was derived from LiDAR data collected in 2009, assuming a water surface elevation of 1060.3 feet above mean sea level. This mean water surface elevation was computed at the LOW Warroad lake level gauge from 4/25/2009-5/30/2009, the time period during which the LiDAR data was collected. For the 1913 TIN, the boundary was extracted from the digitized contour map. Only the main portion of Zippel Bay was used in developing the 1913 TIN, since the bathymetry data in the west and south arms of the Bay are poorly represented, only having few point measurements and the boundary. The TINs generated by ArcGIS are shown in **Figure 4** and **Figure 5** for the 2013 and 1913 bathymetry data, respectively.

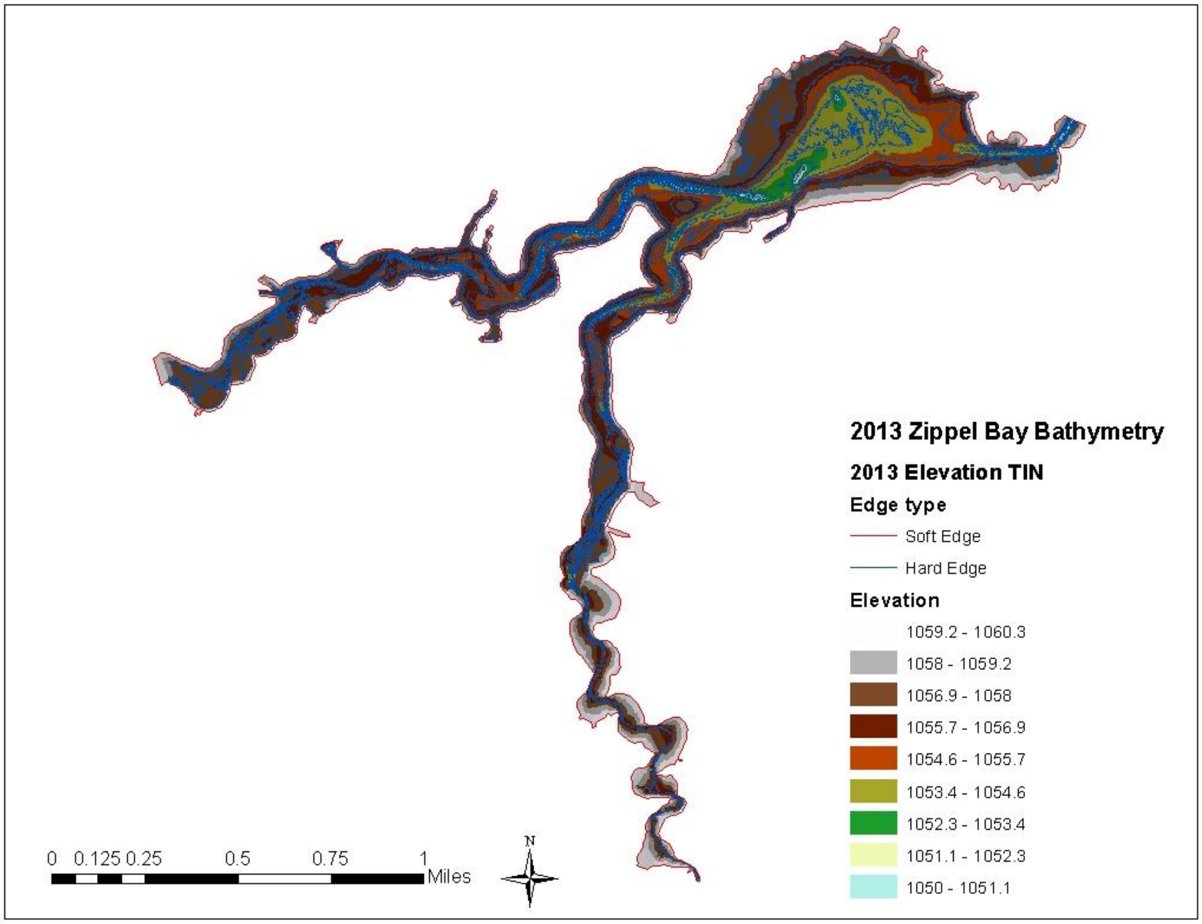

Figure 4: 2013 TIN of Zippel Bay Bathymetry, LOW, Minnesota

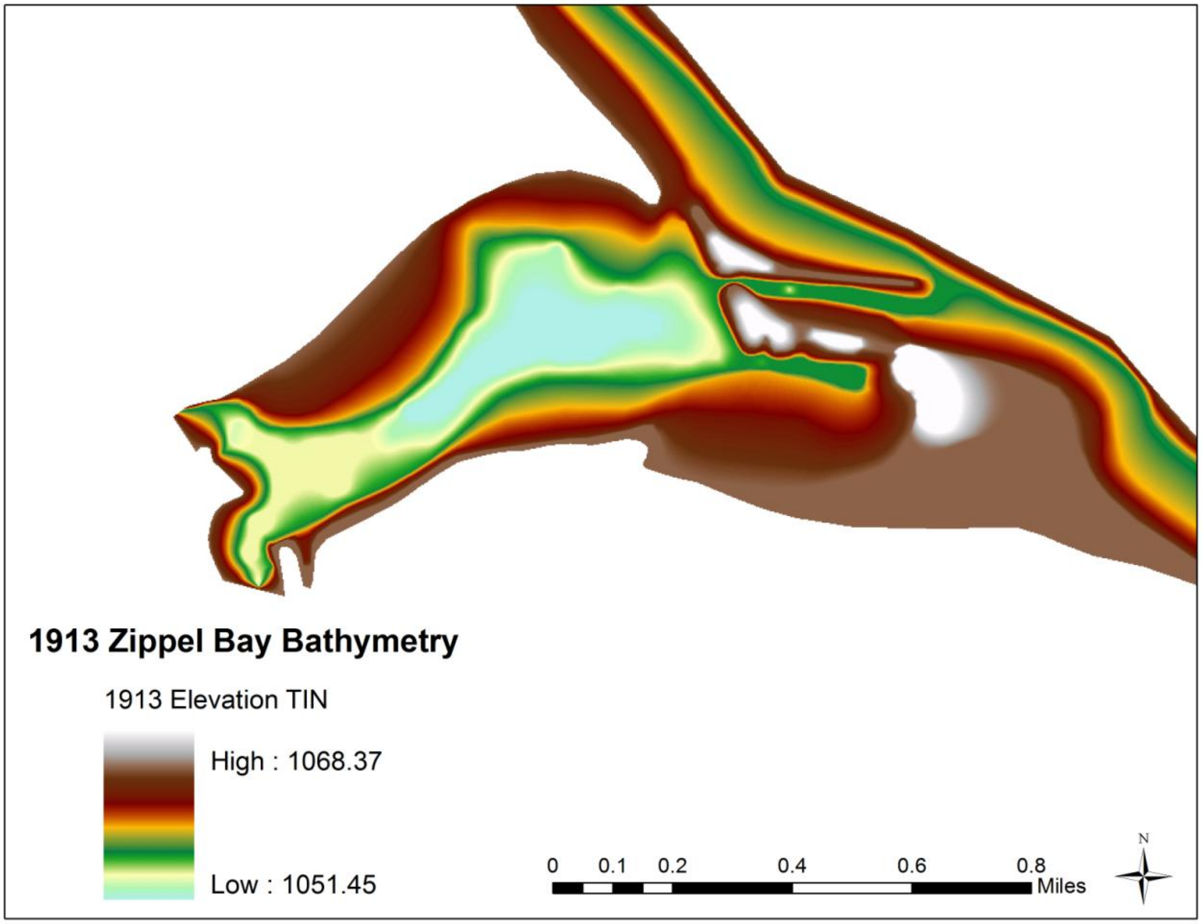

Figure 5: 1913 TIN of Zippel Bay Bathymetry, LOW, Minnesota.

