BUFFALO REEF AND STAMP SAND SUBSTRATE MAPPING PROJECT.

by

Esteban D. Chiriboga and William P. Mattes

GLIFWC

Administrative Report 08-04

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GREAT LAKES INDIAN FISH AND WILDLIFE COMMISSION

P.O. Box 9

Odanah, WI 54861

(715) 682-6619

Introduction.

Shallow deposits of copper enabled the Keweenaw Peninsula to became one of the most productive mining regions of the country between 1864 and 1930. During this period, stamp mills were built near lakes and rivers to crush the ore and separate the copper from the rock by flotation. The waste material from these mills, referred to as stamp sands, was deposited in vast quantities in the vicinity of the stamp mills. These deposits of fine grained mine tailings (sand size particles or smaller) were deposited into nearshore environments of Lake Superior or piled along the shores of the Keweenaw Peninsula. By the end of the mining era, approximately half a billion tons of stamp sands were deposited throughout the Keweenaw Peninsula (Kolak et al. 1999).

While copper mining activities ended at most sites many decades ago, stamp sand deposits persist and have had a marked effect on the region. The geomorphology of lakes, streams and shorelines was changed by the deposition of the mine waste. It is estimated that Portage Lake lost 20% of its volume to infill from stamp sands (Cusack and Mihelcic, 1999). After initial deposition, waves and currents reworked the stamp sands leaving the coarsest materials along stream banks and creating extensive sand bars and expanded beaches (Kerfoot and Lauster, 1994). Of these features, the Gay peninsula is among the most prominent. This peninsula, located immediately south of the town of Gay (and its copper smelter) is composed almost entirely of stamp sands. Weathering processes have caused this extensive stamp sand area to erode and stamp sands have moved south along the coast and into Lake Superior away from the area of initial deposition.

Migration of stamp sands may pose significant environmental hazards. Leaching of trace metals from stamp sands has been well documented (Jeong et al. 1999, Cusack 1999). Research has shown that many areas of stamp sands are unable to support vegetation. In addition, lakes into which stamp sands have been dumped have been found to be nearly devoid of benthic animals and concentrations of mercury and copper in sediments are high compared to uncontaminated areas of the lake (Kerfoot et al. 1999). Concentrations of metals in water have been found above toxicity thresholds for many animal and plant species and mining wastes have been identified in the Lake Superior Lakewide Management Plan 2000 (LaMP 2000) as a principal stress to aquatic habitat in Lake Superior (LaMP 2000, p. 8-10). In addition, the habitat objective for Lake Superior established in the Fish Community Objectives calls for "no net loss of the productive capacity of habitat supporting Lake Superior fishes" (Horns et al. 2003). Of equal concern are the effects that the addition of large amounts of fine material may have on the habitat of the region. Fish species often depend on interstitial spaces and small openings in the rock to provide shelter for eggs and young fish. The filling of these spaces by an influx of stamp sands could drastically reduce suitable habitat.

The stamp sand deposit south of Gay, Michigan was the focus of this study and is of concern to GLIFWC member tribes (Map 1a and 1b). Tribal members maintain a commercial whitefish and lake trout fishery and harvest of these fish is an important cultural and economic activity for tribal members. Fish harvested from Lake Superior have become increasingly important as GLIFWC helps tribal members promote and market Lake Superior fish and more generally the health benefits of traditional foods (Mazina'igan, Summer 2007 edition). Tribal fish harvesters have become increasingly concerned about the effects that the stamp sand deposits may have on Buffalo Reef, an important spawning reef for the harvested species, which is located south of the Gay Michigan stamp sand area. Anecdotal evidence from tribal fishermen has suggested that the sands were moving toward the reef, which could impact the continued ability of the reef to support spawning sites for whitefish and lake trout. The impairment of this reef could lead to a decline in these important species, an impairment to federally guaranteed treaty reserved rights, and an impact on the tribal population that depends on this resource. Buffalo Reef was identified as an important spawning area by tribal members as well as through GLIFWC's previous work that digitized the "Atlas of the Spawning and Nursery Areas of Great Lakes Fishes, Volume 2" (Map 2a and 2b).

The objectives of this project were: first, to map the extent of the stamp sands in relation to the reef in order to provide both a baseline of the spatial relationship between the stamp sands and the spawning areas on the reef, second, to confirm the importance of Buffalo Reef as a spawning area and third, to provide a preliminary assessment of the vulnerability of the reef to contamination by the stamp sands. The results obtained from the study can be used by tribal fishery managers and others to evaluate whether the reef is currently impacted by stamp sands and determine what follow up management action may be necessary.

To characterize the spatial extent of the stamp sands and their relationship to Buffalo Reef, GLIFWC contracted with the National Water Research Institute (NWRI) of Environment Canada to conduct sonar mapping of the area surrounding Buffalo Reef. The substrate classification developed by NWRI differentiates the areas of likely stamp sand from the rocky substrate of the reef. In addition, detailed bathymetry data provide information about areas that may be encroached upon by stamp sands. GLIFWC also conducted expanded fishery assessments throughout the reef. These data, along with published research conducted on sediment transport dynamics of stamp sands in other areas of Lake Superior were used to map areas of the reef of greatest use and to provide a preliminary assessment on the vulnerability of the areas that are used most heavily by lake trout and whitefish species.

Methods

A substrate classification for the Grand Traverse Bay which encompasses Buffalo Reef was conducted by NWRI using the RoxAnn seabed classification system. The system processes information collected by sounding equipment generated through an in-hull transducer. The NWRI launch sounded transects across the reef area at 50 meter offsets and transects across other areas of the Bay at 100 meter offsets. NWRI also collected underwater video of the substrate at 43 sites. The sites were selected based on a preliminary substrate classification in order to provide visual representation of all substrate types found in the area. In addition, NWRI collected sediment samples at 21 sites and particle size analysis was conducted. Positional data was maintained at all times by GPS equipment. The sampling design was described in an EPA approved QAPP (Appendix 1) and no deviations were recorded by NWRI. A detailed report prepared by NWRI on aspects of the substrate mapping fieldwork is included in Appendix 2.

GLIFWC Lake Superior fisheries staff conducted expanded assessments at several locations in and around Buffalo Reef. Sampling occurred on 10 days between October 17 and November 16, 2005. The survey area was divided into 5 categories (Map 3) and the results are displayed in table 1.

GLIFWC Environmental Section staff imported the substrate mapping and fishery assessment data into GLIFWC's Geographic Information System (GIS) software and created a series of thematic maps that illustrate the spatial relationships between the sample locations, substrate and fish abundance. GLIFWC staff also used data collected by NWRI on the hardness and roughness of the substrate to digitize the outline of the Buffalo Reef (Map 4a and 4b). This information provides the basis for a preliminary assessment of the vulnerability of the various sections of the reef to stamp sand incursion.

Results

Results of GLIFWC's fishery assessments confirm that Buffalo Reef is an important spawning area for lake trout and whitefish. Catch rates for adult lake trout and whitefish were highest in the tip of the reef area, which is the easternmost portion of the exposed rocky substrate adjacent to deeper open waters of Lake Superior. This suggests that this reef tip area is an important spawning area for both species of fish. Adult lake trout were also relatively abundant in the interior of the reef but adult whitefish were not found in large numbers in this area. Summer beach seining found juvenile whitefish were in the near-shore sand areas (GLIFWC unpublished data). This suggests that the area adjacent to the reef may be an important nursery area (Map 3).

Species	Area Set	Number Captured	Gillnet Effort (feet of net)	Catch per 1,000 feet of net
Lake Trout	Inside of Reef	79	1,750	45.1
	NE Tip of Reef	9	250	36.0
	Near Shore Sand	11	2,000	5.5
	Tip of Reef	323	2,250	143.6
	Very Near Shore	2	250	8.0
Whitefish	Inside of Reef	3	1,750	1.7
	NE Tip of Reef	1	250	4.0
	Near Shore Sand	17	2,000	8.5
	Tip of Reef	45	2,250	20.0
	Very Near Shore	7	250	28.0

Table 1. Results of the GLIFWC expanded fishery assessment for Buffalo Reef.

Data collected by NWRI provide a detailed classification of Buffalo Reef and the surrounding area. The lakebed was classified into 7 categories and 4 of those were acoustically distinct types of sand substrate. (Map 5) As indicated in NWRI's report (Appendix 2) the acoustic classification method was not able to distinguish areas of stamp sand from areas of native sands. This may be due to mixing of sands that has occurred since that stamp sands were deposited. Further work should be done to ascertain if a clear boundary exists between native sands and stamp sands. A visual inspection of sediment samples collected in the field by NWRI indicates that the area of sands immediately north of Buffalo Reef appears to be stamp sands regardless of its acoustic signature. Particle size analysis of the sediment samples is available in appendix 2. Field staff also observed transport and mixing of sands due to wave action. Therefore, despite the uncertainty regarding the precise nature of the sands, it is reasonable to assume that stamp sands continue to be transported from the areas immediately surrounding the town of Gay into areas of Lake Superior immediately north of Buffalo Reef.

Underwater images captured by NWRI provide clear indicators of the character of the substrate for each habitat type (Map 6). Figures 1 through 4 provide representative examples of the substrate types found in Grand Traverse Bay. All photos collected by NWRI are available in appendix 2.

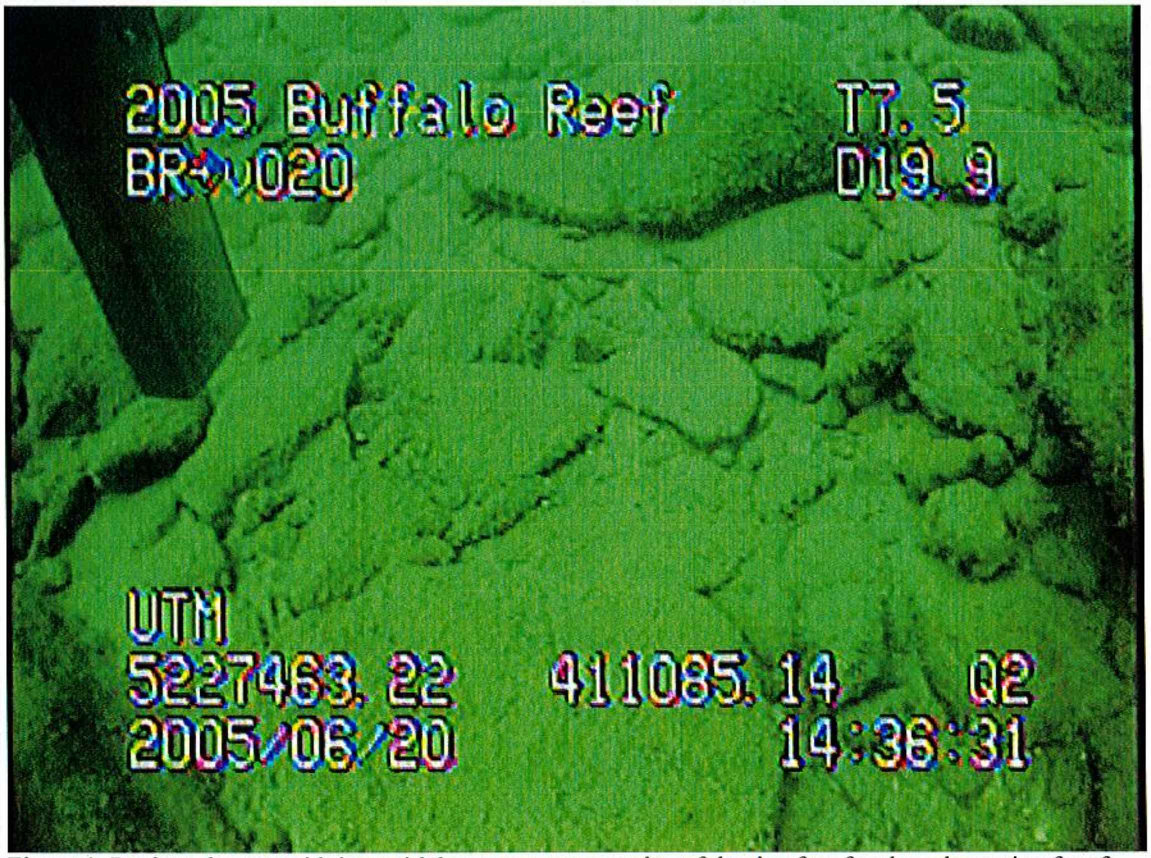

Figure 1. Rocky substrate with interstitial spaces representative of the tip of reef and northeast tip of reef habitat areas.

Figure 2. Rocky substrate with interstitial spaces representative of the inside of reef habitat area.

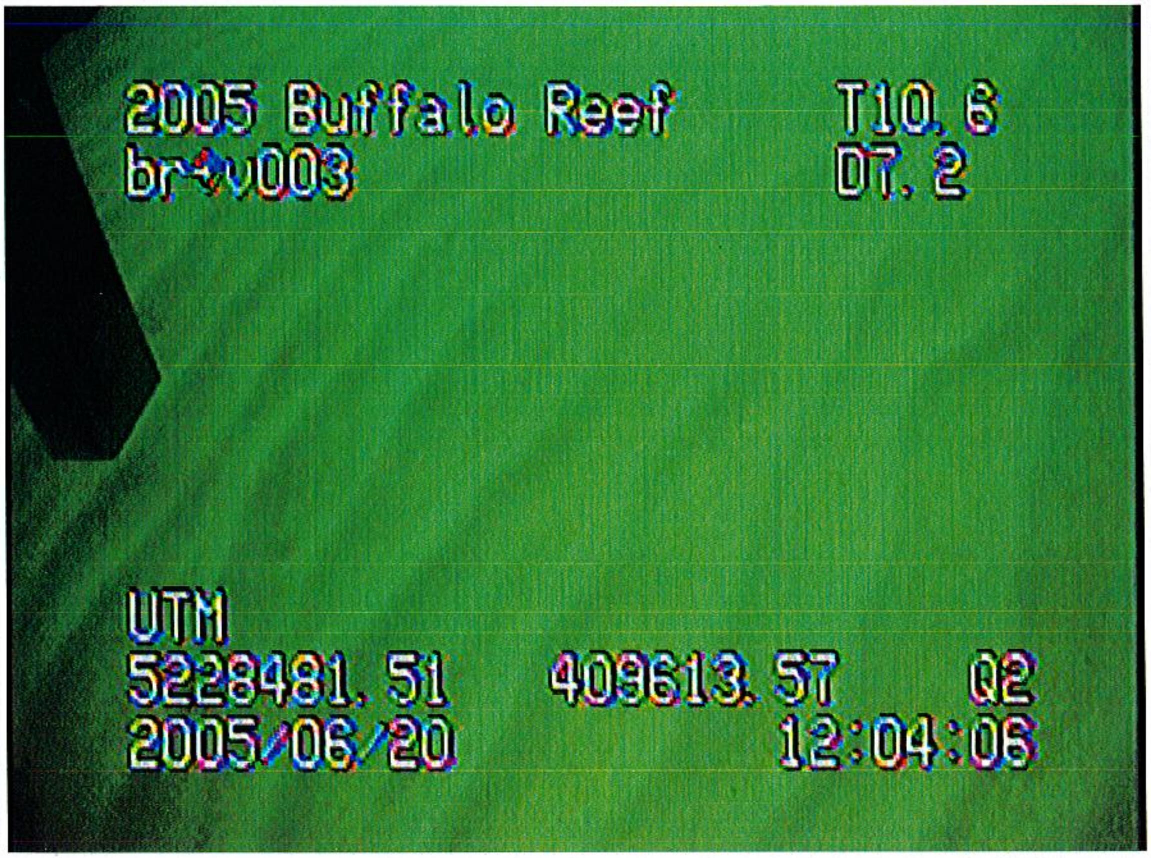

Figure 3. Fine Sand substrate representative of the near shore sand habitat area

Figure 4. Mixed sand and gravel substrate representative of the very near shore habitat area..

As previously indicated, this project provides an initial baseline of the spatial relationship between sands and Buffalo Reef. A preliminary assessment of the vulnerability of the reef and the fishery that it supports was made based on available literature and detailed bathymetry data collected for Grand Traverse Bay (Map 7). Gravity is one of the primary factors affecting transport of stamp sands. After the initial dumping of the mine waste along the waterways of the Keweenaw Peninsula, the stamp sands moved down gradient along the stream channels until they reached Lake Superior. At this point the stamp sands began to flow into the Lake and settle because the large body of water provided a low energy environment compared to the inland rivers and streams. In addition to the settling that resulted from the lower energy environment of Lake Superior, Buffalo Reef itself provides a topographical barrier to the incursion of stamp sand dunes into Grand Traverse Bay. The topographical barrier was defined by calculating profiles of the shape of the lakebed (Map 8). Profiles 1, 7 and 8 (Appendix 3) illustrate a typical lakebed cross-section with depth increasing gradually as the distance from the coast increases. However, profiles 2 through 6 indicate areas where the rock outcropping of Buffalo Reef prevents gravity from moving stamp sand dunes into the deeper areas of Lake Superior.

In addition to gravity, literature indicates that there are two forces that influence the movement of stamp sands in Lake Superior in general and in Grand Traverse Bay in particular. The first force is the strong coastal flow of water that caused stamp sands to move along the coast of the Keweenaw Peninsula and to be deposited along beaches (Kerfoot et al. 2007). This effect is apparent in figure 5 where the white native sands can be distinguished from the gray stamp sands.

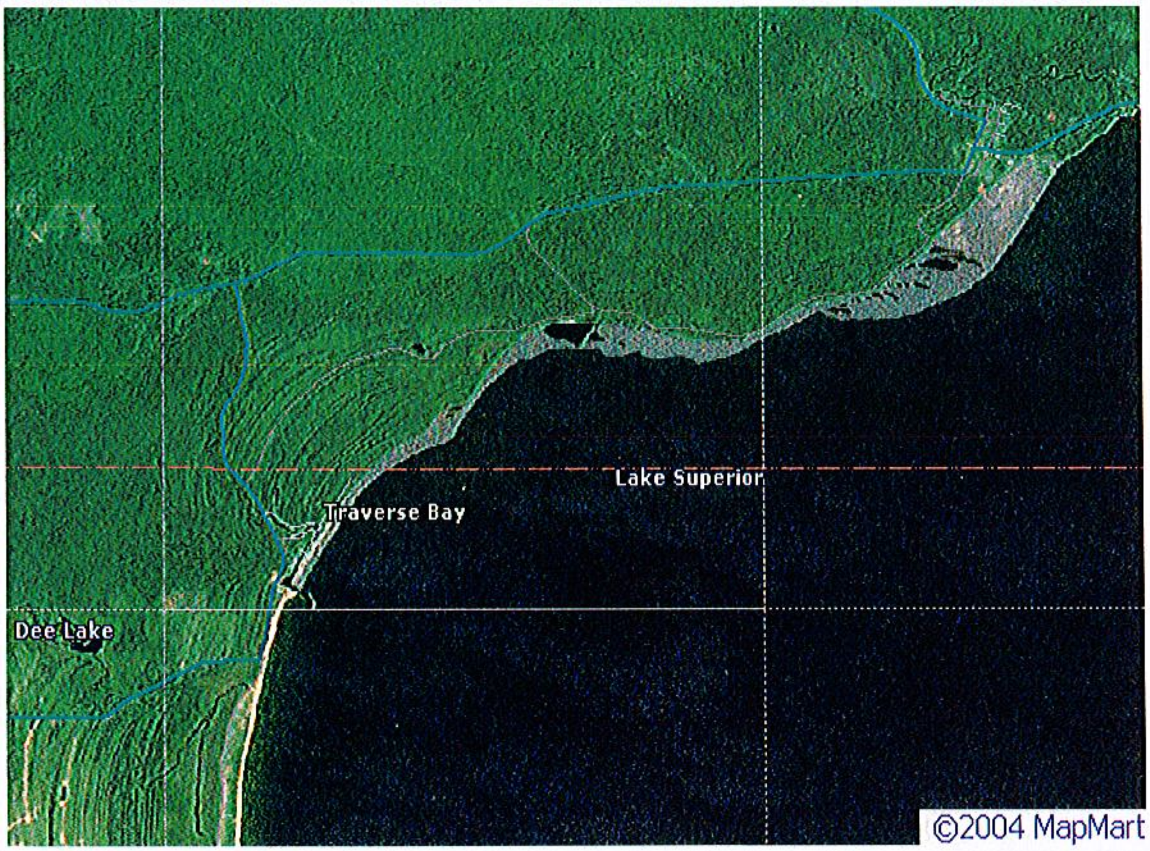

Figure 5. Aerial photo of the northern shore of Grand Traverse Bay. Stamp sands deposited at Gay (top right of image) have migrated southward along the shoreline.

The second force involves plumes of fine stamp sands that become suspended in the water during periods of increased water turbulence. Observations in the area of Buffalo Reef indicate that plumes of this fine material move into the deeper sections of Grand Traverse Bay and over Buffalo reef itself (Figure 6). It is reasonable to assume that some quantities of these particles are deposited over the reef. Over time, this deposition may negatively affect the spawning and nursery functions of the reef through the filling of interstitial spaces in the substrate and through chemical contamination of the habitat.

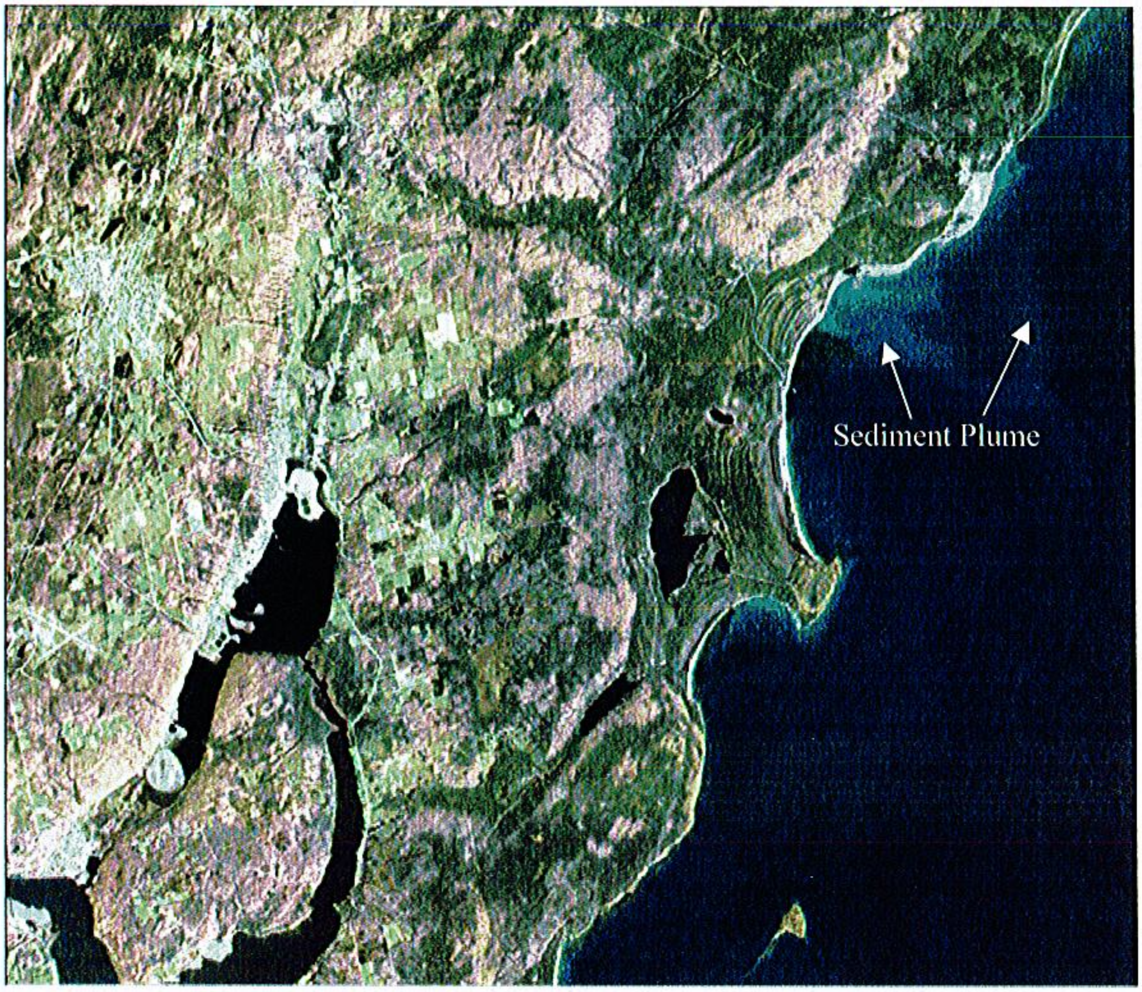

Figure 6. Satellite image showing a plume of stamp sands originating along the north shore of Grand Traverse Bay and moving into deeper waters of Lake Superior.

Conclusion

It is clear that stamp sands are mobile and are encroaching on Buffalo reef, as has been reported by tribal fishermen. The addition of the large mass of fine material has increased deposition in the area of Buffalo Reef beyond what would normally occur. This study provides a baseline from which future movement of the sands can be quantified. However, the nature of the encroachment on portions of Buffalo Reef that are most important for fish spawning and nursery areas appears to be the result of diffuse deposition of stamp sands that become suspended in the water column during periods of turbulence such as storms or high winds. Further research is needed to quantify the rate of that deposition within the reef in order to provide an assessment of the effects on suitable spawning areas. Furthermore, chemical testing of the sediment samples collected by NWRI may provide an indication of the degree to which waters of the Buffalo Reef area have been chemically impacted by stamp sand deposition. The substrate classification method employed by NWRI, was unable to discern differences between native sands and stamp sands. Therefore additional sediment sampling, which should include chemical analyses of the samples, should be conducted in the near-shore sand habitat area to determine if a clear boundary between the two sand types exists.

