



# Bathymetry Basics

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**Missouri Water Science Center**

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# Topics

- **Survey Set-up**
  - Equipment/Software
  - Vertical Control
  - Office Preparation
- **Data Collection**
  - Field Preparation
  - Transects/Obliques
  - Target Points
  - Miscellaneous
- **Data Processing**
  - Surface creation
  - Map and Area/Capacity Table
  - Accuracy Assessment



## **Procedural Documentation and Accuracy Assessment of Bathymetric Maps and Area/Capacity Tables for Small Reservoirs**



Scientific Investigations Report 2006–5208

U.S. Department of the Interior  
U.S. Geological Survey





**Reference to brand names does not constitute endorsement by the U.S. Geological Survey.**

# Topics

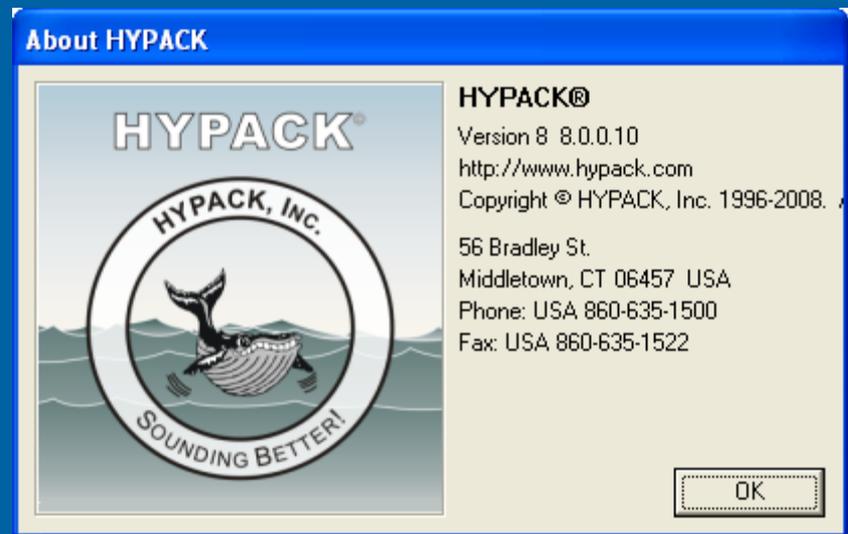
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# Equipment

- Boat
- Survey Grade Echosounder
  - ODE Bathy 500 Bathometer
    - 200 kHz Transducer 3° Beam
- Trimble Ag GPS System
  - OMNI Star Differential Correction
- Trimble Survey GPS System

# Software

- **Hypack**
  - Survey planning
  - Navigation
  - Bathymetry data collection
- **Trimble Survey Office**
  - DGPS pre-deployment data entry and post processing
- **ArcGIS**
  - Survey set-up
  - Bathymetry surface, map, area/capacity table creation and accuracy assessment



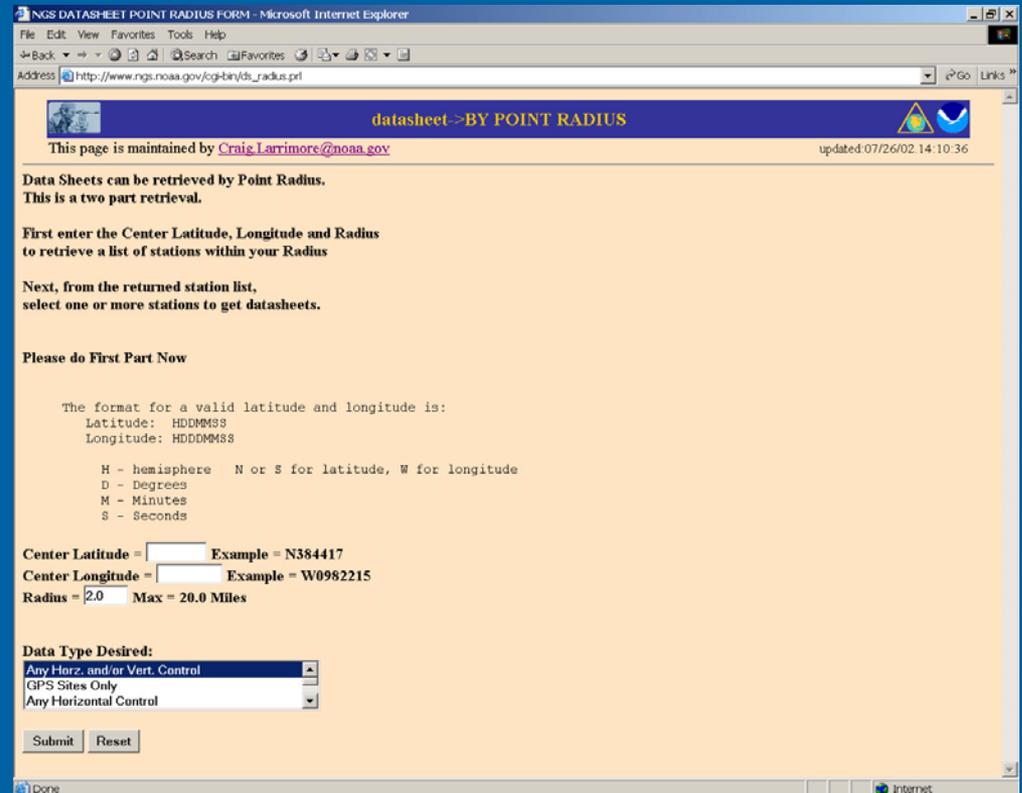
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# Vertical Control

- Bench Marks

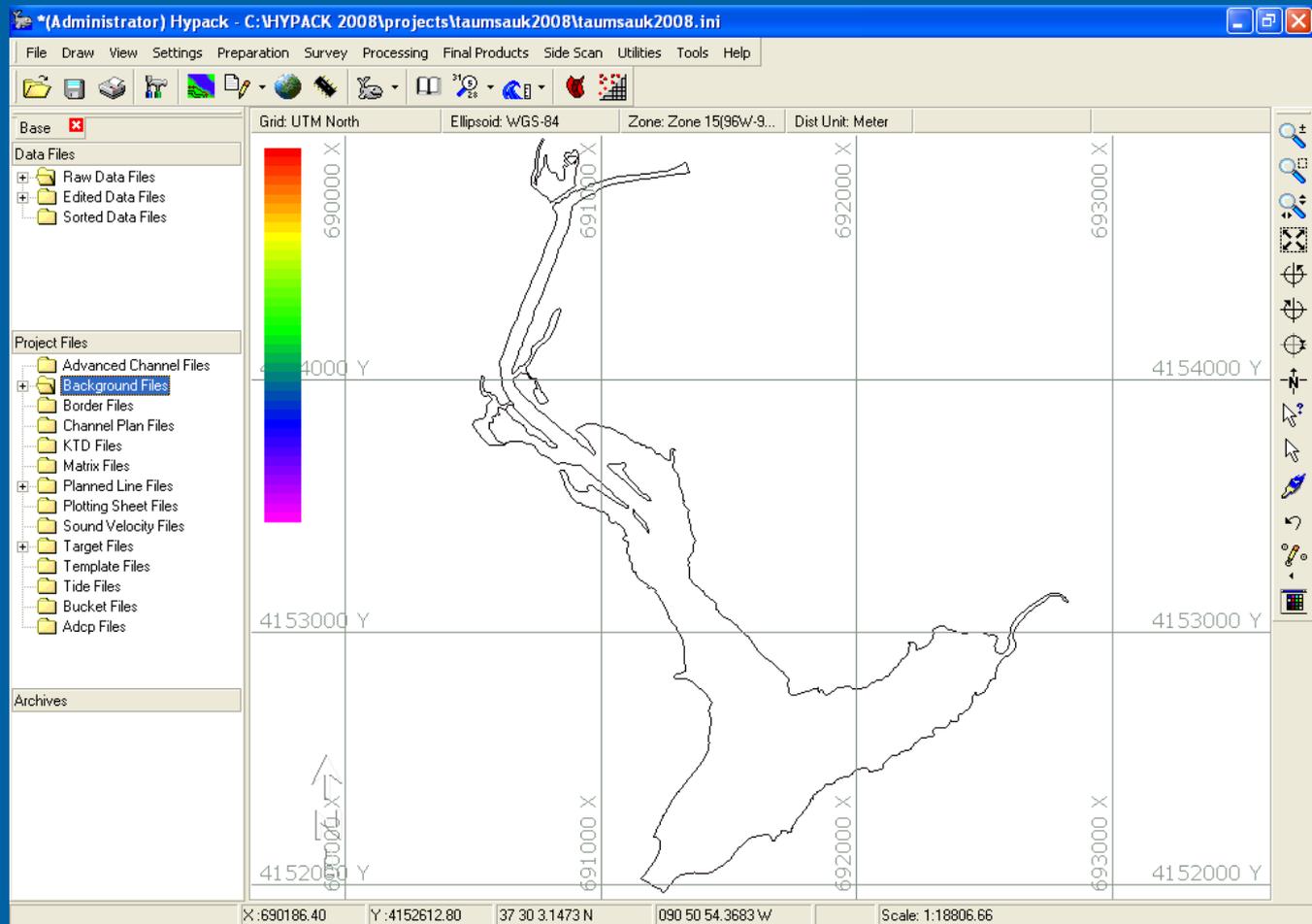
- [www.ngs.noaa.gov/cgi-bin/ds\\_radius.prl](http://www.ngs.noaa.gov/cgi-bin/ds_radius.prl)



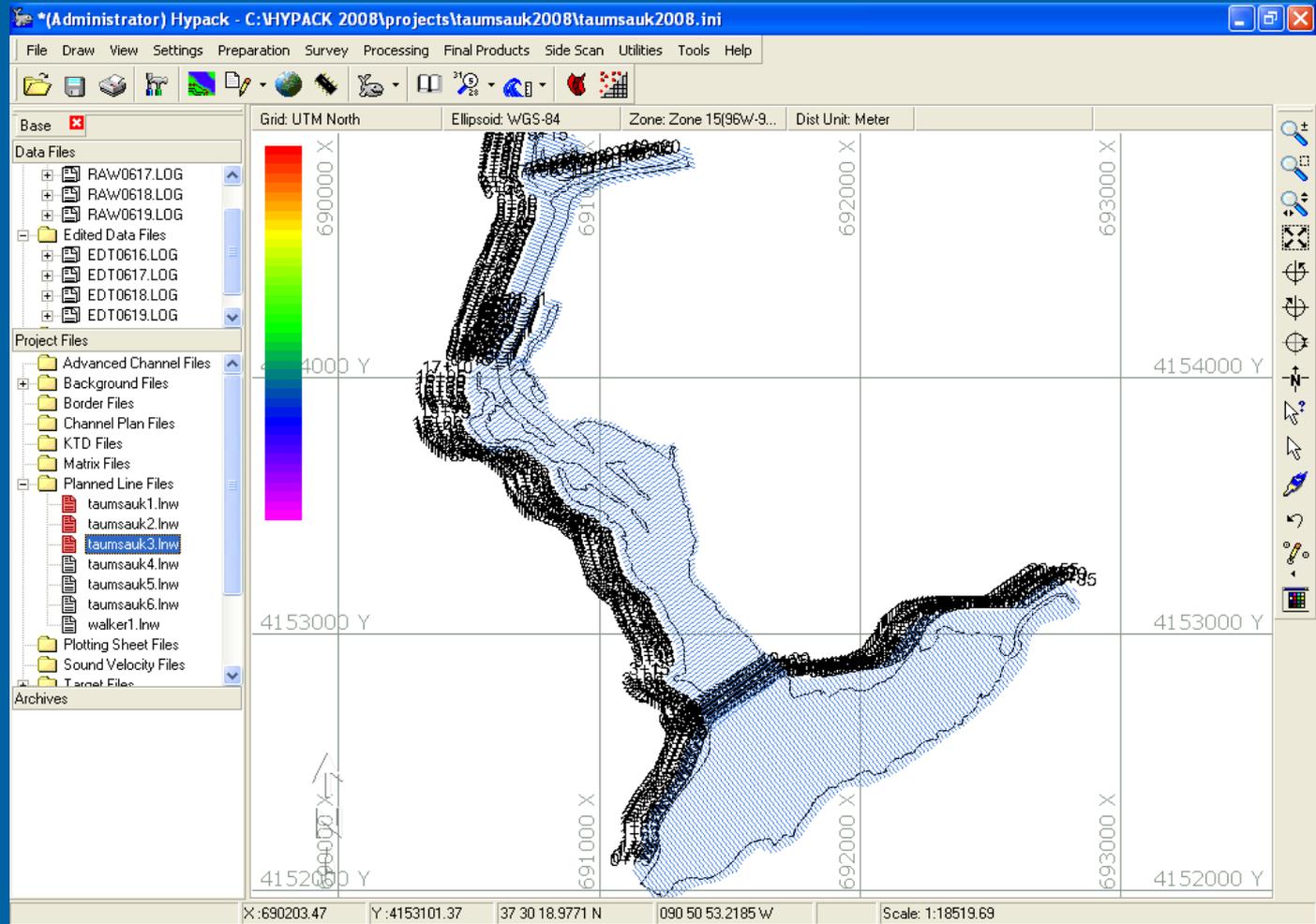
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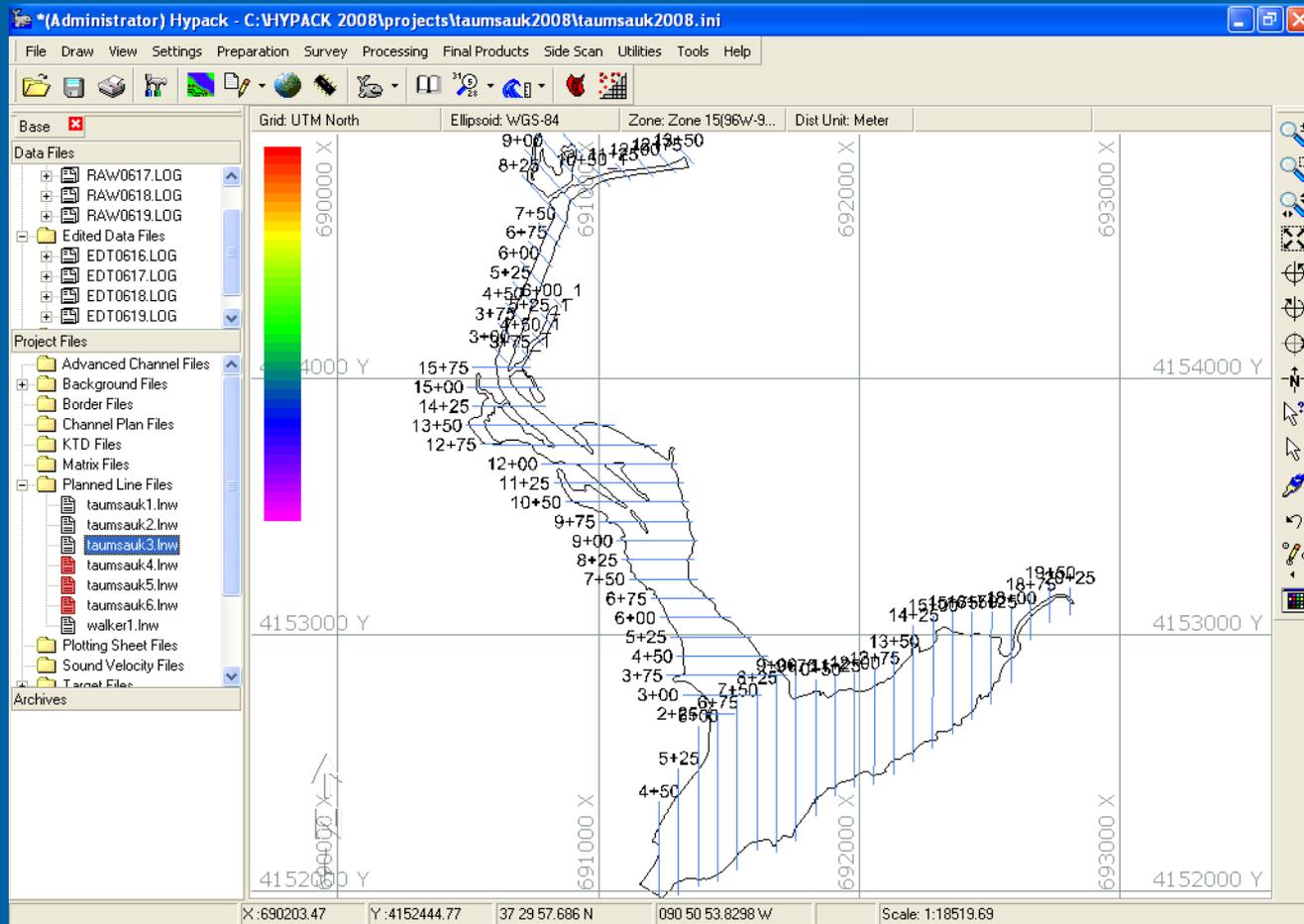
# Lake boundary (best available)