Comparison between 2013 and 1913 Bathymetry

Comparisons were made between the 2013 and 1913 bathymetry data to investigate how depths in Zippel Bay have changed over time and identify areas where dredging may be needed to return to historical depths. It should be noted that like any natural system, the shoreline boundaries of Zippel Bay (i.e., extent of the bathymetry data) are not consistent over time. The bay's boundaries have changed over the last hundred years, as shown by mapping the extents of the 2013 bathymetry data and the 1913 bathymetry data in **Figure 6**. Some of this difference in boundaries may be due to the quality of the mapping in 1913, another component of the difference may be due to sedimentation or other changes experienced in the Bay during this time period. The depths comparison and analysis could only be conduct on overlapping areas between the two data sets.

Figure 6: Boundary Comparison between 1913 and 2013 Bathymetry Data Extents.

The change in lake bed elevations from 1913 to 2013 (**Figure 7**) was found using tools in ArcGIS. First, raster layers were created from the 1913 and 2013 TINs using the TIN-to-Raster tool in the 3D Analysis Toolbox. Next, the 1913 lake bed elevation raster was subtracted from the 2013 lake bed elevation raster using the Raster Math-Minus tool. Results of this analysis show the changes in bathymetry elevations from 1913 to 2013 and are shown in **Figure 7**. The darker blue to lighter blue areas are increases in lake bed elevation (i.e., were sediment has filled in), the light red to dark red areas are decreases in lake bed elevation (i.e., areas of bulk scouring).

Figure 7 shows that the main Zippel Bay area has a mix of increased and decreased bed elevations. The increases in bed elevation generally occur in the center of the Bay with decreases in elevation along the banks. This is typical of sedimentation where as the deeper areas fill in, to compensate for the decreased cross-sectional areas, the shallower areas are scoured. The average 1913-2013 (net) elevation change in Zippel Bay was computed at -0.02 feet. The maximum computed net deposition value was 5.84 feet; the maximum computed decrease in elevation (i.e., net erosion) was -11.25 feet. The largest negative values of the analysis generally occur near the outlet of Zippel Bay to LOW, where the 1913 bathymetry data was most uncertain. It is important to note that the results of this analysis are simple comparisons of the 1913 and 2013 datasets and do not account for any dredging or other sediment management practices that may have occurred in Zippel Bay during this time period. As such, the results are net deposition/erosion estimates, without knowledge of how much impact various forces (e.g., dredging or deposition of eroded streambanks) had on the results.