Sources Cited

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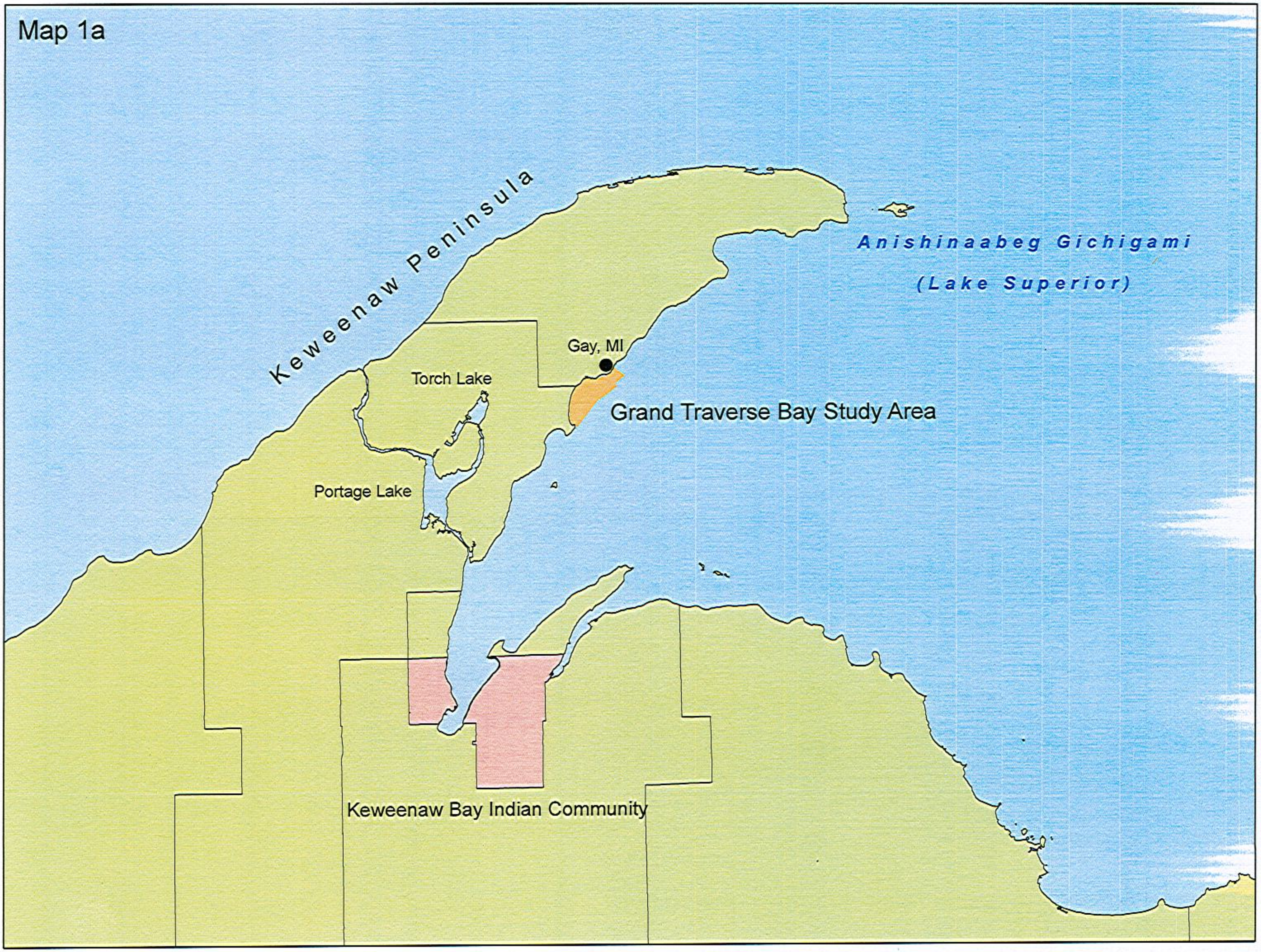
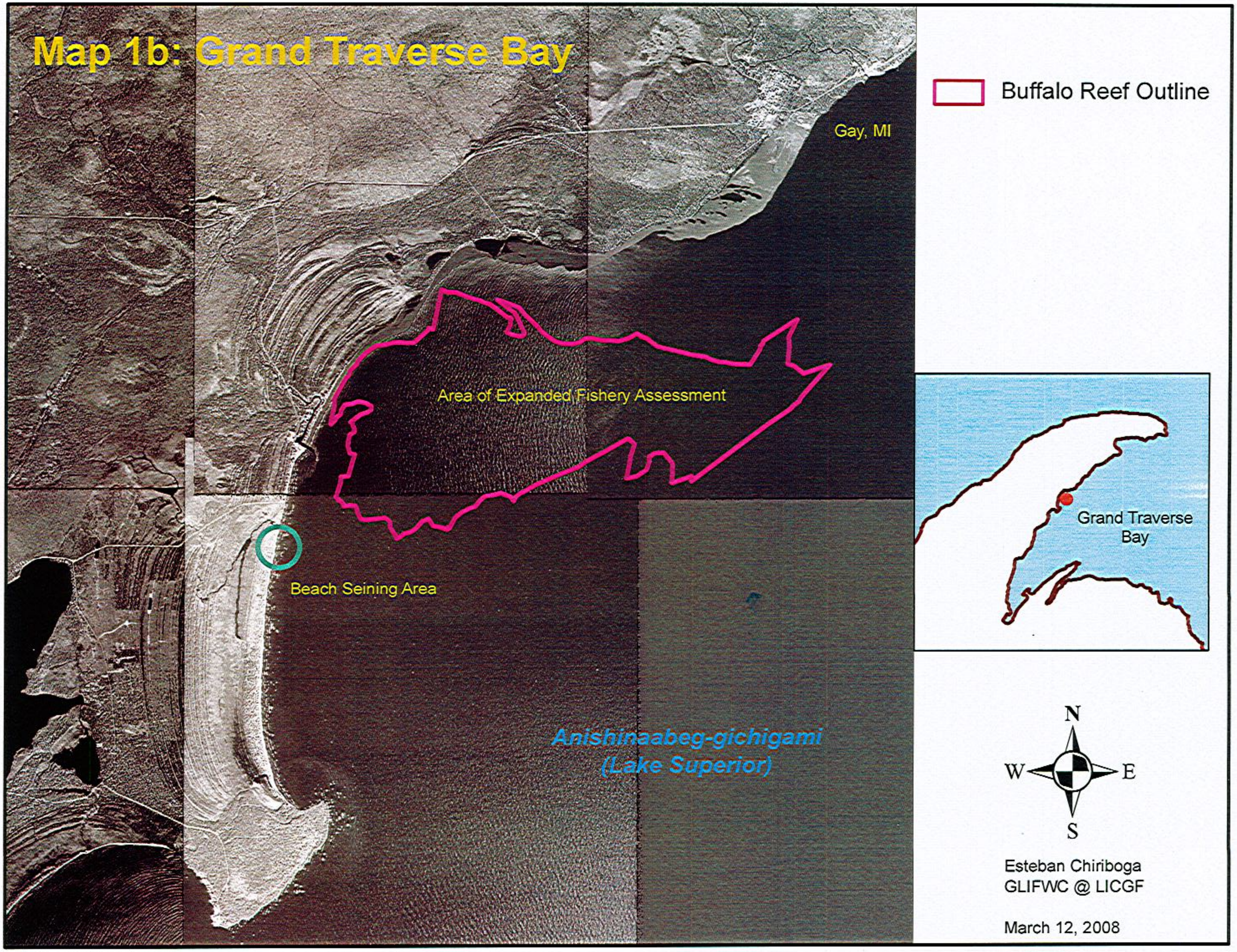

Map 1a
Keweenaw Peninsula
Anishinaabeg Gichigami
(Lake Superior)
Gay, MI
Torch Lake
Grand Traverse Bay Study Area
Portage Lake
Keweenaw Bay Indian Community


Map 1b: Grand Traverse Bay
Buffalo Reef Outline
Gay, MI
Area of Expanded Fishery Assessment
Beach Seining Area
Anishinaabeg-gichigami
(Lake Superior)
Grand Traverse Bay
N
W
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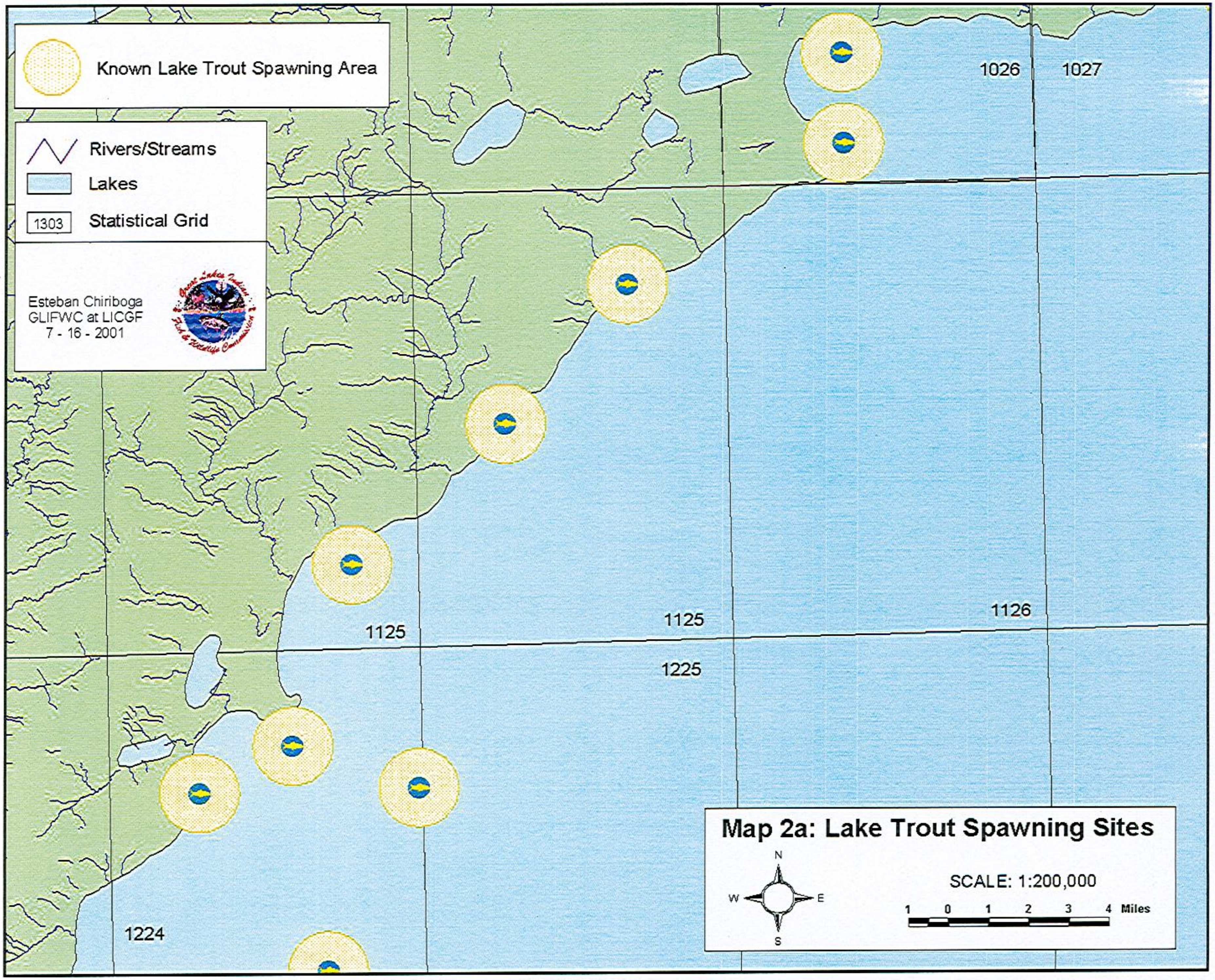
Esteban Chiriboga
GLIFWC @ LICGF
March 12, 2008


Known Lake Trout Spawning Area
Rivers/Streams
Lakes
1303
Statistical Grid
Esteban Chiriboga
GLIFWC at LICGF
7 - 16 - 2001
1026
1027
1125
1125
1126
1225
1224
Map 2a: Lake Trout Spawning Sites
N
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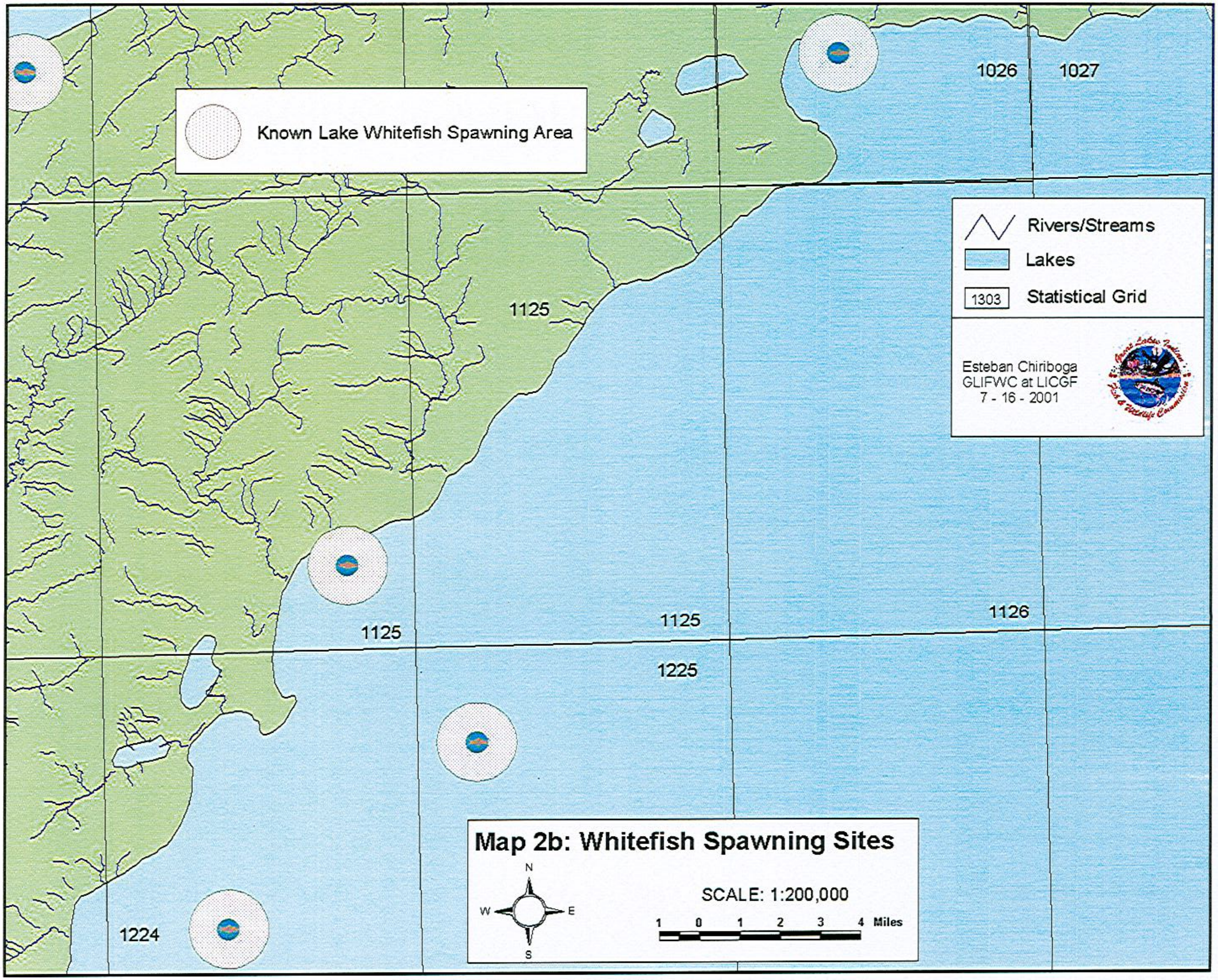
S
SCALE: 1:200,000
1 0 1 2 3 4 Miles



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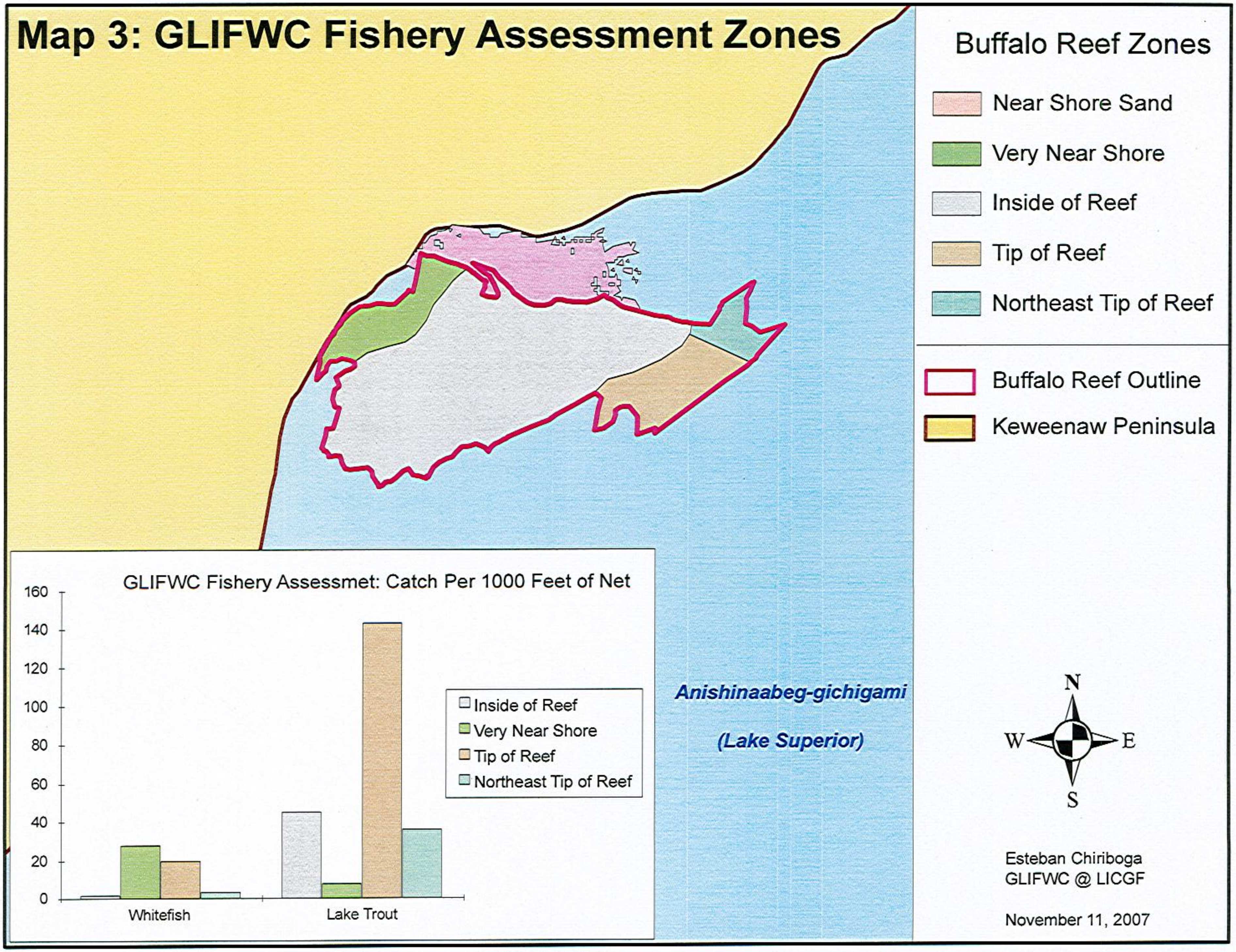
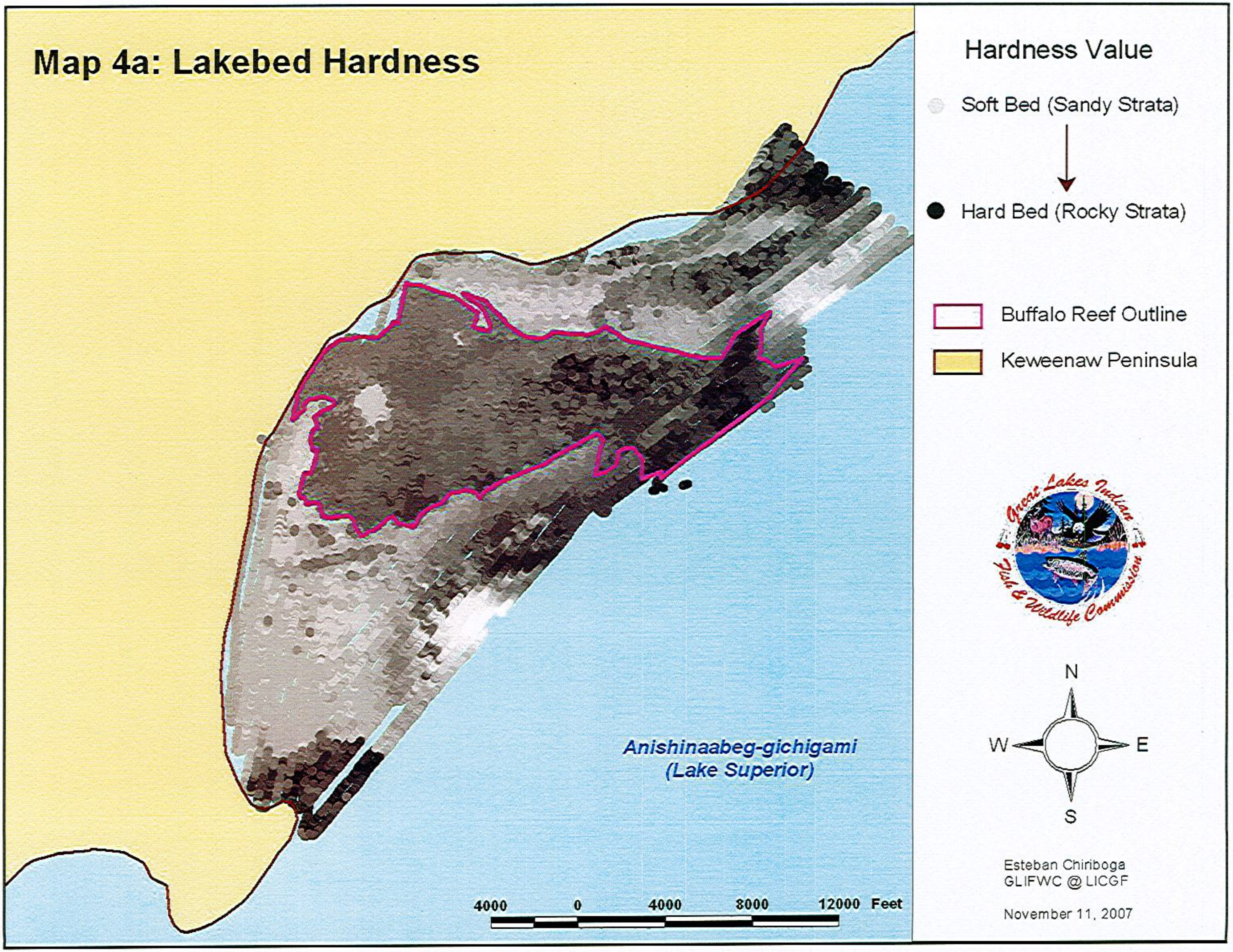
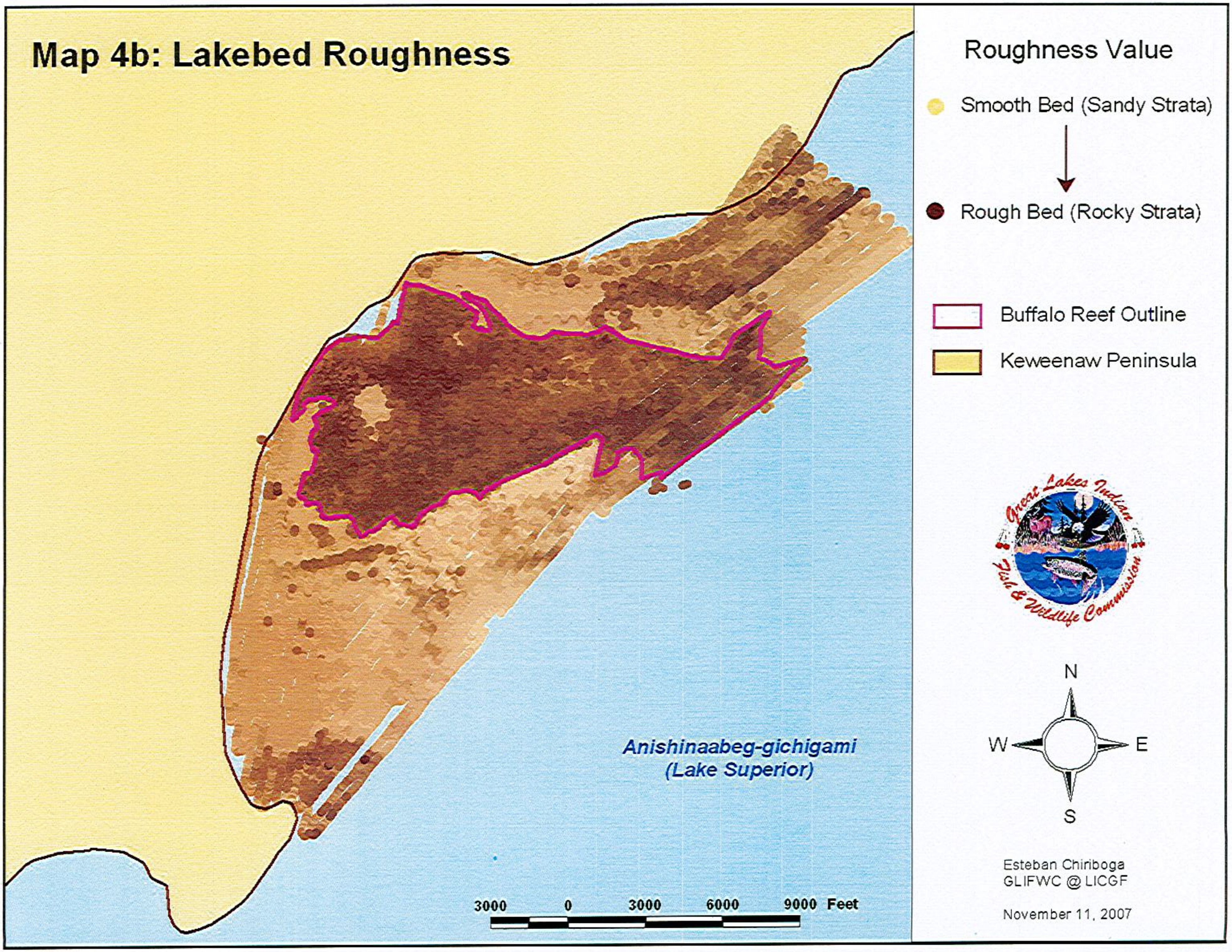
Map 3: GLIFWC Fishery Assessment Zones