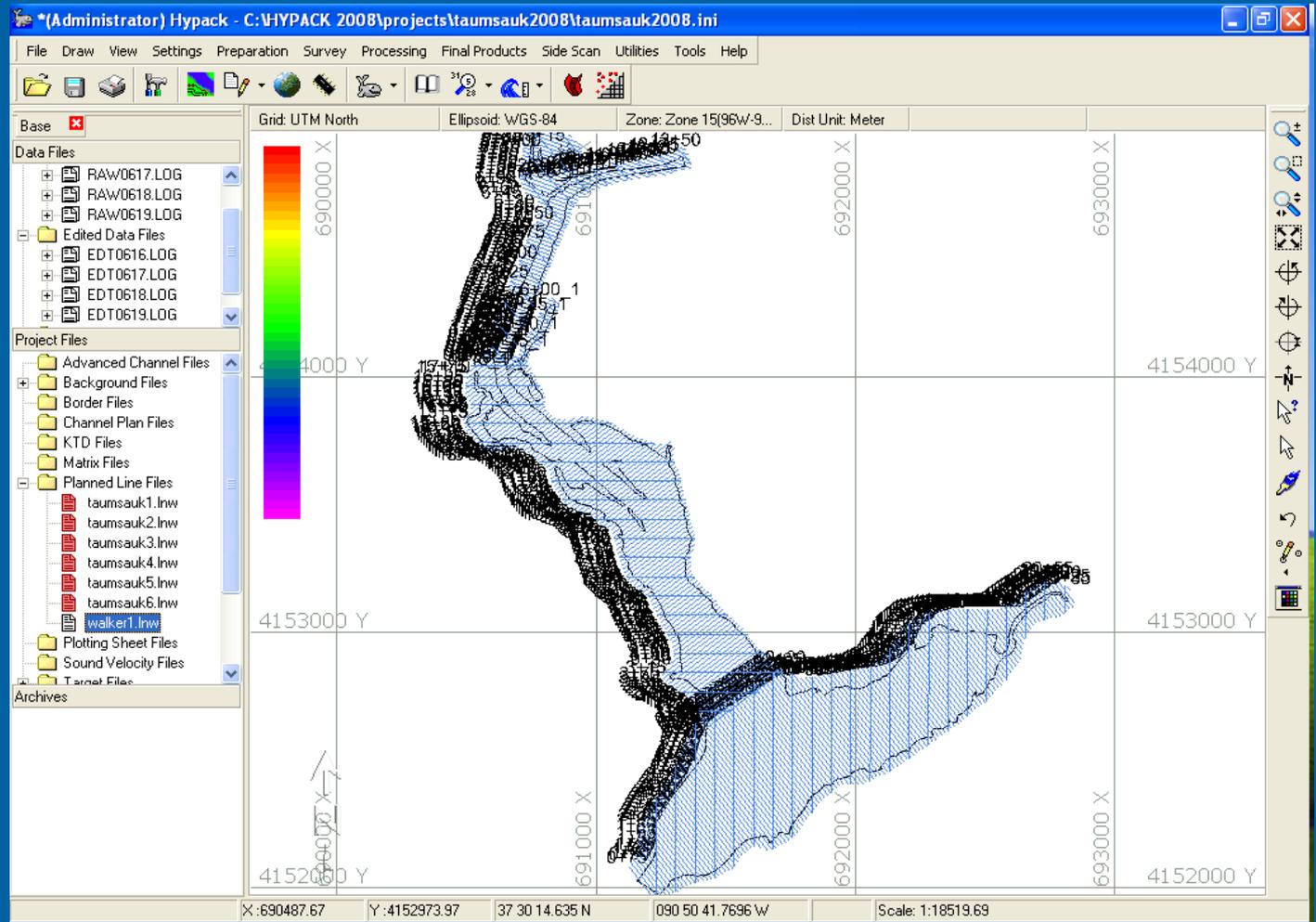
# Survey plan lines (Transects)



# Survey plan lines (Obliques)



# Survey plan lines (all transects)



# Time estimates

- 1 day office preparation for technician
- 1 day office preparation for GIS person
- Minimum 1 day for crew to establish control at lake (depends on benchmark availability and location and location of lake)
- Survey time can be estimated by sum of transect lengths divided by avg. boat speed of 2.5 mph (this takes into account calibration and target points BUT does not take into account land based surveying)
- 1 week minimum processing time to create surface and area/capacity table
- Report time depends on author and additional information in the report

# Recent Example

- 360 acre lake surveyed in June
- Surveyed at 0.5% transect spacing
- Typical office prep
- 3.5 days lake surveying (12 hr days = 40 hrs)
- 1 week to create surface

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# Establish vertical control at Lake



# Calibration of Echosounder (Bar Check)



# Topics

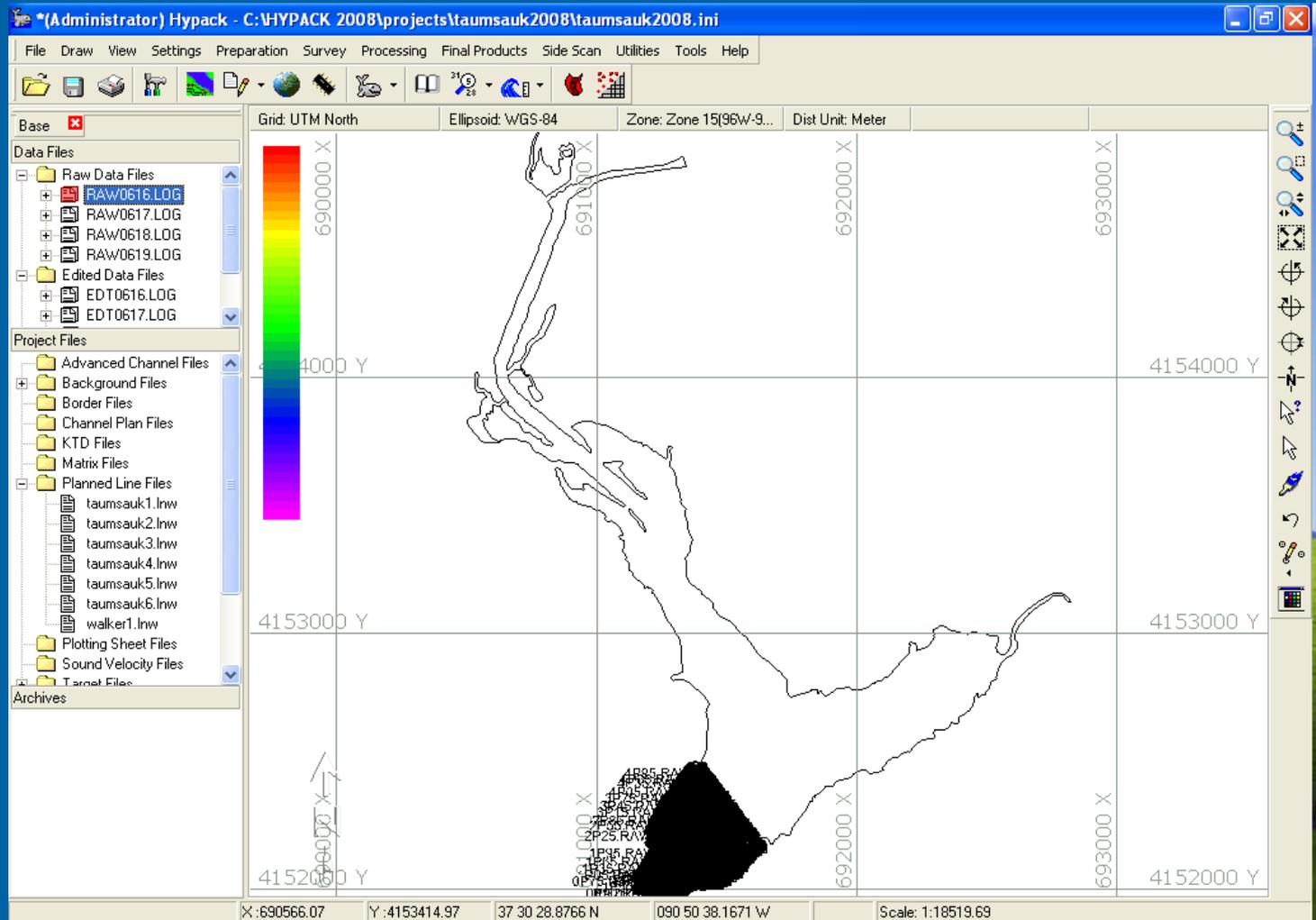
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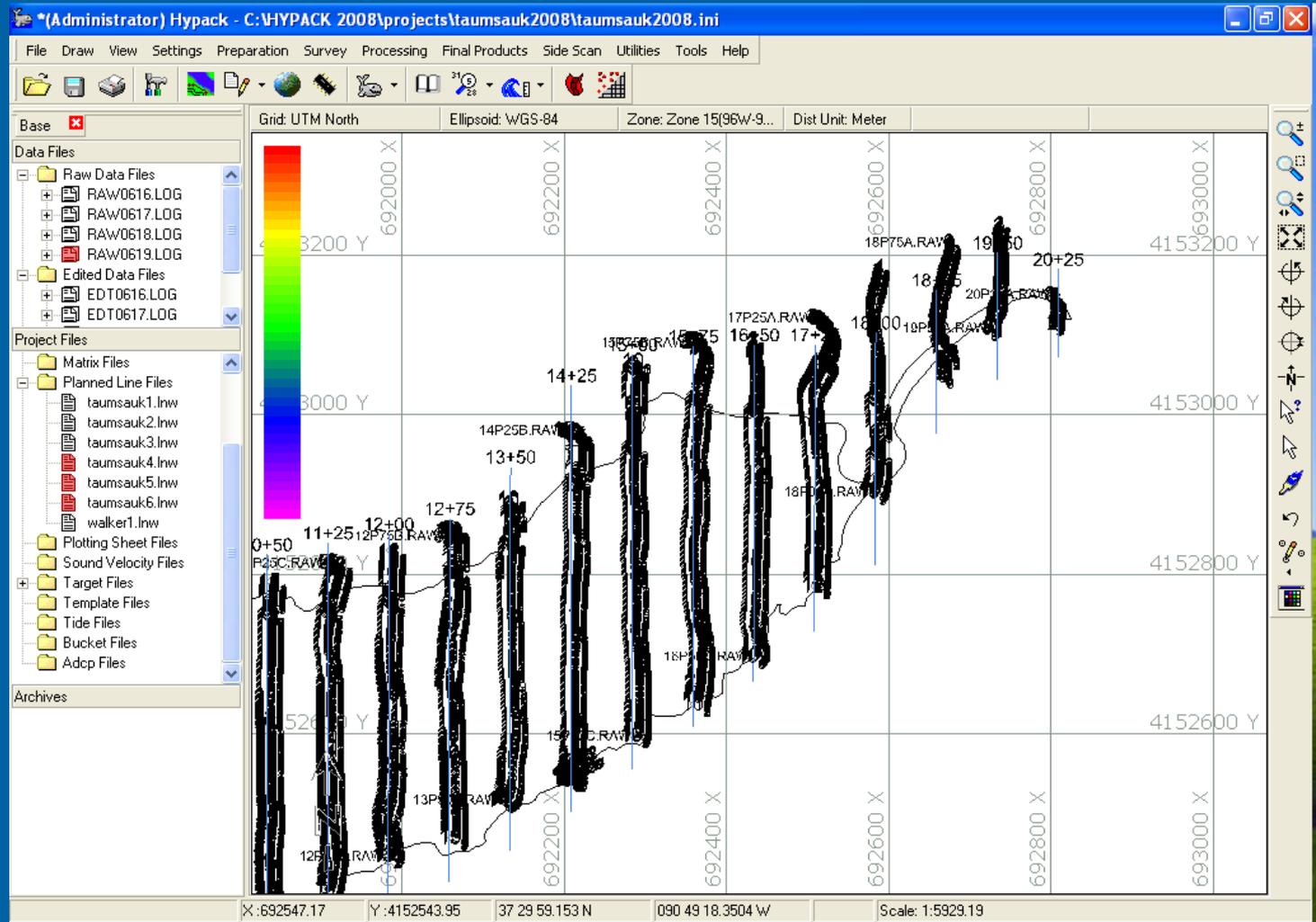
# Following Survey Plan Lines



