NOAA COASTAL MAPPING PROGRAM
PROJECT COMPLETION REPORT

PROJECT WI0401

Sheboygan, Wisconsin

Introduction

This project was undertaken to test the image quality of the Z/I Imaging Digital Mapping Camera (DMC), its applicability for shoreline mapping, and to measure the accuracy of the digital land-water interface produced from its imagery. This project was located along 10 miles of the western shore of Lake Michigan from Foster Road in the Township of Holland, near Oostburg, Wisconsin at the south to Vollrath Park in the City of Sheboygan, Wisconsin at the north.

The project limits for WI0401 are approximately:

43º46’ north latitude, 87º43’ west longitude
43º46’ north latitude, 87º39’ west longitude
43º37’ north latitude, 87º46’ west longitude
43º36’ north latitude, 87º43’ west longitude

The area is depicted within NOAA nautical charts 14903 and 14922. The project includes planning, aerial imagery acquisition, ground control survey, aerotriangulation, map compilation, tide/shoreline definition, and report writing. Aerial imagery was acquired over the project area shoreline and used to produce shoreline mapping. Water level observations were made during image acquisition from two water level stations and one water staff onsite.

The project database consists of information measured and extracted from Airborne GPS/IMU controlled aerial imagery and land-water interface data. Project survey data is referenced to the North American Datum of 1983 (NAD 83). Aerotriangulation was conducted in softcopy. Map compilation was accomplished using a DAT/EM Summit Evolution Softcopy Stereoplotter. Preliminary map review was performed on Pentium 4CPU, 2GHz computer workstations using MicroStation software. The final map editing and formatting was completed using ESRI’s ArcGIS software. Preliminary shapefiles were submitted for NOAA’s review. Review comments were incorporated into the digital files and final shapefiles were delivered.

Project Design

AERO-METRIC, INC. designed the project. The design was based on Coastal Mapping Program Specifications for Shoreline Mapping and Project Instructions prepared by NOAA, June 15, 2004. Project Instructions were revised August 18, 2004 in accordance with contract negotiations.

The project limits were overlaid on NOAA Nautical Chart 14903 and were used to depict the approximate locations of the shorelines to be mapped. Both color and infrared (using a 740 nanometer filter) imagery was planned to adequately cover the land-water interface in stereo within the project area. Two different flying heights were planned to allow discrete points to be measured to horizontal accuracies of one meter and two meters. Three flight lines were planned at 1:33,000 scale and three more flight lines were planned at 1:66,000 scale. The flight lines were planned with 60% forward overlap. Imagery acquisition was planned to take place when the wind speed was less than five miles per hour, the wave run-up (on the beach) was less than one foot, and the water levels remained constant during the acquisition of the imagery and during the ground shoreline land-water interface surveys.

The sun angle for all imagery was to be at or above 30 degrees above the horizon. Weather conditions were to be suitable for acquisition with no clouds present. Minimum visibility at the time of exposure was to be 8 miles. Flight crews were to coordinate with ground personnel who were monitoring weather conditions along the shoreline to determine if the conditions were adequate for image acquisition.

Airborne GPS/IMU control was planned for the project. Base stations were to be deployed on two published geodetic control marks near the project area. In addition, GPS data was to be downloaded from a CORS station in Milwaukee during the imagery acquisition. The maximum range of the aircraft during image acquisition from the GPS base stations near the project site was planned not to exceed 30 km.

Thirty ground checkpoints were to be surveyed at well-defined, photo identifiable locations evenly distributed throughout the project area. Check points were to assist in determining the relative accuracy found within the DMC imagery. In addition, four supplemental control points at well-defined, photo identifiable locations were surveyed to support the aerotriangulation.

During the imagery acquisition, AERO-METRIC personnel were to mark the land-water interface along a minimum of 50% of the shoreline within the project area. Personnel were to mark the land-water interface at approximately 100-foot intervals. As soon as possible after the imagery acquisition, these markers were to be surveyed using kinematic GPS methods. Four of these markers would be later reoccupied using static GPS methods to confirm the accuracy of the kinematic GPS survey.

See Survey Control Report for NOAA, Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated July 12, 2005. (Revised October 31, 2005.)

See Aerial Photography (Imagery) Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated September 28, 2005. (Revised December 21, 2005.)

See Airborne Positioning and Orientation for Aerial Photography Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated January 24, 2006.

See WI0401 Western Shoreline of Lake Michigan at Sheboygan, WI, Image Scale 1:33,000, NOAA Aerotriangulation Report, dated October 2005.

