Determining a Dredge Production Constant through GIS: HYPACK

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Abstract

This research study examined factors related to dredging and evaluated the dredge production formula constant using dredge river sand from the Upper Mississippi River. Data collection and related procedures were used in conjunction with the United States Army Corps of Engineers (USACE) dredging operations in the Upper Mississippi River to maintain the 'Nine Foot Channel Navigation Project.' A preliminary interpretation of dredge data using the Dredge Quality Management Program was analyzed using the HYPACK mapping software suite. Through use of HYPACK, bathymetric surveys were organized to calculate and determine a dredging constant value (c) for the Chippewa Delta (Wisconsin-Minnesota, U.S.) dredge study location. Dredge constants differ from location to location, and year to year in the same location, due to changing sediment transportation amounts in river systems. Findings from the study help to reduce the risk for exploring sites, improve planning, and develop a system for accurate dredge constants and production formulas.

Introduction

Across the world, from seaports to marinas, man-made canals to natural river systems, and recreational waters, there is a quintessential sound – a droning, whistle of a turbo, or rumble of material moving through pipelines that accentuates the atmosphere, excites a person's ear, grabs their eyes, and makes them ask the question, "What is this operation?"

Sounds of river or lake dredging operations such as those described are a regular occurrence on river and lake systems around the world requiring navigable water passage. Navigable waters in areas may vary depending on need and purpose, but in many lake and river systems, water depth is essential. In some instances, maintaining water depth is required for commercial and recreational boat traffic. Without navigable waterways, commercial and recreational water traffic for transportation of goods and services may be severely hindered. In addition, maintaining water depths may be important for fisheries and localized ecosystems located in rivers, lakes, and streams.

Research Study Purpose

The main objective in this study was to spatially and statistically analyze raw bathymetric and Dredge Quality Management (DQM) Program data to determine a sand constant for the Dredge Goetz, a hydraulic dredge which operates in the Upper Mississippi River. This study serves as an instrument for ongoing analysis to better understanding what types of material and production rates can be

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expected on an annual basis.

What is Dredging

Dredging is a unique process filled with sophisticated technology, physical equations, and trial and error. A simple definition of dredging is that it is the subaqueous or underwater excavation of soils and rocks (Bray and Cohen, 2010). Typical dredging processes consist of four phases:

- Excavation
- Vertical Transport
- Horizontal Transport
- Placement or use of material dredged

From definition, excavation of material occurs underwater; hence, the terrain and materials are often difficult to observe and illustrate during the process. Bathymetric surveys are typically performed in order to visualize areas beneath the water surface requiring excavation. During the survey process, estimates of volume and quantity of work to be performed can be generated. Early forms of bathymetric surveys consisted of a sounding pole and a type of data log, such as a book or note pad. Since the 1920s, most surveys are conducted with an eco-sounder, and now data are recorded with computers (Figure 1).

To understand the nature of materials to be dredged, geological and geophysical exploration methods may be employed (Bray and Cohen, 2010). The nature and complexity of dredging is not well understood except by those actually engaged in the activity (Bray and Cohen). This is often the case with subject matter experts who regularly experience challenges firsthand and develop best-practices for operations in given areas for which they are most familiar. For example, stakeholders not involved with direct dredge operations tend to consider only the excavation phase and overlook the importance of transportation and placement phases of an entire project.

When comparing intricate phases of dredging processes, the number of important planning stages may increase with complexity of river sediment and site location. As a result, management of planning, design, construction, and maintenance of projects continually changes and evolves.