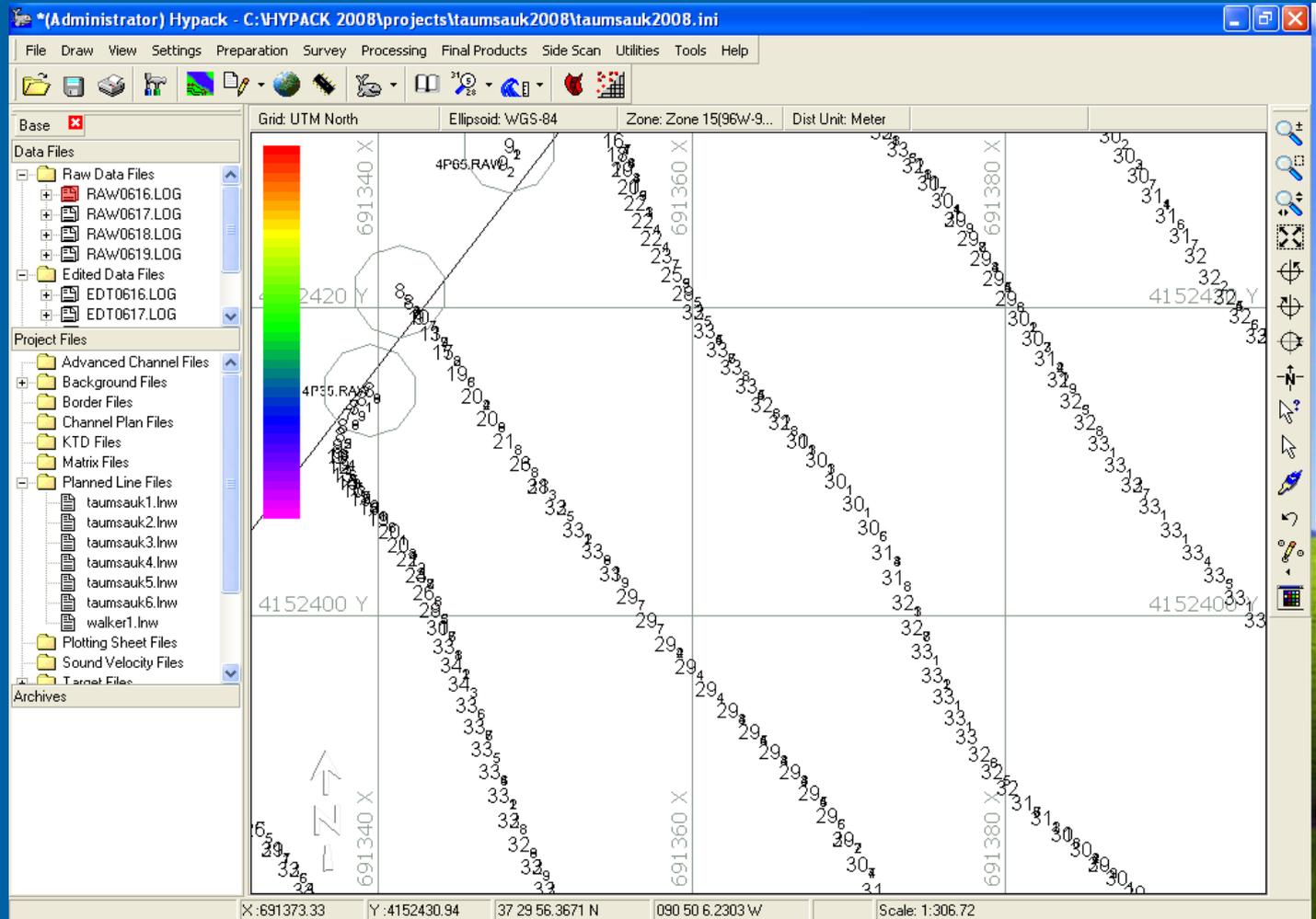
# Survey Plan lines in HYPACK



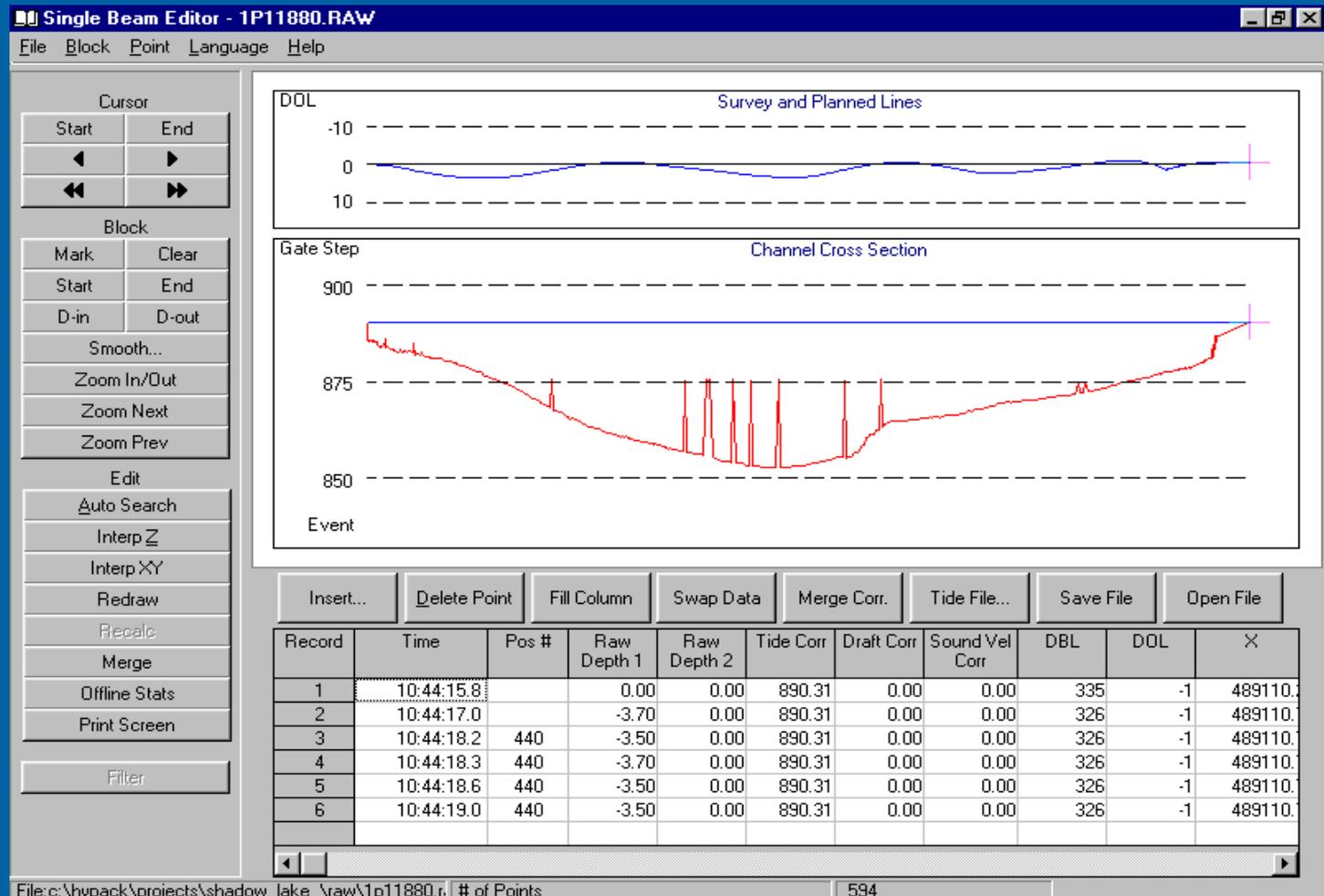
# Survey Plan lines in HYPACK



# Survey Plan lines in HYPACK



# Survey Plan Lines (cross-section view)



# Editing cross-section

**Single Beam Editor - 1P11880.RAW**

File Block Point Language Help

Cursor  
Start End  
◀ ▶  
◀▶ ▶◀

Block  
Mark Clear  
Start End  
D-in D-out  
Smooth...  
Zoom In/Out  
Zoom Next  
Zoom Prev

Edit  
Auto Search  
Interp Z  
Interp XY  
Redraw  
Recalc  
Merge  
Offline Stats  
Print Screen  
Filter

DOL  
Survey and Planned Lines  
-10  
0  
10

Gate Step  
Channel Cross Section  
900  
875  
850  
Event

Insert... Delete Point Fill Column Swap Data Merge Corr. Tide File... Save File Open File

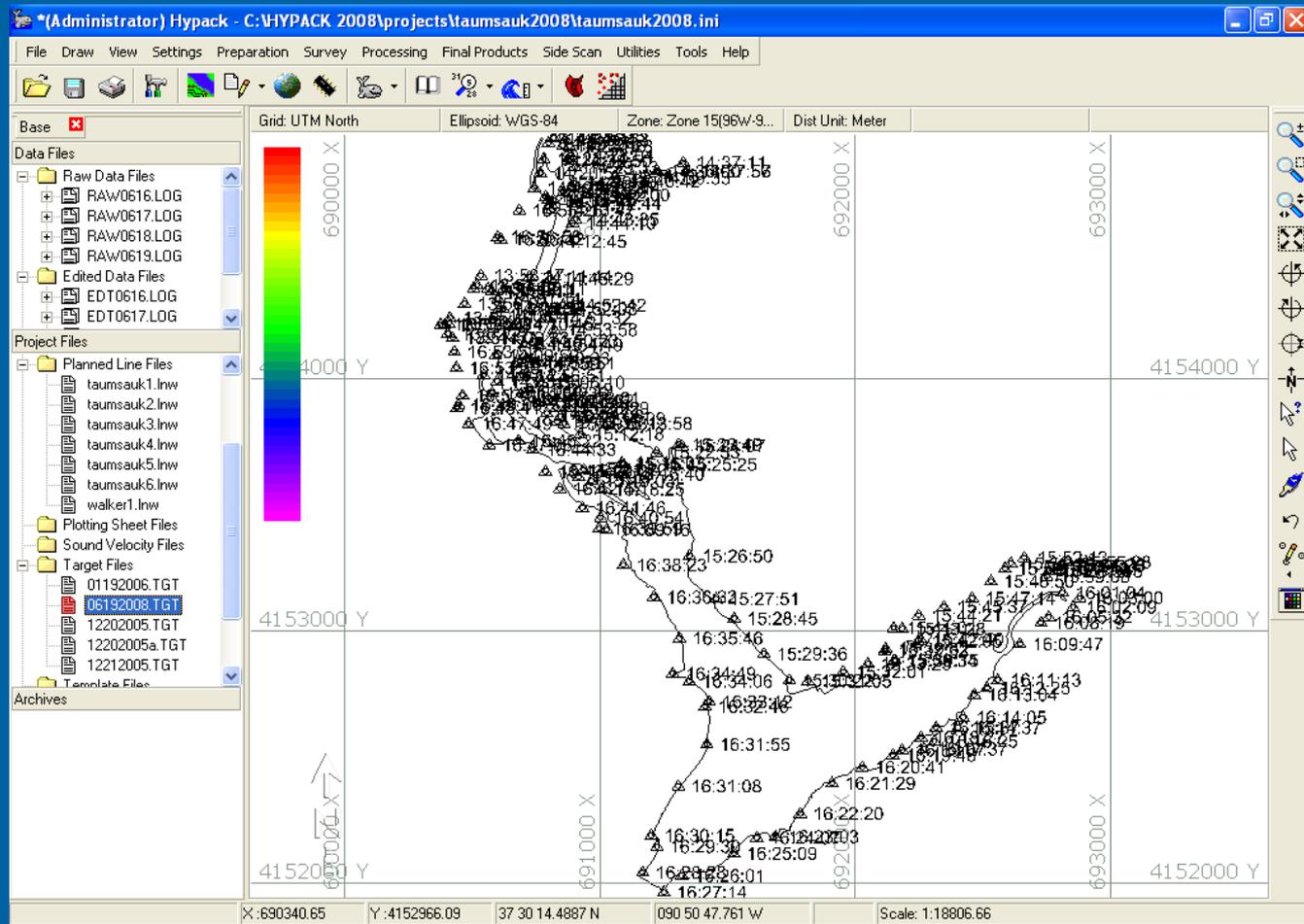
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530	10:47:24.4	441	-6.30	0.00	890.31	0.00	0.00	107	0	489124.2
531	10:47:24.7	441	-6.40	0.00	890.31	0.00	0.00	107	0	489124.2
532	10:47:24.9	441	-6.15	0.00	890.31	0.00	0.00	107	0	489124.2
533	10:47:25.4	441	-5.90	0.00	890.31	0.00	0.00	106	0	489124.2
534	10:47:25.7	441	-6.00	0.00	890.31	0.00	0.00	106	0	489124.2
535	10:47:26.0	441	-6.40	0.00	890.31	0.00	0.00	105	0	489124.2
536	10:47:26.4	441	-6.00	0.00	890.31	0.00	0.00	105	0	489124.2