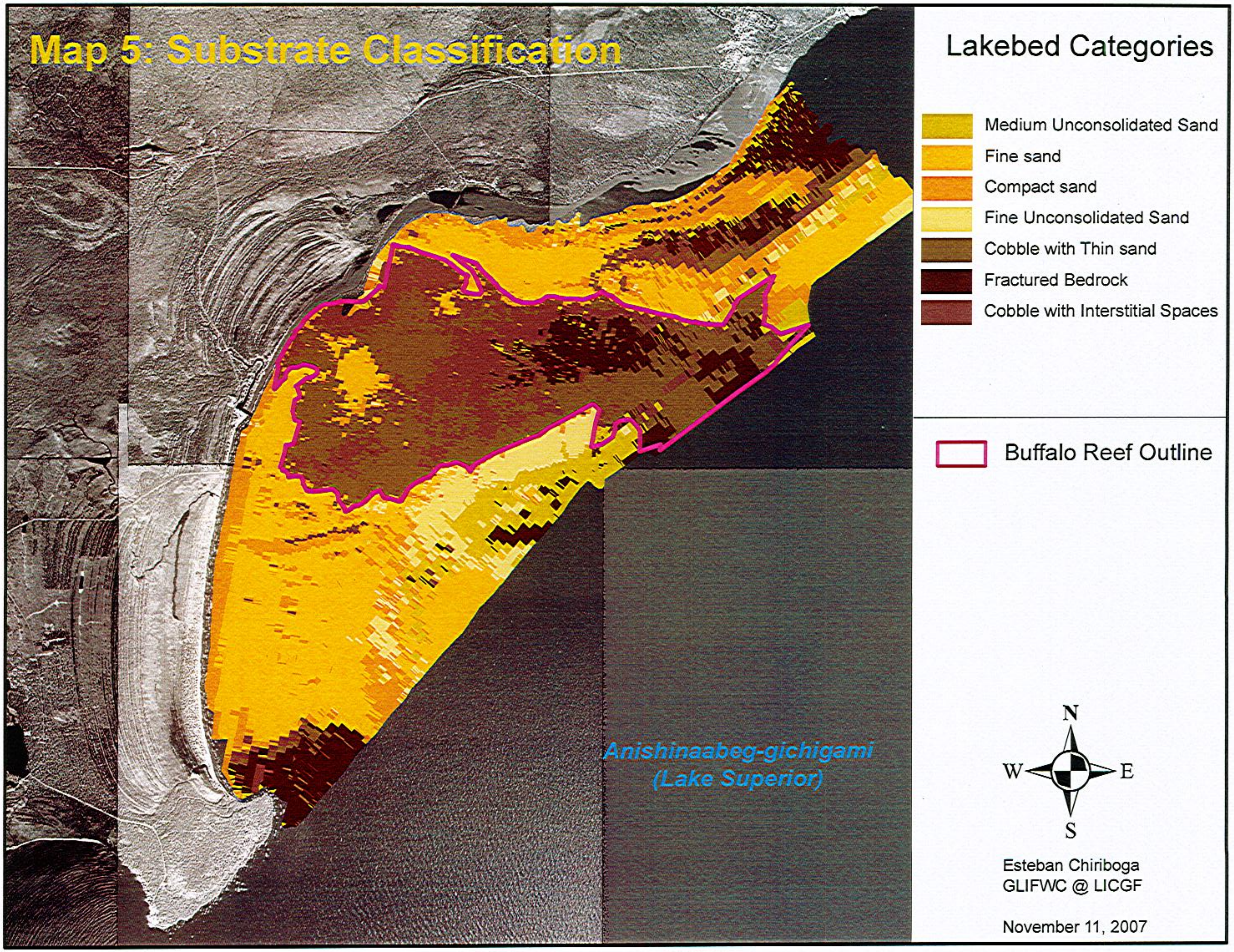


Map 4a: Lakebed Hardness



Map 4b: Lakebed Roughness

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Medium Unconsolidated Sand
Fine sand
Compact sand
Fine Unconsolidated Sand
Cobble with Thin sand
Fractured Bedrock
Cobble with Interstitial Spaces
Buffalo Reef Outline
Anishinaabeg-gichigami
(Lake Superior)
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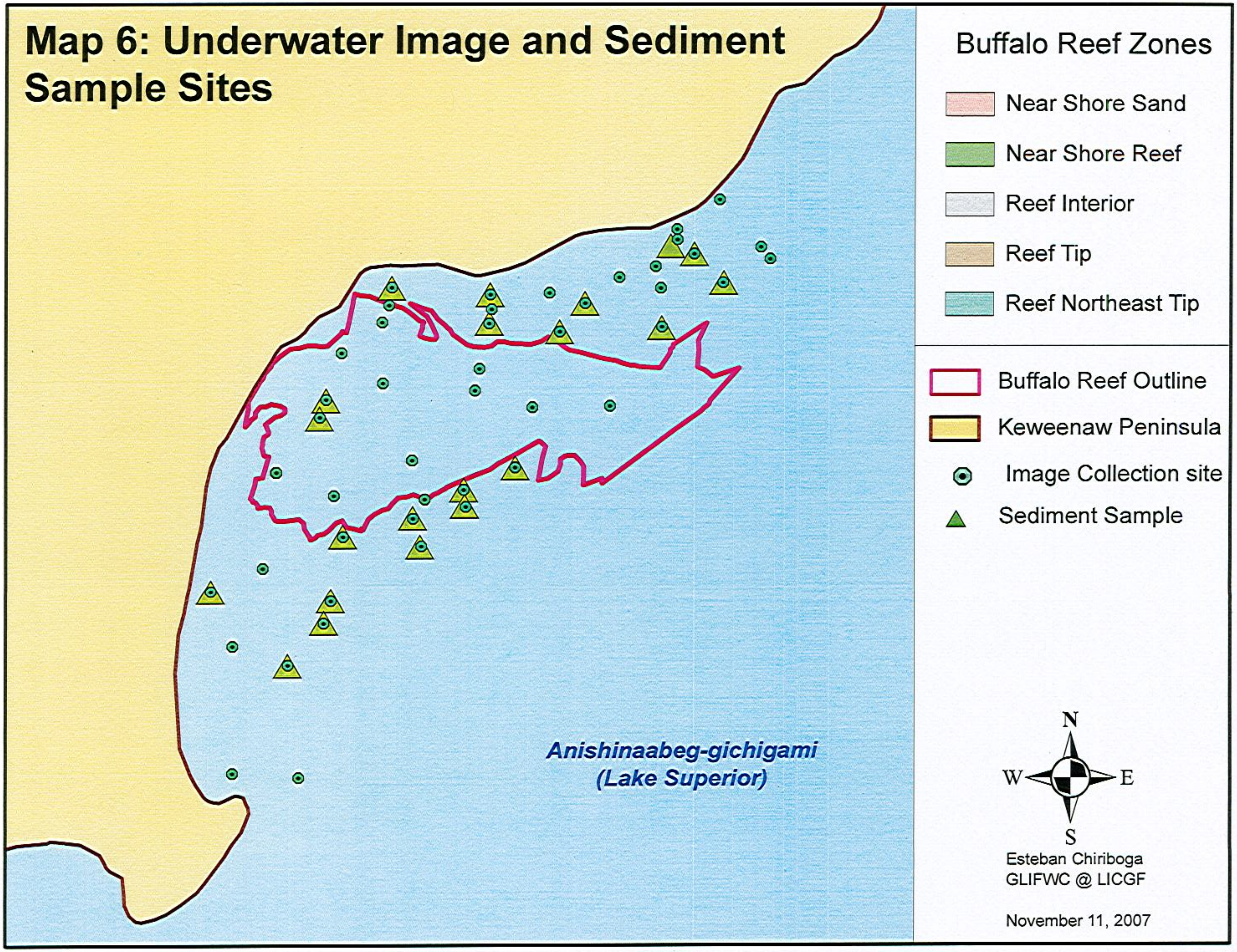
Esteban Chiriboga
GLIFWC @ LICGF
November 11, 2007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Near Shore Reef
Reef Interior
Reef Tip
Reef Northeast Tip
Buffalo Reef Outline
Keweenaw Peninsula
Image Collection site
Sediment Sample
Anishinaabeg-gichigami
(Lake Superior)
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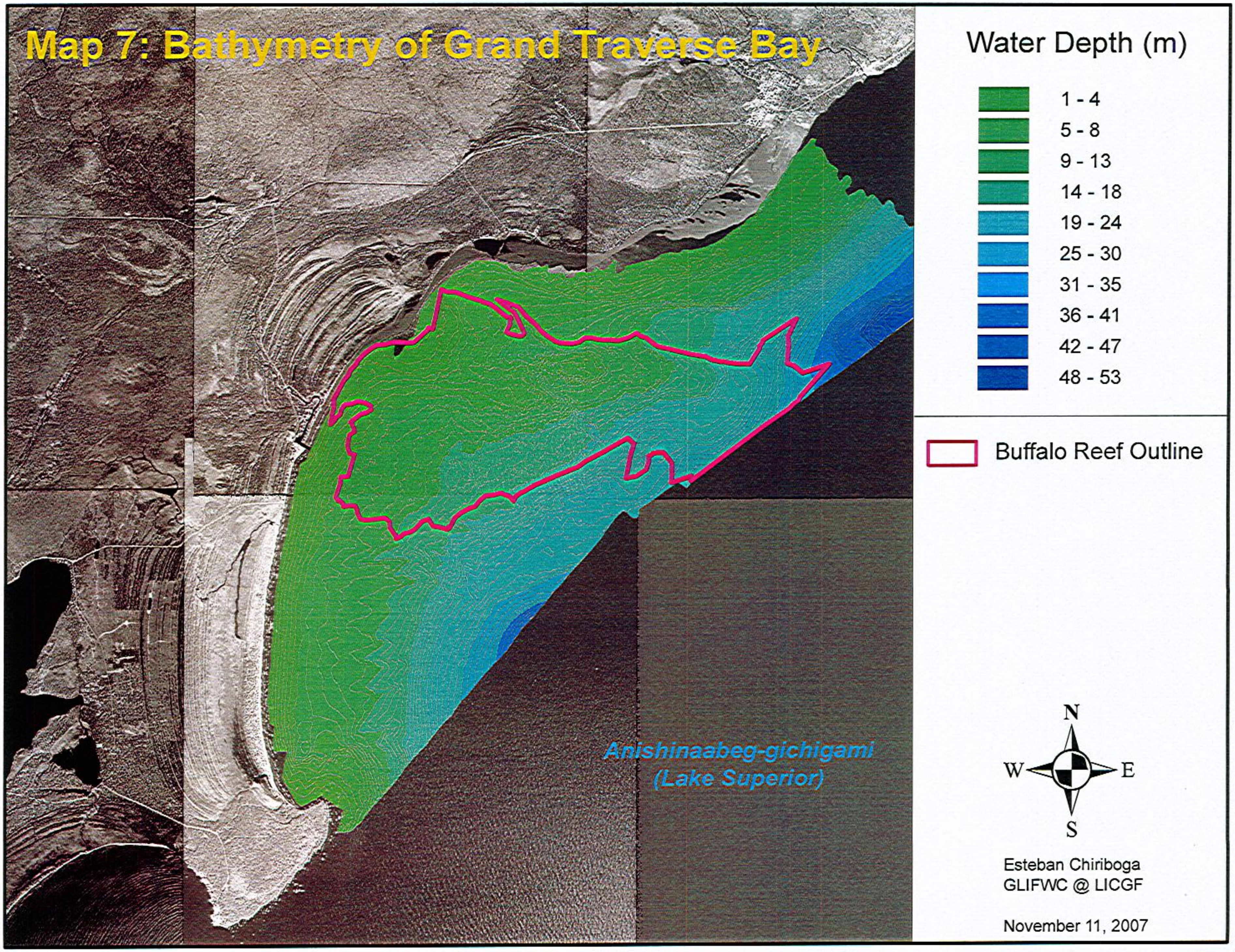
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Water Depth (m)
1 - 4
5 - 8
9 - 13
14 - 18
19 - 24
25 - 30
31 - 35
36 - 41
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48 - 53
Buffalo Reef Outline
Anishinaabeg-gichigami
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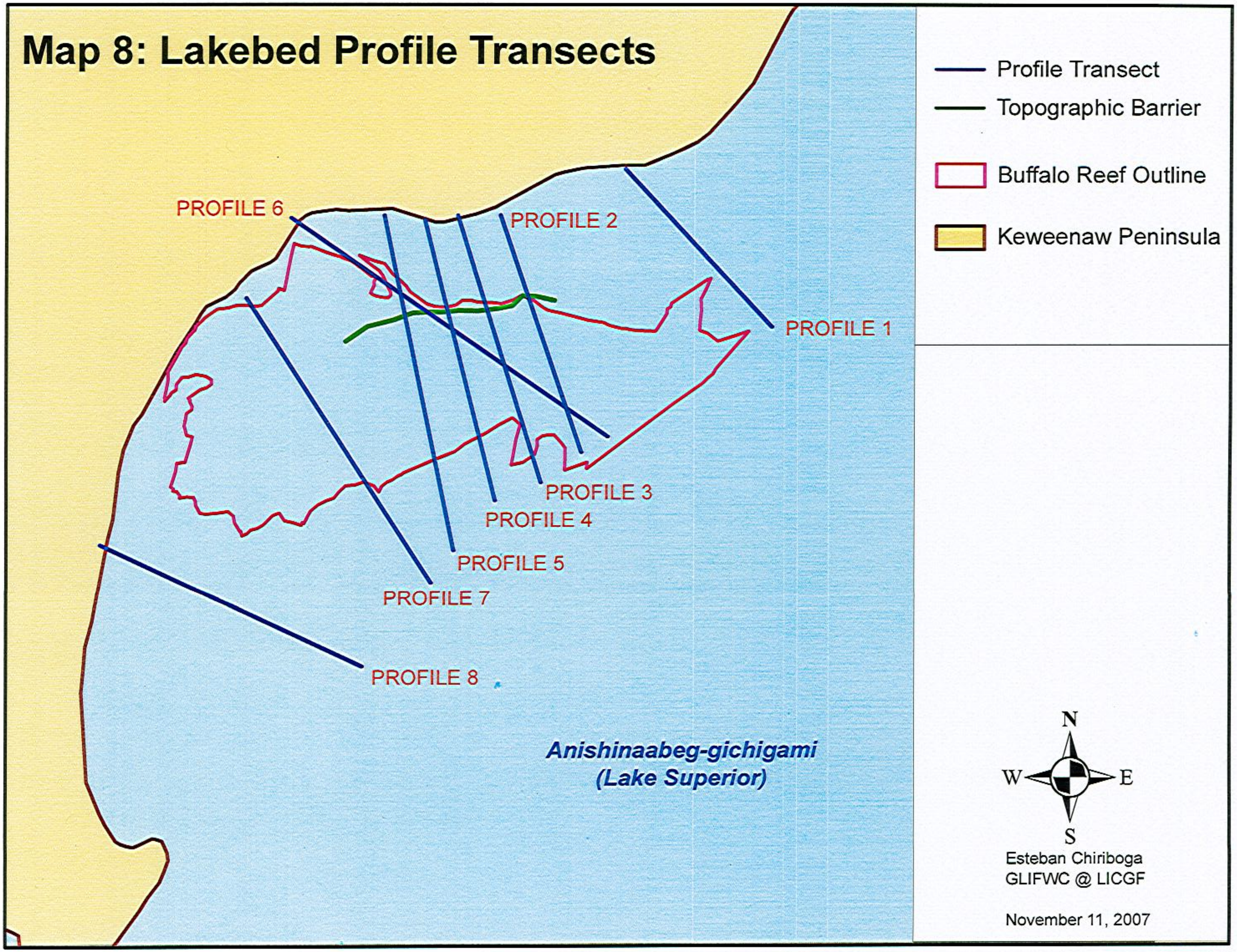
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Buffalo Reef Outline
Keweenaw Peninsula
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PROFILE 2
PROFILE 3
PROFILE 4
PROFILE 5
PROFILE 6
PROFILE 7
PROFILE 8
Anishinaabeg-gichigami
(Lake Superior)
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Esteban Chiriboga
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Appendix 1:

Quality Assurance Project Plan (QAPP)

QUALITY ASSURANCE PROJECT PLAN
GREAT LAKES INDIAN FISH AND WILDLIFE COMMISSION BUFFALO REEF AND STAMP SANDS SUBSTRATE MAPPING USING EPA SUPPLEMENTAL FUNDING

EPA Grant#: 96540801-0

June 14, 2005

Prepared by:
Esteban Chiriboga

Great Lakes Indian Fish and Wildlife Commission (GLIFWC)
At
Land Information and Computer Graphics Facility (LICGF)
University of Wisconsin-Madison
550 Babcock Dr. Rm B-102
Madison, WI 53706

APPROVED BY:

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Elizabeth LaPlante, EPA Project Manager Date

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Louis Blume, EPA Quality Assurance Manager Date

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Neil Kmiecik, GLIFWC Biological Services Director Date

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Bill Mattes, GLIFWC Great Lakes Section Leader Date

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Johann (Hans) Biberhofer, Environment Canada NWRI Date

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Esteban Chiriboga, GLIFWC GIS Mapping Specialist Date

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SECTION 1: PROJECT MANAGEMENT

1.1 QAPP Distribution List

EPA Project Manager: Elizabeth LaPlante

EPA Quality Assurance Manager: Louis Blume

NWRI Project Manager: Johann (Hans) Biberhofer

GLIFWC Biological Services Director: Neil Kmiecik

GLIFWC Great Lakes Section Leader: Bill Mattes

GLIFWC GIS Mapping Specialist: Esteban Chiriboga

1.2 Introduction

Buffalo reef is located in the Michigan waters of Lake Superior within Keweenaw Bay, and is roughly 1 mile by 1 mile (640 acres) with a smaller 1/2 mile by 1/2 mile (160 acres) area extending northeast toward Gay, Michigan. GLIFWC conducted fisheries assessments on this reef between 1986 and 2002 and documented that this is an important spawning reef for whitefish and lake trout.

Shallow deposits of copper enabled the Keweenaw Peninsula to become a productive mining region between 1864 and 1930. During this period, stamp mills were built near lakes and rivers to crush the ore and separate the copper from the rock by flotation. The waste material from these mills, referred to as stamp sands, was deposited in vast quantities in the vicinity of the stamp mills. Researchers from Michigan Technological University believe that approximately half a billion tons of stamp sands were either discharged directly into Lake Superior or into its tributaries from Keweenaw Peninsula mining operations.

While copper mining activities ended at many sites over 70 years ago, stamp sand deposits persist and are unable to support vegetation. It is interesting to note that the Gay Peninsula was artificially created out of stamp sands that were deposited in Lake Superior. It is this peninsula that continues to erode stamp sands into Lake Superior.

The Torch Lake Area of Concern is heavily impacted by the presence of similar stamp sands. Lakes into which stamp sands have been dumped have been found to be nearly devoid of benthic animals. Continued leaching of trace metals from the ore causes high concentrations in surface waters, concentrations that have been found above toxicity thresholds for many animal and plant species. Mining wastes have been identified in the Lake Superior Lakewide Management Plan 2000 as a principal stress to aquatic habitat in Lake Superior (LaMP 2000, p. 8-10.) In addition, LaMP 2000 identifies mapping of habitat in Lake Superior as a high priority goal. This goal suggests "using remote sensing and advance global positioning systems to describe the distribution and quantity of Lake Superior bottom substrates. . . especially in areas where habitat has been destroyed or altered." (LaMP 2000, p. 8-20.)

The National Water Research Institute (NWRI) of Environment Canada in partnership with the Keweenaw Bay Indian Community has mapped the location of sands south of this project area in Keweenaw Bay. The information collected by GLIFWC will help to complete the picture of the aquatic substrate distribution in Keweenaw Bay and will complement the tribes' work. Data collected by GLIFWC will use the same methods, researcher, and technology as was used in the Keweenaw Bay study. Therefore, these data are expected to be fully compatible. It will also provide additional detail for one of the spawning grounds documented by GLIFWC under a previous Great Lakes National Program Office (GLNPO) grant. Under that grant, GLIFWC used the Atlas of the Spawning and Nursery Areas of Great Lakes Fishes, Volume 2, Lake Superior (Goodyear et al. 1982) to map the general locations of all known Lake Superior spawning and nursery grounds. Those maps can be viewed at: www.lic.wisc.edu/glifwc/lake_superior.html.

The migration of stamp sands within Lake Superior is a concern because of the potential impact to Buffalo Reef. Some lake trout are known to use certain locations for spawning and will continue to return to those areas even if the substrate is no longer suitable. See, Scott C. McAughey and John M. Gunn. 1995. The behavioral response of lake trout to a loss of traditional spawning sites. Journal of Great Lakes Research Volume 21, Supplement 1, pages 375-383.

Anecdotal evidence from tribal fishermen suggests that the sands are indeed moving toward the reef. The extent of the stamp sands in relation to the reef needs to be determined so that fishery managers can evaluate whether the reef is currently impacted by stamp sands and determine what follow up management action may be appropriate.

1.3 Project Description

GLIFWC in collaboration with the National Water Research Institute (NWRI) of Environment Canada will use an acoustic seabed classification system (RoxAnn™) to conduct preliminary mapping of the extent of the Buffalo Reef spawning area to determine the boundaries of the suitable habitat on the reef and provide general information as to the extent of targeted substrates (both on and adjacent to the reef). The study will also investigate if the acoustic seabed classification system can discriminate an acoustic characteristic difference between stamp sands and native sands. Underwater video will also be taken in areas known to contain stamp sands and in areas of native sand in order to determine whether the sands can be distinguished visually. Samples of the sands will be collected for grain-size analysis (Shipek sampler). These samples will be archived in the event future chemical analyses are required. Once mapping of the reef is complete, mapping will advance to the northwest until stamp sands are encountered and confirmed by underwater video.

Should this study prove that it is technically feasible to map stamp sands as a unique substrate it will provide a baseline so that later surveys can document any migration of the stamp sands. The results of this work will be combined with an expanded lake trout and whitefish assessment that GLIFWC will conduct later in the year. GLIFWC will set six nets instead of the three that are normally set in a typical year. This information, along with GLIFWC's assessment data gathered over the past 15 years, will be entered into a database and GIS maps will be created that combine substrate information with fish distribution. This will help managers assess whether fish are spawning in the part of the reef that is most likely to be impacted by the migration of stamp sands, and determine the magnitude of the likely impact if the stamp sands do indeed move onto Buffalo Reef.

1.4 Project Organization

1.4.1 Management Responsibilities

US Environmental Protection Agency:

Project Director: Elizabeth LaPlante

1. Address issues presented by the project manager with regards to quality assurance and quality control.
2. Administers the grant and provides coordination between GLIFWC and the EPA.

Great Lakes Indian Fish and Wildlife Commission:

Project Manager: Neil Kmiecik

1. Review and approve the QAPP.
2. Review and approve the final report describing results of substrate mapping.
3. Review and approve reports to EPA.

Field Manager: Bill Mattes

1. Assist the GIS Mapping Specialist in the preparation of the QAPP.
2. Conduct Lake Trout and Whitefish assessments.
3. Prepare GLIFWC Project Report as final report and assist in the preparation of project status reports to EPA.
4. Ensure quality control and perform any needed corrective actions for fishery assessment work.

GIS Mapping Specialist: Esteban Chiriboga

1. Write the QAPP.
2. Develop maps from substrate data received from NWRI.
3. Develop maps from fisheries assessment results.
4. Assist in the preparation of the final and project status reports to EPA.

National Water Research Institute (NWRI):

NWRI Project Manager: Johann (Hans) Biberhofer

1. Design in collaboration with the GLIFWC and implement the logistics of the field program for acoustic mapping of the aquatic substrates.
2. Analysis and interpretation of the acoustic and relevant ground-truth data (underwater video and sediment samples)
3. Author a report detailing the acoustic survey study, the analysis and the results.
4. Provide GLIFWC with copies of the report (digital PDF format), thematic map layers of analyzed aquatic substrate and bathymetry data in ESRI ArcGIS format (Note bathymetry is for 3D spatial context only, not to be used for navigation).
5. Ensure quality control and perform any needed corrective actions for the acoustic mapping of the aquatic substrates.

1.4.2 Organizational Chart

Project Manager: Neil Kmiecik______________________Elizabeth LaPlante
| |_____ Louis Blume
|
Field Manager: Bill Mattes_____|_____GIS Specialist: Esteban Chiriboga
|
|
Acoustic Mapping: Johann (Hans) Biberhofer

1.5 Data Quality Objectives

- PDQO 1: Delineate the boundary of the Buffalo Reef.
- PDQO 2: Determine the extent of stamp sand encroachment into Lake Superior and the proximity of the sands to the spawning reef.
- PDQO 3: Combine the data obtained from this study with previous data gathered by the Keweenaw Bay Indian Community to provide a regional picture of stamp sand presence along the eastern shore of Keweenaw Bay.

1.6 Documentation and Records

NWRI will prepare a report detailing the acoustic survey, analysis and results and provide copies to GLIFWC. The GLIFWC field manager and GIS Specialist will prepare a report detailing the results of the fishery assessments at Buffalo Reef and a set of maps illustrating the results of both the acoustic survey and the fishery assessments. These reports will be submitted to the GLIFWC Project Manager for review and comment and a final report will be submitted to the EPA Project Director at the end of the project. All reports will be provided in both digital and hardcopy form.

1.7 Project Schedule

NWRI and GLIFWC are familiar with sampling locations on Buffalo Reef. NWRI will conduct the substrate data collection in July 2005 and will complete the work by the end of August 2005. GLIFWC will conduct the expanded fish spawning assessments in October and November 2005.

SECTION 2: DATA AQUISITION

2.1 Sampling Design

This project entails two phases: substrate mapping and fish spawning assessments. Substrate mapping will be accomplished through recognized RoxAnn technology that allows characterization and quantification of substrate types at bottom depths from 2-40 meters. The different substrate types identified by RoxAnn will be verified through videotaping and physical sediment sampling. The data will be collected from ship-mounted equipment. The boat will tend to run (on contour) along northeast/southwest transects in the area of Buffalo Reef with a series of intersecting transects. Sampling in other areas of the Great Lakes dictate 50 meter offsets in nearshore areas with water depths less than 20 meters. Boat speed will be maintained at 2 to 5 meters/second. The acoustic labels will be assigned substrate categories based on underwater video and sediment sampling that will target acoustically differentiated regions. Video sampling may also target areas of transition between substrate types. A specific NMEA GPS string (GPGST) will be logged to record the accuracy of the vessel's location. Computer generated RoxAnn data, navigation data and bathymetry will be backed up daily with a CD drive or external hard drive for later analysis.

Fishery assessment surveys will be conducted to determine the distribution and pattern of use of Buffalo Reef by spawning lake trout and whitefish. This information, along with GLIFWC's assessment data gathered over the past 15 years, will be put into a database and GIS maps will be created that combine substrate information with fish distribution.

2.2 Sample Methods

2.2.1 Substrate Mapping

Positioning Equipment:

The NovAtel OEM4 GPS has the capability to use several differential correction inputs. The more accurate of the two (listed below) that will be employed for the survey as determined by statistics reported by the GPS:
1. This study will be exploiting the recently available Canadian Differential Global Positioning System. (CDGPS). Corrections from geostationary satellites are received by a dedicated receiver as part of the shipboard electronics. A firmware upgrade of the NovAtel OEM4 allows for real-time corrections of the GPS position solution. Coverage maps indicate this service is available in Keweenaw Bay with expected 2D positional accuracy of 1-2 m.
2. Wide Area Augmentation System (WAAS). WAAS is designed to improve the accuracy and ensure the integrity of information coming from GPS satellites testing. The United States Federal Aviation Authority (FAA) in September 2002 confirmed accuracy performance of 1 – 2 meters horizontal and 2 –3 meters vertical throughout the majority of the continental U.S. and portions of Alaska. NWRI testing with this receiver in Michipicoten Bay on the north shore of Lake Superior reported accuracies consistent with the FAA findings.

One of the output strings from the NovAtel receiver provides pseudo-range measurement of noise statistics (GPGST) (NovAtel Volume 2 section 3.4.19, page 160) These statistics provide information on standard deviation of position and will be logged at 10 second intervals as an ASCII computer file during the field survey.

The GPGGA string (NovAtel Volume 2 section 3.4.19, page 156) will also be logged at 1 second intervals. In addition to providing position information, field 7 reports the GPS quality index. This log can then be used to assess quality of position as well as determine which differential correction was used for the GPS fix. Data without differential correction will be censored from the mapping data set.

Censoring the data for GPS error has no effect on the RoxAnn measurement but it does impact the spatial location of the measurement. The intent of this study is to provide the best spatial representation of the submerged substrate. As GPS technology has improved it is now possible to log GPS error and it is now possible to consistently have standard deviation in the GPS solution of less than 3m. The data is censored so that for any RoxAnn measurement, there is a position solution for which standard deviation is less than 5m for both the northing and the easting. Errors greater than 5m have generally found to be short-term interruptions in GPS quality. Censoring the data based on GPS error improves the quality of the data providing a tighter tie-in with ground truthing efforts and substrate maps are more representative of the actual surveyed area.

The GPS antenna is mounted directly above the transducer well that houses the transducer. During sediment sampling and underwater video recording the antenna is located on the davit immediately above the cable block.

Knudsen 320M Sounder:

The sounder used for substrate mapping is a digital hydrographic sounder Knudsen 320M (Knudsen Engineering Limited, 10 Industrial Road Perth, Ontario, Canada, K7H 3P2). The sounder is equipped with a dual frequency (50 kHz and 200 kHz) in-hull transducer.
At present, the data from the 200 kHz frequency is used for substrate mapping. Other software tools are being investigated for possible use the 50 kHz data as value added. The depth data for both sounder frequencies are displayed on a computer monitor in real-time, as well as being recorded via a SCSI connection to a dedicated computer as a digital file in the manufacturer's proprietary format. The software control of the sounder, data logging and post-survey interrogation is done through proprietary software provided by Knudsen Engineering Ltd.

Seabed Mapping:

The surveys will be run using two RoxAnn units (SonaVision Ltd, 16 Denmore Industrial Estate. Denmore Road. Aberdeen, AB23 8JW United Kingdom). The units are dedicated to a specific frequency and are operated at a set gain for each frequency as standard operating practice. Each RoxAnn unit receives the return echoes of the Knudsen sounder transmit pulse. To confirm RoxAnn system stability and appropriate signal response a standard artificial echo is generated with an external pulse generator. The pulse is varied to simulate a range of depths and compared against established values. The range of depths covers the time-variable gain (TVG) ramp to ensure linearity in response values. The signal input is generated using a depth sounder test set (DSTS-4A) (Electronic Devices, Inc. P.O. Box 15037, Chesapeake, VA 23328). An in-house computer program changes the depth and amplitude settings with input to the DSTS-4A via RS-232 interface. The output is recorded in a RoxAnn calibration file and compared with standard values.

During surveys, the vessel speed is kept between 2 ms^{-1} and 5 ms^{-1} as these speeds have been found to be the best operating range for the RoxAnn units (Rukavina, personal comm.). The system performance is further monitored through a pair of diodes mounted on the front panels of each instrument. A stable solid green is indicative of good performance whereas an unbalanced or no light is a warning that the system is not at optimum performance.

Software:

Datalogging

Positional data and input from the RoxAnn units is integrated using either a marine survey software package Microplot (Sea Information Systems, 5 Queens Terrace, Aberdeen AB10 1X1 United Kingdom) or Hypack (Hypack Inc.56 Bradley St. Middletown, CT 06457USA). The preliminary data as per a generic classification scheme data is displayed in real-time during the survey on a computer monitor. This makes it possible to further investigate changes in seabed features when encountered during the survey.

Navigation

HyPack software (Hypack Inc.56 Bradley St. Middletown, CT 06457USA) is used for setting and running survey lines. The survey grid is displayed on a computer monitor and the coxswain is able to navigate both by boat position relative to track-line as well as using the left-right indicator window. Survey position information is also recorded using HyPack as an ancillary data set.

Substrate Classification:

A combination of underwater video and sediment sampling is used to ground-truth and classify the recorded acoustic data. The sampling effort is a function of the variability of the substrate maps. Sampling target areas include both zones of homogeneity as well as regions of transition. Target areas are often where survey lines intersect.