See WI0401 Western Shoreline of Lake Michigan at Sheboygan, WI, Image Scale: 1:61,000, NOAA Aerotriangulation Report, dated October 2005.

Field Operations

Field Operations – Aerial Imagery

All imagery for WI0401 was obtained on May 31, 2005. The imagery mission was conducted with a Turbo Aero-Commander AC-690 fixed wing aircraft. Color and infrared imagery was acquired using a Z/I Imaging Digital Mapping Camera (DMC). Flight crews coordinated with ground personnel who were monitoring shoreline conditions to determine if conditions were suitable for imagery acquisition. Imagery was acquired at the nominal scales of 1: 33,000 and 1:61,000 along with the simultaneous collection of kinematic GPS and IMU positioning and orientation data. Two differential base stations (Stations **SBM B** and **WILSON GPS**) were deployed and used to capture simultaneous GPS data in the project area. In addition, GPS data was downloaded from a CORS station (**MIL1**) in Milwaukee during the imagery acquisition. All base stations were observed with dual frequency GPS receivers. The number of GPS satellites tracked by the aircraft was six or more at all times and the PDOP never exceeded 3.0. The sun angle for all photography was at or above 30 degrees above the horizon. Weather conditions were clear to an occasional high thin cirrus layer during the flight mission. Minimum visibility at time of exposure exceeded 8 miles.

See Aerial Photography (Imagery) Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated September 28, 2005. (Revised December 21, 2005.)

Field Operations- Static GPS Control/Check Survey

Check surveys for photogrammetric mapping were conducted from June 1 through June 20, 2005 by AERO-METRIC using GPS observations obtained with dual frequency GPS receivers. GPS static techniques were used to survey photo ID checkpoints, supplemental photo ID control points, and land-water interface verification points. The purpose of the survey was to determine NAD83 horizontal coordinate and NAVD88 orthometric height positions of the surveyed points in support of testing the image quality of the DMC imagery.

At least two sessions of 1-hour duration were observed at all static GPS stations. All observations were with dual frequency GPS receivers and processed relative to existing local NGS GPS control with NAVD88 orthometric heights. Baselines were processed with Leica - Static Kinematic Professional software (SKI-PRO), version 2.10 and adjusted with GeoSurv - GeoLab2 series of programs (Geolab version 2.4d).

Two NGS control stations (**SBM B** and **WILSON GPS**) were observed as base stations for the airborne positioning and orientation survey, the static GPS ground survey, and the kinematic GPS ground survey. Data from CORS station **MIL1** was downloaded from the NGS CORS website and used in addition to the two NGS base stations for the airborne positioning and orientation survey. Photo ID points were surveyed near the shoreline and land-water interface points at the shoreline.

GPS observations were made using a combination of dual frequency receivers: four Wild/Leica SR9500 receivers, three Wild/Leica SR530 receivers, and one Wild/Leica SR399 receiver. Data was downloaded to laptop computers.

All of the observation files were processed using Leica - Static Kinematic Professional software (SKI-PRO), version 2.10. All input parameters were applied, HI (ARP) and type of antenna. IGS final orbits were used to process the data. The published NAD83 coordinate for station **SBM B** (PID DG5553) was used as the "seed coordinate" for processing. The selected interval for processing was 5 seconds. A minimum angle of 15 degrees above the horizon was selected as the cut-off elevation for all carrier phase observations. The troposphere correction model used was the Modified Hopfield Model.

Baselines were exported out of SKI-PRO in Leica SKI ASCII format. These files were input into the GeoSurv - GeoLab2 series of programs (Geolab version 2.4d). Geolab was used to perform the unconstrained and final constrained adjustments of the static survey.

See Survey Control Report for NOAA, Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated July 12, 2005. (Revised October 31, 2005.)

Field Operations- Kinematic GPS Land-Water Interface Survey

Land-water interface surveys were conducted on May 31, 2005 by AERO-METRIC using GPS observations obtained with dual frequency GPS receivers. GPS kinematic techniques were used to survey the land-water interface points. The purpose of the survey was to determine NAD83 horizontal coordinate and NAVD88 orthometric height positions of the surveyed points in support of testing land-water interface determination of the DMC imagery.

GPS observations were made using a combination of dual frequency receivers: two Wild/Leica SR9500 receivers and two Wild/Leica SR530 receivers. Data was downloaded to laptop computers.