File:c:\hypack\projects\shadow lake \raw\1p11880.r | # of Points 563

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# Water Surface edge points



# Target Points



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# GPS DATA

- Water surface elevations
- Spillway elevations (Primary and Emergency)
- Top of dam
- Bridge/Culvert details
- Land surface elevations

## Spillway elevations



## Dam elevations



## Water surface elevations



# Field Notes

Tide gauges for end of Cove

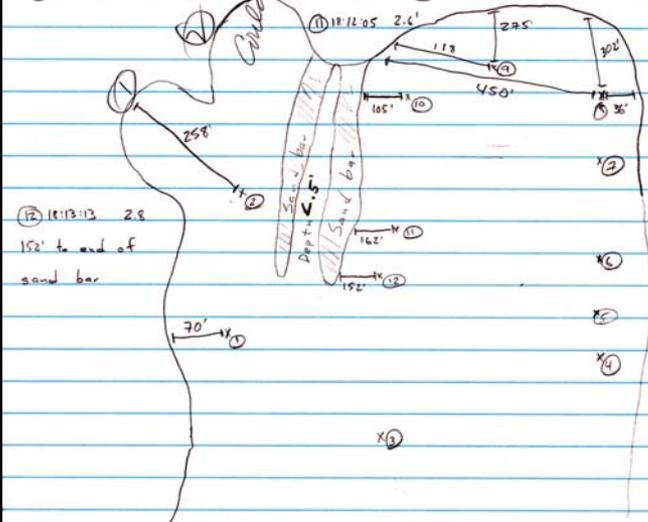
Time	Depth
16:45:00	4.0
16:45:30	3.2
16:46:02	2.9
16:46:25	2.0
16:50:00	1.8
16:47:17	2.1
16:18:11	3.9
16:51:12	2.0
16:51:38	3.1
16:51:59	3.4

17:13:29 2.6



Target Depth

①	17:38:26	1.5'	⑥	18:02:06	2.0'
②	17:42:42	1.4'	⑦	18:03:40	1.7'
③	17:50:04	4.6'	⑧	18:04:50	1.6'
④	17:56:01	2.0'	⑨	18:07:51	2.0'
⑤	18:00:33	2.6'	⑩	18:10:28	2.8'



⑫ 18:13:13 2.8  
152' to end of sand bar

@ 1820 td from RP = 0.93  
Calm water

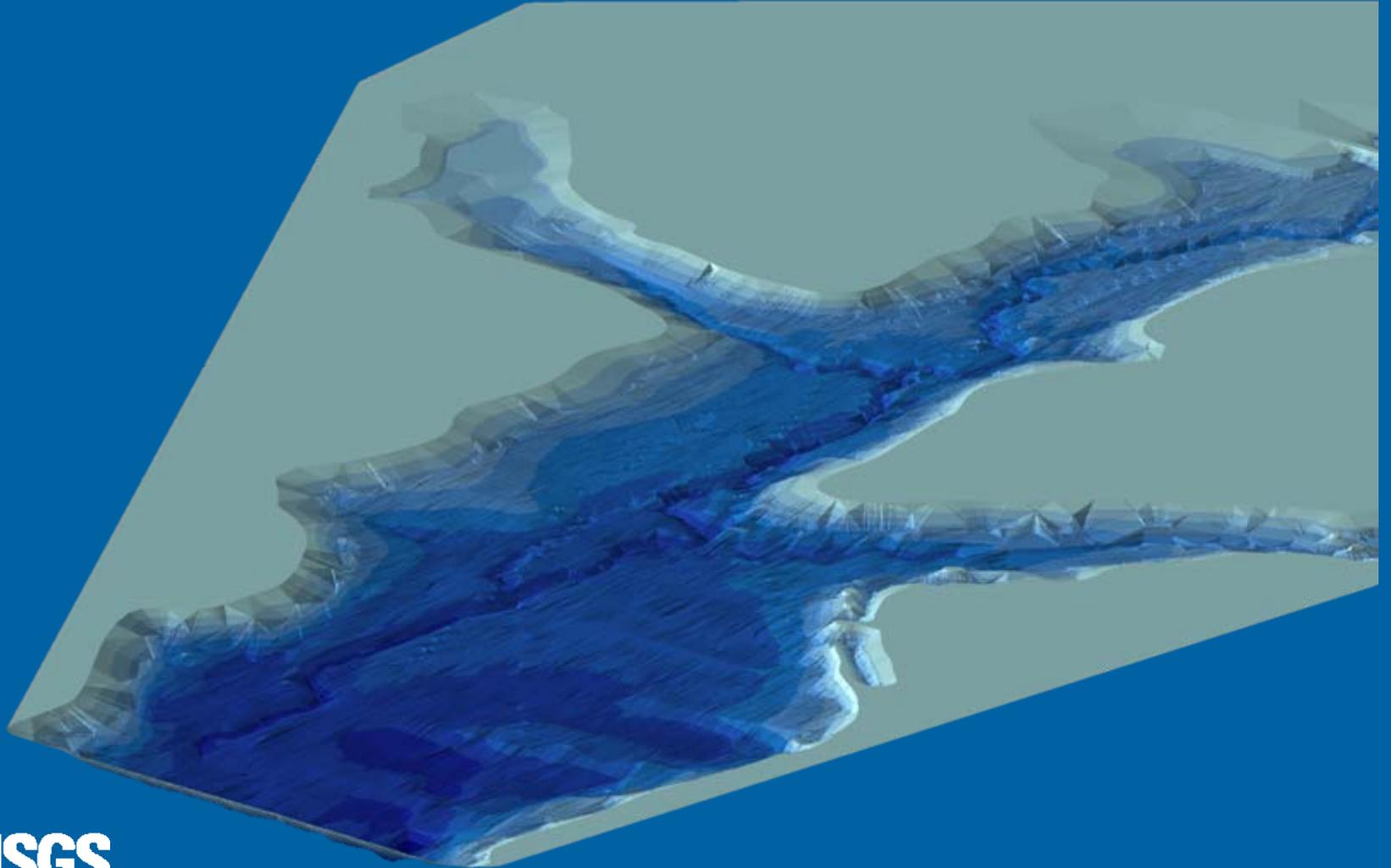
# Photographs



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# Bathymetry Surface (TIN)



# Bathymetric map creation

- Post process echosounder data with bathymetric mapping software
- Convert raw data to common projection and vertical datum
- Generate point data from raw data files
- Enforce ridge, drain, and bluff linearity in data set
- Convert point data to Triangulated Irregular Network (TIN)
- Contour TIN
- Inspect contours for errors
- Investigate errors and remove erroneous point data
- Regenerate new TIN
- Contour new TIN
- Cartographically edit contours for map production

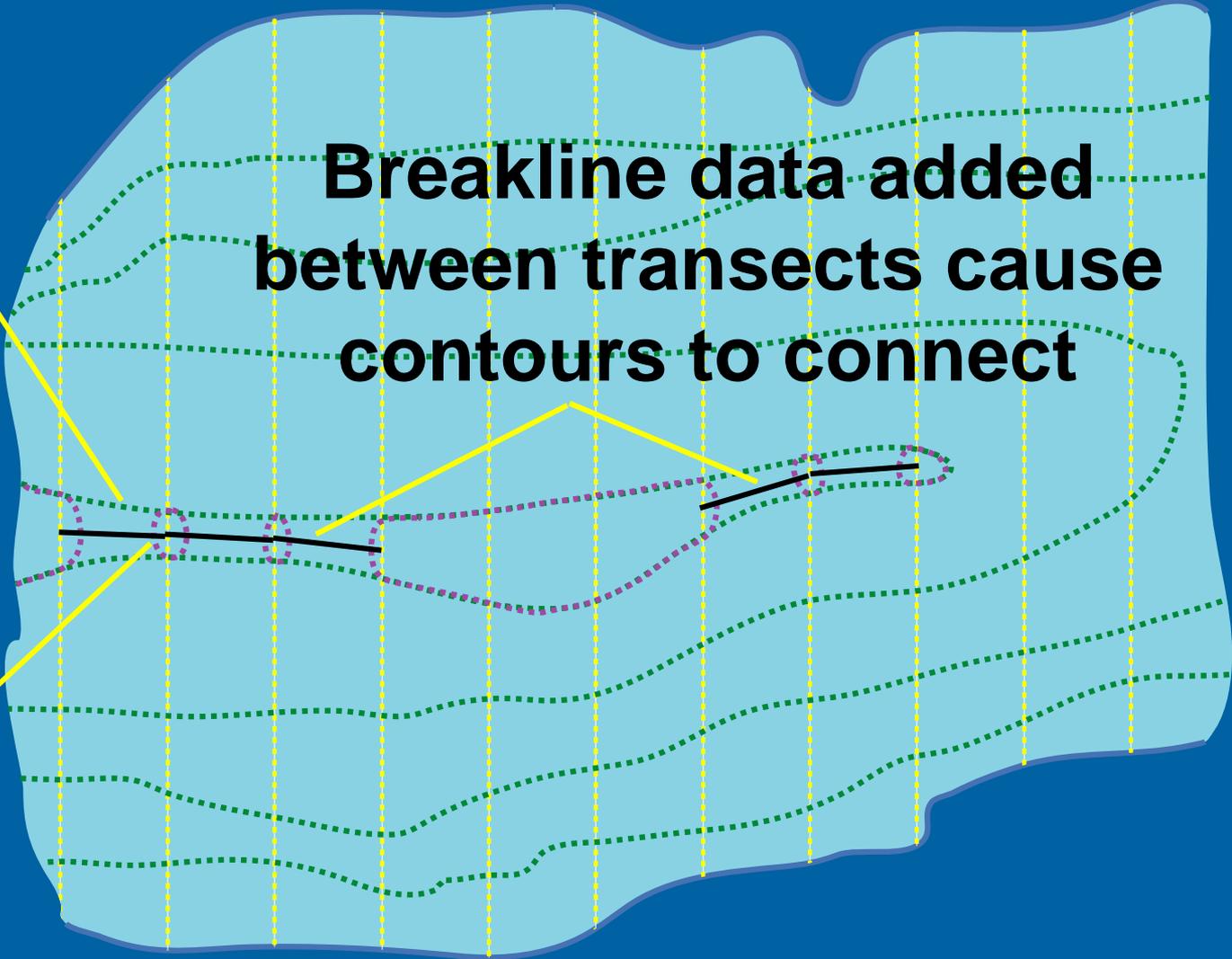
# Linear Enforcement

(drain or ridge)

“Correct”  
contour

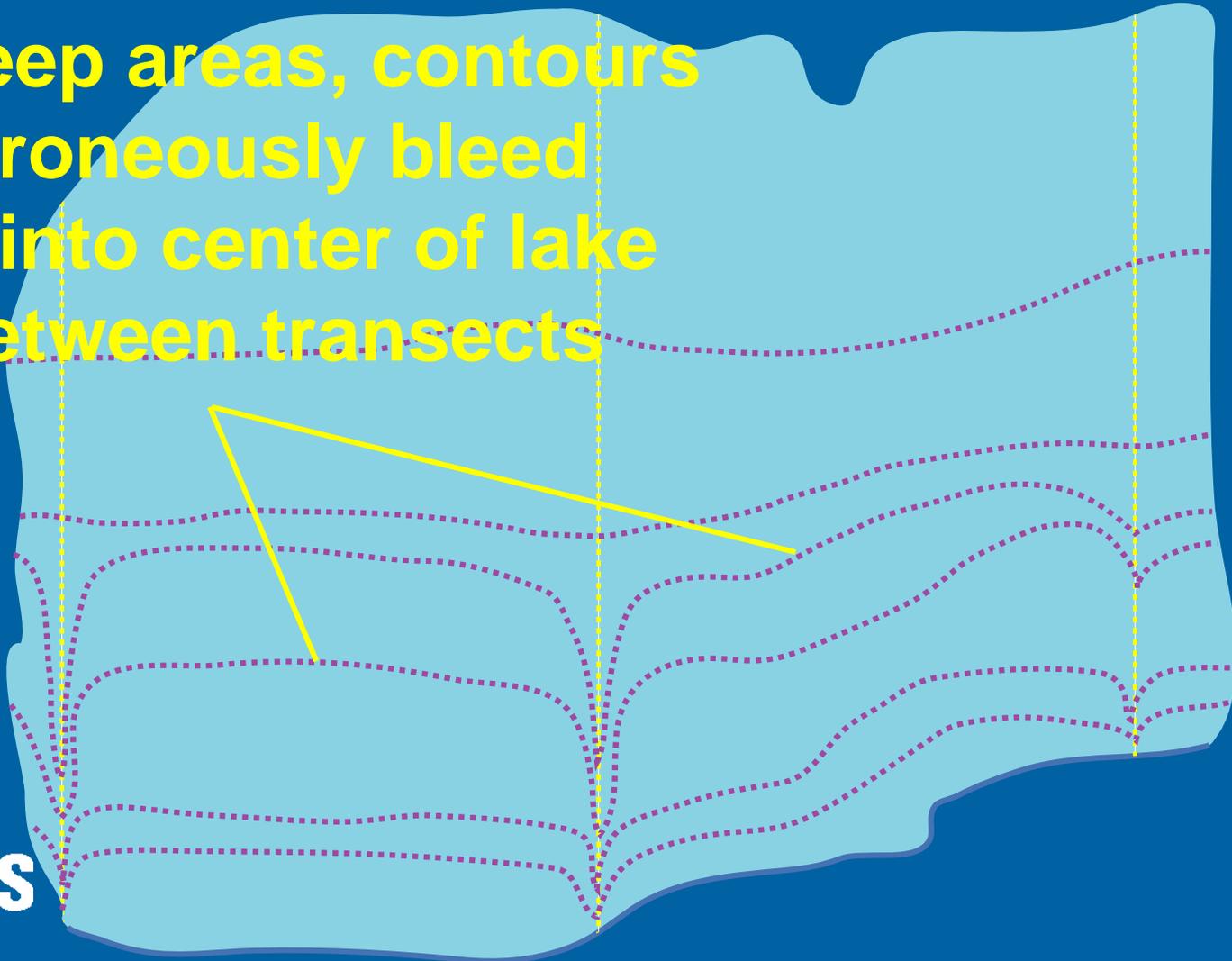
**Breakline data added  
between transects cause  
contours to connect**