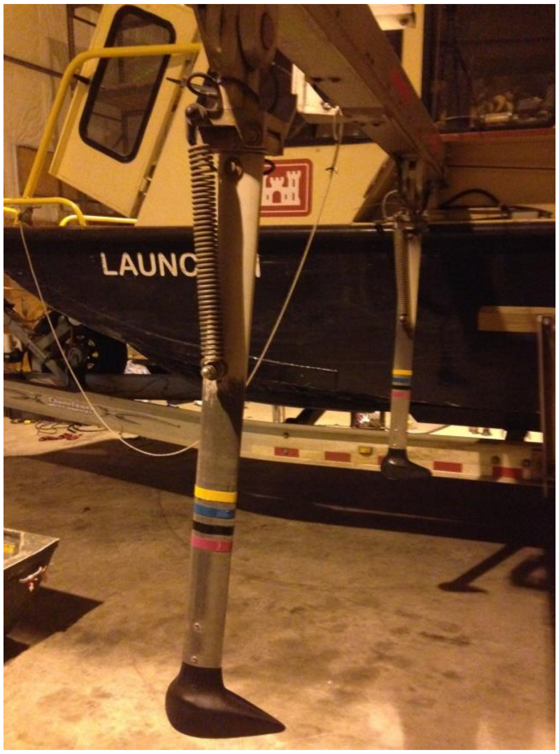

Figure 1. Eco-Sounder from Launch 21 United States Army Corps of Engineer Survey Vessel (Cottrell, 2014).

The importance of valid and reliable data used for dredge operations and the fine line between environmental concerns and engineering needs are often underestimated (Cottrell, 2014). Consequently, evaluations of practice, data, and impact of operations are beneficial to address for research and evaluation purposes.

The Importance of Dredging

From the beginning of civilization and the evolution of established communities, there has been a need to transport people, equipment, materials, and commodities by water (Bray and Cohen, 2010; Janvrin, 2011).

Demographic developments indicate human involvement with water-related needs will continue to increase. Global population rose to an ever-increasing 6.9 billion in 2010, with approximately 3 billion people – about half the world's population – living within 124 miles of a coastline (Herbich, 1991). By 2025, the population living next to water is predicted to increase by 50%, and by 2050, the global population is predicted to surpass 9 billion (Herbich, 1991).

An increase in population will have an enormous impact on demand for goods and services. As demand grows for larger ports, harbors, and waterways that already require maintenance dredging, those same waterways will then require access dredging in order to increase depths and widths of expansion projects to accommodate larger ships (Wilson, 1996; Yell and Riddell, 1995). Examples of these types of projects are occurring in ports such and Miami, Florida and Savanna, Georgia (USACE Learning Center, 2014).

Reasons for dredging include navigation, construction and reclamation, beach nourishment, environmental remediation, flood control, mining, and other general inquires (USACE Learning Center, 2014). The concept seems simple: 1) take underwater material and, 2) place it elsewhere according to standards and expectations agreed upon between environmental and engineering stakeholders of the project.

The Dredging Industry

Just like reasons for basic dredging vary from job to job, so do the ways in which the work is performed. In the United States, approximately seventy percent of all dredging work is performed by contractors (USACE Learning Center, 2014).

Dredging equipment involves expensive dredge power plant investment, specially trained operators, logistical support, and experienced project managers (Herbich, 1992; Richardson, 2002.) Contractors in these positions are presented the greatest challenge during the project development process.

Environmental regulations have limited boundaries and are closely evaluated in dredging projects, as they involve everyone from the public, as an observer, to stakeholders, who help fund the project, to the company, which is trying to complete the job within budget (CEDA, 1991).

Dredging has utilized a collaborative approach throughout the industry. Substantive and comprehensive environmental assessments are required before each project. All factors presented in an assessment are important, but the type of sediment or material may be the single most important factor within a dredging project.

Importance of Dredge Production Formulas

Complexity of dredging lies within the production formula. In each formula for hydraulic dredging, a valid sand constant (c) is required. A constant is used to convert from volume by weight to volume by cubic yards. This is necessary as a hydraulic dredge creates slurry (sand and water mixture) to transport material from the bottom of a river or sea to a placement site.

Environmental assessments are important to the constant because it relays what kind of materials, rocks, sand, clay, or silt exists in the area to be dredged. Type of material present is critical to each dredging process to determine what kind of dredge and related equipment should be used to complete the job effectively as well as to transport and remove the sediment correctly.