All of the observation files were processed using Leica - Static Kinematic Professional software (SKI-PRO), version 2.10. All input parameters were applied, HI (ARP) and type of antenna. IGS final orbits were used to process the data. The published NAD83 coordinate for station **SBM B** (PID DG5553) was used as the "seed coordinate" for processing. The selected interval for processing was 1 second. A minimum angle of 15 degrees above the horizon was selected as the cut-off elevation for all carrier phase observations. The troposphere correction model used was the Modified Hopfield Model.

Baselines were exported out of SKI-PRO in Leica SKI ASCII format. These files were input into the GeoSurv - GeoLab2 series of programs (Geolab version 2.4d). Geolab was used to perform the unconstrained and final constrained adjustments of the kinematic survey.

See Survey Control Report for NOAA, Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated July 12, 2005. (Revised October 31, 2005.)

Field Operations- Land-Water Interface Markers

Once the decision was made to acquire imagery, AERO-METRIC called upon 26 personnel as beach runners to mark the land-water interface while the imagery was being acquired. The beach runners received their assigned locations and flags and all personnel reviewed their instructions approximately 1.5 hours before the imagery acquisition mission was to take place. Each person was responsible to be at their assigned shoreline location by 1:00pm CDT. As the aircraft flow overhead, they began placing one of their 11 flags every 100 feet along approximately 1,000 feet of shoreline.

Once their flags had been successfully deployed, AERO-METRIC asked that the personnel stand near their assigned location to insure that the flag positions would not be tampered until the Surveyors could establish GPS positions.

See Aerial Photography (Imagery) Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated September 28, 2005. (Revised December 21, 2005.)

Field Operations- Tide Staff Monitoring

Once the decision was made to acquire imagery, AERO-METRIC assigned one person to make staff readings while the imagery was being acquired. This person reviewed his instructions approximately 1.5 hours before the imagery acquisition mission was to take place. Staff readings were made at fifteen-minute intervals for a period of ninety minutes. The staff was located at the U.S. Coast Guard station in Sheboygan. This location was within the project area.

See Aerial Photography (Imagery) Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated September 28, 2005. (Revised December 21, 2005.)

GPS Data Reduction

During the aerial imagery mission, three GPS base stations were collecting data. The two NGS base stations (**SBM B** and **WILSON GPS**) were deployed for the photo mission and one NGS CORS station (**MIL1**) was continuously operating as part of the CORS network. The baseline separation from the NGS base station **SBM B** at the Sheboygan County airport to the furthest extent of the WI0401 project area was less than 19 km. The baseline separation from the NGS base station **WILSON GPS** to the furthest extent of the WI0401 project area was less than 11 km. The baseline separation from the NGS

CORS station **MIL1** in the city of Milwaukee to the furthest extent of the WI0401 project area was less than 87 km.

For details regarding the deployment, collection and processing of the static GPS data see Survey Control Report for NOAA, Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated July 12, 2005. (Revised October 31, 2005.)

The processing of the airborne positioning data was carried out using the suite of software supplied by Applanix that is collectively called POSPac. POSPac version 4.02 was used for the processing of this data set.

The raw airborne data is logged in a series of time sequential files each approximately 12.2 MB in size. The first step in the processing stream is to combine these files together and then extract them into individual data files that contain the raw GPS data, raw IMU data and camera event times. During this step the raw GPS data and the raw IMU data are checked for any lapses in data continuity.

When the data extraction is completed the next step is to process the airborne GPS data. For this project a total of three GPS trajectories were processed and then combined to create the final GPS positions for the aircraft antenna. For each base station the forward and reverse solutions were combined using a weighting scheme based upon the quality of the solution for each epoch. The combined solutions from each base station were then combined to create the final position file.

The GPS data was processed using a 10-degree elevation cutoff. The L2 frequency was utilized for kinematic ambiguity resolution as well as for ionospheric correction of the long trajectory. No satellites were rejected from the solution. The general quality of the airborne GPS trajectories was excellent. The solutions were all fixed integer and the trajectory comparisons were mostly less than 5 centimeters and never exceeded 10 cm.

The next step in the processing flow was to take the final GPS trajectory and blend this with the IMU data collected during the mission. This step is carried out using the program POSProc that is also part of the POSPac suite. The general theory behind the POSProc processing is to create a blended solution that utilizes the strengths of the two systems to create an optimum solution.

The blending of these solutions is done in three steps. First the data is processed forward in time, and then reverse in time and finally these two solutions are blended to create the final output. The other task that POSProc does in this step is to transfer the measurements from their source to the perspective center of the camera.