Underwater Video:

An auto-iris underwater camera (Ocean Systems Ltd. 3901 Smith Avenue, Everett, Washington 98201 USA) is mounted on a tripod fabricated in-house at NWRI. The tripod is weighted to 40 kg and has graduated markings on the legs to measure depth of penetration in the sediment. The video feed from the camera is mixed with a VideoStamp unit (Intuitive Circuits LLC, 2275 Brinston Avenue, Troy, MI 48083 USA) to overlay the GPS position data, survey and site information. This combined image is recorded in a digital format either on 8 mm tape or on a digital video recorder.

Sediment Sampling

Sediment samples are collected with a Shipek or mini-ponar sampler from acoustic classes of sediment. The samples are described, digital photos are taken and the images are catalogued. The samples are described and subsampled for grain-size analysis. Sites selected for grain size analyses will be a subset of the sites investigated with underwater video. Samples are not attempted on rock or coarse gravel substrates. Sampling is intended to have representation of the different substrates encounter during the survey. Analysis is a combination sieve-sedigraph procedures described in: Duncan, G.A. and LaHaie, G.G. 1979. Size analysis Procedures Used in the Sedimentology Section. NWRI. Hydraulics Division Manual, September 1979.

2.2.2 Fish Spawning Assessments

To assess the distribution and pattern of use of Buffalo Reef by spawning lake trout and whitefish on Buffalo Reef, an expanded lake trout and whitefish spawning assessment will be executed. Descriptive data (i.e. age, sex, length, and weight) will be collected from individual fish.

The GLIFWC Great Lakes section will collect distribution data on lake trout and whitefish during the 2005 fall season (October-November) using gangs of gill nets. Lake trout spawn during mid-October to early-November over boulder or rubble bottom in waters less than 120 feet when water temperatures fall to 51 °F (Freshwater Fishes of Canada Bulletin 184 Fisheries Research Board of Canada, Ottawa 1973. Scott WB and Crossmand EJ). The net gangs will be deployed in <50 ft of water. The collection location in Lake Superior will be tracked by a GPS system.

Both ends of the gang will be marked with orange flags and buoys stating "GLIFWC Assessment". The nets will be removed within 24 hours of deployment or as soon as weather permits. Lake trout will be sampled using multifilament nylon gill nets, and whitefish with monofilament gill nets. Three gangs of gill nets (3 X 750 ft/gang) will be deployed at each lake trout sampling site. Each gang will consist of three 250 ft net segments connected end to end to make a total length of 750 ft. Within a single gang, one net segment will have a 4.5-inch stretch mesh, one net segment will have 5.0-inch stretch mesh, and one net segment will have 5.5 inch stretch mesh.

Fish will be identified to species by an experienced GLIFWC Lake Superior fisheries biologist or technician, measured for total length, round weight, and sexed. Data will be encoded on a field data sheet. Furthermore, an otolith from the trout and a scale from the whitefish that die during the survey will be collected and used to age the fish. The descriptive data will be recorded on the envelopes containing the otolith or scale.

Descriptive Fish Data:

Length

Total length of the fish will be used to select the samples. Total length will be collected using a ruler graduated to 1/10 of an inch. The total length of the fish will be from the anterior-most portion of the fish to the tip of the longest caudal fin rays when the lobes of the caudal fins are compressed dorso-ventrally.

Round Weight

The round weight is measured prior to removing any fish tissues. The round weight will be collected using a calibrated scale.

Collecting Aging Tissue

For dead lake trout the sagittal otolith will be removed from behind the brain of the fish. The head of the fish will be turned upside down and gripped firmly by the eye sockets with one hand; a cut will be made to remove the gills and expose the ventral portion of the prothesus bone. A second cut will be made through this bone. To expose the otoliths, quick downward pressure will be applied to the nose of the fish. The otoliths will be gently removed from the fish using tweezers and placed into a labeled envelope. Whitefish scales will be collected from below the dorsal fin of the fish. The fish will be laid on its side and the flat edge of a knife will be used to scrape scales from the side of the fish. Otoliths and scales will be aged and maintained by the Great Lakes Section Leader and his Technician.

Sex Determination

Sex of the live fish will be determined in the field by squeezing the fish and observing the extrusion (GLIFWC SOP Tf.005). When males are squeezed milt (a white creamy substance) is excreted and for females eggs (orange round balls) are excreted. Verification of the sex of all dead fish will be determined at by cutting open the peritoneal cavity and observing the gonads

(GLIFWC SOP Tf.003). The sex of the fish will be recorded in the appropriate location on the scale envelope and a field data sheet.

2.3 Sample Handling and Custody

All computer generated data, including RoxAnn data, navigation and bathymetry data will be backed up daily with a CD drive or external hard drive for later analysis. NWRI will maintain computer records of RoxAnn acoustic labels and position data, sediment samples, field notes and digital images of underwater video on 8 mm tape.

NWRI will prepare a report detailing the results of the survey. NWRI will also provide digital substrate data to GLIFWC in ESRI compatible format.

Sample scales and otoliths will be removed from the fish and placed into scale envelopes labeled with a unique number. This unique number will be recorded on the fall assessment datasheet along with biological data collected from the fish (i.e. length, weight). Each fall assessment datasheet will contain a unique number that corresponds to a location form containing information on the net set (i.e. GPS coordinates, depth). The field manager will transport the labeled scale envelopes to the GLIFWC main office where aging of the fish will be done. After aging is completed, the sample scales and otoliths are returned to the scale envelopes for permanent storage at the GLIFWC main office.

2.4 Quality Control

2.4.1 Field Activities

Computer generated RoxAnn labels will be assigned substrate classes based on underwater video and sediment sampling at specific sites depending on substrate signal and sub-region of the reef. Staff with 15 years of experience in fishery assessment methods will supervise fish assessments.

2.4.2 Precision

Acoustic labels will be compared at transect line intersects to confirm the precision of the RoxAnn processing. Underwater video taken during the soundings will provide visual ground truth information for the RoxAnn labels. In areas where video evidence is inconclusive, sediment samples will provide ground truth information for the RoxAnn labels. Precision during the fishery assessments will be ensured by cross checking of results among assessment team members and supervision by experienced staff.

2.4.3 Accuracy

As part of the position data a GPS data string (GPGST) will be logged throughout the surveying at 10-second intervals. This particular string contains statistics for the standard deviation in meters for longitude and latitude error. Differential GPS position data using either CDGPS or Wide-Area Augmentation System (WAAS) varies with location but in previous studies on Lake Superior has been found to be within 1 to 2 meters. Running 10% of all samples as duplicates ensures accuracy of the grain size analysis. Accuracy during the fishery assessments will be ensured by cross checking of results among assessment team members and supervision by experienced staff.

2.4.4 Sensitivity

The acoustic integrity for RoxAnn unit equipped with a 200 kHz sounder is limited to a range of 2 to 40 meters. Sensitivity is not applicable to fish spawning assessments.

2.4.5 Completeness

It is anticipated that whenever valid data are collected in the field and returned to shore, valid data will be generated for the substrate mapping. All of the analytical procedures in this project can be repeated in the event of a QC problem. As a result, it is anticipated that all data will be reported. Therefore, the amount of valid data obtained in this study shall likely be ≥90%. GLIFWC staff will survey the entire Buffalo Reef area. Therefore, completeness will be 100%

2.4.6 Representativeness

Representativeness is a qualitative parameter that is dependent upon the proper design of the sampling program. The sampling design will provide data representative of substrate types and fishery quality conditions. For substrate mapping this will be confirmed with underwater video and/or sediment sampling at several areas that have comparable acoustic labels. For the fishery assessment, GLIFWC staff will draw upon 15 years of experience conducting fisheries assessments in Lake Superior.

2.4.7 Comparability

The extent that existing and planned analytical data will be comparable depends on the similarity of the methods of sample collection and analytical methods. The study design of the substrate mapping effort will be comparable to data collected and reports written for a similar projects conducted by the Keweenaw Bay Indian Community. The fish spawning assessment will be conducted by GLIFWC based on 15 years of data collection experience.

2.4.8 Substrate Mapping

Accurate mapping requires that the acoustic signal data hardware and the positioning system, the spatial reference for the acoustic data, are operating at optimal performance and if there are deviations in the data that these points are flagged and rejected from further processing. The quality control information logged and used to censor data includes:

- Boat speed, which is to be limited to a range of 2 $m.s^{-1}$ to 5 $m.s^{-1}$
- Water depth – operating range 2 m to 40 m
- GPS accuracy – standard deviation of error – less than 3 m for both longitude and latitude
- Data are collected in suitable sea state conditions

2.4.9 Fish Sampling

Quality control of the fishery assessments will be provided by the presence and supervision of experienced GLIFWC staff. GLIFWC has been conducting this type of fishery assessment for over 15 years and GLIFWC staff are familiar with the area to be surveyed.

2.5 Instrument and Equipment Testing and Maintenance

Equipment	Testing and Preparation
GPS Reciever	Operation and maintenance according to manufacturer's instructions.
Knudsen 320M Sounder	Operation and maintenance according to manufacturer's instructions.
RoxAnn seabed mapping unit and Microplot software	Operation and maintenance according to manufacturer's instructions.
Shipek sediment sampler	Operation and maintenance according to manufacturer's instructions.
Underwater video camera	Operation and maintenance according to manufacturer's instructions.

Table1. List of equipment and equipment maintenance specifications.

2.6 Instrument Calibration and Frequency

Maintenance of all instruments and measuring equipment used for conducting field and analytical tests are necessary to assure they are functioning properly. Instruments and equipment will be calibrated prior to each use. Field instruments are calibrated according to manufacturer's specifications with a frequency sufficient to insure accurate measurements. In general, all equipment shall be calibrated prior to each use. A specific schedule of calibration providing dates and times of equipment calibration cannot be projected. Calibration information is maintained in a logbook for each piece of equipment to assess the history and frequency of the calibration of a given instrument. Equipment is calibrated according to standards established by the manufacturer of the instrument.

Equipment will be examined before each use to verify it is in good working order. Field notes from the previous trip will be reviewed to insure that any equipment problems previously noted have been resolved. Records of the time and results for all instrument calibrations will be kept either in a logbook associated with a given instrument or in the field notebook.

SECTION 3: DATA ASSESSMENT AND OVERSIGHT

3.1. Performance and System Audits

Performance and system audits of field activities are conducted to verify that sampling and analysis are performed in accordance with the procedures established by this QAPP. Both internal and external audits are used by NWRI. Experienced GLIFWC biologists will direct the fishery assessments and will audit the methods used in field data collection.

3.2. Corrective Actions

3.2.1 Field Activities

Project personnel are responsible for reporting all suspected technical, QA nonconformance, or any other suspected problems with any activity, to the Project Manager. The Project Manager is responsible for assessing the suspected problem through consultation with EPA Region 5 GLNPO personnel. Correction actions may include:

- Repeat measurement to check for error
- Check for proper instrument correction settings e.g. temperature setting
- Check batteries
- Check calibration
- Service the instrument

Problems not involving measurements may also be encountered that may require corrective action. If for some reason a sampling site becomes unusable, careful consideration is given to the designation of an alternative site, and how this might impact the comparability of the data.

SECTION 4: DATA VALIDATION AND USABILITY

4.1 Data Reduction, Validation and Reporting

4.1.1 Data Reduction

NWRI will report the results of the substrate sounding fieldwork and provide ESRI compatible data to GLIFWC's GIS Mapping Specialist. The results of the fishery assessments will be enter into a computer spreadsheet under the supervision of the Great Lakes Section leader.

4.1.2 Data Validation

All analytical data is reviewed at several levels. Mr. Biberhofer will review NWRI data as collected by field staff. The Biological Services Division Leader approves the reports that GLIFWC will prepare and submit to the EPA. Copies of all raw data will be maintained by GLIFWC and will be available for review by the US EPA.

4.1.3 Data Reporting

As required by the grant, GLIFWC will prepare semi-annual progress reports and submit them to the EPA Project Manager. These progress reports will describe the status of all work performed by GLIFWC and NWRI as of the date of the report. The progress reports will include any changes to the project schedule, changes to the QAPP, and any problems or corrective actions taken during the fieldwork.

NWRI will prepare a report to GLIFWC from data collected and analyzed by NWRI. GLIFWC's Lake Superior Biologist and GIS Mapping Specialist will also be provided copies of the resulting thematic maps for additional interpretation and integration with the other study components. This report will be reviewed by GLIFWC's Biological Services Director and delivered to the Project Officer in Region 5 of the US EPA. Within this report shall be a summary of all data collected to date, a summary of results and interpretations of the data, a summary of the findings from the assessment involving the reconciliation of the data with the data quality objectives and the current status of the project relative to its objectives. If there is need to revise the QAPP, project schedule or objectives, these will also be included as well as the basis for any revisions.

4.2 Custody of Data Records

Copies of the raw results from the substrate mapping analyses shall be stored in digital format at the GLIFWC satellite office in Madison, Wisconsin. Data sheets and samples from the fish spawning assessments at Buffalo Reef will be stored at the GLIFWC main office in Odanah. Copies of final results, reports, and field logbooks will be stored at both GLIFWC locations. All data will be stored for as long as GLIFWC exists.

Data compiled into Excel and ArcGIS computer databases shall be stored in the Madison office of the GIS mapping specialist with backup versions stored on the GLIFWC web server. All data will be stored for as long as GLIFWC exists.

NWRI archives all seabed mapping data and sediment samples collected during the project.

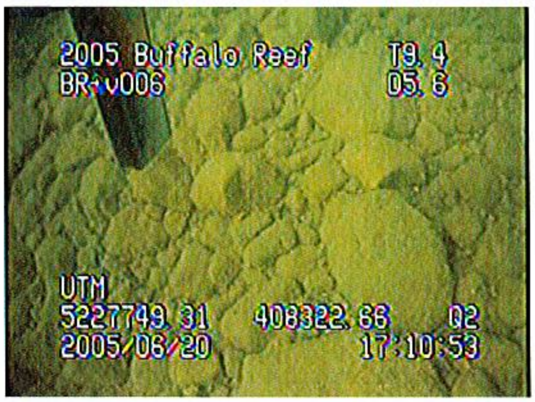
Appendix 2:

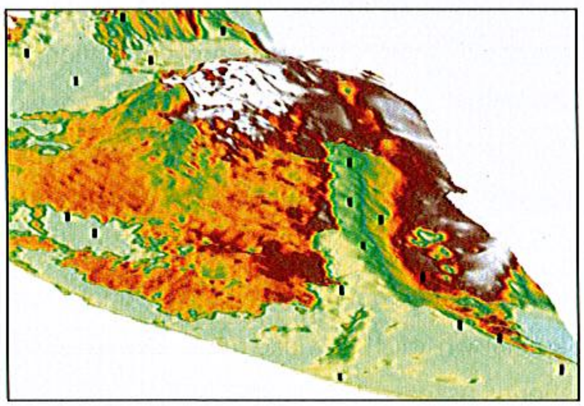
Delineation and Characterization of Aquatic Substrate Features On and Adjacent to Buffalo Reef, Keweenaw Bay, Lake Superior.

National Water Research Institute (NWRI)

Delineation and Characterization of Aquatic Substrate Features on and Adjacent to Buffalo Reef, Keweenaw Bay, Lake Superior.

DRAFT





Prepared by:

J. Biberhofer and

C.M. Prokopec

Environment Canada

National Water Research Institute

NWRI Technical Note No. AEMRB-TN06-XXX

Introduction

The discovery and exploitation of shallow copper-rich ore deposits in the Keweenaw Peninsula resulted in this region being one of the most productive mining regions in the United States from the mid 1800's to the early 1900's. Waste material from the ore processing facilities was discarded adjacent to and in nearby lakes and rivers. This legacy of mining waste continues to represent a significant threat to local and regional environment even though the mining activities ended over 30 years ago (Kerfoot *et al*, 1999). Erosion and transport of shore-based stamp sand inventories are suspected to be encroaching on critical aquatic habitats including those used for spawning of valued fish species.

Mining wastes have been identified in the Lake Superior Lakewide Management Plan 2000 (LaMP 2000) as a principal stress to aquatic habitat in Lake Superior (LaMP 2000). In addition, the LaMP 2000 identifies mapping of habitat in Lake Superior as a high priority goal. This goal suggests "using remote sensing and advance global positioning systems to describe the distribution and quantity of Lake Superior bottom substrates. . . especially in areas where habitat has been destroyed or altered." (LaMP 2000)

While copper mining activities ended at many sites over 70 years ago, stamp sand deposits persist and are unable to support vegetation. The Gay Peninsula was artificially created out of 22.6 million metric tons of stamp sands that were deposited along and in Lake Superior (Kerfoot and Robbins, 1999) and this peninsula continues to erode stamp sands into Lake Superior and towards Buffalo Reef (Rasmussen *et al*, 2002).

Buffalo Reef Keweenaw Bay, Lake Superior provides critical spawning habitat for Lake Superior whitefish and lake trout. Great Lakes Indian Fish and Wildlife Commission conducted fisheries assessments on this reef between 1986 and 2002 and documented the fact that this is an important spawning reef for whitefish and lake trout. In 2005 the National Water Research Institute of Environment Canada in collaboration with the Great Lake Indian Fish and Wildlife Commission undertook to map and classify substrate types for Buffalo Reef and Grand Traverse Bay. The quantification of substrate types will provide an estimate of spawning habitat as well as describe the adjacent substrates. This study also investigates if it is possible to differentiate with acoustics between stamp sand and natural sand deposits.

Stamp sands have been documented to be encroaching on Buffalo Reef and could potentially compromise the spawning habitat.

Study Area

Buffalo Reef is situated approximately mid-latitude on the eastern side of the Keweenaw Peninsula, north of Keweenaw Bay, Lake Superior (Figure 1). The reef is somewhat triangular in shape and is approximately 9 km^2 in area. The western edge of the reef is immediately adjacent to the shallow waters of Grand Traverse Bay, whereas the eastern extent is delineated by deeper waters (>40 m). The southern boundary of the reef borders on natural sands within Grand Traverse Bay. Immediately north of Grand Traverse Bay and Buffalo Reef are the relicts of the shore-based ore processing site and its associated peninsula of stamp sands located in Gay, Michigan

Field Procedures

Positioning

A NovAtel 3151W differential Global Positioning System (DGPS) with a 2 carrier signal antenna was used to determine position coordinates for the soundings, underwater video and sediment sampling. The accuracy of the DGPS was enhanced by integrating an ePing receiver to receive differential corrections based on the MSAT satellites of the CDGPS network (http://cdgps.com/e/desc.htm). In the event that the MSAT signal was lost the DGPS is also enabled to include real-time Wide Area Augmentation System (WAAS) corrections as part of the DGPS solution. Position accuracy was monitored throughout the survey effort by recording the NMEA GPGST output string from the DGPS at one second intervals. The GPGST string includes information on the standard deviation of the longitude and latitude of the DGPS solution.

Survey lines and target positions were created and displayed in Hypack © version 4.3 navigation software. The software provides a real-time left-right indicator and target proximity information for the coxswain. Tracklines were generally run within 5 m or better of the planned lines and positioning for video and sediment sampling were typically within 1-2 m of target position.

Substrate Mapping - RoxAnn

Acoustic mapping of surface sediment with a RoxAnn™ seabed-classification system (Rukavina 1998, Rukavina and Cadell 1997) has been used at a number of sites in the Great Lakes basin to investigate the distribution of substrate types. This technology has recently been applied to map aquatic substrates to identify and quantify critical fish habitat in Lake Superior (Biberhofer 2003, 2004 and 2005).

The survey vessel Petrel, a 7 m aluminium launch, was equipped with a dual-frequency (50 kHz and 200 kHz) digital Knudsen sounder (Model 320M) with a combined in-hull transducer. The return signal from each frequency of the sounder transmit was measured and processed with a dedicated RoxAnn seabed-classification system unit. This study will report only on the high-frequency data. The RoxAnn survey efforts were conducted June 15-19, 2005 inclusive. Sounding lines were determined to provide the most efficient coverage of the reef; typically lines over the reef were at 50 m offsets while other areas within Grand Traverse Bay were at 100 m offsets. The survey area was 27.79 km^2 with a total of 488.8 km of sounding lines (Table 1, Figure 2).

The RoxAnn output signal, G1 (roughness) and G2 (hardness), was converted to an acoustic label based on the position of the G1 and G2 variables on a Cartesian plot established in the Microplot™ survey software running on a dedicated rack-mount computer. The Microplot software logs the labels and the corresponding water depth and DGPS positions at 1-second intervals which are displayed in real time on a geo-referenced map (Figure 3).

The integrity and stability of the acoustic data acquisition system was assessed by measuring the RoxAnn outputs in response to a programmed range of simulated sounder transmits. These data were logged at the beginning and end of each survey day to confirm equipment performance and integrity.

Underwater Video

An underwater camera mounted on a weighted tripod was used to collect underwater video records of the substrate at 43 sites that were selected based on preliminary classification of the acoustic data (Table 2, Figure 4). The legs of the tripod have 10 cm colour gradations useful for comparing substrate size and depth of penetration when the camera is lowered onto the substrate. A DGPS antenna was mounted on the davit used for lowering the camera (Figure 5). At fixed target sites efforts were made to keep the boat stationary or at very low speeds to optimize the vertical and position accuracy between the antenna and the camera lowered in the water. Station information, real-time position data as well as camera depth and water temperature combined using custom software are combined and then overlaid on the video signal from the camera with a VideoStamp ™ processor (Figure 6).

At some sites, particularly those sites that transitioned from sand to cobble or at sites where the substrate was heterogeneous due to debris, it was useful to record video transects as the boat drifted or moved slowly under power. During some instances, the position information was degraded up to 3 metres due to the slope of the line from the davit to the camera's tripod.

The video was recorded in a digital format on 8mm tape. Selected segments of the video were then extracted as computer video files and representative still images were captured as ground-truth data (Appendix 1). Digital video and still images can were also hyperlinked in Geographic Information System (GIS) layouts to compare substrate maps with video data.

Sediment Sampling

Sediment samples were collected at 21 sites which were a subset of the underwater video sites (Table 3, Figure 7). A Shipek sampler was employed, which is very effective at collecting surface sediment. This depth of sediment (0-3 cm) represents the characteristics discriminated by the high-frequency return echo recorded with the RoxAnn seabed classification system. The sampler was deployed from a winch and davit setup on the launch with a DGPS antenna mounted on the davit, similar to the setup for the underwater video. The sediment was described, photographed and a sub-sample was collected, freeze-dried and submitted for particle size analyses (Duncan and LaHaie, 1979) (Appendix 2).

Data Analysis

Position data

There was a total of 103,379 records for both position and sounding data. The position solutions were evaluated based on the standard deviation values for both the east and north components. Records that had standard deviations greater than 5 m for either the north or east direction (n= 28) were excluded from the dataset. Frequency distribution analysis results are that for east component 99% data had a standard deviation of 1 m or less and 98.5% of the north component of the solutions were at 1.5 m or less standard deviation (Figure 8).

Bathymetric data

The water depth data can be collected over a wider range of vessel speeds and depths than the RoxAnn measurements. The bathymetric dataset (June 15-19, 2005) includes the depth data logged during RoxAnn sounding lines and during transit when the vessel speed was less than 8 $m.s^{-1}$.

The water depth data was adjusted to International Great Lakes Datum 1985 (IGLD85) using the 6-minute water level data. Two sites were possible for corrections; Marquette, MI (Station identification Number: 9099018) located 91 km southeast of the survey area and Ontonagon, MI station (Station identification Number: 9099044) located 91 km southwest (http://glakesonline.nos.noaa.gov/geographic.html, 2005). The Marquette site as deemed the most appropriate for water level corrections as it would be exposed to comparable wind events as the survey area. The water level at Marquette varied by 0.11 m over the survey time periods similar to Ontonagon which had a range of 0.129 m. Mean station elevations were 183.425 m (n=1006) and 183.413 (n=1006) for the Marquette and Ontonagon stations respectively. Even though both stations which are located on either side of the Keweenaw Peninsula reported similar levels, it is possible that water levels at Grand Traverse Bay may have been affected by local wind conditions or other phenomena that was not realized at the water level gauging stations.

A spatial raster model of the final bathymetric data (cell size = 3 m) was generated using the natural neighbour algorithm of the 3D Analyst extension of ArcGIS © (Environmental Systems Research Institute Inc (ESRI)). The 3D model provides both a spatial context for the substrate data as well as identifying submarine topographical features that may modify the expected acoustic return data (Figure 9).

Substrate Mapping – RoxAnn

RoxAnn data were edited using spreadsheet macros to remove records for which the actual water depths were less than 2 m or greater than 40 m which are the operational limits for the high-frequency RoxAnn system. The data were further edited to remove soundings that were collected at boat speeds of less than 2 $m.s^{-1}$ or greater than 5 $m.s^{-1}$. Vessel speeds outside the 2 to 5 $m.s^{-1}$ range can result in shifts of RoxAnn labels to coarser and harder sediment classes than are actually present (N. Rukavina, personal comm.). Air bubbles or eddies under the vessel's hull compromise the RoxAnn signal integrity and are sometimes encountered when the velocities exceed the upper limit of speed range or when the seas are too rough. Processing for water depth and velocity resulted in the raw dataset of 103,379 soundings being reduced to 96,178 soundings for seabed classification.

The edited RoxAnn dataset was imported into Systat ® (Version 11, Systat Software Inc.) a Windows based statistical software package. The records were then clustered using the Systat K-means procedure with Euclidean distance as the distance metric and number of iterations set to 20. Several combinations were tested using G1, G2 and $\log_{10}$G1, $\log_{10}$G2 as the variables. The number of clusters was varied from 6 to 9.

The dataset and the resulting cluster identifier file were merged and exported into an ArcGIS ArcMap © (Environmental Systems Research Institute Inc (ESRI)) readable format. The cluster identifier was then mapped as a substrate class in an ArcMap GIS project. A number of classification schemes were evaluated, with the final assignments being derived from a combination of splitting overlapping groups and consolidating others that represented a similar substrate (Figure 10).

Spatial Analysis

To quantify the areal distribution of the substrates types, the classified RoxAnn data was ingressed into MapViewer ® (Version 6, Golden Software Inc.) as the data source for generating Thiessen polygons. The procedure creates polygon boundaries from point data such that a region is drawn around each point and every element of the boundary of that region is closer to that point than to any other point. The substrate classification of the associated data point was assigned to the area represented by the polygon. The boundaries of the analysis were limited to the nearshore extents of the edited soundings.

As the extent of an individual Thiessen polygon is an extrapolation to the boundary of the adjacent polygon, the accuracy of the substrate area estimates can be affected by distance offset between track lines and the degree of natural variability of the underwater features. Regions that tend to be uniform over larger areas are well represented with the Thiessen polygon procedure. The nearshore areas are often more heterogeneous which is often captured with tighter survey patterns resulting in smaller polygons and shorter distances to extrapolate. It is possible that there may be features that were not detected. However, based on the sounding coverage used for the survey, the Thiessen polygon method is expected to provide a reliable estimate of the distribution of the substrate types based on the classification techniques employed. The resulting polygon themes were ingressed into ArcMap for further processing and integration with other thematic data.

Results and Discussion

Bathymetry of Buffalo Reef

The survey covered 27.79 km^2 from immediately south of Gay, MI to the southern extent of Grand Traverse Bay. The bathymetry data ranged from 2 to 53 m with the deeper waters delineating the eastern offshore extent of the survey area. Table 4 provides details of the water depth distribution calculated using the same procedure employed to generate polygons for substrate distribution.

The reef is the prominent feature of the submerged landscape that projects from the shore just north of the entrance to the harbour and extends in a west to east direction. The raster model of the bathymetry indicates that a crevice or trough that bisects the reef and continues to the edge of the slope deeper waters (Figure 11). There are plateaus of bedrock at the north and south extents of the survey area. The beach south of Buffalo Reef extends out as a gentle slope for approximately one quarter of the survey extent and as the slope increases and the depth contours become scalloped with a series of ridges and troughs. It is important to note that the vertical dimension has been exaggerated by a factor of 30 to be able to identify bathymetric features within the extent of the study area.

Substrate Classification

The substrate for the survey area ranges from exposed bedrock to cobble and then sands both natural and stamp sands. Seven distinct substrate classes were derived based on the analysis of the processed acoustic data in conjunction with sediment particle size data and underwater video imagery. Representative images of the substrate types are shown in figure 12.