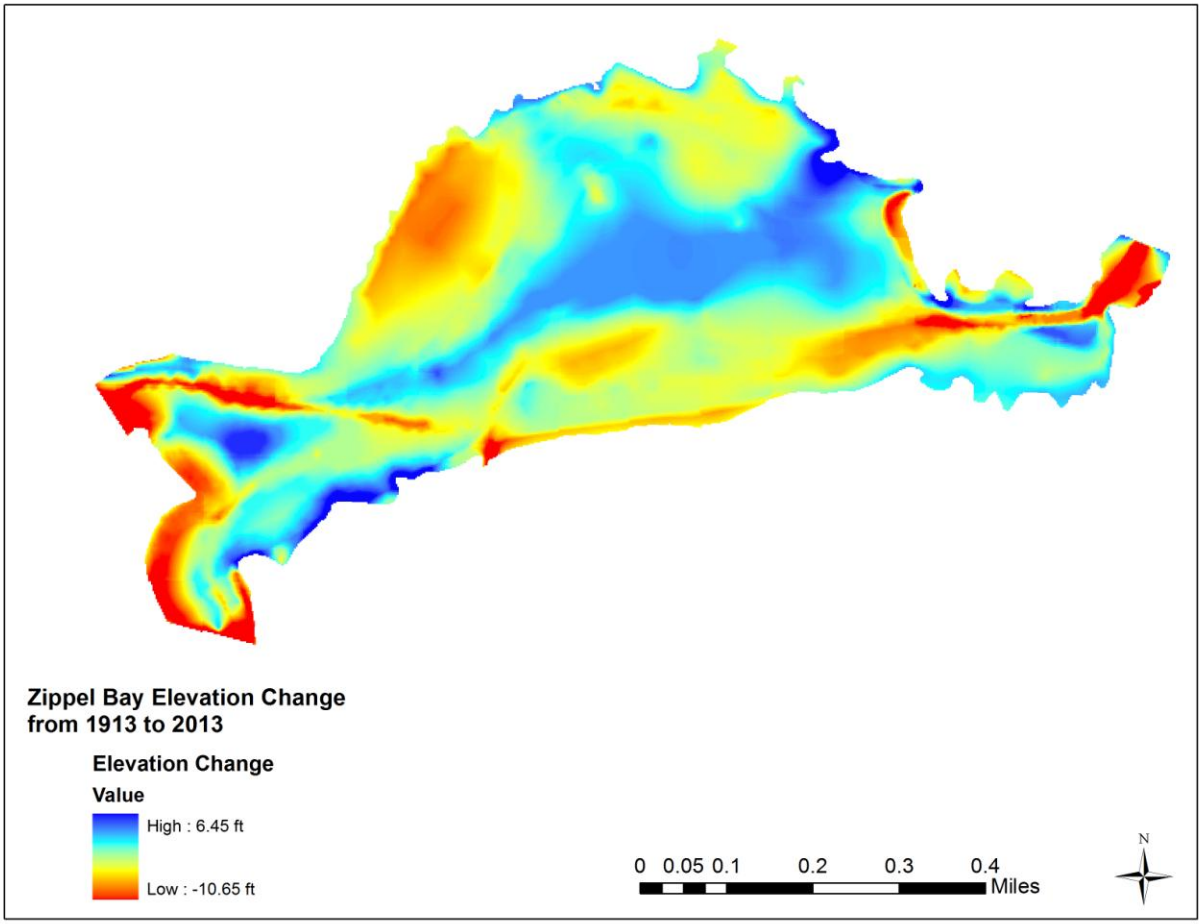

Figure 7: Change in Lake Bed Elevation from 1913 to 2013. Positive elevation changes indicated deposition, while negative changes indicate scouring.

Following subtraction of the two rasters, the Cut/Fill tool in ArcGIS was used to highlight areas where sediment has deposited (shown as “net gain” in the map) or scoured (shown as “net loss” in the map) in Zippel Bay over the past 100-years. **Figure 8** shows the results, with red areas indicating net deposition and blue areas indicating net scour.