Study Area

An area known as the Chippewa Delta Sediment Trap is located at river mile 763.4 on the Upper Mississippi River. This area also falls within Pool 4 of the Mississippi River. As a result of the area requiring annual, extensive dredge work, the Chippewa Delta area was selected for its direct impact on localized project efforts. This area is shown in Figure 2 for reference.

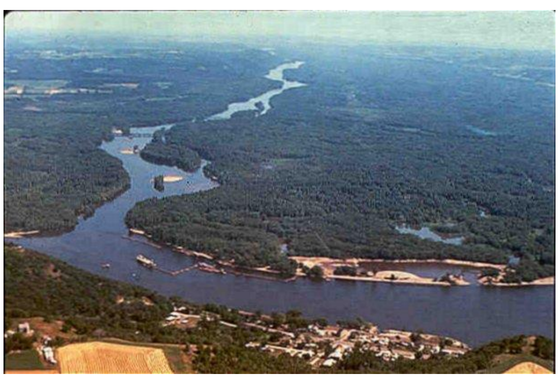

Figure 2. Chippewa Delta meets Mississippi River (Cottrell, 2014).

Background of River Dynamics in Study Area

The Chippewa River is one of the largest rivers in Wisconsin, flowing 103 miles, while encompassing 5 flowages and 69 miles of free-flowing river (Voss and Beaster, 2001). The Chippewa River flows south and westerly until it reaches the Mississippi River (Figure 3).

Figure 3. The circle (center of figure) represents the study area located at the intersection of the Chippewa River Delta and Mississippi River. The study site area is located between the states of Minnesota and Wisconsin (Google Maps, 2015).

Prior research conducted by the hydraulics department of the United States Army Corps of Engineers, St. Paul District (Hendrickson and Lien, 2014) indicated the Chippewa River is a relatively young river, meaning it is still trying to establish its bottom.

Hendrickson and Lien (2014) estimates 1,350,000 tons, or 833,333 cubic yards, of sand washed from the Chippewa River into the Mississippi in 2014, resulting in large amounts of dredging for Pool 4 of the Upper Mississippi River and river closures to commercial traffic and the tow industry (Figure 4).

Hendrickson and Lien (2014) state the Chippewa River, on average, moves 500,000 cubic yards of sediment into the Mississippi each year, making Pool 4 a popular place for dredging needs; the Chippewa Delta sediment trap is the largest dredging project on an annual basis for the United States Army Corps of Engineers (Figure 5).

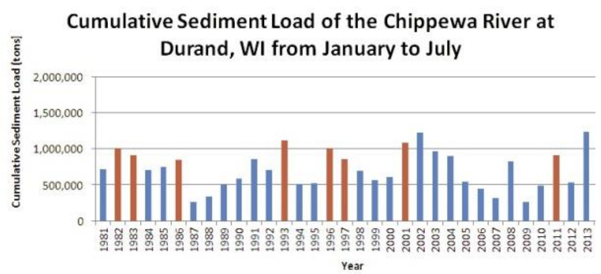

Figure 4. Sediment load on the Chippewa River at Durand, WI. Flood years highlighted in red (Hendrickson and Lien, 2014).

Figure 5. Chippewa Delta sediment trap (Cottrell, 2014).

Methodology

Principles of establishing a methodology for this study are grounded in evaluating spatial and descriptive statistical analyses on raw pre- and post-dredge bathymetric data to determine the in-situ volume of sand before and after hydraulic dredging in the study area. Post-bathymetric survey volumes derived in HYPACK software were compared to production formula volume estimate calculations derived from the Dredge Quality Management (DQM) software. After comparison, volumes were analyzed to derive a modified dredging sand constant (c) for the Dredge Goetz.

HYPACK suite software, an industry-leading software for bathymetric data, was used for spatial analysis and calculating in-situ volume estimates for the Chippewa Delta hydraulic dredging area. HYPACK was utilized to display the sediment trap located at the delta, which was dredged in early 2014.