The end result of the POSProc processing is an SBET (Smoothed Best Estimated Trajectory) file. This file contains x,y,z coordinates as well as roll, pitch and yaw orientation angles for every 0.005 seconds during the entire mission.

The final step in the data processing stream is to create x,y,z coordinates and roll, pitch and yaw orientation angles for the exact moment the camera shutter opened for each image. This step is carried out using POSEO. The undulations for each exposure station were calculated from Geoid03 and the final EO file was output with NAD83-UTM Zone 16 coordinates and NAVD88 elevations. Coordinates and elevations were expressed in meters. The results of this step produce a text file which can be imported to a software package for the airborne triangulation process. The reformatted form of the POSEO is contained in the Aerotriangulation Reports for WI0401.

See Airborne Positioning and Orientation for Aerial Photography Report, Test of the Z/I Imaging Digital Mapping Camera (DMC) on the Western Shoreline of Lake Michigan in the State of Wisconsin, NGS Project No. WI0401, dated January 24, 2006.

Aerotriangulation

AERO-METRIC acquired imagery for WI0401 on May 31, 2005. Imagery was good quality with 60% forward overlap. The camera used was a Z/I Imaging DMC camera equipped with Forward Motion Compensation, serial number 040000061, with a focal length of 120 mm. The project area was flown at scales of 1:33,000 and 1:61,000. The imagery acquired was color and infrared (using a 740 nanometer filter). The final resolution of the imagery was 12 microns. The current Z/I Imaging camera calibration certificate and the NASA in-situ calibration reports for this camera were submitted to NOAA.

Aerotriangulation was conducted in soft copy using a Dell PWS670 workstation, running under Windows XP Professional, Version 2002 Service Pack 2. The Dell workstation has a 3.20 GHz Xeon CPU processor and 2 GB of memory. Z/I Imaging's Image Station Automatic Triangulation (ISAT) software was used to complete the analytical aerotriangulation. Point matching was done in images along a strip and in images of overlapping strips. The image coordinates from point matching were used with the airborne GPS/IMU exposure stations and ground surveyed control in the robust bundle block adjustment, which automatically detects and removes any large point matching errors. Corrections for atmospheric refraction and earth curvature were enabled in the adjustment.

Four control points were measured in order to stabilize the aerotriangulation block's poor geometry due to the amount of water in the imagery.

The checkpoints were measured and analyzed with good horizontal residuals, but showed a vertical bias. The bias was 0.4 meters for the 1:33,000 and 2.6 meters for the 1:61,000 scale imagery. The elevations of the ABGPS image centers were lowered to remove the vertical bias. The shift was accomplished by adding the bias value to the *Z* component of the GPS antenna within the ISAT software rather than by changing the actual input data to the aerotriangulation blocks.

For the 1:33,000 imagery, the bundle solution was acceptable. The image RMS was 2.1 microns in the X direction and 2.8 microns in the Y direction. The 95% confidence circle

radius for the horizontal accuracy of all ground points was 0.5 meters. The RMS values of the checkpoints were: X=0.253, Y=0.305, and Z=0.551 meters.

For the 1:66,000 imagery, the bundle solution was acceptable. The image RMS was 0.8 microns in the X direction and 0.02 microns in the Y direction. The 95% confidence circle radius for the horizontal accuracy of all ground points was 0.8m. The RMS of the checkpoints were: X=0.699, Y=0.734, and Z=1.169 meters.

The project database consisted of project parameters and selected options, camera calibration data, control file data, refined image coordinates, Airborne GPS data, IMU orientation angles of camera centers, adjusted exterior orientation parameters for each image, a positional listing of all ground points used in the project, and a stereo model review. Positional data was based on the North American Datum of 1983 (NAD 83), and was referenced to the UTM Coordinate System, Zone 16.

See WI0401 Western Shoreline of Lake Michigan at Sheboygan, WI, Image Scale 1:33,000, NOAA Aerotriangulation Report, dated October 2005.

See WI0401 Western Shoreline of Lake Michigan at Sheboygan, WI, Image Scale 1:61,000, NOAA Aerotriangulation Report, dated October 2005.