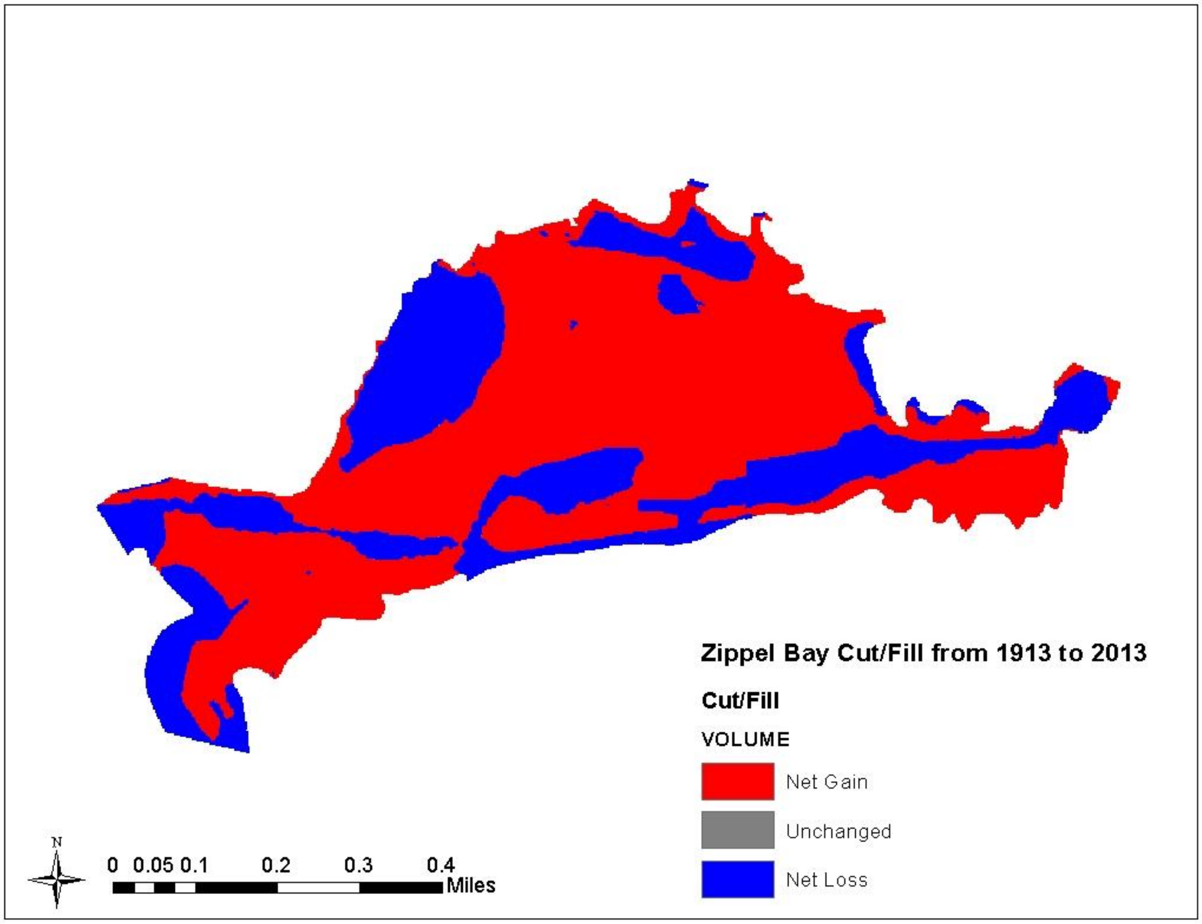

Figure 8: Cut/Fill Map of Zippel Bay for Elevations in 1913 and 2013.

To investigate the changes in the south and west arms of the Bay, the point measurements in the 1913 data (see **Figure 3**) were compared to the 2013 survey data and an average change in elevation was computed. The average change in bed elevation for the west arm of Zippel Bay is approximately 1.6 foot (19 inches), meaning the bed elevation increased, on bulk average, by one and a half feet between 1913 and 2013. The average change in bed elevation for the south arm of Zippel Bay is 3.28 feet (39.4 inches). A similar comparison of point elevations in the main part of the Bay (see **Figure 3**) showed an average difference of 2.9 feet (34.8 inches). Individual comparisons between the point elevations of the 1913 data are given in the Appendix.

Discussion of Results

The results of comparing the 2013 and 1913 bathymetry data were, generally, as expected, showing areas of significant net sediment deposition in the Bay. Again, no information was available to account for dredging or other sediment management practices that may have occurred in Zippel Bay during this time period. As such, the 2013 to 1913 comparisons result in net deposition/erosion estimates, without knowledge of how much impact various forces had on the results.

A 2005 sediment coring study in the main part of Zippel Bay found that approximately 22 inches of sediment has deposited in the area since 1900 (Reavie and Baratono, 2007). Additional results of that work estimated deposition (since 1900) in the south arm of the Bay at 20 inches and the west arm of the Bay at 11 inches. This study's results in the arms of Zippel Bay compare reasonably well with an estimated 39 inches of deposition in the south arm and 19 inches in the west arm. The value of deposition computed for the main portion of the Bay using the raster datasets (0.6 feet or 7 inches) was less than what was found by Reavie and Baratono. However, the comparison of 1913 point elevations (to current elevations) in the main part of the Bay showed an average 35 inches of net deposition. The difference in these findings may be due to the sampling location for the Reavie and Baratono study, which was near the middle of the Bay and, perhaps, more indicative of deposition rates in that general area. It may also be impacted by the issues discussed below or any dredging/sediment management that may have occurred in the Bay between the time of the Reavie and Baratono study and the bathymetry data collection in 2013.