DQM is a relatively new data management program. The purpose of the management program is to help analysts plan, operate, and respond to dredging operations in real-time all while logging data for analysis. Data used in DQM is best-suited for spreadsheet analysis.

Data Acquisition

Datasets were acquired from the Army Corps of Engineers, St. Paul District Channel & Harbors Project Office. Data included: (a) raw pre- and post-dredge bathymetric survey data, (b) dredge cuts matrix files, (c) shapefiles illustrating river features, and (d) dredge quality management (DQM) data.

Projection

All data used in this study were projected and collected in order to keep all datasets aligned. The following projection was used in the study:

NAD 1983 State Plane Minnesota South FIPS 2203 Feet
WKID: 26851 Authority: EPSG

Projection: Lambert Conformal Conic
False Easting: 2624666.666666666
False Northing: 328083.333333333
Central Meridian: -94.0
Standard Parallel 1: 43.78333333333333
Standard Parallel 2: 45.21666666666667
Latitude of Origin: 43.0
Linear Unit: Foot US (0.3048006096012192)

Geographic Coordinate System: GCS North America 1983
Angular Unit: Degree (0.0174532925199433)

Prime Meridian: Greenwich (0.0)
Datum: D North America 1983
Spheroid: GRS 1980
Semi Major Axis: 6378137.0
Semi Minor Axis: 6356752.314140356
Inverse Flatting: 298.257222101

Analysis

Raw Bathymetic Data

Raw bathymetric data were entered in HYPACK software to produce a map and estimate volume of sediment to be removed. Channel design was incorporated to determine side slopes and the amount of sediment to be removed during dredge operations of the Chippewa Delta project.

Raw xyz data points were collected based on current river conditions and benchmarks placed by Real-Time Kinematic (RTK) systems and the Minnesota Virtual Reference System (VRS network). Locations were then used to interpolate a water surface elevation for river mile 763.5 – the study location. In addition, a 'mapper.xyz file' was created from editing Triangulated Irregular Network (TIN) data to ensure full x, y, z coverage of the study area.

Dredge matrixes were extracted in relation to historic dredge cuts where environmental assessments were conducted in the study area in the past and present. Matrixes were placed based on where sediment was accumulating and how much sediment was allowed to be removed due to placement site area holding capacity.

All data were analyzed using a 3x3 cell size with contours of one foot. Channel design was used with side slope of 2:1 on dredge cut sides that did not border other dredge cuts to include infill while dredge operations were being conducted.

Data integrity was of utmost importance; if volume area calculations were determined using past information, it would likely result in a sand constant (c) value inconsistent with current conditions.

Raw Dredge Quality Management Data (DQM)

Data extracted for this study consisted of raw data collected directly from dredge equipment. Input data were recorded by a velocity meter and nuclear density meter. Both equipment inputs were essential to help determine production rates. These pieces of equipment imported data into the DQM software to create a production formula:

d = Inside diameter of pipe
v = Velocity in feet per second
SG = Specific Gravity of slurry
c = Sand constant

$$\text{cu yd/hr} = d^2 \times v \times (SG-1) \times c$$

According to Turner (1996), the sand constant (c), should equal 0.661. The Goetz Dredge sand constant, c, that was used in the preliminary DQM data collection for the study was 0.60606. The diameter of the inside pipe for the Dredge Goetz equals twenty inches. What is underlying in the formula is that d is actually the area of a pipe – not just the diameter of the pipe. The constant, c, holds more constants for Turner's equation, than what is shown. Modifying the production formula accordingly to allow a controllable sand constant:

A = $(\pi/4) \times (d^2)$ where d = 20 inches
v = velocity meter output in ft/s
SG = density meter output
c = 0.60606

$$\text{cu yd/hr} = (\pi/4)(20^2) \times v \times (SG-1) \times 0.60606$$

This value was used as a generic standard in prior dredging projects. However, this value may not be accurate in all dredging projects. It is for this reason analysis was conducted to determine a more effective sand constant to be used in DQM. DQM is instantaneous data, and creates output data every few seconds. It is not a continuous evaluation of productivity, although attempts are made to use it as such.