The classes are described as:

1. **sand (fine - medium, often with waves)**
2. **sand (compact or coarse)**
3. **sand (fine - medium, unconsolidated)**
4. **sand (medium to coarse, unconsolidated)**
5. **cobble (interstitial spaces)**
6. **cobble (pavement or with thin sand patches)**
7. **bedrock or fractured bedrock**

The classified RoxAnn soundings lines (Figure 13) and the resulting substrate distribution Thiessen polygon model (Figure 14) highlight the prominence of the reef material and how it intersects the Grand Traverse Bay with sand regions on each side of the reef. The areal distribution of the substrate classes are summarized in table 4.

Categorical assignments of substrate classes can sometimes obscure the transitional gradients that may exist. Raster models (nearest neighbour algorithm, cell size = 5m) of the hardness and roughness variables provide additional information as to how definitive the substrate classes are with respect to degree of change measured by the acoustics (Figures 15 and 16). The raster models have good agreement with the substrate classes and emphasize that the boundaries between the substrate classes are well defined with limited margins of transition.

Buffalo Reef represented approximately 9 km^2 or 32% of the study area based on the central portion of cobble and bedrock. It was possible to discriminate between cobble that formed a pavement or had patches of thin sand with areas of cobble that had interstitial spaces. The latter which was 3.8 km^2 or 42% of the reef is potentially the area of optimal spawning habitat based on substrate as the interstitial spaces would provide protection from wave energy and as have well oxygenated surface water (Marsden *et al*, 2005).

While the sand substrate classes were acoustically distinct, the environmental relevance has yet to be determined. These classes were retained as it recognized that differences in compaction and other physical attributes such as grain size can modify the suitability of substrates as well as being indicative of physical processes.

Subsets of the acoustic records were selected for an area that was primarily stamp sands and from another that was composed of natural sand. The subsets were assigned identifiers and then combined in a scatter plot to determine if there were any acoustic biases that could be used classify stamp sands as a unique substrate. The data overlap of the two sets of sounding values confirmed that it is not possible to differentiate the sands with RoxAnn technology based on original material. However, it is of value to note the sands classified as sand (coarse or compact) north of Buffalo Reef do appear to be stamp sands based on visual inspection of substrate samples.

Analysis of the grain size data reveals that physical sorting of stamp sands has been taking place as the material is transported along the shoreline. The grain size distribution shifts predominantly coarse sand (BR_s017) to medium-fine sands (BR_s001) to mainly fine sands (BR_s007) (Appendix 2). This is congruent with expected wave energy gradient. On-shore waves erode and mobilize the stamp sands deposited along the shore. As material is transported the protection provided by the bedrock shelf to the south of Gay and Buffalo Reef comes into effect and the material sorts along the shoreline with the fines accumulating in the lower energy zones. Suspended fine-grain material originating from the stamp sand deposits along the shore was noticed in the water column when north-east winds were prevalent. This would represent a fraction of fine-grained material that could be transported over the reef and beyond (Figure 17).

The substrate class sand (fine-med, unconsolidated) is a curiosity in that it has a comparable grain size distribution with the class sand (fine-medium, with waves) but is an acoustically distinct class with well defined boundaries. This definition is consistent in both the categorical assignment of the substrate attributes as well as when the hardness attribute (G2) is mapped as a continuous variable (Figure 16). Most of the material as mapped, was limited to the offshore boundary of the cobble with sand patches with the majority deposited at the southern base of Buffalo Reef. There were also some smaller sections offshore of the bedrock shelf at the northern extent of the survey area. At both locations most of the material was bounded between the 21 and 26 m contours. A small fraction was found in waters up to 30 m in depth. There is also a subtle ridge of sand (fine-med, unconsolidated) evident for the southern deposit when the vertical scale is exaggerated (Figure 18). It could be speculated that this material represents sands being transported to deeper waters and possibly the 21 m contour is the lower limit of the wave energy. Also at both sites, there was a parallel offshore band medium to coarse sand that was also unconsolidated and represented another unique class. Offshore coarser material may be affected by deep water currents as this material may extend out past the protection provided by Buffalo Reef.

Summary

The substrate in Grand Traverse Bay ranges from fine sands through to cobble and bedrock. Lake trout spawning habitat consistent with the descriptions by Fitzsimons (1995) and Marsden *et al* (2005) that represents approximately 42% Buffalo Reef and 13.5 % of the survey area. Buffalo Reef and Grand Traverse Bay as a whole were bounded along the offshore eastern extent by deeper waters (> 50 m) (NOAA Chart 14964_1). The degree of slope approaching the reef is not as steep as sites describe as lake trout spawning for Lake Ontario by Fitzsimons (1995); however assessment studies by Great Lakes Indian Fish and Wildlife Commission have confirmed that Buffalo Reef is an important spawning area for lake trout and whitefish.

While the acoustic technology used in the study could not differentiate between the origins of the sands, it could clearly discriminate the boundaries between sand and other substrates. Changes in the boundaries could be measured in future mapping surveys. This effort could be enhanced with a sediment sampling program targeting the areas mapped as sand substrate north of Buffalo Reef. Combining the boundary information and the sand's origin from the sediment samples it would be possible to determine the rate at which the stamp sands are encroaching on the reef. Visual observations of the shoreline material and the limited number of bottom sediment samples do indicate that the stamp sands have migrated towards the northern boundary of Buffalo Reef. Buffalo Reef and the break wall at the harbour entrance appear to be affording some protection to the southern portion of the bay from the stamp sand incursion.

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MapViewer is a registered product of Golden Software

Tables:

Table 1: Survey Effort.

RoxAnn Sounding Tracks								
Collection Date	Raw Start Time	Raw Finish Time	Number of Records			Distance Covered (km)		
			Raw	RoxAnn Edited	Bathymetry Edited	Raw	RoxAnn Edited	Bathymetry Edited
15/06/2005	10:21:32	16:41:21	19842	19694	19832	79.010	78.633	78.994
16/06/2005	10:01:18	16:56:15	20921	19766	20916	90.325	89.096	90.306
17/06/2005	8:50:58	19:05:52	27114	25586	26917	126.577	120.228	123.602
18/06/2005	9:13:32	17:32:19	21575	18465	20963	118.341	93.495	109.163
19/06/2005	9:19:26	14:59:39	13927	12667	13884	74.570	62.773	74.362
		Total:	**103379**	**96178**	**102512**	**488.823**	**444.224**	**476.427**

Shipek and Video Sounding Tracks								
Collection Date	Raw Start Time	Raw Finish Time	Number of Records			Distance Covered (km)		
			Raw	RoxAnn Edited	Bathymetry Edited	Raw	RoxAnn Edited	Bathymetry Edited
2005-06-20v	10:38:36	17:58:52	20766	N/A	N/A	45.028	N/A	N/A
2005-06-21s	9:26:06	14:28:54	15873	N/A	N/A	26.881	N/A	N/A
		Total:	**36639**	**N/A**	**N/A**	**71.909**	**N/A**	**N/A**

Table 2: Location of Underwater Video Sites.

Site	Date	Easting	Northing
BR_V001	20/06/2005	409627.88	5228838.43
BR_V002	20/06/2005	409643.30	5228656.27
BR_V003	20/06/2005	409613.57	5228481.51
BR_V004	20/06/2005	409494.31	5227922.19
BR_V005	20/06/2005	409441.31	5227653.84
BR_V006	20/06/2005	408322.66	5227749.31
BR_V007	20/06/2005	408428.70	5228924.33
BR_V008	20/06/2005	408394.19	5228704.35
BR_V009	20/06/2005	408311.90	5228497.96
BR_V010	20/06/2005	407631.24	5227545.78
BR_V011	20/06/2005	407551.50	5227327.53
BR_V012	20/06/2005	410781.84	5228729.39
BR_V013	20/06/2005	410474.11	5228379.49
BR_V014	20/06/2005	409931.05	5226713.30
BR_V015	20/06/2005	412458.35	5228984.12
BR_V016	20/06/2005	412411.06	5230014.00
BR_V017-1	20/06/2005	412918.36	5229426.05
BR_V017-2	20/06/2005	411898.72	5229518.10
BR_V017-3	20/06/2005	411897.06	5229646.78
BR_V018	20/06/2005	412105.02	5229342.29
BR_V019	20/06/2005	413028.03	5229279.12
BR_V020	20/06/2005	411085.14	5227463.22
BR_V022	20/06/2005	411698.70	5228918.30
BR_V024	20/06/2005	409301.30	5226437.86
BR_V025	20/06/2005	408687.31	5226081.16
BR_V026-1	20/06/2005	408674.14	5226797.51
BR_V026-2	20/06/2005	408675.72	5226797.63
BR_V027	20/06/2005	408788.79	5225736.12
BR_V028-1	20/06/2005	407687.23	5225054.78
BR_V028-2	20/06/2005	407689.53	5225052.25
BR_V029	20/06/2005	406490.08	5222905.25
BR_V030	20/06/2005	407297.79	5222853.98
BR_V031	20/06/2005	407166.82	5224255.63
BR_V032	20/06/2005	406490.38	5224490.42
BR_V034	20/06/2005	407834.99	5225853.95
BR_V035	20/06/2005	407726.52	5226363.61
BR_V036	20/06/2005	406860.92	5225464.42
BR_V037	20/06/2005	408827.08	5226318.81
BR_V038-1	20/06/2005	407016.03	5226654.07
BR_V038-2	20/06/2005	407027.14	5226653.61
BR_V038a	20/06/2005	410139.37	5227449.93
BR_V040	20/06/2005	407815.79	5228117.29
BR_V041	20/06/2005	409327.76	5226227.88
BR_V044	20/06/2005	411636.31	5229186.43
BR_V045	20/06/2005	411715.02	5228437.64
BR_V046	20/06/2005	411197.26	5229049.25
BR_V047	20/06/2005	410346.02	5228858.98
BR_V048	20/06/2005	407602.09	5224773.59
BR_V049	20/06/2005	406230.28	5225175.19

Table 3: Location of Sediment Sample Sites.

Label	Date	Easting	Northing
BR_S001	21/06/2005	409620.55	5228839.22
BR_S003	21/06/2005	409602.70	5228484.08
BR_S007	21/06/2005	408421.18	5228920.02
BR_S010	21/06/2005	407630.85	5227530.48
BR_S011	21/06/2005	407547.78	5227317.95
BR_S012	21/06/2005	410769.35	5228726.20
BR_S013	21/06/2005	410464.96	5228380.14
BR_S014	21/06/2005	409931.37	5226712.87
BR_S015	21/06/2005	412446.12	5228996.97
BR_S017	21/06/2005	411815.41	5229442.93
BR_S018	21/06/2005	412102.03	5229348.38
BR_S024	21/06/2005	409303.38	5226439.22
BR_S025	21/06/2005	408682.99	5226083.69
BR_S027	21/06/2005	408754.45	5225725.92
BR_S028	21/06/2005	407682.82	5225065.40
BR_S031	21/06/2005	407164.25	5224251.80
BR_S033	21/06/2005	406216.98	5225182.69
BR_S034	21/06/2005	407834.42	5225864.37
BR_S041	21/06/2005	409317.83	5226237.31
BR_S045	21/06/2005	411705.33	5228427.59
BR_S048	21/06/2005	407603.51	5224802.43

Table 4: Black Bay depth (IGLD85-corrected) Thiessen polygon areas

	Survey Area		
Depth (m)	# of Polygons	(m2)	(km2)
0.00-0.99	0	0	0.00000
1.00-1.99	968	150487	0.15049
2.00-2.99	6294	1119690	1.11969
3.00-3.99	5521	1164318	1.16432
4.00-4.99	4478	1016977	1.01698
5.00-5.99	3814	993222	0.99322
6.00-6.99	4642	1118667	1.11867
7.00-7.99	5142	1216485	1.21649
8.00-8.99	5387	1274259	1.27426
9.00-9.99	5999	1535395	1.53539
10.00-10.99	5369	1480336	1.48034
11.00-11.99	5213	1356771	1.35677
12.00-12.99	5956	1534953	1.53495
13.00-13.99	4355	1113393	1.11339
14.00-14.99	3205	818174	0.81817
15.00-15.99	3393	949821	0.94982
16.00-16.99	2824	778698	0.77870
17.00-17.99	2496	759491	0.75949
18.00-18.99	2347	687447	0.68745
19.00-19.99	2094	652850	0.65285
20.00-20.99	2315	706825	0.70682
21.00-21.99	1823	658783	0.65878
22.00-22.99	1320	485478	0.48548
23.00-23.99	1717	625128	0.62513
24.00-24.99	1893	665928	0.66593
25.00-25.99	1885	665396	0.66540
26.00-26.99	1767	620901	0.62090
27.00-27.99	1354	606586	0.60659
28.00-28.99	1475	738892	0.73889
29.00-29.99	819	400487	0.40049
30.00-30.99	508	265451	0.26545
31.00-31.99	580	302169	0.30217
32.00-32.99	635	331036	0.33104
33.00-33.99	376	190102	0.19010
34.00-34.99	462	241321	0.24132
35.00-35.99	333	178948	0.17895
36.00-36.99	242	115344	0.11534
37.00-37.99	199	93287	0.09329
38.00-38.99	243	88172	0.08817
39.00-39.99	207	71243	0.07124
40.00-40.99	58	18176	0.01818
41.00-41.99	8	1144	0.00114
42.00-42.99	4	186	0.00019

Table 5: Distribution of Substrate Classes (km^2).

Substrate Class	Survey Area	Percent Coverage
Sand (fine-medium, often with waves)	8.2841	29.81
Sand (compact or coarse)	4.0427	14.55
Sand (fine-medium, unconsolidated)	1.6869	6.07
Sand (medium-coarse, unconsolidated)	2.0850	7.50
Cobble (pavement or with thin sand patches)	4.7264	17.01
Cobble (interstitial spaces)	3.7563	13.52
Bedrock or fractured bedrock	3.2111	11.55
Total	**27.7924**	**100.00**

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Figures

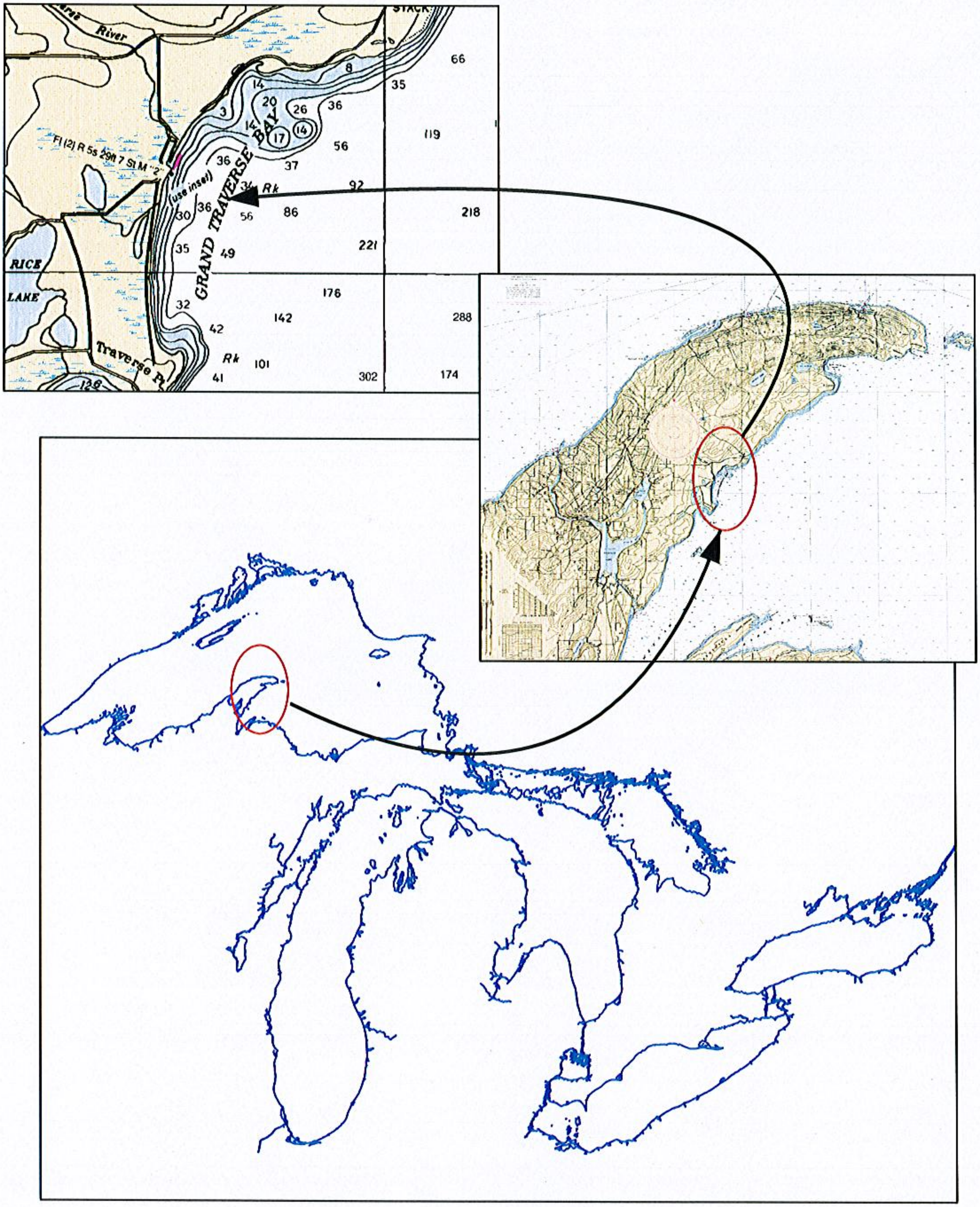


Figure 1: Study area.

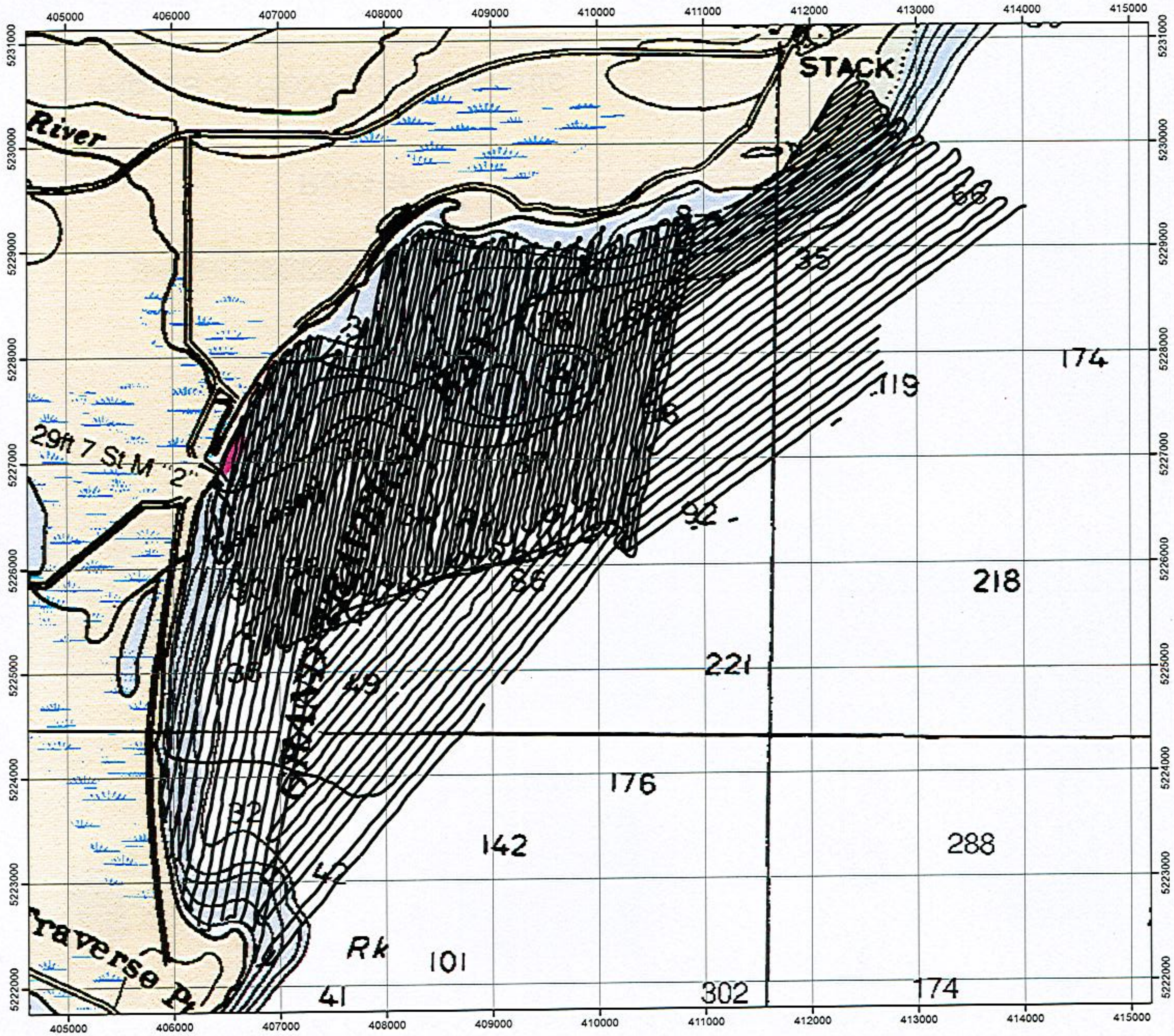


Figure 2: Survey tracklines.

NAD 83
UTM Zone 16

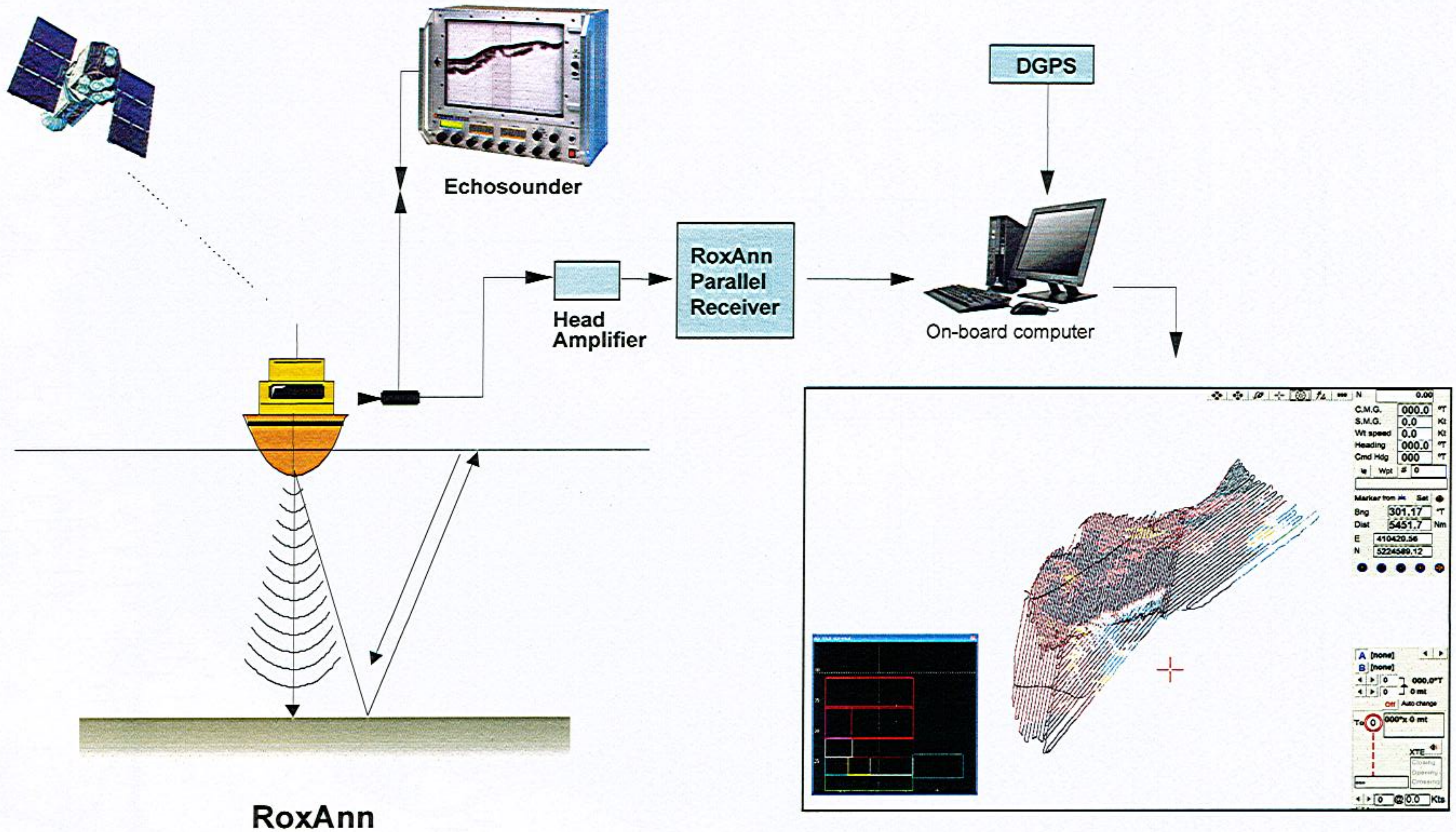
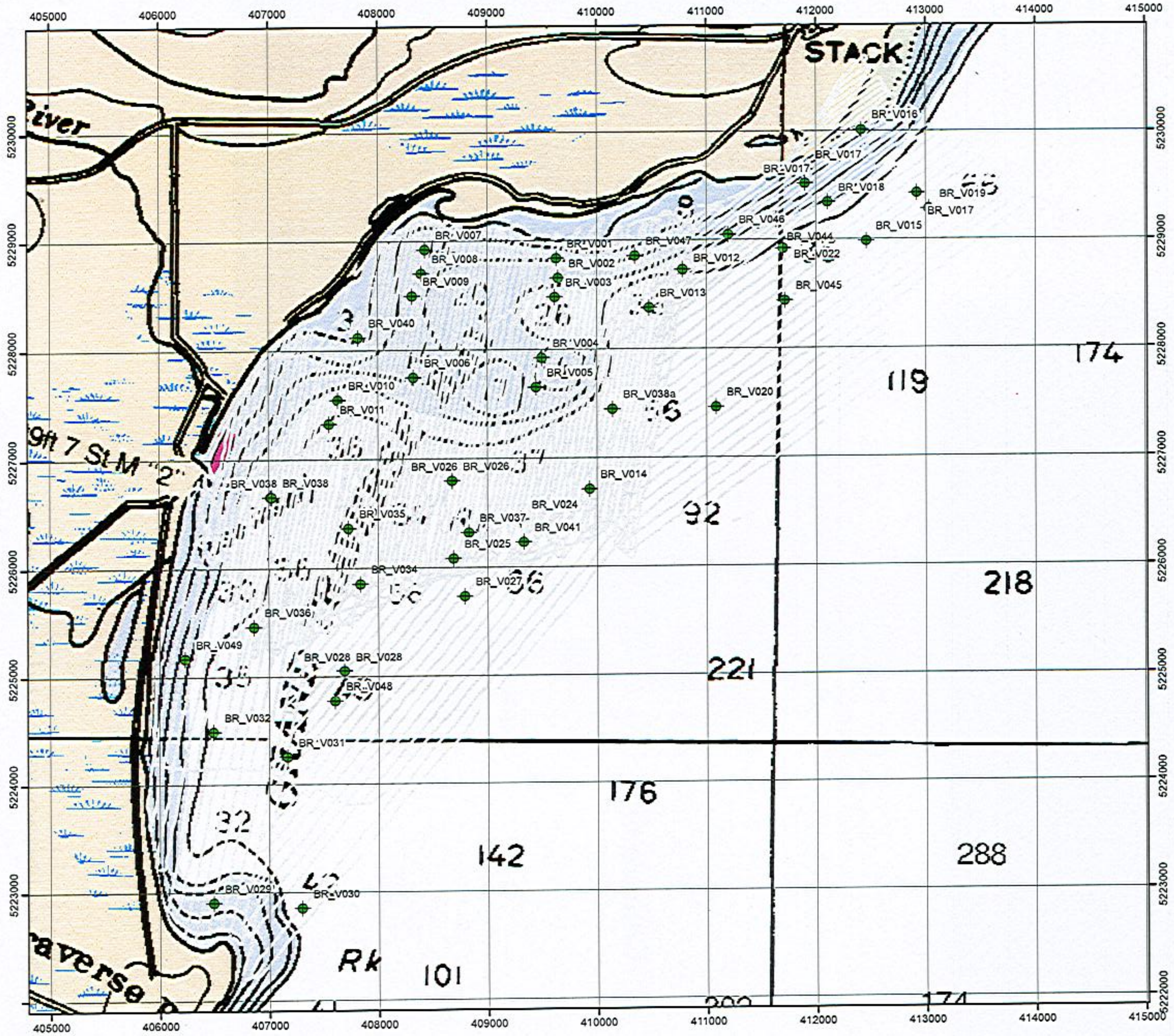


Figure 3: RoxAnn schematic.