Potential explanations for the discrepancies in results seen between this analysis and other work in Zippel Bay include issues with the accuracy of the 1913 bathymetry maps or trouble associated with converting the 1913 map's datum for comparison to the 2013 data. Additional considerations may include isostatic rebound that's been occurring in the area, which has been documented to impact elevations by up to 12 cm (4.7 inches) (Tackman, et al. 1999).

References

Reavie, E.D. and N.G. Baratono. 2007. Multi-Core Investigation of a Lotic Bay of Lake of the Woods (Minnesota, USA) Impacted by Cultural Development. Journal of Paleolimnology. 38: 137-156.

Tackman, G.E., B.G. Bills, T.S. James, and D.R. Currey. 1999. Lake-gauge Evidence for Regional Postglacial Tilting in Southern Manitoba. GSA Bulletin. 111 (11): 1684-1699.

APPENDIX

Table A.1 Change in Elevation form 1913 to 2013 for Points in 1913 data (see Figure 3)

FID*	1913 Elevation	2013 Elevation	Change in Elevation	Zippel Bay Section
0	1052.26	1055	2.74	Main Bay
1	1051.26	1054	2.74	Main Bay
2	1051.26	1054	2.74	Main Bay
3	1052.26	1054	1.74	Main Bay
4	1051.16	1054	2.84	Main Bay
5	1052.76	1055	2.24	Main Bay
6	1054.36	1058	3.64	Main Bay
7	1053.36	1060.3	6.94	Main Bay
8	1050.76	1054	3.24	Main Bay
9	1052.46	1053	0.54	Main Bay
10	1052.76	1054	1.24	Western Arm
11	1052.76	1055	2.24	Western Arm
12	1054.76	1057	2.24	Western Arm
13	1052.76	1055	2.24	Southern Arm
14	1054.66	1057	2.34	Southern Arm
15	1051.16	1055	3.84	Southern Arm
16	1056.16	1057	0.84	Southern Arm
17	1056.76	1057	0.24	Western Arm
18	1050.76	1053	2.24	Western Arm
19	1056.76	1057	0.24	Western Arm
20	1052.76	1055	2.24	Western Arm
21	1055.76	1057	1.24	Western Arm
22	1052.76	1054	1.24	Western Arm
23	1056.76	1057	0.24	Western Arm
24	1054.76	1055	0.24	Western Arm
25	1053.26	1057	3.74	Western Arm
26	1052.76	1056	3.24	Western Arm
27	1055.76	1058	2.24	Western Arm
28	1054.76	1056	1.24	Western Arm
29	1056.26	no data available	N/A	Western Arm
30	1054.76	no data available	N/A	Western Arm
31	1055.26	no data available	N/A	Western Arm
32	1056.76	no data available	N/A	Western Arm
33	1056.76	no data available	N/A	Western Arm
34	1055.76	no data available	N/A	Western Arm
35	1056.76	no data available	N/A	Western Arm
36	1056.26	no data available	N/A	Western Arm

37	1057.76	no data available	N/A	Western Arm
38	1056.16	1060.3		Southern Arm
39	1051.76	1056	4.24	Southern Arm
40	1054.16	1056	1.84	Southern Arm
41	1053.26	1058	4.74	Southern Arm
42	1056.26	1054	-2.26	Southern Arm
43	1055.76	1055	-0.76	Southern Arm
44	1054.76	1060.3	5.54	Southern Arm
45	1056.26	1060.3	4.04	Southern Arm
46	1056.76	1060.3	3.54	Southern Arm
47	1056.26	1060.3	4.04	Southern Arm
48	1053.26	1060.3	7.04	Southern Arm
49	1054.76	1060.3	5.54	Southern Arm
50	1056.26	1060.3	4.04	Southern Arm
51	1056.26	1060.3	4.04	Southern Arm
52	1054.26	1060.3	6.04	Southern Arm
53	1055.26	1060.3	5.04	Southern Arm
54	1057.26	1057	-0.26	Southern Arm
55	1054.76	1060.3	5.54	Southern Arm
56	1059.26	1060.3	1.04	Southern Arm

*FID is the Feature ID (FID) label in the attribute table of the 1913 point elevations in ArcGIS.