Original  
contour



# Linear Enforcement (bluff)

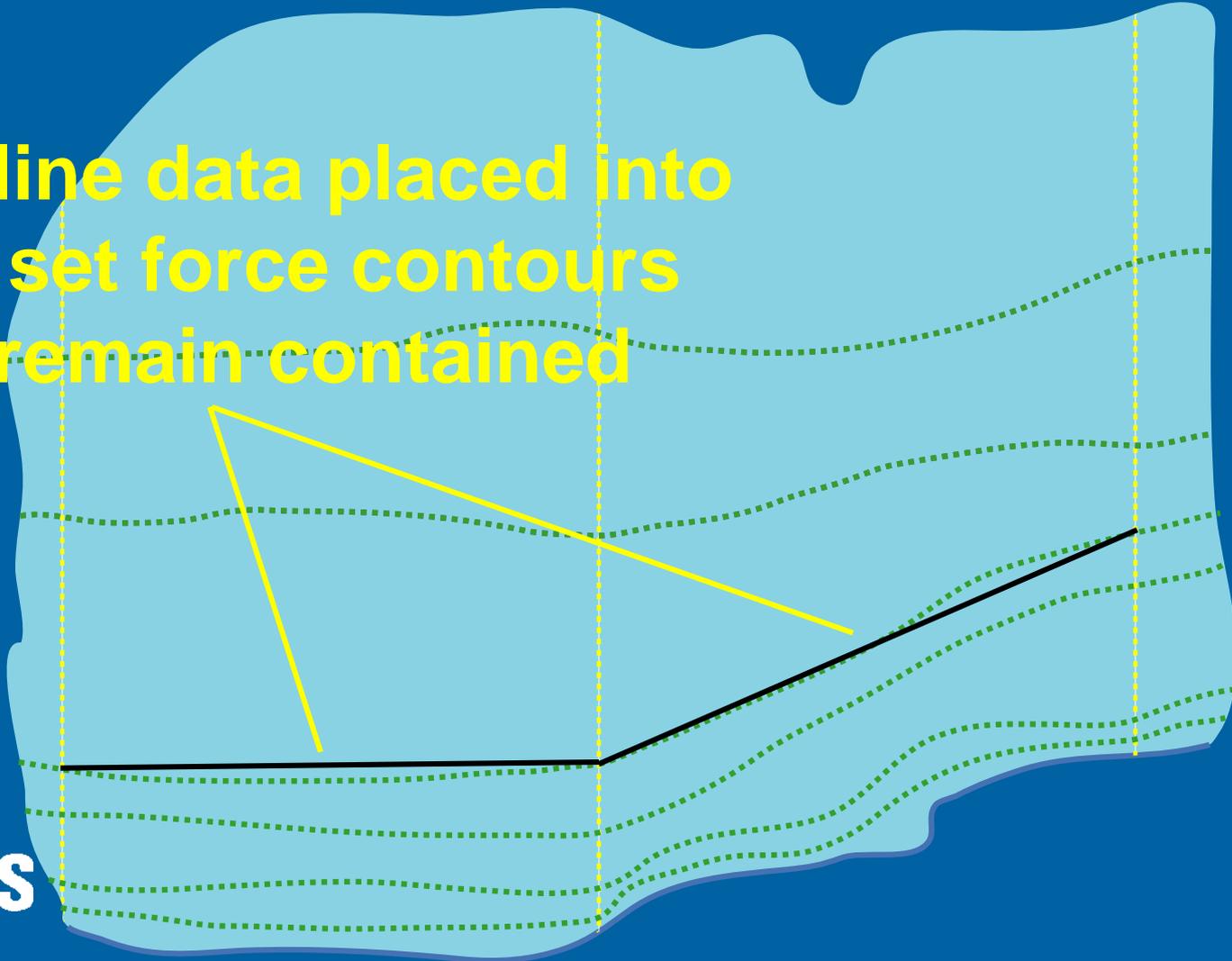
In steep areas, contours erroneously bleed out into center of lake between transects



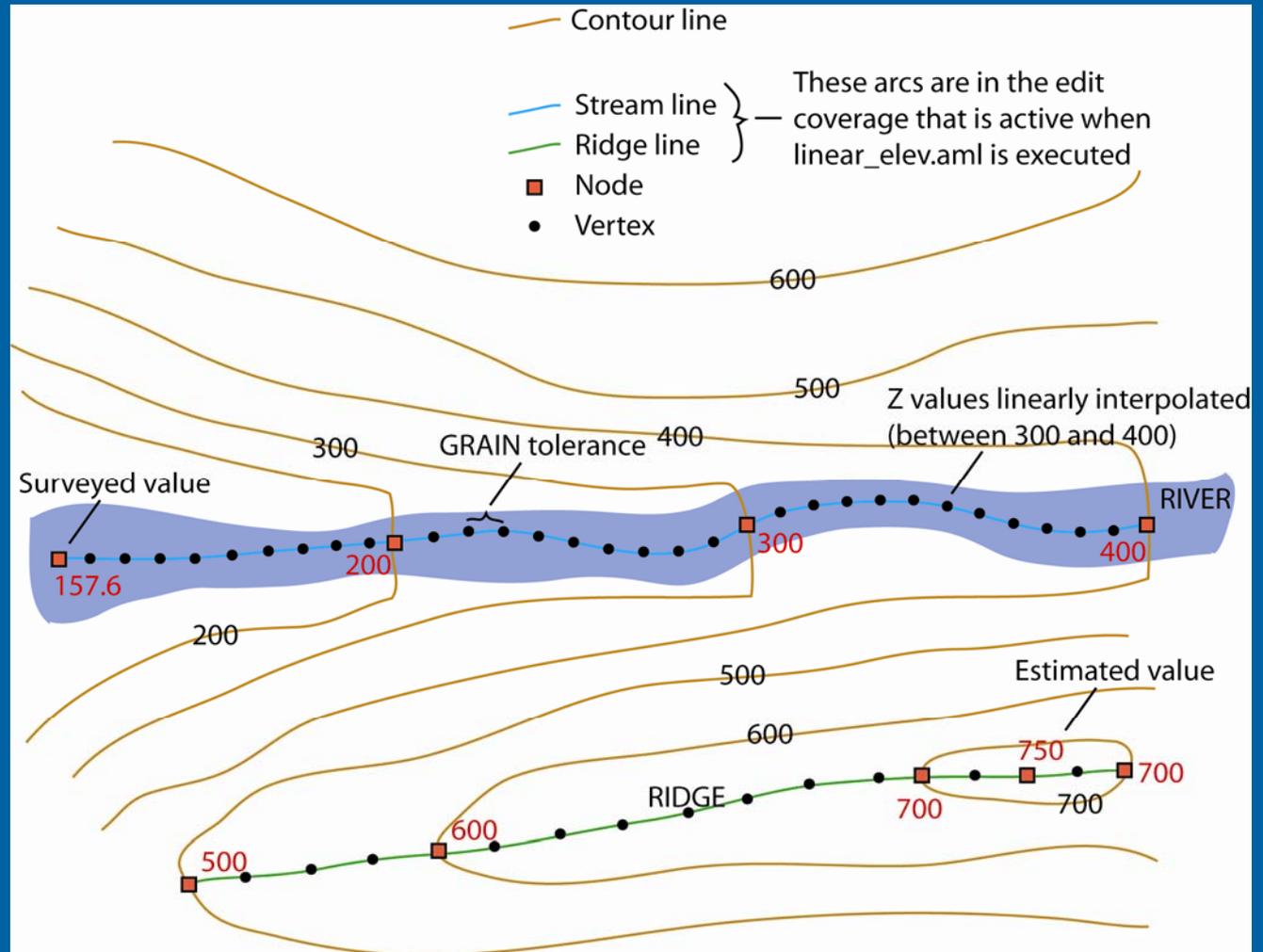
# Linear Enforcement

(bluff)