DQM data was then analyzed in Microsoft Excel. Equations and relationships between instantaneous velocity and density inputs were examined based on a velocity (v) greater than 0.0, and a density (SG) greater than 1.0 to derive volume calculations.

Results

Results were derived from three stages of comparative analysis: a) HYPACK was used to derive an in-situ volume of sediment removal by comparing pre- and post-survey bathymetric volume data (before and after sediment removal), b) the DQM program used the preliminary, or unevaluated, sand constant of .60606 to calculate total volume of sediment removed from the study area using a production formula rate (this constant is what is being evaluated), and c) calculations were made to compare volumes generated between HYPACK and DQM production formulas to revise the sand constant based off known amounts of sand removed from HYPACK to augment a refined sand constant (c) to be updated in DQM.

The pre-dredge bathymetric survey was an essential building block when computing volumes removed from the study area because it provided the baseline to determine volume of sediment removed. This derived volume was then compared to the production formula in the DQM program to make necessary revisions to the preliminary sand constant (0.60606) tested during the study.

Pre-Bathymetric Data

Results from the pre-bathymetric survey estimated 115,445 cubic yards of sediment to be dredged from the study area. Two cuts existed for the 2014 Chippewa Delta Project: Cut-1 being 200’ wide ×1690’ long with a side slope of 2:1 existing on the right descending side, and Cut-2, being 200’ wide ×1370’ long with a side slope of 2:1 existing on the left descending side (Appendix A).

Post-Dredge Bathymetric Data

Results from the post-dredge bathymetric survey estimated 108,744 cubic yards of sediment dredged from the study area (Appendix B). This value was analyzed and subsequently derived using HYPACK software. The value of 108,744 cubic yards was the actual volume of sediment removed from the study area; it also was the value compared to DQM to learn the impact of incorrect sand constant values.

Quality Management Data

DQM data was analyzed in Excel to determine production of cubic yards for the dredge. Figure 6 provides results from the input data. To illustrate (Figure 6), top columns spanning left to right (in green) equate to parameter outputs per day; specifically, cubic yards output daily (Daily CY), effective work time in minutes and seconds (EWT), and day number of dredging (Sheet). Totals for each column are represented at second from bottom (in yellow) with averages of all columns represented at the very bottom (in orange). Other values represented are used for production rates based on pipeline length as well as lift to a placement site.

Sheet	Daily CY	EWT	CY/Pump Hr.	Vacuum	D. Pressure	Pump RPM
1						
2	8865.88	11.27	786.62	9.18	76.47	420.06
3						
4						
5	15890.33	20.11	790.01	8.83	78.66	421.51
6	19762.21	21.45	921.14	8.63	88.96	437.73
7	6889.34	14.87	463.24	9.37	76.57	428.26
8	20790.00	22.14	939.11	9.23	91.22	442.68
9	4570.83	4.96	921.02	7.58	91.37	444.72
10						
11						
12						
13						
14						
15						
Total	76768.59	94.81				
Average	12794.76	15.80	803.52	8.80	83.87	432.49

Figure 6. Results of collected and interpreted DQM data to determine total sediment removed. Total estimated sediment removed suggests a total of 76,768.59 cubic yards using a sand constant value of 0.60606.

Using post-volume results from HYPACK (108,744) and DQM data (76,768.59) results in the following modified sand constant (c) value for greater accuracy in DQM:

$$\frac{\underline{108{,}744 \text{ cu yds}}}{c} \times \frac{\underline{76{,}768.59 \text{ cu yds}}}{0.60606}$$

Where:

$c = 0.8584988498 \approx 0.85850$

The sand constant for the Chippewa Delta study area was determined to be c = 0.85850, suggesting material settling within the Chippewa Delta contains more gravel and larger size sand than finer sand and silt.

Discussion

The production meter on the hydraulic Dredge Goetz has a few different input parameters. If one input is changed, the sand constant value changes in DQM because they are on the same side of the mathematical equation. The Dredge Goetz equipment does possess settings to change the velocity meter setting but does not have capabilities to change the density meter (factory pre-set values).