Figure 4: Underwater video sites.



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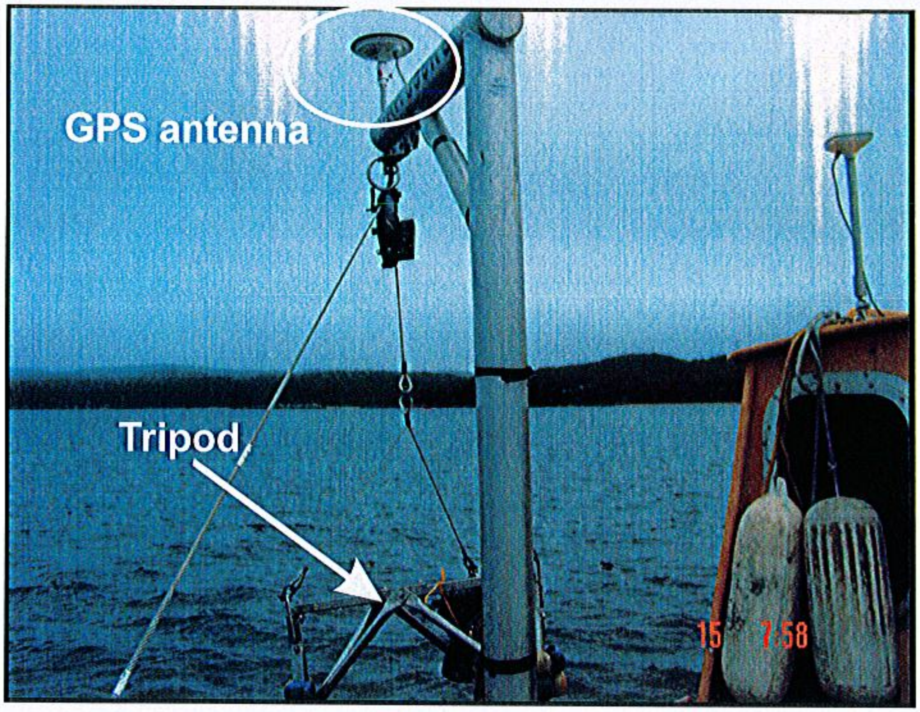


Davit setup on Petrel

Camera tripod

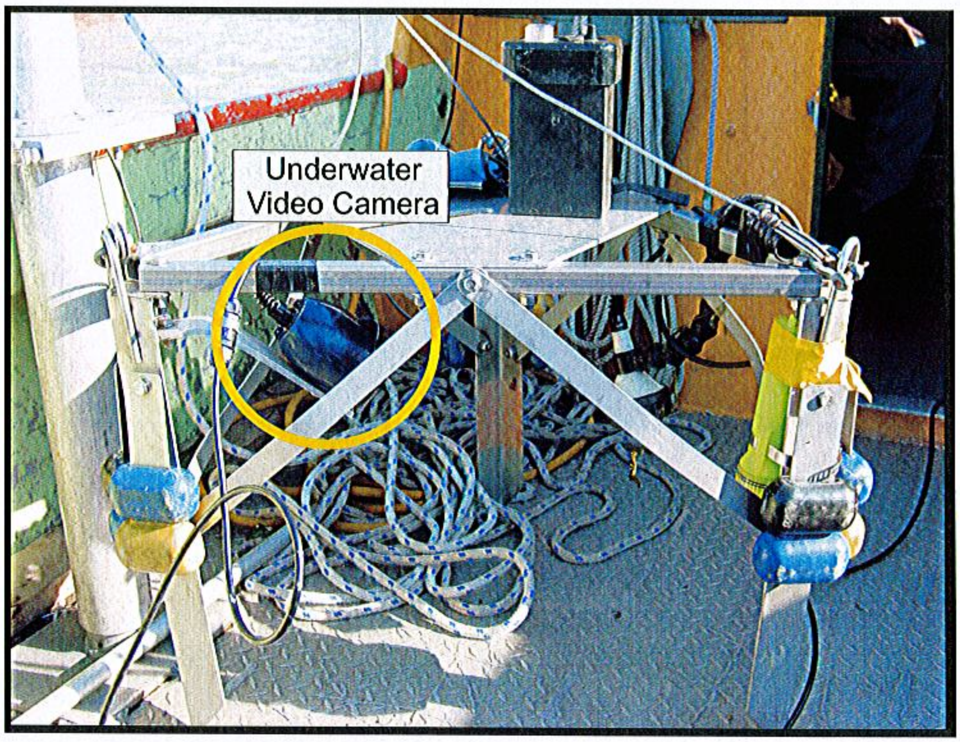


Figure 5: Underwater video system.

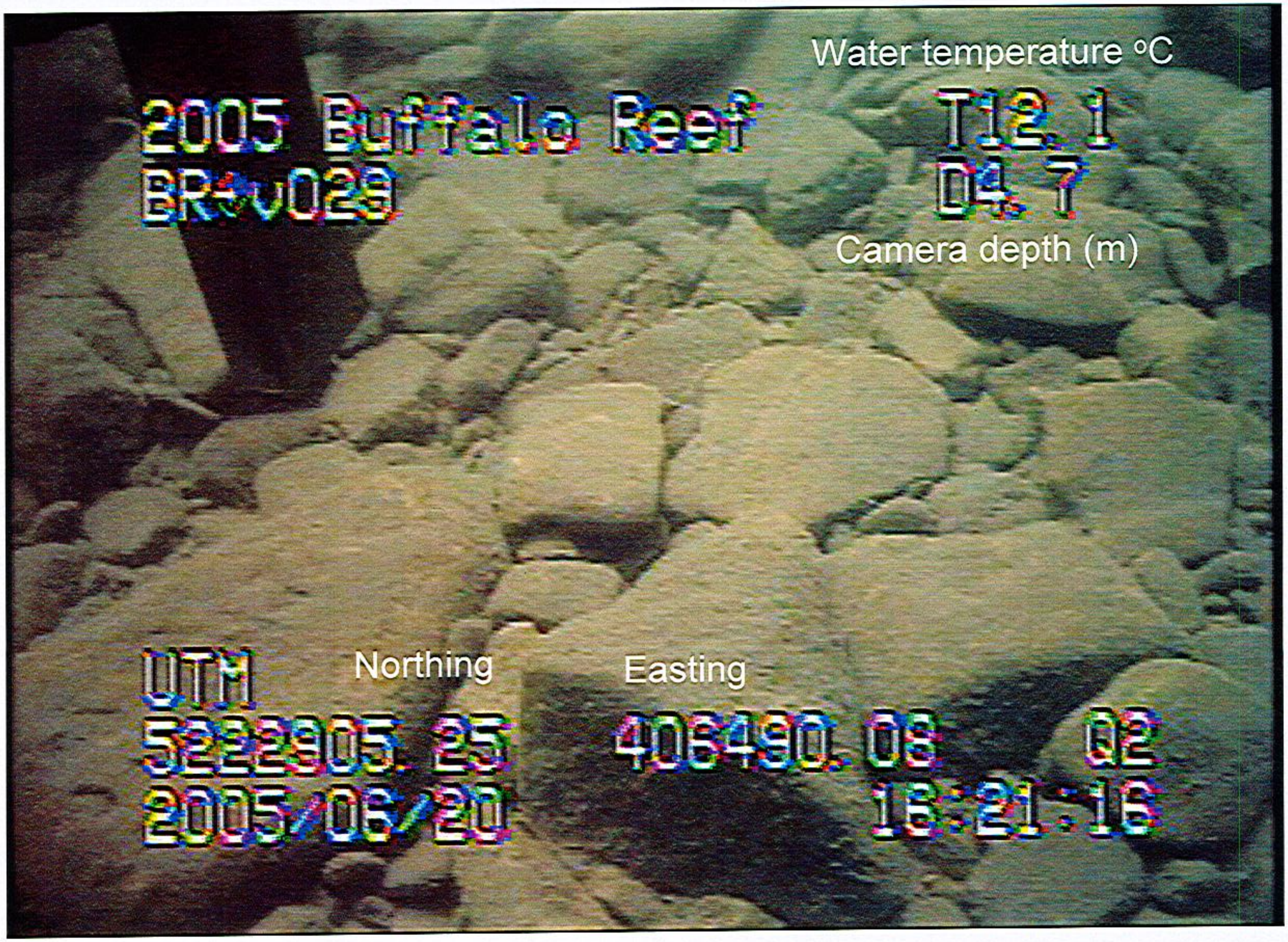


Figure 6: Underwater video image with data overlay.

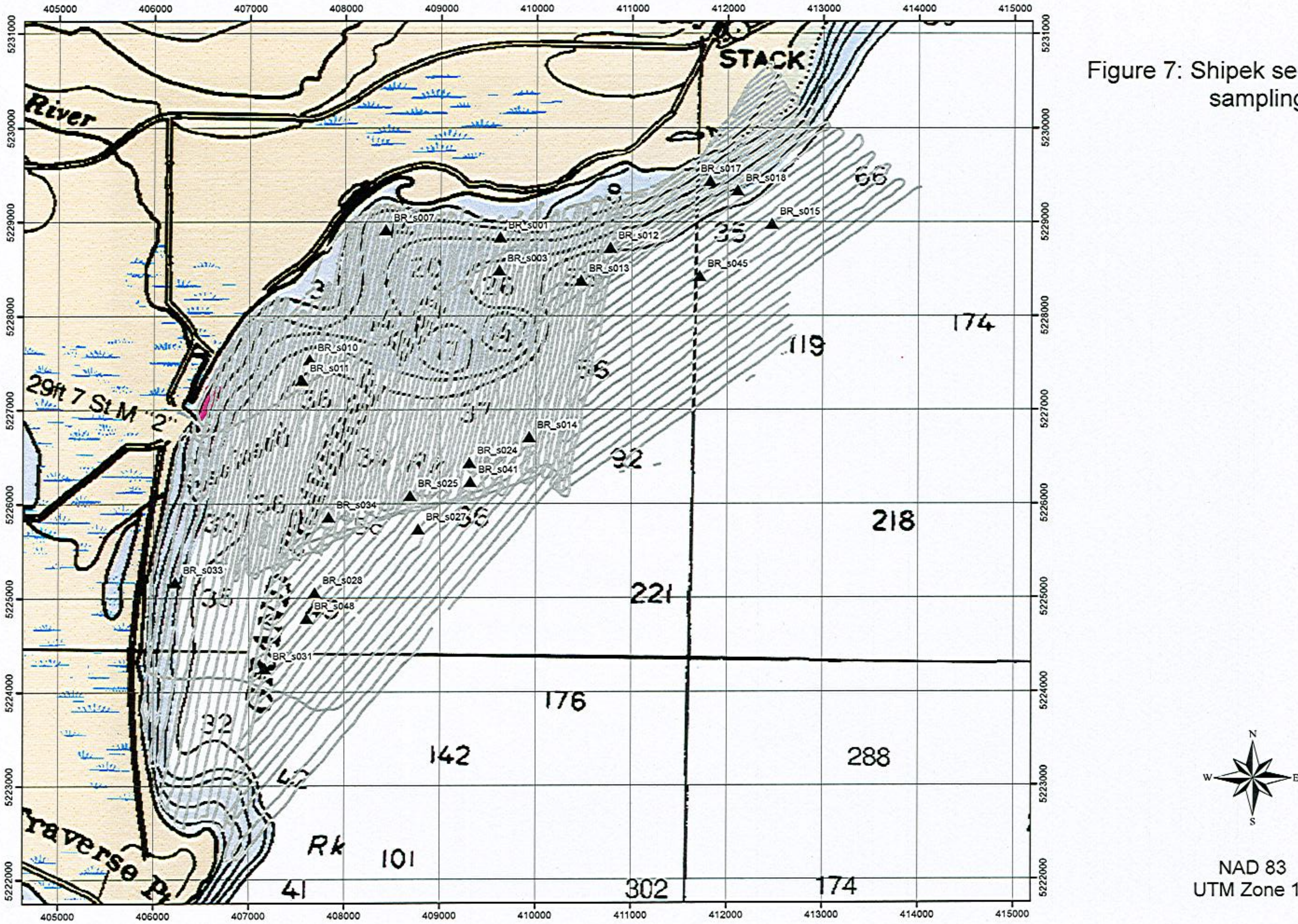


Figure 7: Shipek sediment sampling sites.

NAD 83
UTM Zone 16

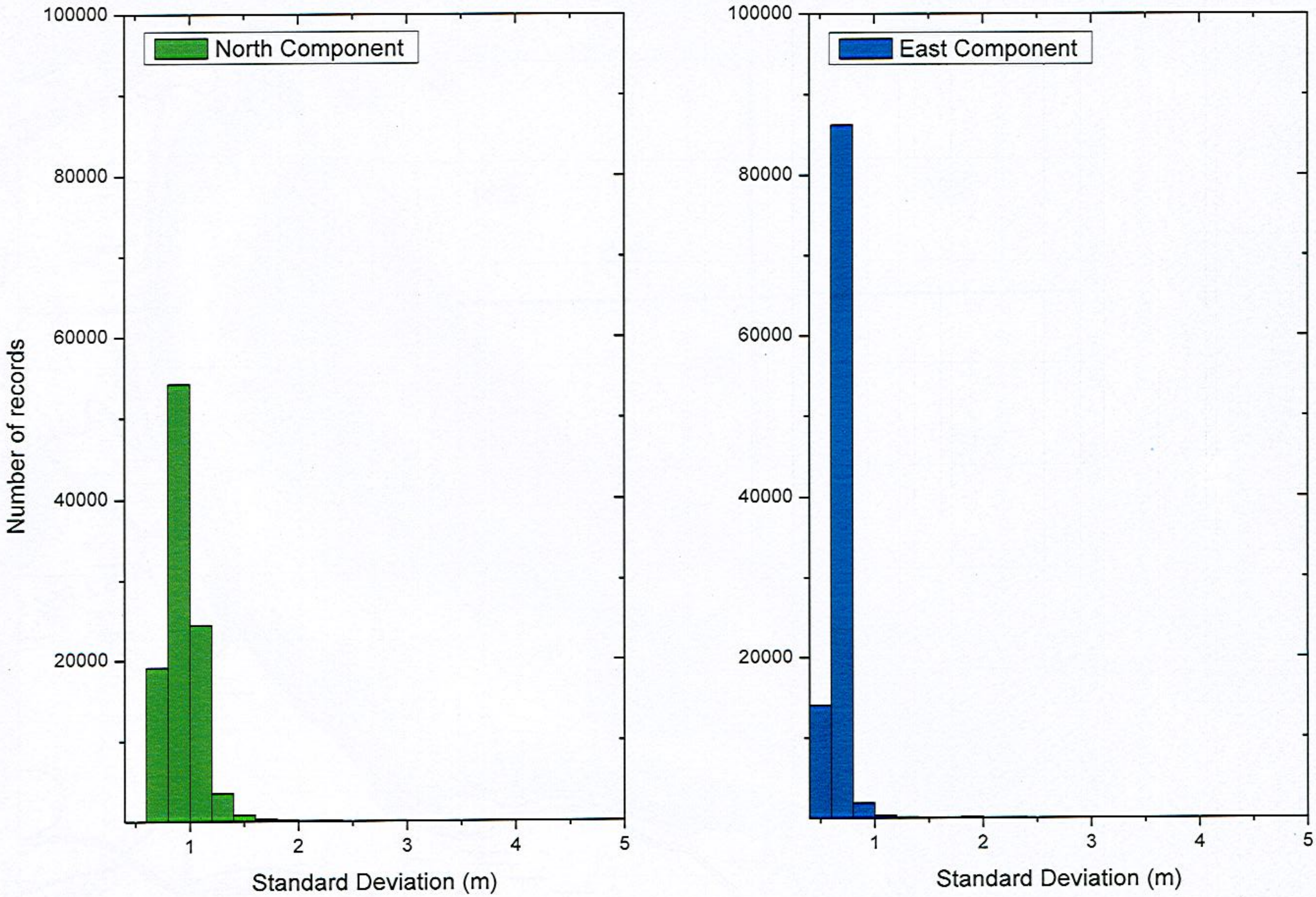
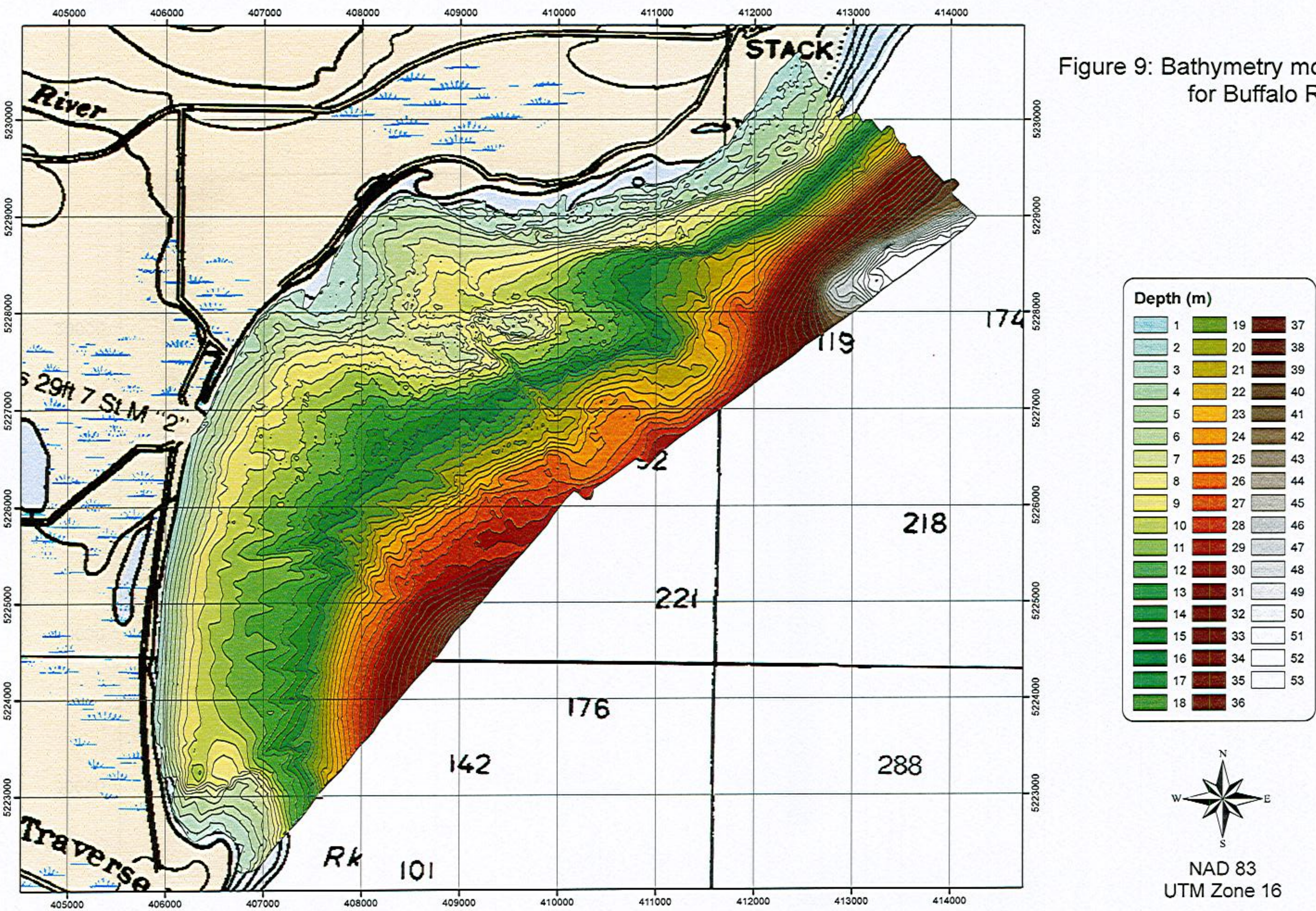


Figure 8: Summary of standard deviations recorded for DGPS position solutions.

Figure 9: Bathymetry model for Buffalo Reef



NAD 83
UTM Zone 16

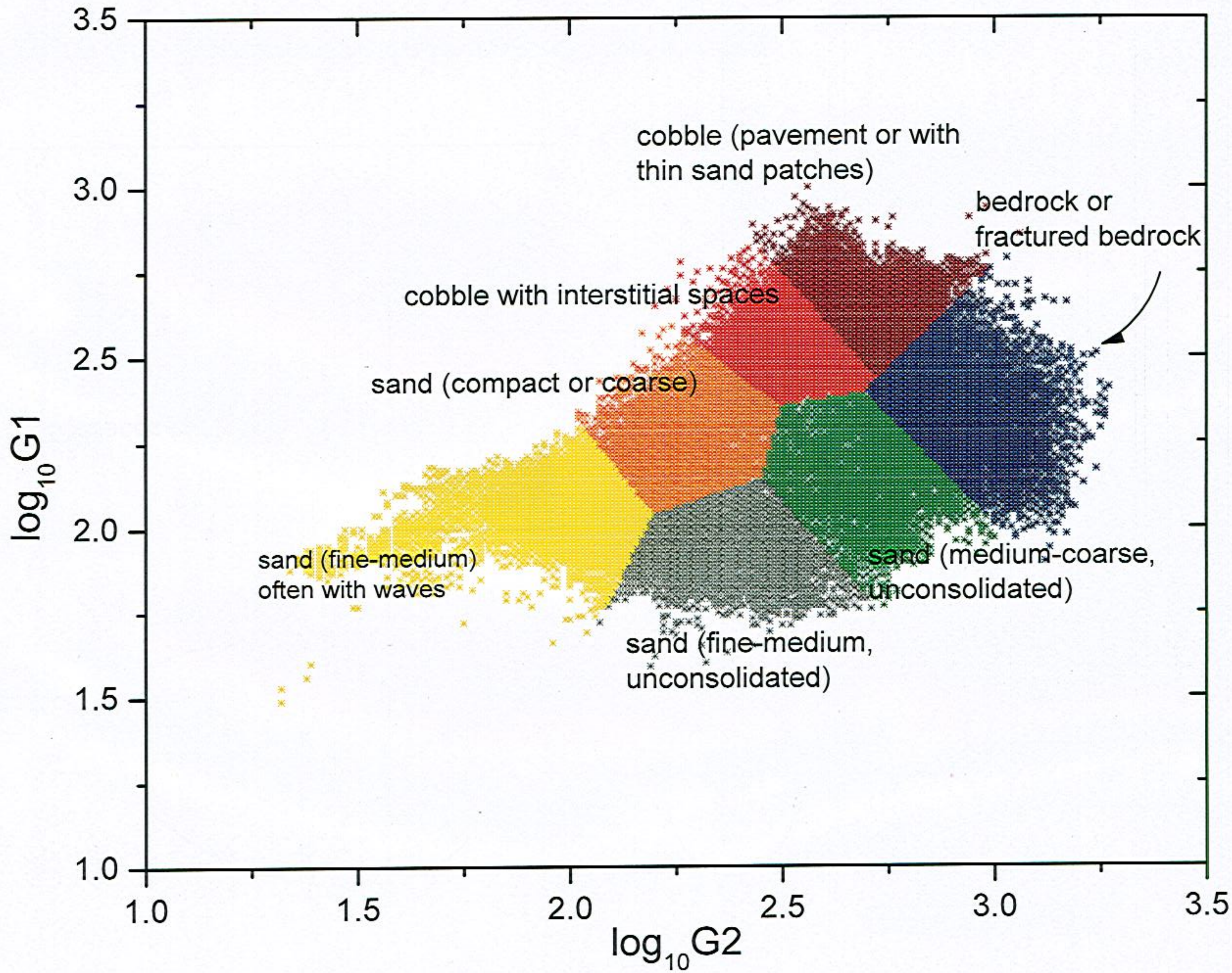


Figure 10: Cluster assignments of acoustic data.

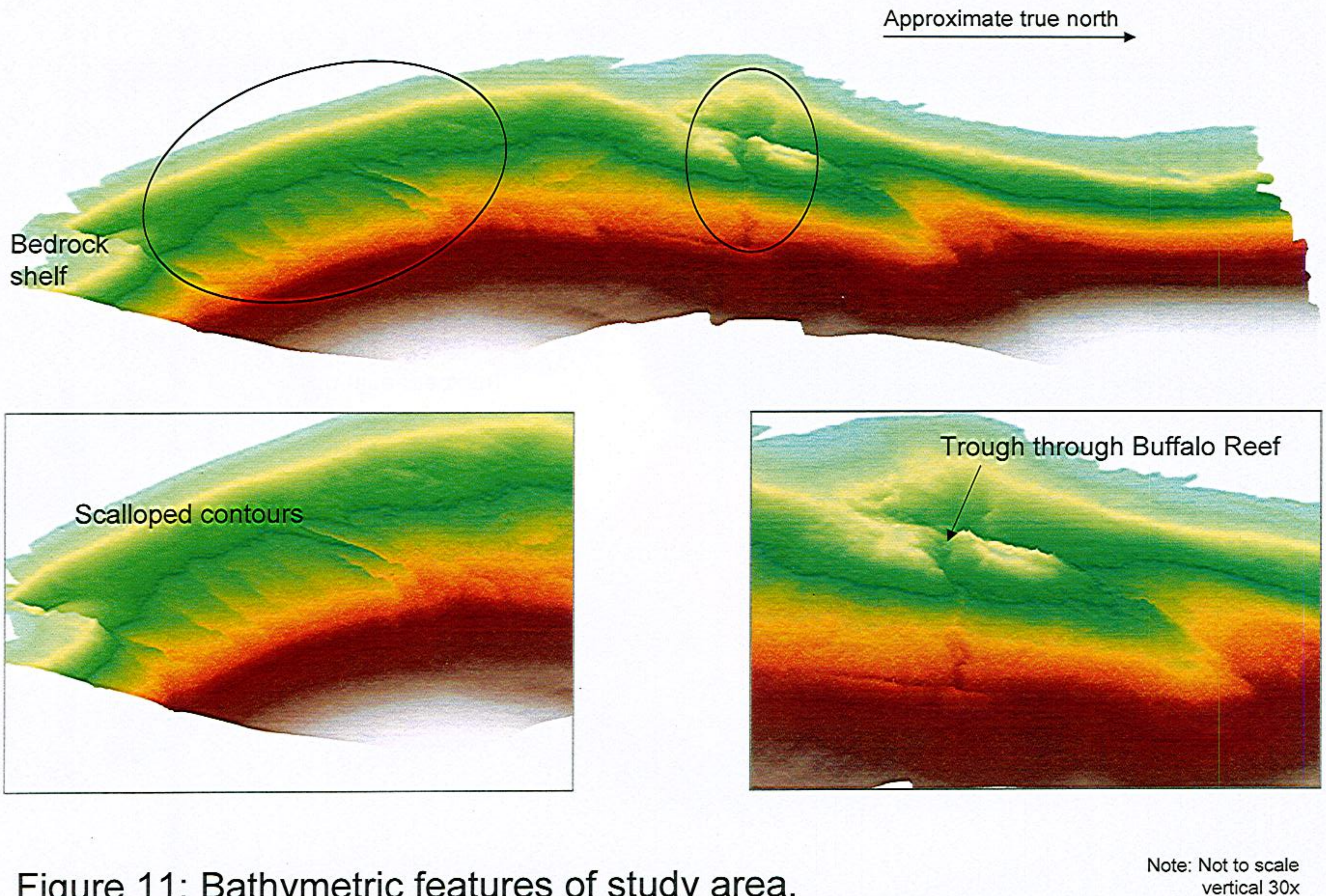
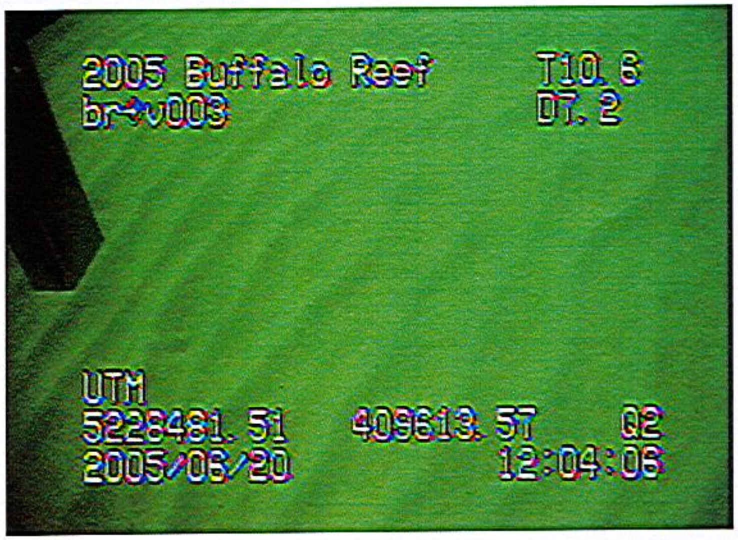


Figure 11: Bathymetric features of study area.