Breakline data placed into  
data set force contours  
to remain contained



# Usage of AML to create interpolated data



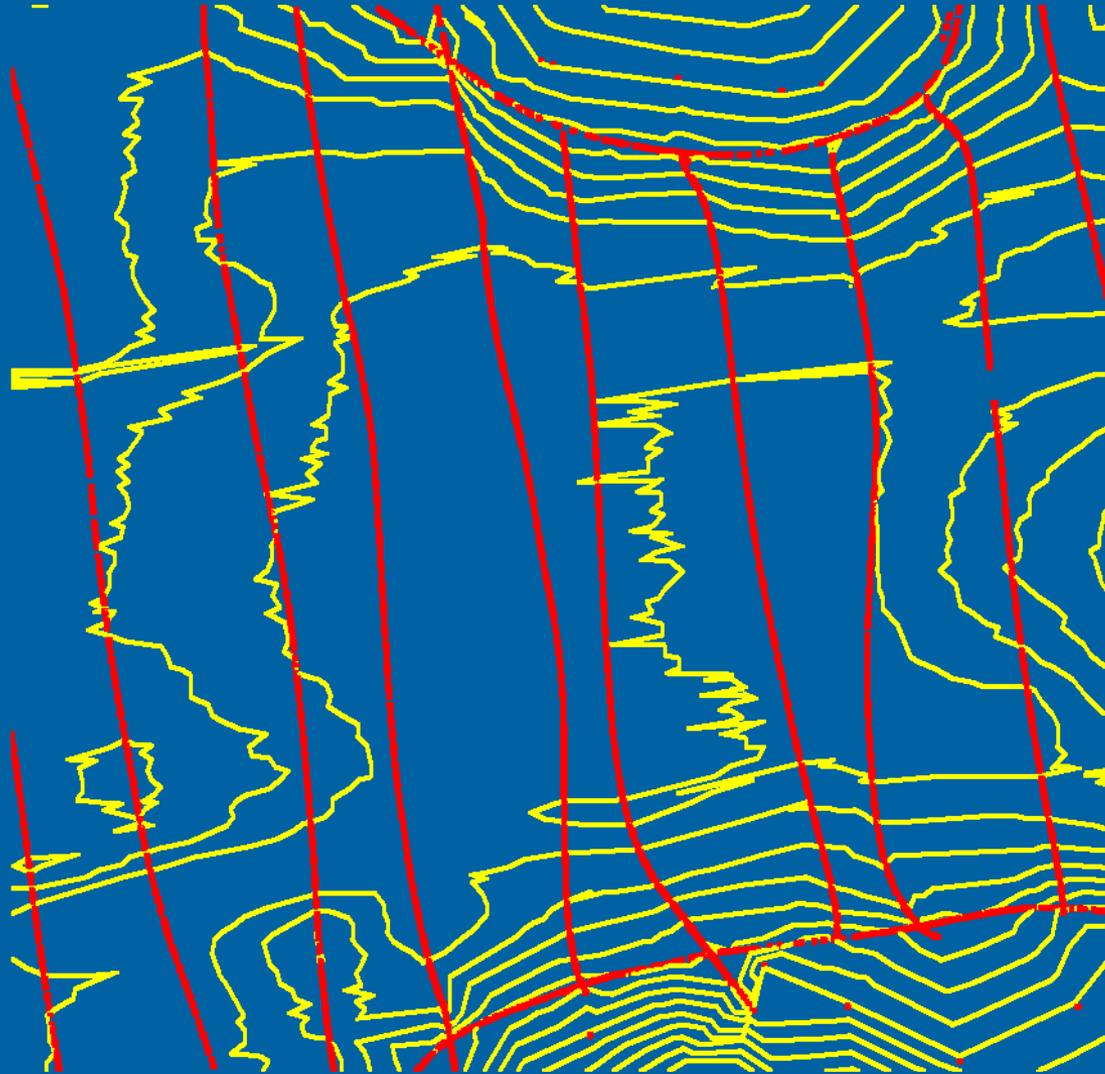
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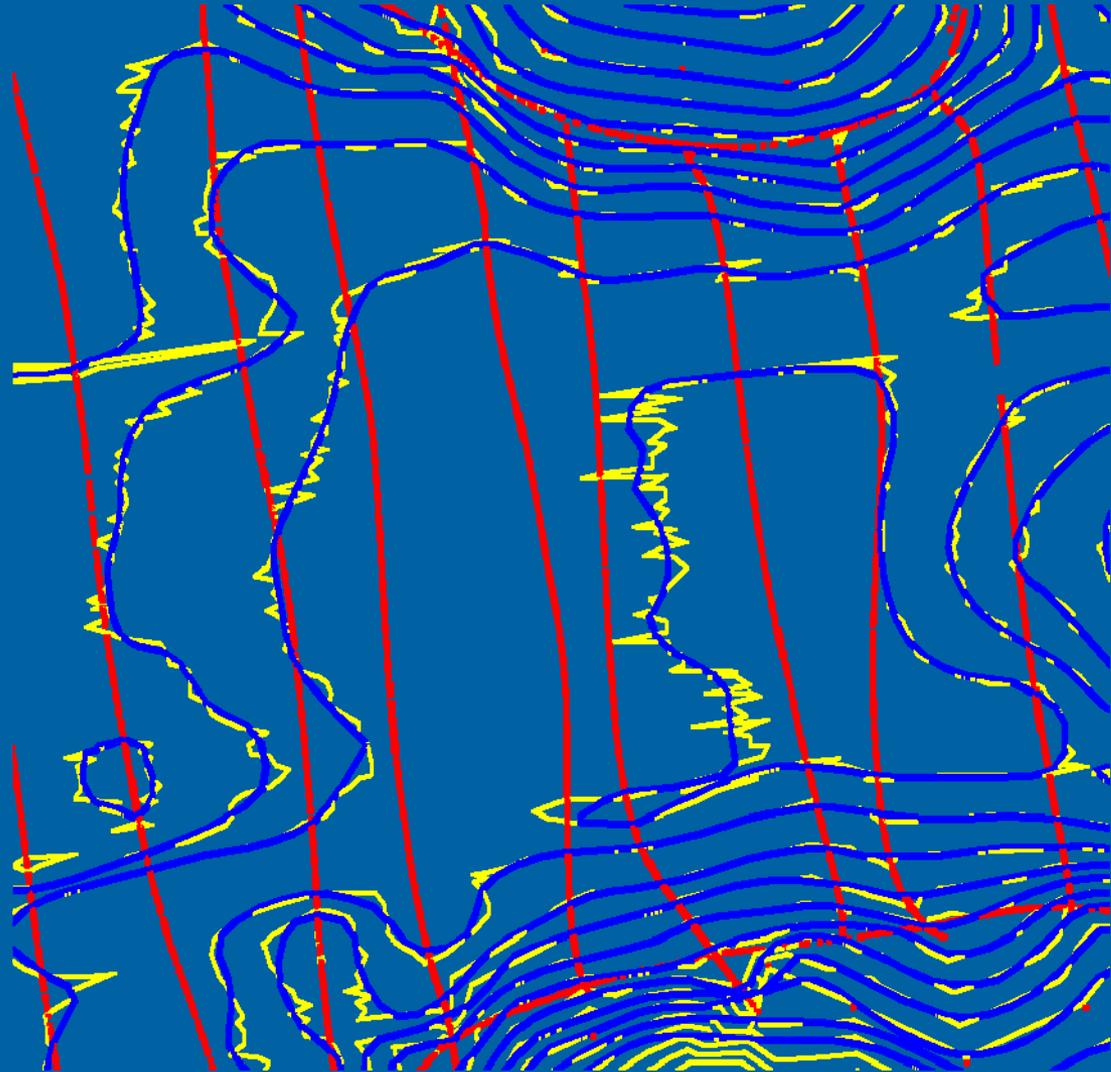
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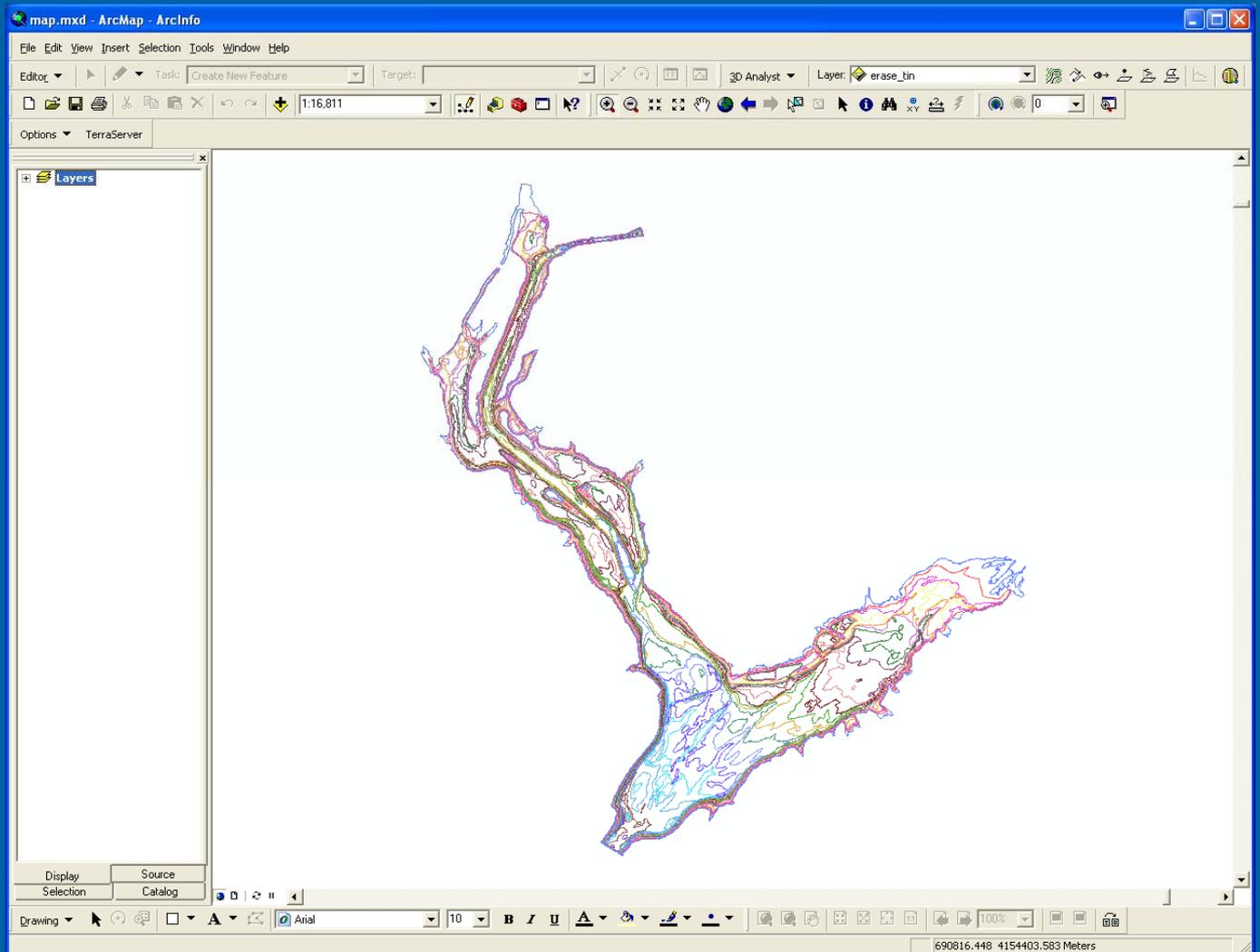
Initial output from surface can be “spiky”



**Contours need “smoothed” for final map product (can be time intensive)**



# Final contours



# Area/Capacity Table

Elevation (feet)	Area (acres)	Volume (acre-ft)
1256.0	0.1	0.0
1258.0	0.5	0.5
1260.0	1.3	2.3
1262.0	2.5	6.1
1264.0	3.9	12.5
1266.0	5.4	21.7
1268.0	6.8	34.0
1270.0	8.5	49.3
1272.0	10	68.2
1274.0	12	91.0
1276.0	15	119
1278.0	18	151
1280.0	21	189
1282.0	26	235
1284.0	29	291
1285.0	31	321

**Table 1.** Lake elevations and respective surface areas and volumes. Approximate elevation of spillway structure is 1285 feet. Elevations referenced to North American Vertical Datum 1988 (NAVD 88).

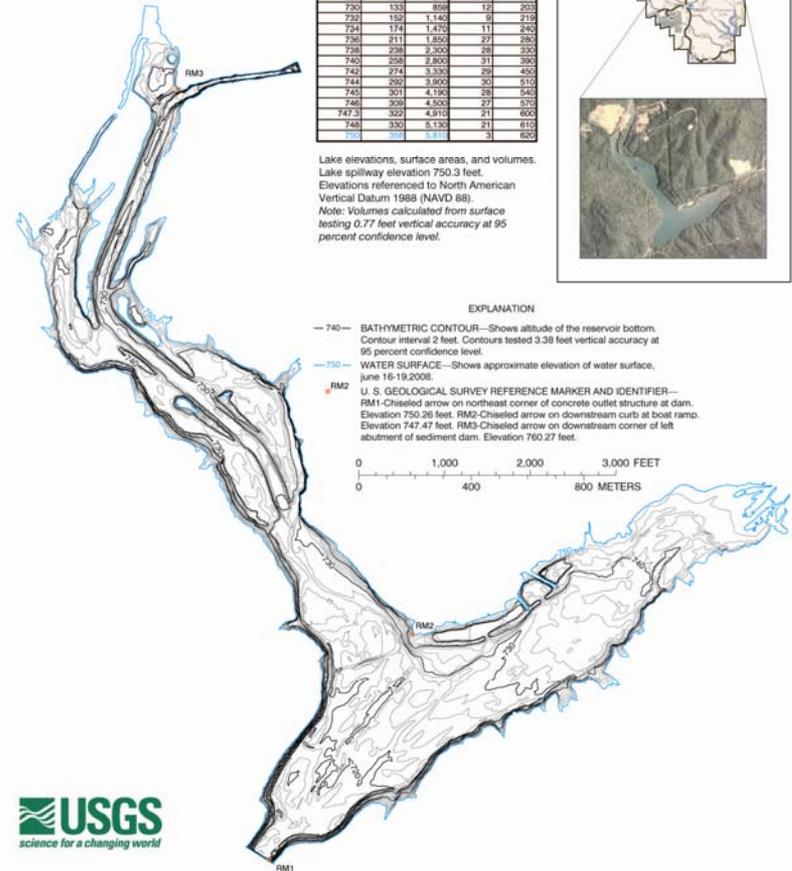
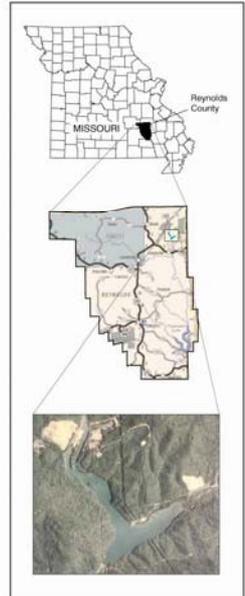
*Note: Volumes calculated from surface testing 1.17 feet vertical accuracy at 95 percent confidence level.*

# Final product (example from Missouri)

## LOWER TAUM SAUK RESERVOIR JUNE 16-19, 2008

Elevation (feet)	USGS 2008		DIFFERENCE 08-08	
	Area (acres)	Volume acre-ft	Area (acres)	Volume acre-ft
692	0	0	-0.13	-0.03
694	0	0	-0.14	-0.3
696	0.02	0.02	-0.13	-0.57
698	0.06	0.1	-0.1	-0.81
700	0.11	0.2	-0.07	-1.0
702	0.13	0.5	-0.06	-1.1
704	0.17	0.8	-0.03	-1.2
706	0.21	1.2	0	-1.3
708	0.25	1.6	0.02	-1.2
710	0.3	2.2	0.06	-1.1
712	0.34	2.8	0.06	-1.0
714	0.39	3.8	0.66	-0.5
716	4.44	7.3	4.15	-3.0
718	14.0	26.6	14.5	-23.3
720	28.7	69.5	28.3	-63.3
722	47.7	144	13.1	-102
724	68.3	203	9.9	-129
726	88.2	417	11.6	-130
728	111	615	14.9	-177
730	133	859	12	-203
732	152	1140	9	-219
734	174	1470	11	-240
736	211	1850	27	-262
738	238	2300	28	-330
740	258	2800	31	-390
742	274	3330	26	-450
744	290	3900	30	-510
745	301	4190	28	-540
746	309	4300	27	-570
747.3	323	4910	21	-600
748	330	5130	21	-615
750	35	0.31	-3	-620

Lake elevations, surface areas, and volumes.  
Lake spillway elevation 750.3 feet.  
Elevations referenced to North American  
Vertical Datum 1988 (NAVD 88).  
Note: Volumes calculated from surface  
testing 0.77 feet vertical accuracy at 95  
percent confidence level.



**EXPLANATION**

— 740 — BATHYMETRIC CONTOUR—Shows altitude of the reservoir bottom. Contour interval 2 feet. Contours tested 3.38 feet vertical accuracy at 95 percent confidence level.

— 750 — WATER SURFACE—Shows approximate elevation of water surface, June 16-19, 2008.

U. S. GEOLOGICAL SURVEY REFERENCE MARKER AND IDENTIFIER—  
RM1-Chiseled arrow on northeast corner of concrete outlet structure at dam. Elevation 750.26 feet. RM2-Chiseled arrow on downstream curb at boat ramp. Elevation 747.47 feet. RM3-Chiseled arrow on downstream corner of left abutment of sediment dam. Elevation 760.27 feet.



Bathymetric map for Lower Taum Sauk Reservoir near Lesterville, Missouri.

PROVISIONAL DATA SUBJECT TO REVISION - DO NOT QUOTE OR RELEASE



# Final product (example from Iowa)

## Abstract

The U.S. Geological Survey, in cooperation with the Iowa Department of Natural Resources, conducted bathymetric surveys on six lakes in Iowa during 2004: Lake Darling, Littlefield Lake, Lake Mononewah, Near Point Lake, Three Mile Lake, and Upper Otter Lake. The surveys were conducted to provide the Iowa Department of Natural Resources with information for the development of lake-level management plans, particularly for estimating sediment load and deposition rates. The bathymetric surveys provide a baseline for future work on sediment load and deposition rates for these lakes. Two of the lakes surveyed in 2004, Lake Mononewah and Upper Otter Lake, are natural lakes. The other four lakes are man-made lakes with fixed spillways.

Bathymetric data were collected using a boat-mounted, differential global positioning system, echo depth-sounding equipment, and computer software. Data were processed with commercial hydrographic software and exported into geographic information systems for mapping and calculating area and volume. Lake volume estimates range from 15,000,000 cubic feet (1.37 million acre-feet) at Lake Darling to 5,500,000 cubic feet (140 acre-feet) at Upper Otter Lake. Surface area estimates ranged from 124,000 square feet (2.8 acre) at Lake Darling to 1,377,000 square feet (31 acre) at Upper Otter Lake.