Findings suggest a higher sand constant was necessary to effectively update the volume of dredge material removed using DQM. This constant should be different at each dredge location, however it may be similar at consistent dredge location sites. Consequently, as with any system, correctly evaluating and obtaining valid raw data is imperative. In addition, settings on equipment (ex. density meter, velocity meter) must be set according to input raw data analysis for the most efficient operation possible.

Since DQM software is new and still changing, data from prior years may require manipulation to help adjust for changing input values and changing tributary sediment and river dynamics year to year.

On-Going Constraints

Issues involved in this study were vast. Determining a sand constant has been an ongoing research problem in the dredging industry and proved to be a problem in this project as well. The sand constant is unique to each project because of the type of material locally deposited in waterways and dredge areas.

One of the issues encountered throughout this study was the number of different ways to compute volume. Volume can be calculated using point data verses raster data, TIN-to-TIN comparisons, and cross sections.

Collecting raw data made tremendous advancements in the last decade – from using poles to sound, to eco-sounders with computers, to multi-beam data. Raw data for this study was collected using a survey sweep boat with six single beam transducers with total coverage.

Devices used in generating data need to be working simultaneously to have good DQM data. If one input is not functioning, the production formula (volume estimates) will not perform as intended.

Also, it was important to have a starting point defined for a sand constant from which to base evaluation from. A sand constant of 0.60606 was used to start the dredging season based on industry analysis. As discussed, DQM is instantaneous data and is not a continuous evaluation of productivity, although attempts are made to use it as such.

Recommendations

It might be advantageous to correlate other variables between dredge location and placement sites. Taking both pre and post quantities removed via bathymetric data and comparing it to a pre and post topographic survey would provide a better idea for computing volume quantities as well as ideas for additional volume computations. Advancement in survey equipment is on the forefront and could be taken into consideration if the research is conducted again in the future.

Each year in the Chippewa Delta, DQM data will increase, advance, and become even more important in determining a sand constant. When considering other dredge locations within Pool 4 of the Upper Mississippi River, reviewing post dredge volumes and comparing them to DQM volumes might lead to a similar sand constant for the area.

Taking into account time unaccounted for during instantaneous outputs of the DQM data might result in a lower sand constant. The time missed by the instantaneous records could be comparing to the total volume to calculate an assumed volume that could be added to the existing total.

Conclusions

Strictly evaluating test data from the Dredge Goetz dredging location of the Chippewa Delta in 2014, analysis showed a sand constant (c) should have been raised to achieve a closer prediction of sediment removed during dredging operations.

As DQM software advances and operators are able to enter in a dredge constant for each new dredge location, dredge sediment should be able to be closely calculated. Although this way of calculating the amount of sediment may not be an exact science, it is still a useful means for evaluating dredge areas to help more accurately predict sediment removal amounts.

Acknowledgements

This research was driven on behalf of the late Mr. Steve Sing. He was a teacher at heart, had a wealth of knowledge about the river, and was the last old river rat to live! He inspired me to face challenges and to solve major problems as they came to me, with the “I told you so” attitude.

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Last, a humble thanks to the close friends, classmates, and people who I crossed paths with that ask questions and allow me to learn from and teach them.