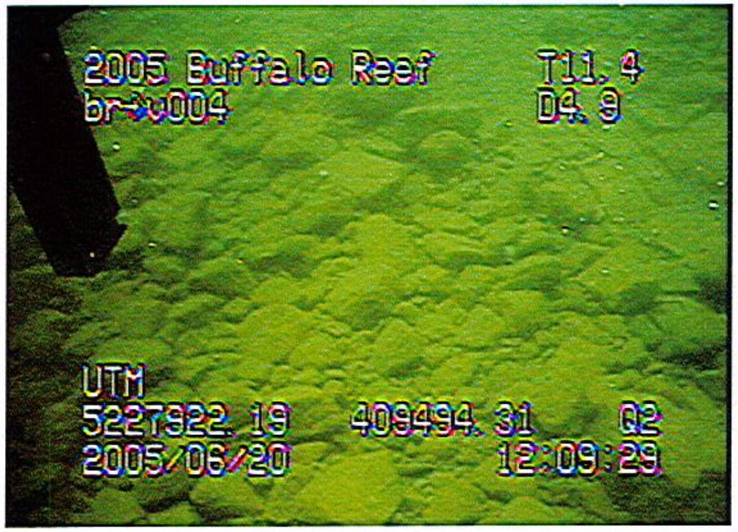
Sand (fine-medium, often with waves)

Sand (compact or coarse)

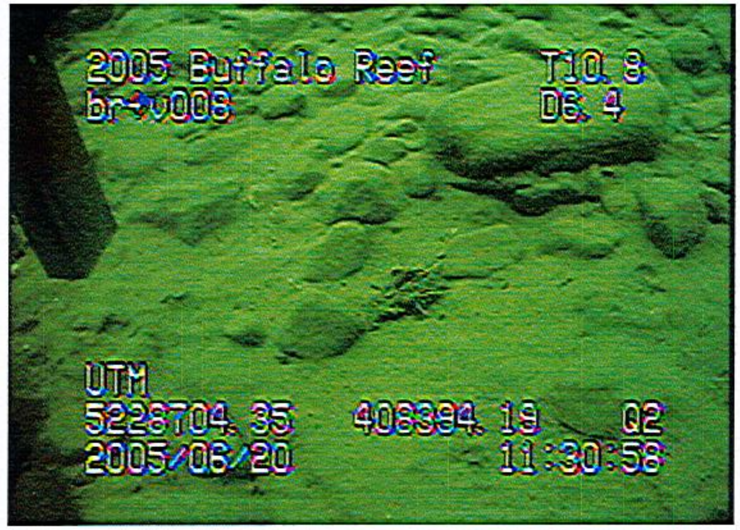
Sand (fine-medium, unconsolidated)

Sand (medium-coarse, unconsolidated)

Figure 12: Examples of substrate classes.



Cobble (interstitial spaces)

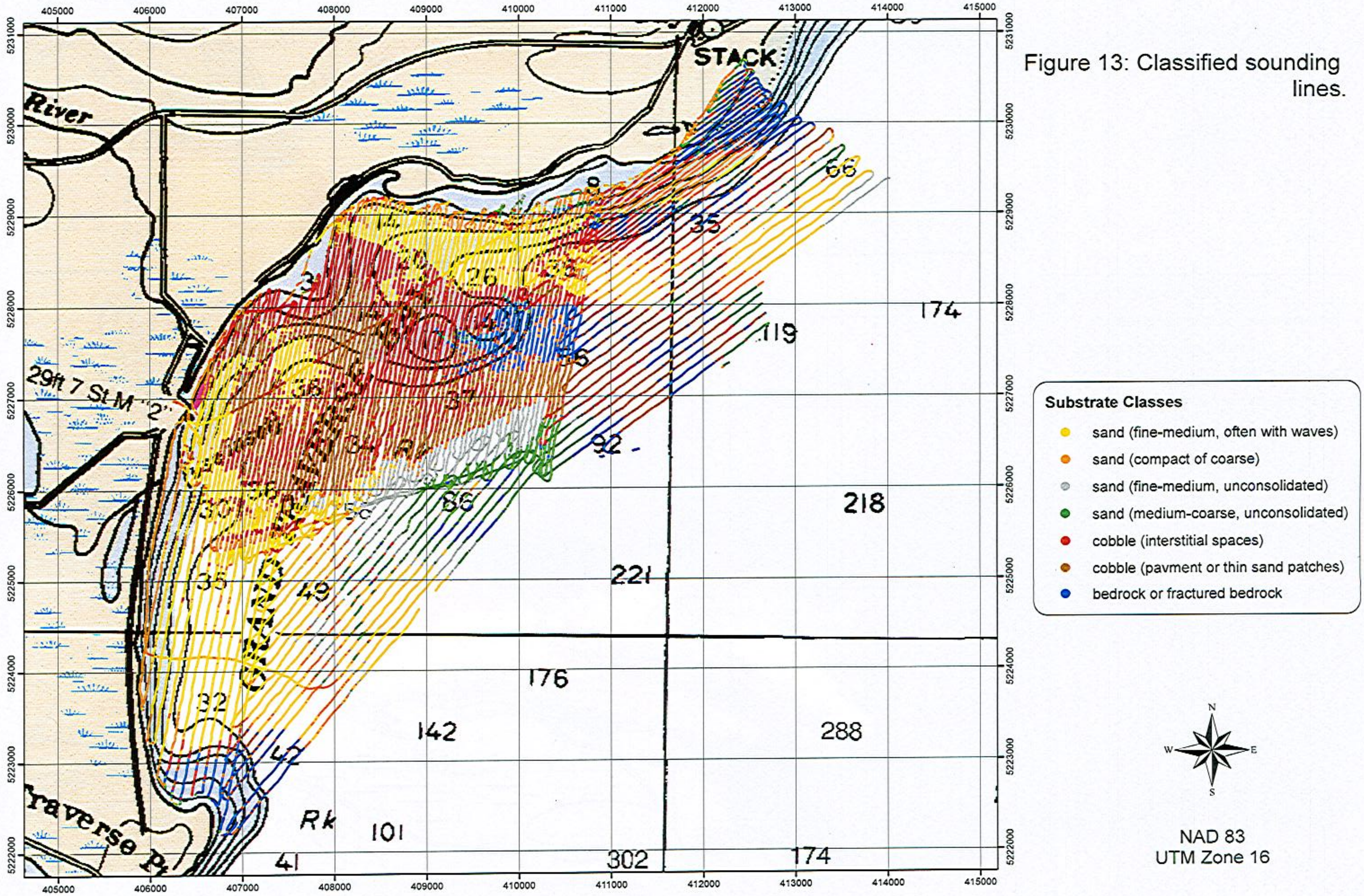


Cobble (pavement or with thin sand patches)

Bedrock or fractured bedrock

Figure 12: Examples of substrate classes (continued).

Figure 13: Classified sounding lines.



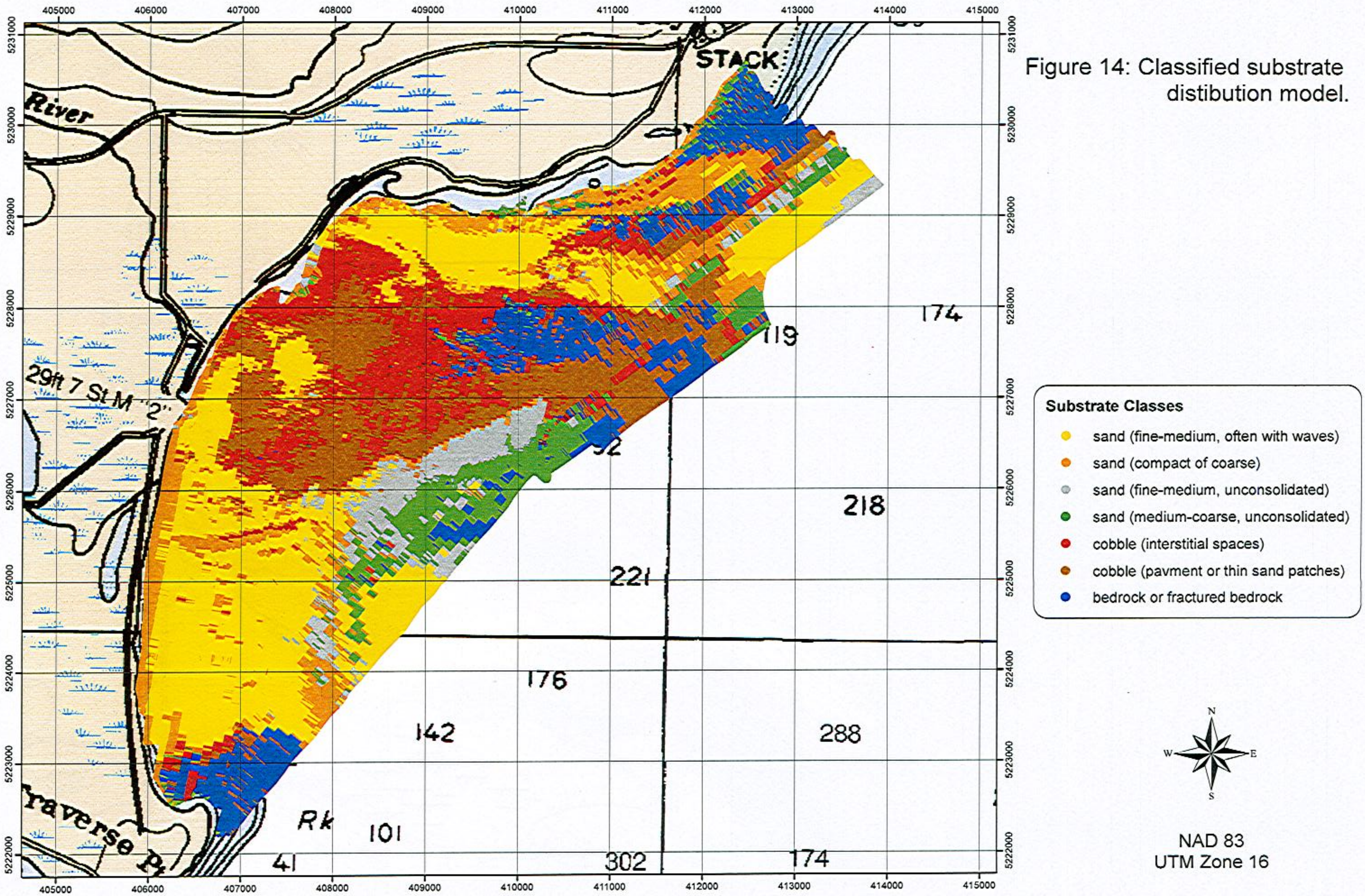


Figure 14: Classified substrate distibution model.

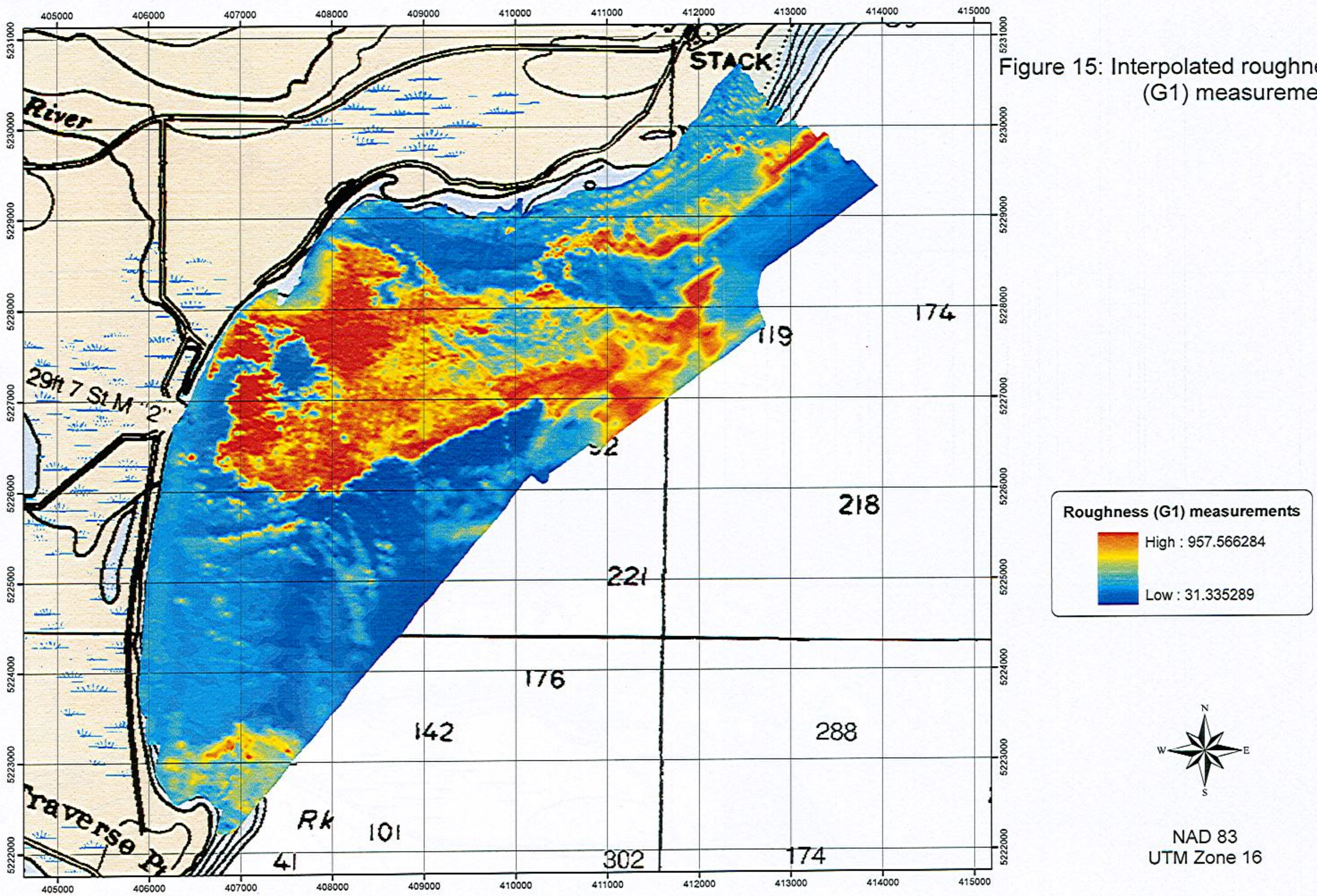


Figure 15: Interpolated roughness (G1) measurements.

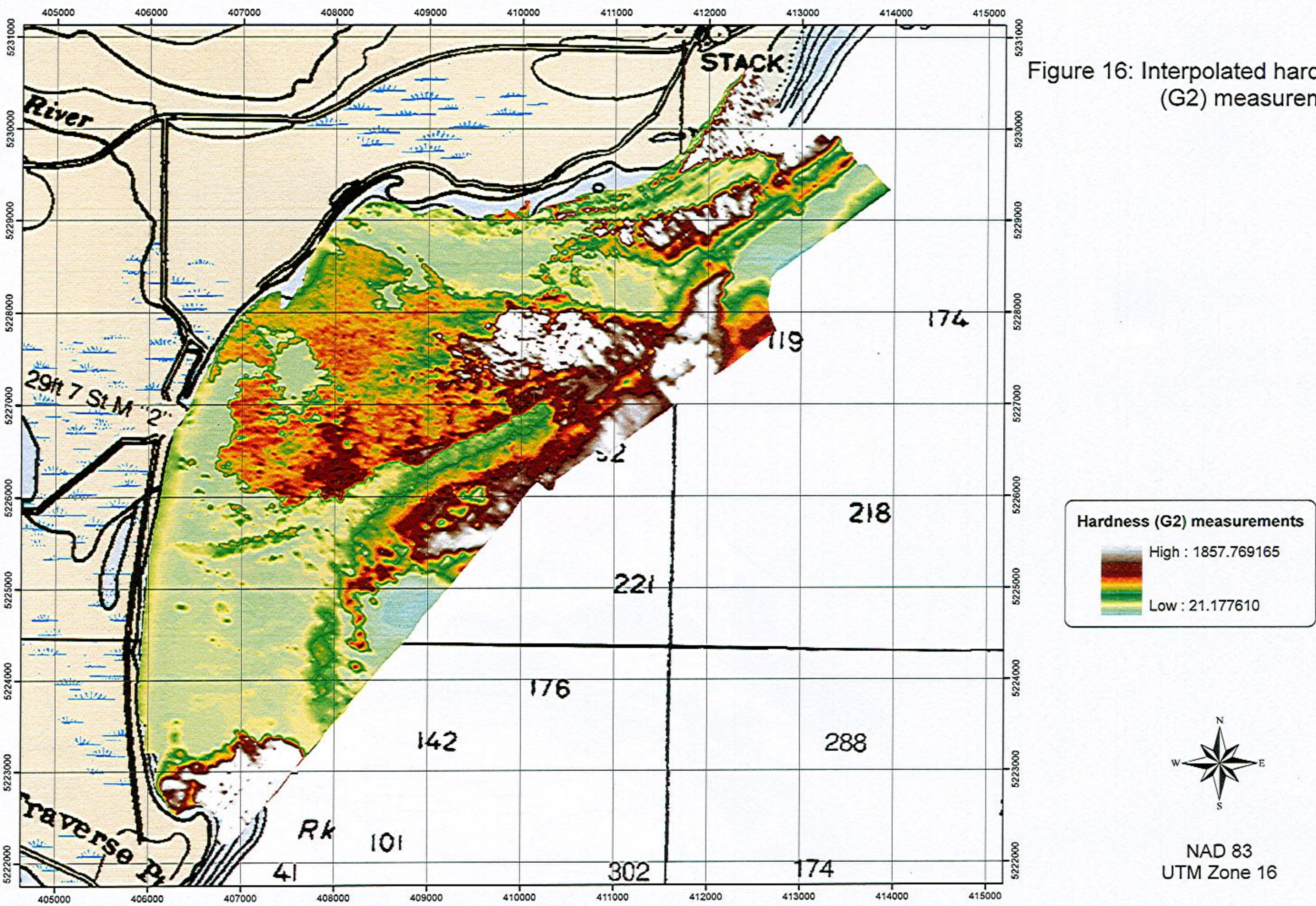


Figure 16: Interpolated hardness (G2) measurements.

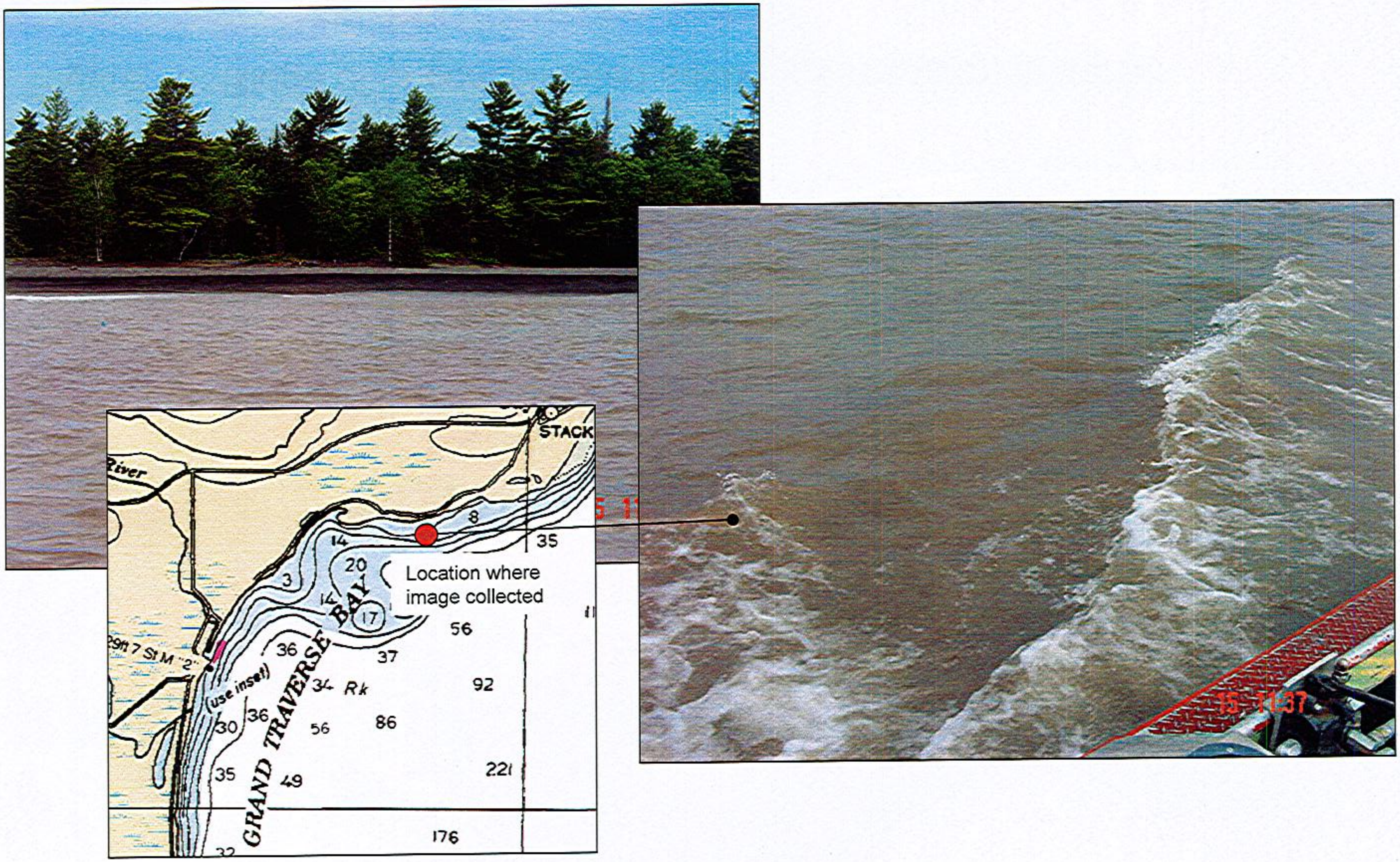


Figure 17: Evidence of continuing erosion and transport of stamp sand materials.

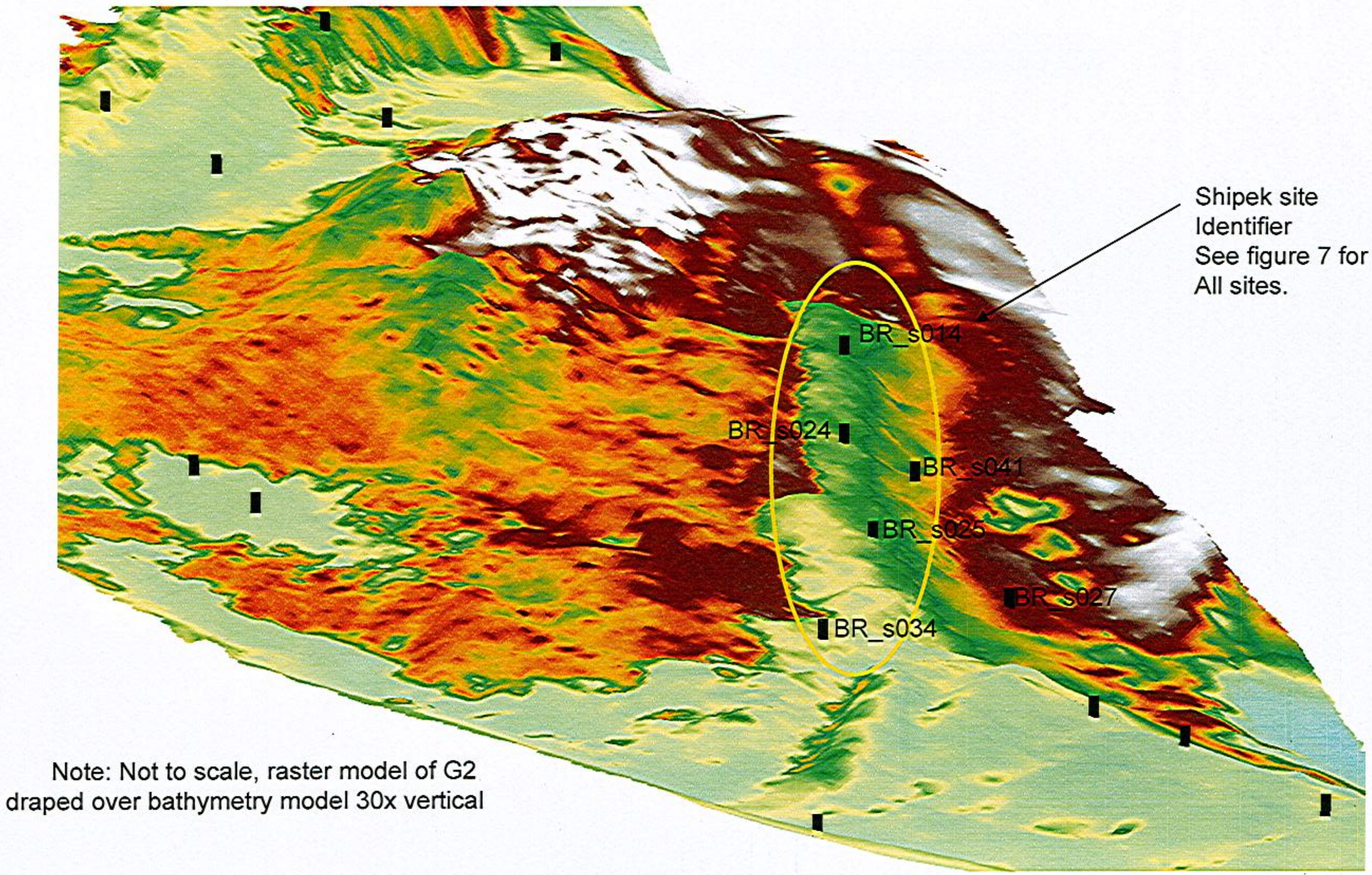
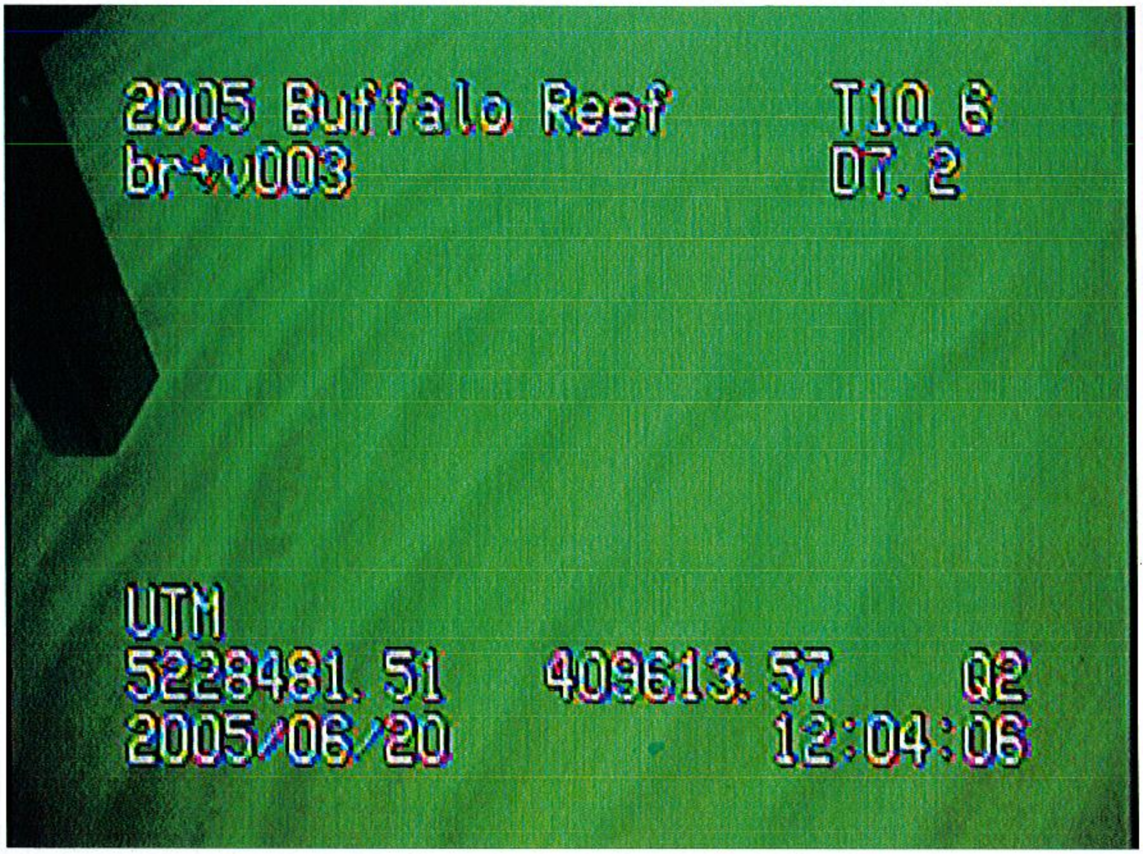