## Introduction

Bathymetric mapping can provide useful information for water-quality managers to address a variety of issues pertaining to lake-level and reservoir. The Iowa Water Science Center of the U.S. Geological Survey (USGS) has a lake bathymetric mapping program in Iowa since 2001 at Lake Dallas in east-central Iowa, which resulted in a published bathymetric map and report (Schroeder and others, 2003). The USGS, in cooperation with the Iowa Department of Natural Resources (IDNR), conducted a bathymetric survey of Lake Darling in 2004. The bathymetric survey was conducted to provide the IDNR with information for the development of lake-level management plans (LMPs), particularly for estimating sediment load and deposition rates. The bathymetric contours data can provide a baseline for future work on sediment load and deposition rates for Lake Darling.

Lake Darling was constructed in 1950 and is located in southeast Iowa, 10 miles west of Englewood in Washington County. Lake Darling is located at Lake Darling State Park and is used primarily for recreational activities. Lake Darling is fed by Dickey Creek from the north and southeast creeks from the northwest and southeast. Discharge from Lake Darling is over a fixed spillway at the southeast end of the lake into Dickey Creek.

## Methods

Bathymetric data were collected on April 14, 2004. Bathymetric mapping was accomplished using a boat-mounted differential global positioning system (DGPS), echo depth-sounding equipment, and computer software. The GPS allowed for accuracy of about 1.0 ft (0.3 m), approximately 1 meter (3 feet) in horizontal direction. The echo sounder emits pulses of sound that are reflected off the lake bottom and measured by a receiver. The echo-sounder transmits at a frequency of 200 kilohertz, and water depths were determined by the echo-sounder based on the speed of sound in water compensated for temperature (Specialty Devices, Inc., 2001). In some areas of the lake, the depth resolution was less than 2.0 ft (0.6 m) at target points using a measuring device marked by 10-ft increments. Using the echo-sounder, the bathymetric data were collected along parallel transect lines spaced 100 ft apart. Individual data collection locations along a transect line generally were 1 to 1.5 ft apart. The depth data were later converted to elevation in the post-processing software (Crescent Oceanographic, Inc., 2002) by subtracting the depth at each location from the reference surface elevation of the lake. The reference surface elevation was determined on the day of bathymetric data collection by measuring from a reference point of known elevation, in this case the high-water structure near the boat ramp. The elevation of the reference point was obtained from the Washington County Engineer's Office record (2004). The bathymetric data files were filtered (fig. 1) to reduce the density of data points and reduce raw geographic information system (GIS) software to produce a three-dimensional surface of the lake-bottom elevations. The three-dimensional surface was contoured, and the contours were adjusted manually to correct for temperature errors. Also, the Lake Darling metadata at <http://water.usgs.gov/lake/darling/> provide for a more detailed explanation of methods used to collect and process the bathymetric data.

## Quality Assurance

A bar check on the echo-sounder was performed at the beginning of the day of data collection following standard practices (U.S. Army Corps of Engineers, 1994). This was done to ensure that the echo-sounder was calibrated correctly. The bar check involved measuring a 2.0-meter (6.6-foot) aluminum plate directly below the echo-sounder. The comparison bar was marked in 0.5-foot increments. An additional calibration was made by entering the speed of sound in the water and then allowing the effect of the temperature on the computer software. The effect on the depth of the measurement below the lake surface. The adjustment plate was then lowered 0.5 ft increments, depending on the speed of depth-sounding, to be incremental, and adjustments to the speed of sound were made until depth readings and the depth of the aluminum plate agreed to within approximately 0.1 ft.

## Bathymetric Contours

The water surface elevation of Lake Darling was 636.1 ft above North American Vertical Datum of 1985 (NAVD83) on April 14, 2004. In general, the depth of water in the lake increases toward the dam (fig. 2). The deepest part of the lake is in the center of the channel at the upper end of the lake, and the lowest elevation measured was 640.3 ft (15.8 ft deep). The average elevation of the lake bottom, based on the three-dimensional surface, is 648.2 ft (17.9 ft deep). The slope of the lake bottom is greatest in the area near the dam and along the western boundary of the upper portion of the lake. The slope of the lake bottom is more gradual along the southern area of the lake. Data from this survey indicate that the surface area of Lake Darling, at a water surface elevation of 636.1 ft, is approximately 10,424,000 square feet (240 acres), and the water volume of Lake Darling is approximately 10,424,000 cubic feet (1.37 million acre-feet).

## References

- Crescent Oceanographic, Inc., 2002. HYPACK MAX, hydrographic survey software user's manual. Middletown, CT, Crescent Oceanographic, Inc. (available paper).
- Schroeder, D.J., Alvey, J.C., Berman, K.R., and Berber, K.D., 2003. Bathymetric mapping, sediment quality, and water quality of Lake Dallas, Iowa, 2001-02. U.S. Geological Survey Water-Resources Investigations Report 03-408, 38 p.
- Specialty Devices, Inc., 2001. Bathymetric survey system HD-15 with constant mounted Puck, T.S. Specialty Devices, Inc., 30 p.
- U.S. Army Corps of Engineers, 1994. Engineering and Design—Hydrographic surveying EM 1110-2-2.003. Washington, D.C., Department of the Army, 342 p., but as it is accessed on January 2004 at <http://www.usace.army.mil/publications/emg-manuals/EM1110-2-2.003-1.pdf>.

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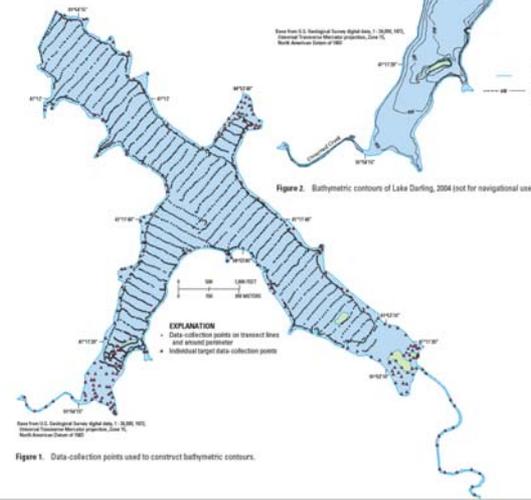


Figure 1. Bathymetric contours of Lake Darling, 2004 for navigational uses.

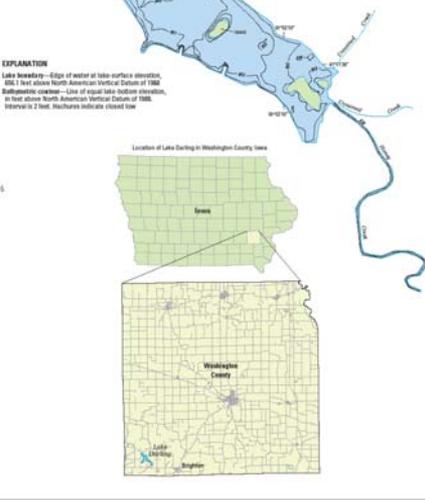


Figure 2. Bathymetric contours of Lake Darling, 2004 for navigational uses.

Figure 1. Data collection points used to construct bathymetric contours.

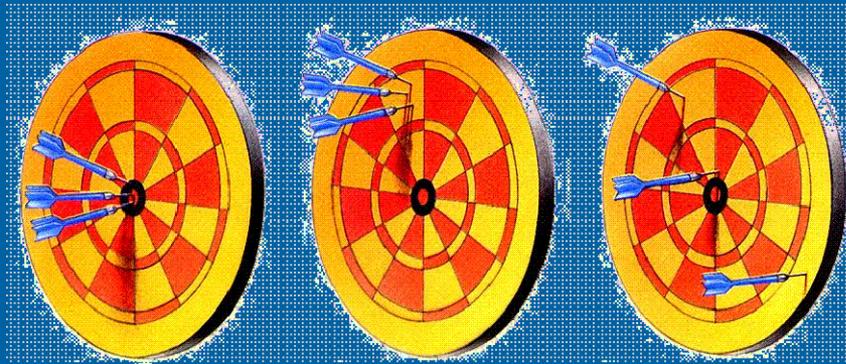


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  - Field Preparation
  - Transects/Obliques
  - Target Points
  - Miscellaneous
- **Data Processing**
  - Surface creation
  - Map and Area/Capacity Table
  - **Accuracy Assessment**

# Accuracy Assessment

- **Echosounder**
- **Area/capacity Tables**
- **Bathymetric Maps**

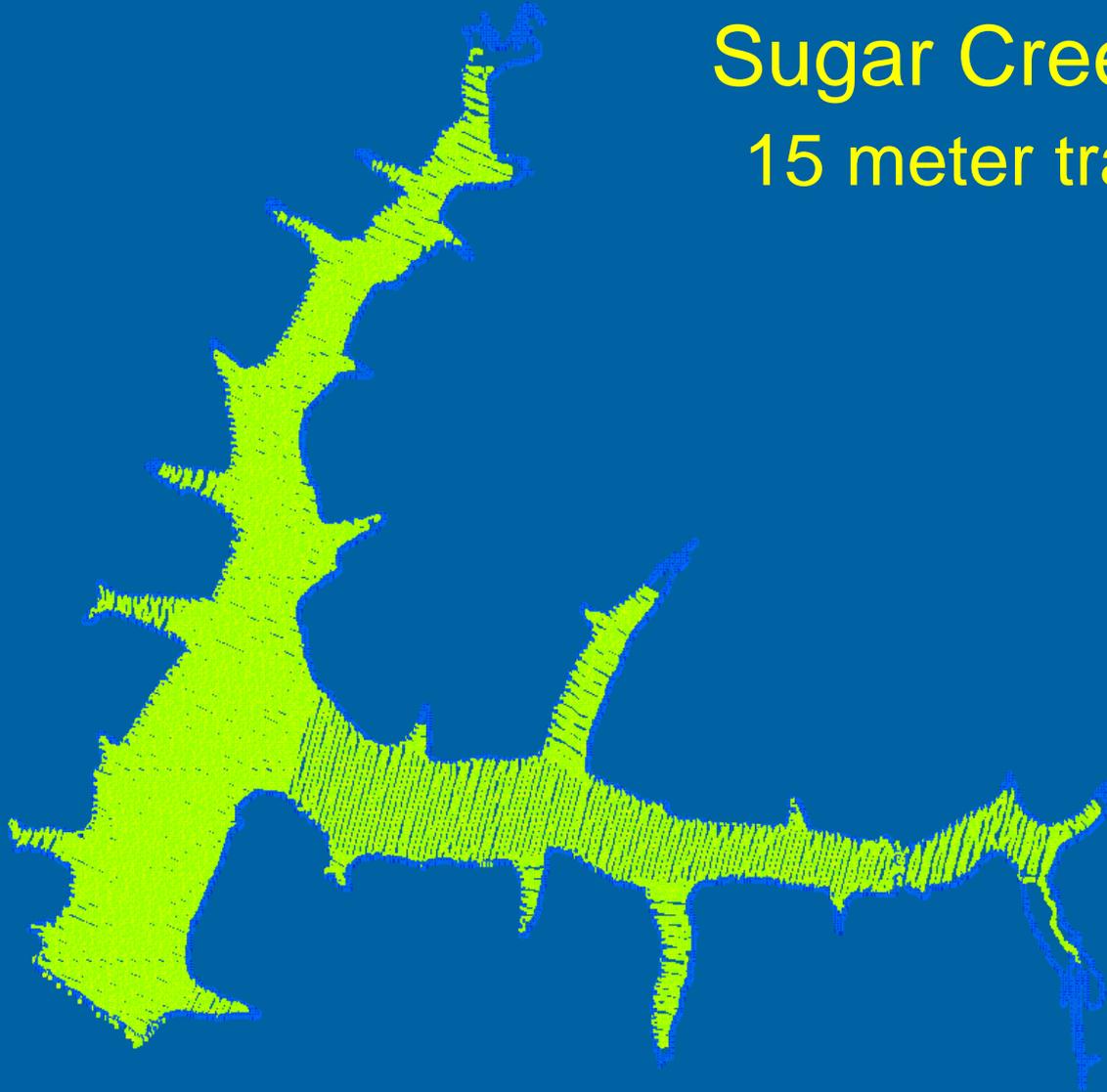


# Data Collection for Accuracy Assessment

- **Sugar Creek Lake (~330 acres)**
- **Collected 15 meter transect spacing**
  - **Created area/capacity tables and maps for 15, 30, 60, 120, and 240 meter transect spacing**
- **Collected 150 meter oblique transects for checking accuracy of TINs and maps**
- **Collected echosounder and hand measurements of depth**