Compilation

The Compilation Phase was accomplished by AERO-METRIC during the period of October 2005 through January 2006. Digital mapping was accomplished using a DAT/EM Summit Evolution Softcopy Stereoplotter. The software used was DAT/EM's CAPTURE. Feature identification and the assignment of cartographic codes were based on image analysis of 1:33,000 and 1:61,000 scale color and infrared imagery and information extracted from the appropriate NOAA Nautical Charts. Cartographic feature attribution was assigned in compliance with the Coastal Cartographic Object Attribute Source Table (C-COAST). Nomenclature was assigned to selected cartographic features to refine general classification.

Cartographic features were compiled to meet a horizontal accuracy of 1.0 meters at a 95% confidence level for the 1:33,000 scale imagery and 2.0 meter at a 95% confidence level for the 1:61,000 scale imagery. The cartographic features were produced according to procedures that have been demonstrated to produce data of this accuracy.

For testing, the shoreline was compiled from both the color and infrared imagery at both 1:33,000 and 1:61,000 image scales. The standard shoreline coastal mapping was compiled from the color imagery at both 1:33,000 and 1:61,000 image scales. Final shoreline data submitted for NCP application was derived from the 1:33,000 color imagery. All imagery was controlled by the airborne GPS/IMU method.

Compilation scales of 1:5,000 were used within the extent of NOAA Nautical Chart 14922 and 1:20,000 elsewhere.

The following table provides information on aerial imagery used in the project completion process:

Date	Time (UTC)	Flight Line	Frame Numbers	Scale (nominal)	Water Level*
31-May-05	18:34-18:35	61001	001-003	1:61,000	0.01 ft
31-May-05	18:49-18:50	61002	004-007	1:61,000	0.01 ft
31-May-05	19:01-19:02	61003	008-012	1:61,000	0.02 ft
31-May-05	19:19-19:20	33001	013-017	1:33,000	-0.01 ft
31-May-05	19:28-19:28	33002	018-023	1:33,000	-0.02 ft
31-May-05	19:37-19:38	33003	024-031	1:33,000	-0.03 ft

* Water levels are referenced to the mean water elevation of 578.12 ft during the time of imagery acquisition. The difference between the highest and lowest observed water levels during imagery acquisition was 0.05 ft.

As the compilation was being completed, preliminary review of the data collected was performed on Pentium 4CPU, 2GHz computer workstations using MicroStation software. Paper check plots were produced and edited off-line. Corrections and additions were incorporated and the final editing and formatting was completed using ArcGIS software. Preliminary shapefiles were submitted for NOAA's review. Review comments were received from NOAA and there were some corrections to incorporate. The final shapefiles were prepared and delivered. Corrections based on NOAA comments were made during January 2006. The shapefiles were accepted as final in February 2006.

Quality Control / Final Review

Senior members of the AERO-METRIC Geo-Spatial and Image/Terrain Departments initiated the final review in October 2005. The digital cartographic feature file (DCFF) was evaluated for completeness and accuracy. Data review consisted of an on-line and off-line evaluation of digital compilation and hard copy products. The on-line review was comprised of reviewing stereo models on a Summit Evolution stereoplotter for cartographic feature codes selection, positional accuracies of features, and nomenclature. The cartographic feature attribution was judged to conform to C-COAST specifications. The off-line evaluation compared hard-copy plots of project data with the largest scale nautical chart available and the natural color images.

Comparisons of the largest scale NOAA Nautical Charts with color and infrared imagery and compiled project data resulted in creation of the Chart Evaluation File (CEF). The following nautical charts were used in the comparison process:

14922, Manitowoc and Sheboygan Harbors, 1:10,000 scale, 19th edition
14903, Algoma to Sheboygan, 1:20,000 scale, 23rd edition

End Products and Deliverables

The following specifies the location and identification of the products generated during the completion of this project:

RSD Applications Branch Archive

- Hardcopy of the Survey Control Report
- Hardcopy of the Aerial Imagery Report
- Hardcopy of the Airborne Positioning and Orientation Report
- Hardcopy of the Aerotriangulation Report (1:33,000 scale Imagery)
- Hardcopy of the Aerotriangulation Report (1:61,000 scale Imagery)
- Hardcopy of the Project Completion Report (PCR)
- Page-size graphic plot of GC10595 file contents, attached to PCR

Remote Sensing Division Electronic Data Library

- Project Database
- Digital copy of DCFF GC10595 in shapefile format
- Digital copy of the PCR in Adobe PDF format
- CEF in shapefile format