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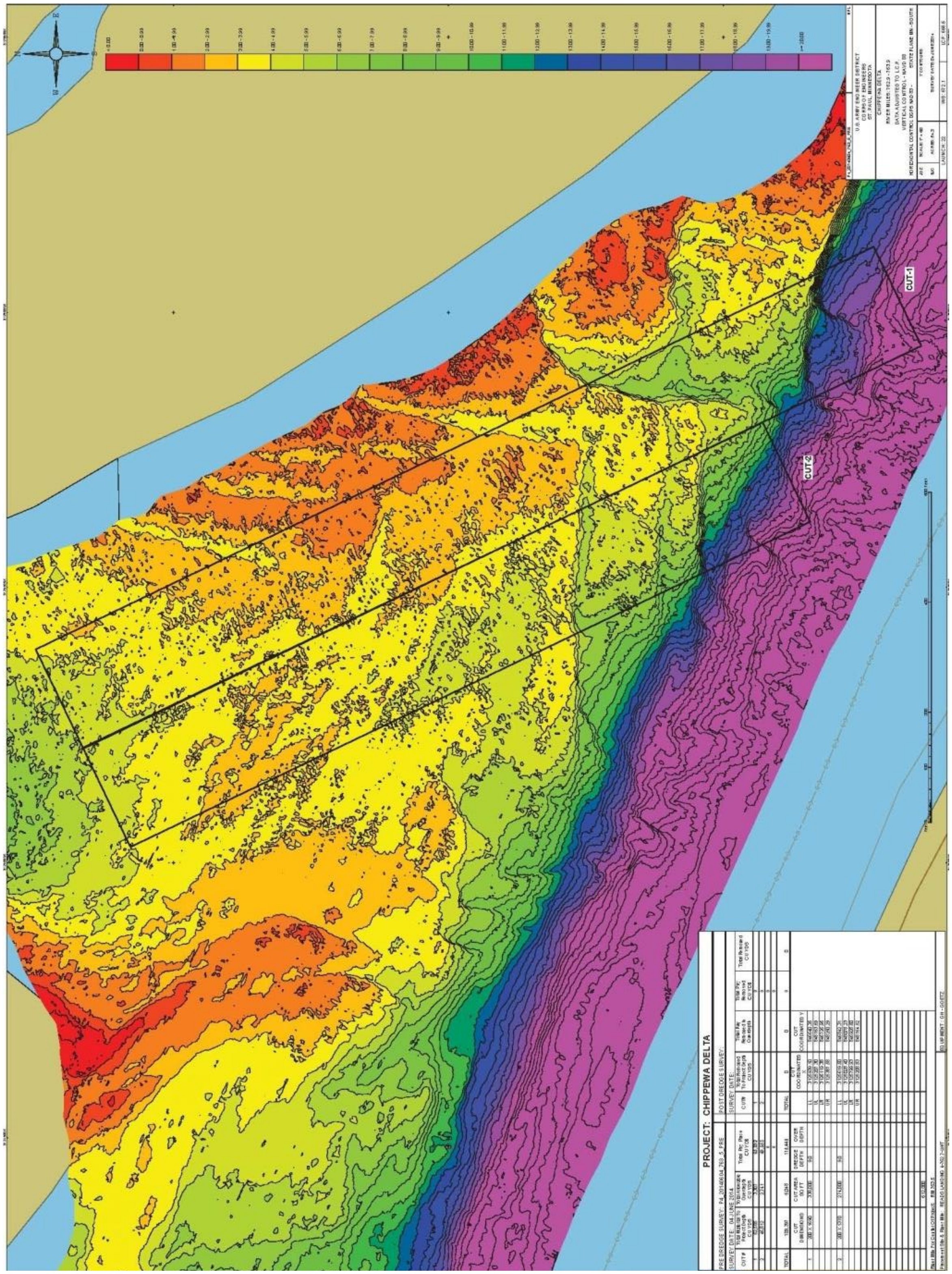
Appendix A. Chippewa Delta Pre Survey (June 4, 2014) Map. Numbers reflect the volume of sediment to be removed in dredge cuts. Dredge Cuts are represented with a black outlined box. Color legend with red being shallow to purple being deep. Metadata box located in SE corner. Dredge quantity information located SW corner. Scale Bar 1"= 60'. C.I = 1'.



Appendix B. Chippewa Delta Post Survey (June 26, 2014) Map. Numbers reflect the volume of sediment removed in dredge cuts. Dredge Cuts are represented with a black outlined box. Color legend with red being shallow to purple being deep. Metadata box located in SE corner. Dredge quantity information located SW corner. Scale Bar 1"= 60'. C.I = 1'.