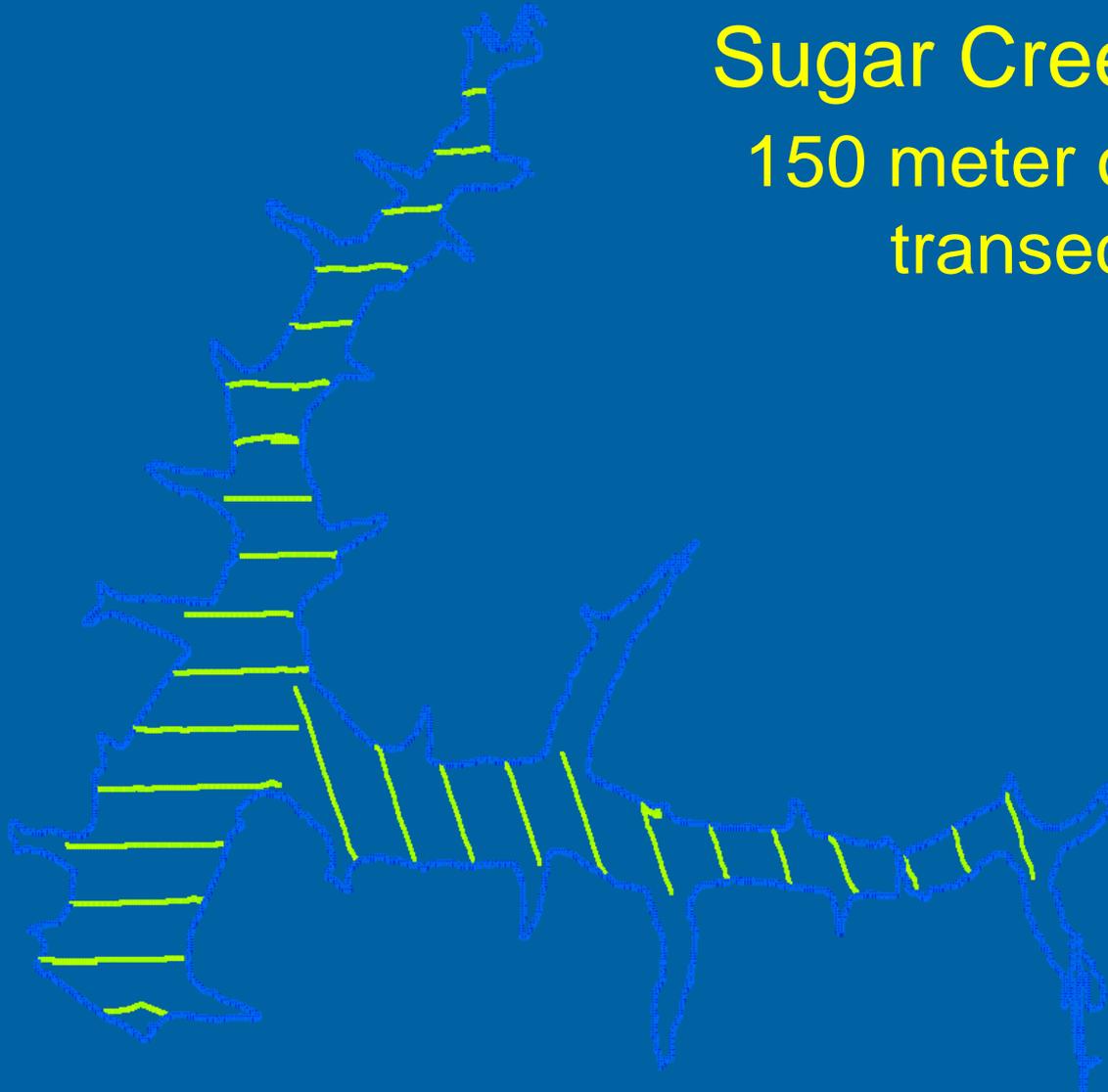
# Sugar Creek Lake

## 15 meter transects



# Sugar Creek Lake

150 meter oblique  
transects



Echosounder Repeatability  
Evaluation Point

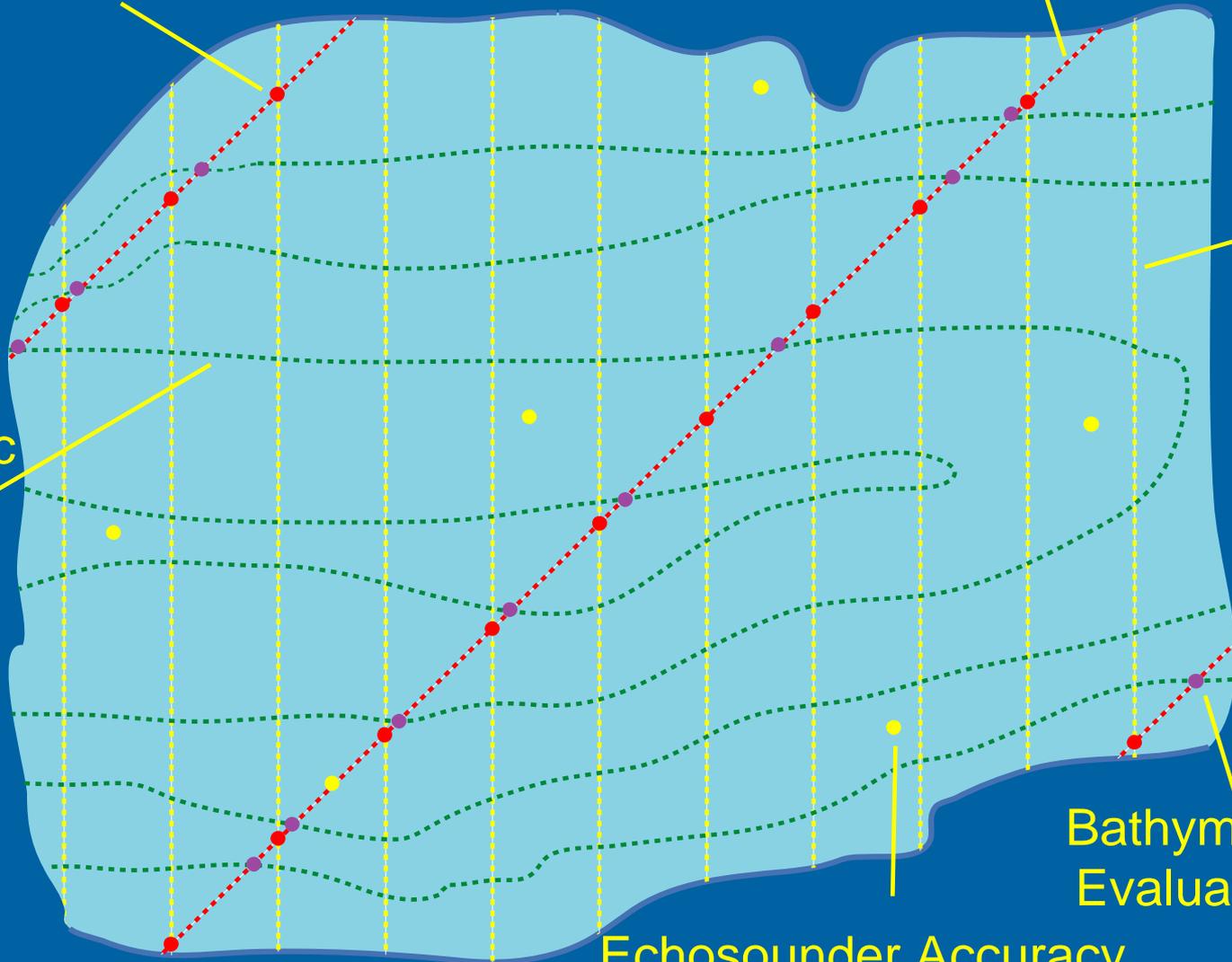
Oblique Transect

Survey  
Transect

Bathymetric  
Contour

Bathymetric Map  
Evaluation Point

Echosounder Accuracy  
Evaluation Point



# Echosounder Repeatability

- Evaluated the error where 15m transects intersected the oblique transects (points coincident within 0.1 meter)
- 105 points met the 0.1 meter requirement
- Minimum = -1.1 ft, Maximum = 1.0 ft, Median = -0.08, Mean = -0.06
- Vertical RMSE = 0.34 ft
- Vertical Accuracy (95% conf.) = 0.67 ft

# Factors Effecting Horizontal Accuracy

- **Global Positioning System (GPS) accuracy during echosounder data collection**
- **Accuracy of tie-in to National Spatial Reference System (horizontal control points)**
- **Vessel velocity (latency time)**
- **Vessel draft/index errors**

# Factors Effecting Vertical Accuracy

- **Type and quality of the depth measurement system**
- **Accuracy of tie-in to National Spatial Reference System (vertical control points)**
- **Vessel velocity, draft, and index errors**
- **Subsurface material density**
- **System calibration**

# Vertical Accuracy Standards

- **National Map Accuracy Standard (NMAS)**
  - Not more than 10% of the elevations tested shall be in error no more than one-half the contour interval
- **National Standard for Spatial Data Accuracy (NSSDA)**
  - Vertical component is a linear uncertainty value such that the true location of the point falls within +/- of that linear uncertainty value 95% of the time

# NSSDA Vertical Accuracy

- Computed as a root mean square error (RMSE) from independent data set

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- 
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- 
- 
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$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^n (z_{\text{data},i} - z_{\text{check},i})^2}{n}}$$

- Accuracy (95% conf.) = 1.960 \* RMSE

# Comparison of NMAS/NSSDA Vertical Accuracy

<b>NMAS Contour Interval</b>	<b>NMAS 90% conf.</b>	<b>NSSDA 95% conf. level</b>
<b>1 ft</b>	<b>0.5 ft</b>	<b>0.60 ft</b>
<b>2 ft</b>	<b>1 ft</b>	<b>1.19 ft</b>
<b>4 ft</b>	<b>2 ft</b>	<b>2.38 ft</b>
<b>5 ft</b>	<b>2.5 ft</b>	<b>2.98 ft</b>
<b>10 ft</b>	<b>5 ft</b>	<b>5.96 ft</b>
<b>20 ft</b>	<b>10 ft</b>	<b>11.92 ft</b>

# Vertical Accuracy of TINs for Sugar Creek Lake

Transect Interval	Accuracy 95% conf.	
	NO Linear enforcement	Linear enforcement
15 m	0.91 ft	0.91 ft
30 m	1.54 ft	1.46 ft
60 m	3.72 ft	2.83 ft
120 m	7.30 ft	3.95 ft
240 m	15.55 ft	5.83 ft



Based on 21,647 check points

# Vertical Accuracy of Bathymetric Maps for Sugar Creek Lake

Transect Interval	Accuracy (95% conf.)	Number of check points
15 m	1.51 ft	363
30 m	2.76 ft	387
60 m	4.54 ft	335
120 m	6.33 ft	325
240 m	7.30 ft	337

# Accuracy Assessment - Conclusions

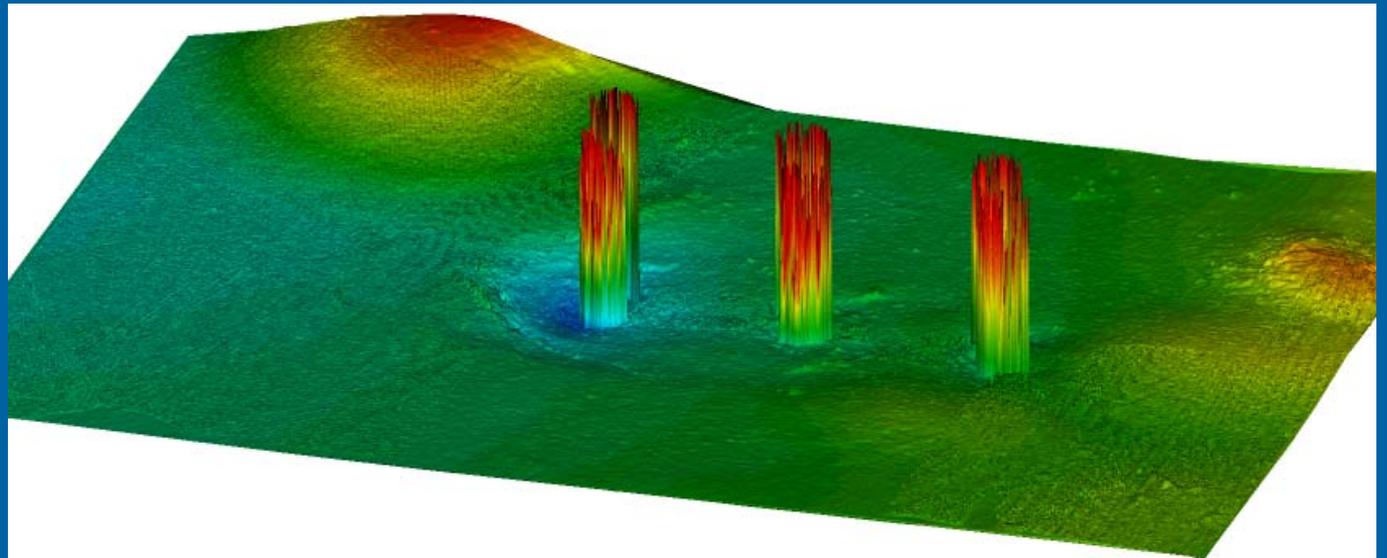
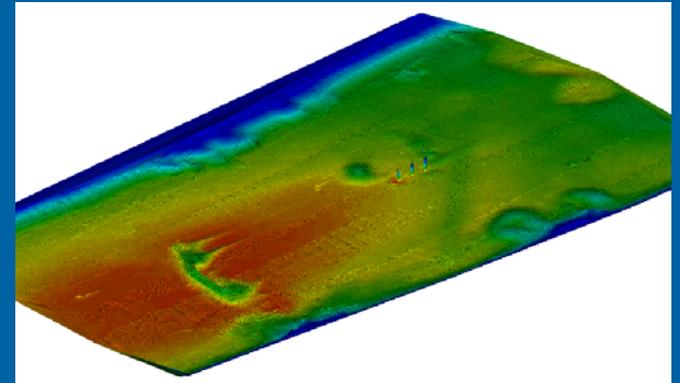
- **Vertical accuracy of area/capacity table better than the bathymetric map**
- **Adding breakline data to survey data improves accuracy of area/capacity tables and bathymetric maps**
- **To evaluate the accuracy of the surveyed data, independent survey data must be collected**

# Accuracy Assessment - Conclusions

- Large transect spacing causes loss of detail in the bathymetric maps
- Transect spacing of 1% of longitudinal length of length produces good results
- Regardless of transect spacing, a 1-foot interval area/capacity table or bathymetric map is unattainable because echosounder repeatability accuracy greater than 0.61 ft
- For Sugar Creek Lake data (15m), the best possible bathymetric contour map interval would be 3 ft

# New Technology: Multi-beam echosounders

- Complete bottom coverage
- Expensive
- Steep learning curve
- Depth limitations



# Questions?

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- <http://pubs.usgs.gov/sir/2006/5208/>



## Procedural Documentation and Accuracy Assessment of Bathymetric Maps and Area/Capacity Tables for Small Reservoirs



Scientific Investigations Report 2006–5208

U.S. Department of the Interior  
U.S. Geological Survey