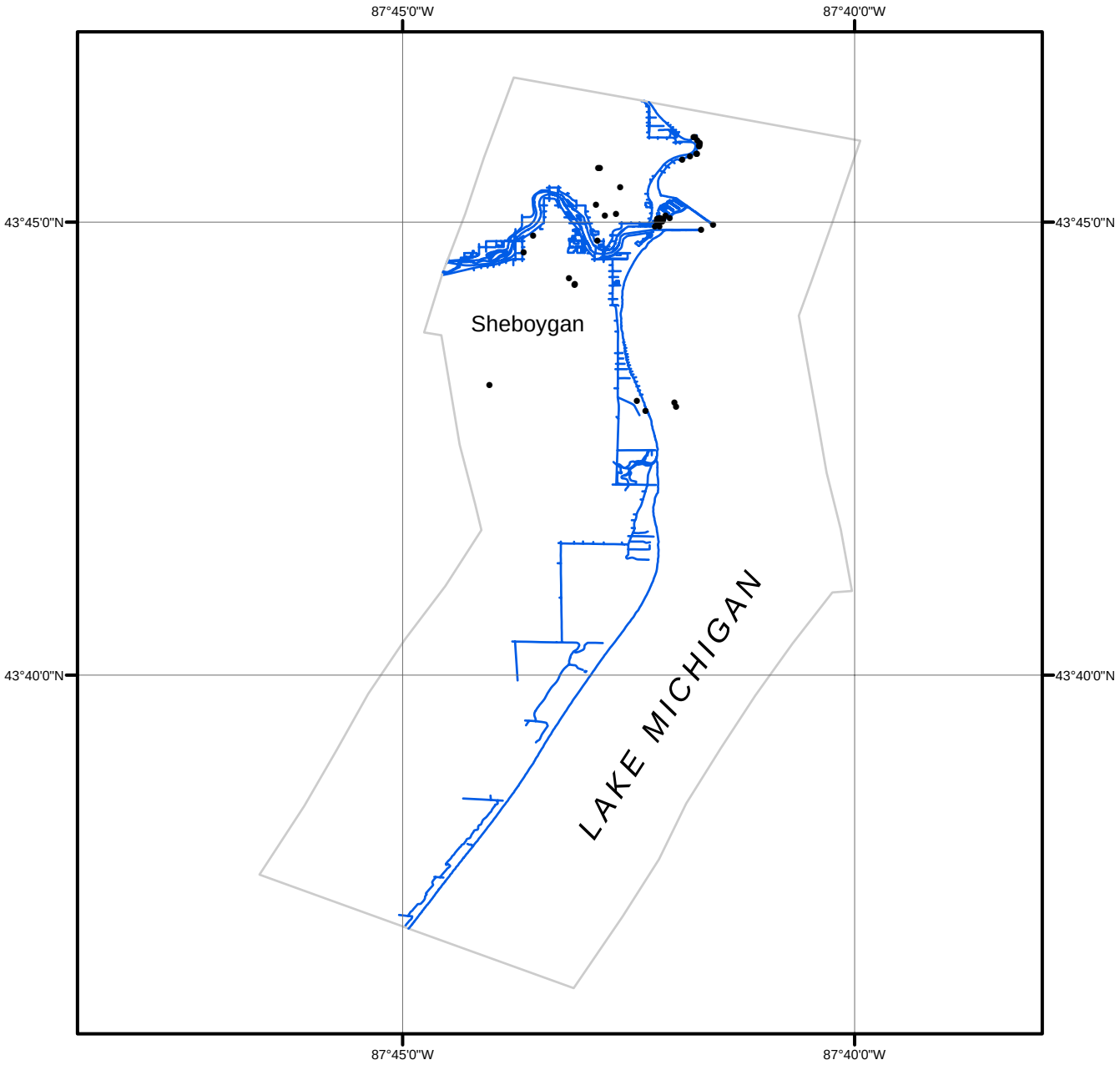
NOAA Shoreline Data Explorer

- DCFF for GC10595
- Metadata file for GC10595
- Digital copy of the PCR in Adobe PDF format

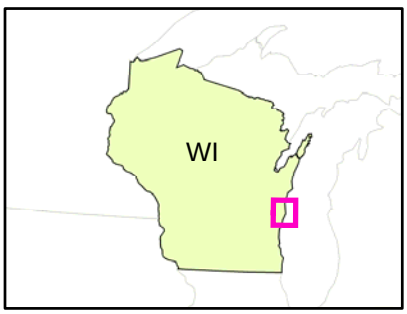
End of Report

SHEBOYGAN

WISCONSIN



Overview



WI0401

GC10595