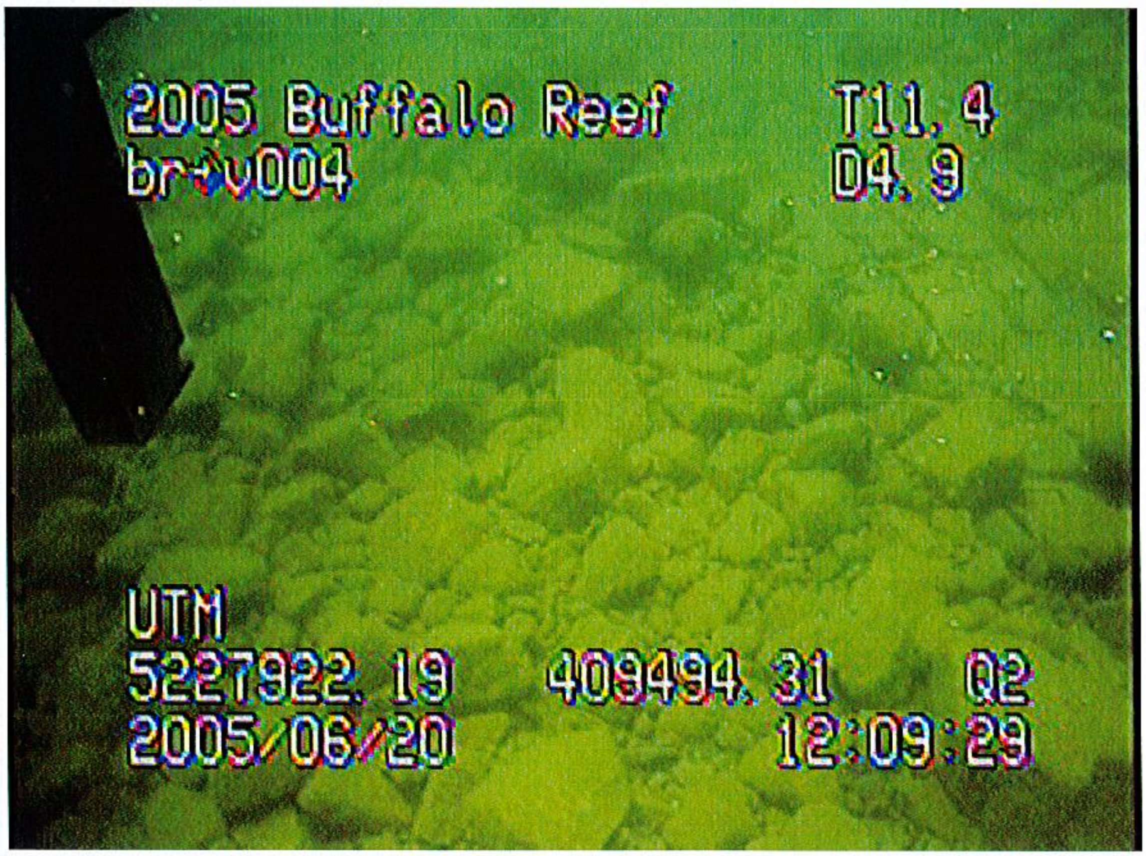
Figure 18: Ridge of unconsolidated sand (fine-medium) material.

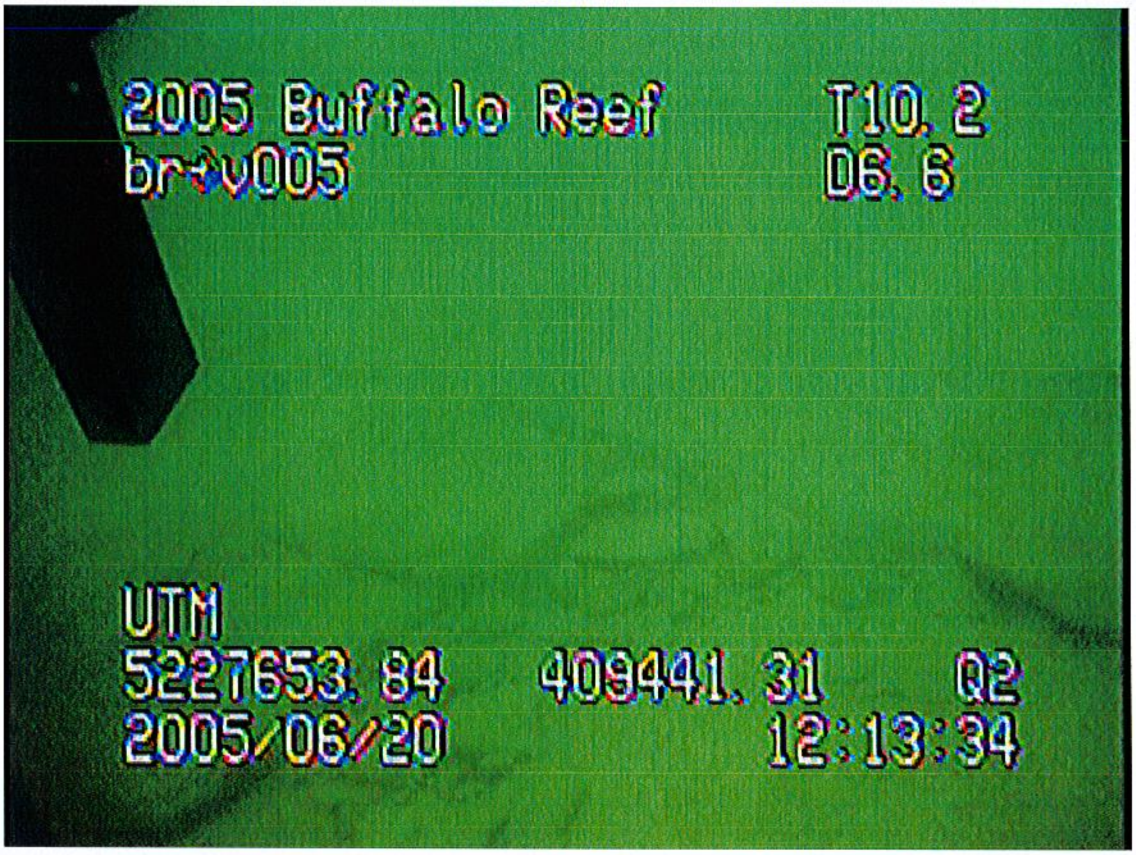
Appendix 1: Underwater video images.

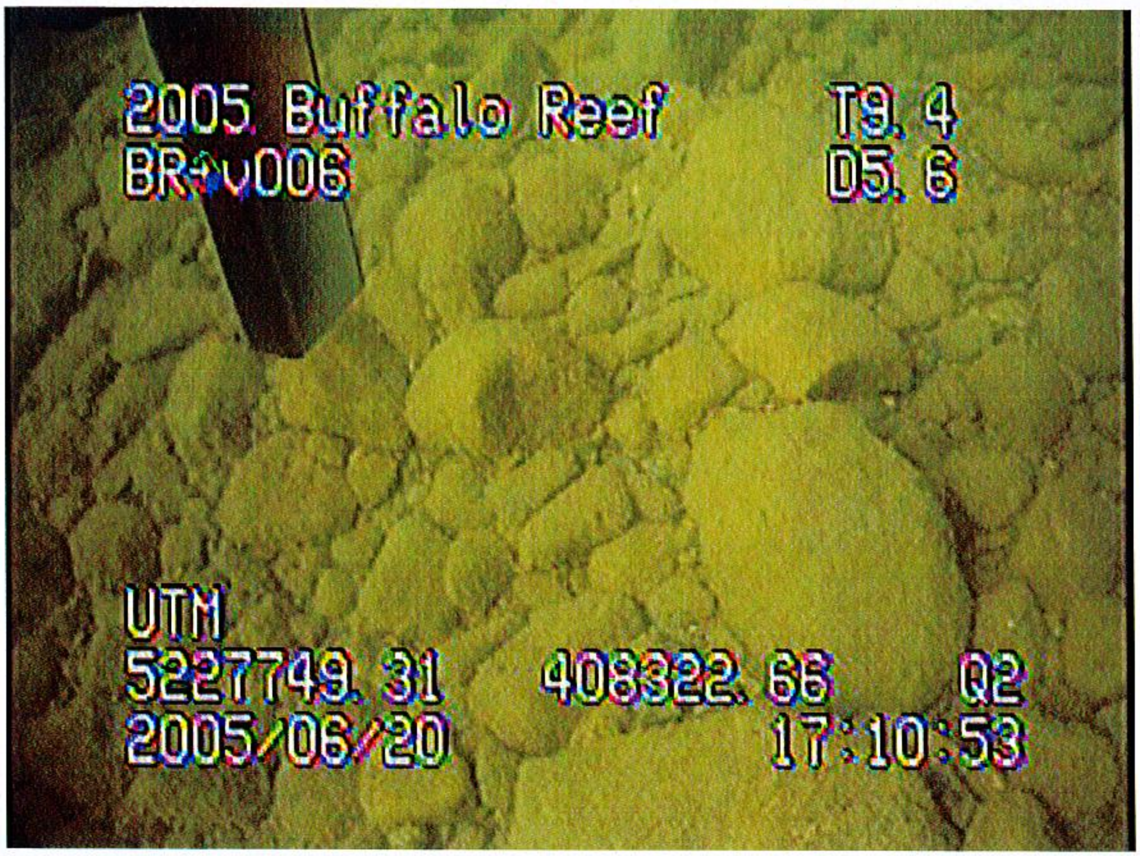

2005 Buffalo Reef T12.1
br-v001 D3.9
UTM
5228838.43 409627.88 Q2
2005/06/20 11:46:40

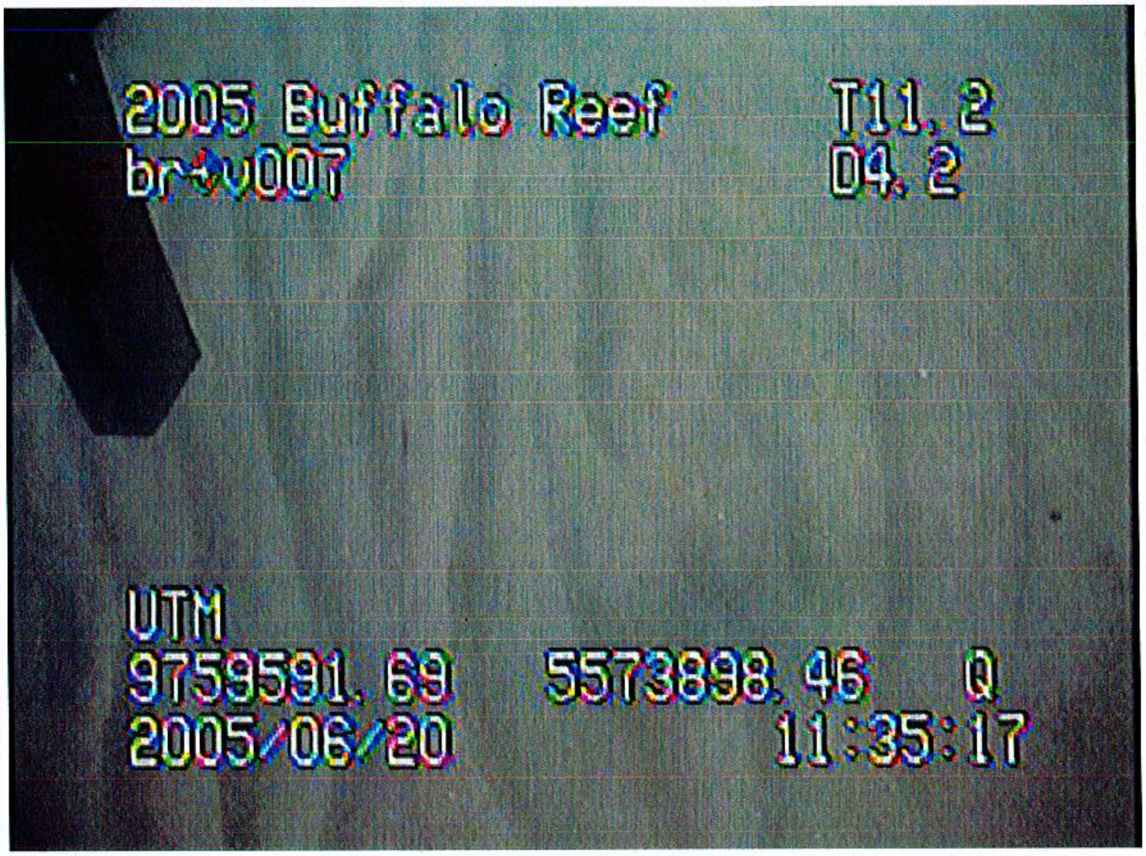

2005 Buffalo Reef T10.3
br-v002 D6.9
U
5228656.27 409643.30 Q2
2005/06/20 11:59:09

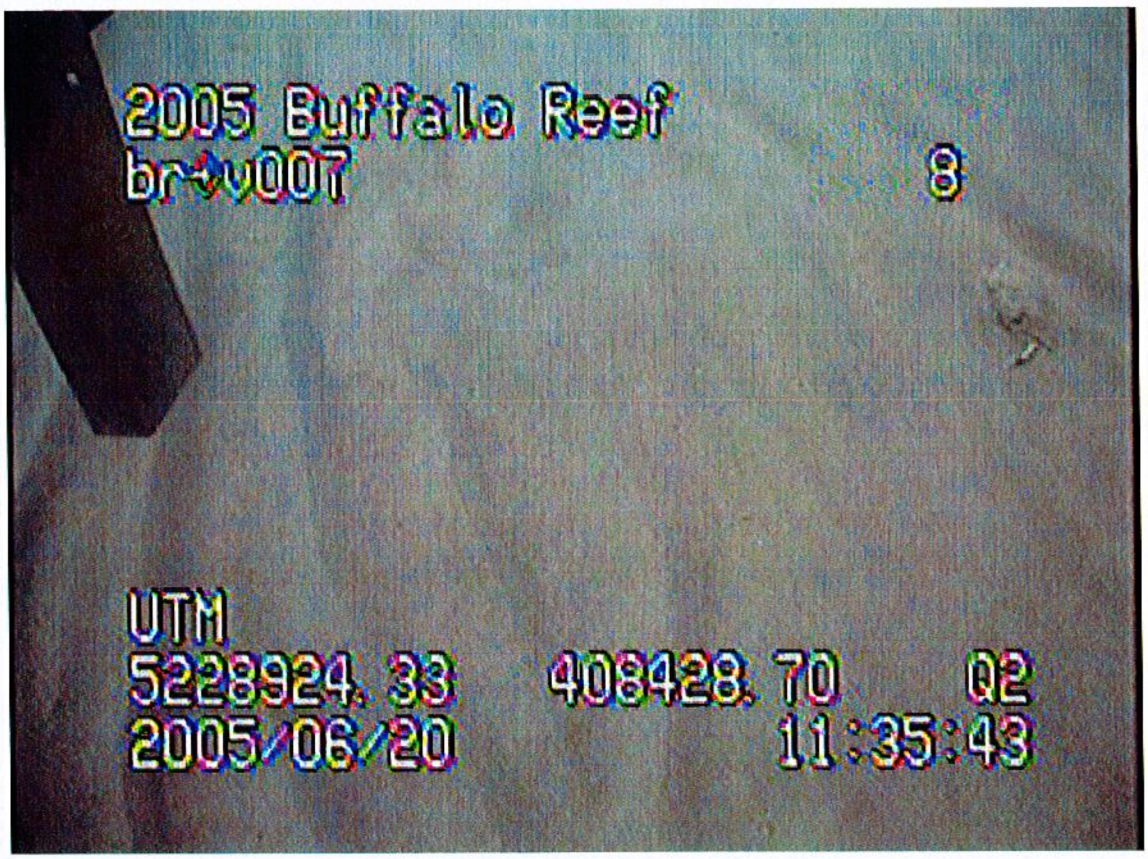

2005 Buffalo Reef
T10.6
br-v003
D7.2
UTM
5228481.51
409613.57
Q2
2005/06/20
12:04:06


2005 Buffalo Reef
T11.4
br-v004
D4.9
UTM
5227922.19
409494.31
Q2
2005/06/20
12:09:29


2005 Buffalo Reef
T10.2
br-v005
D6.6
UTM
5227653.84
409441.31
Q2
2005/06/20
12:13:34


2005 Buffalo Reef
T9.4
BR-v006
D5.6
UTM
5227749.31
408322.66
Q2
2005/06/20
17:10:53

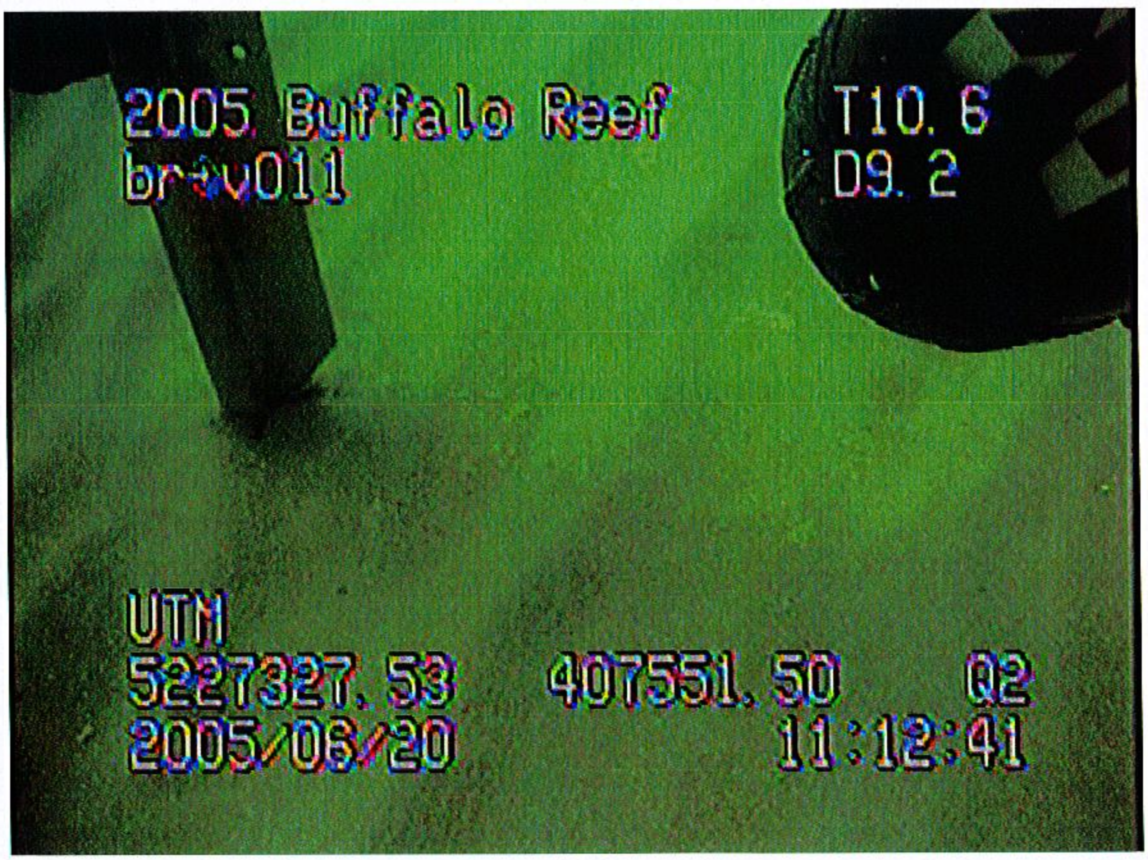

2005 Buffalo Reef
T11.2
br v007
D4.2
UTM
9759591.69
5573898.46
Q
2005/06/20
11:35:17

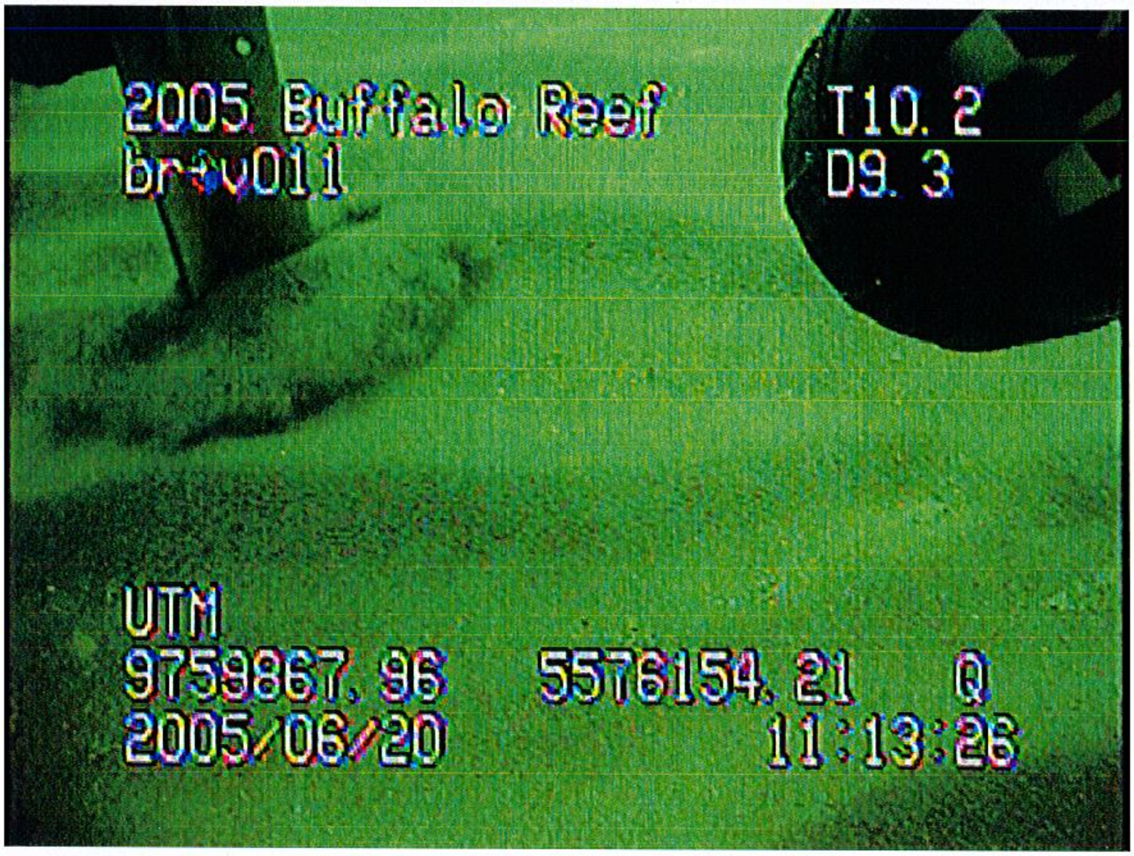

2005 Buffalo Reef
br v007
8
UTM
5228924.33
408428.70
Q2
2005/06/20
11:35:43


2005 Buffalo Reef
T10.8
br→v008
D6.4
UTM
5228704.35
408394.19
02
2005/06/20
11:30:58


2005 Buffalo Reef
T11.0
br→v009
D5.7
UTM
5228497.96
408311.90
02
2005/06/20
11:28:06


2005 Buffalo Reef
T10.5
br-v010
D8.2
UTM
5227545.78
407631.24
Q2
2005/06/20
11:16:47


2005 Buffalo Reef
T10.6
br-v011
D9.2
UTM
5227327.53
407551.50
Q2
2005/06/20
11:12:41


2005 Buffalo Reef
brtv011
T10.2
D9.3
UTM
9759867.96 5576154.21 Q
2005/06/20 11:13:26


2005 Buffalo Reef
brtv012
T9.7
D8.2
UTM
5228729.39 410781.84 Q2
2005/06/20 12:37:39

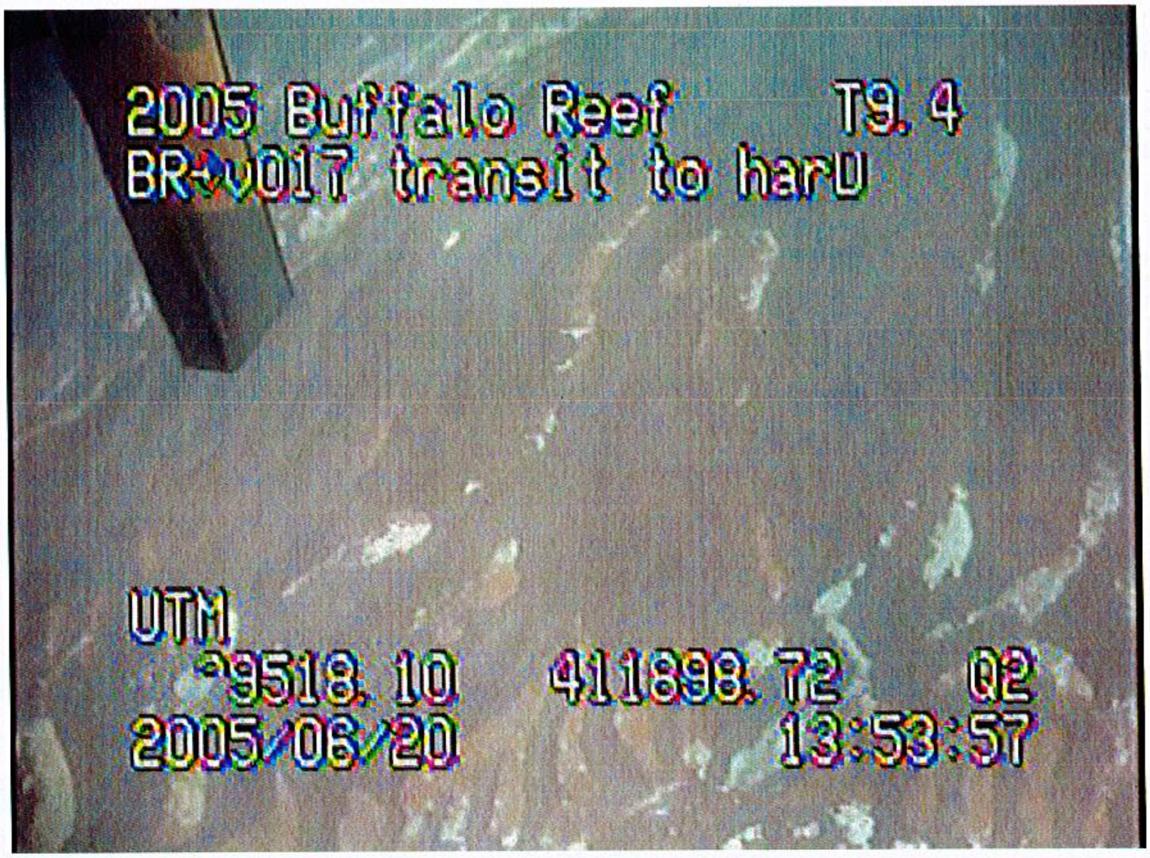

2005 Buffalo Reef
T8.5
br-v013
D13.0
UTM
5228379.49
410474.11
Q2
2005/06/20
12:27:34


2005 Buffalo Reef
T7.6
BR-v014
D20.7
UTM
5226713.30
409931.05
Q2
2005/06/20
14:48:11


2005 Buffalo Reef
T7.5
BR-v015
D19.6
UTM
5228984.12
412458.35
Q2
2005/06/20
14:23:26

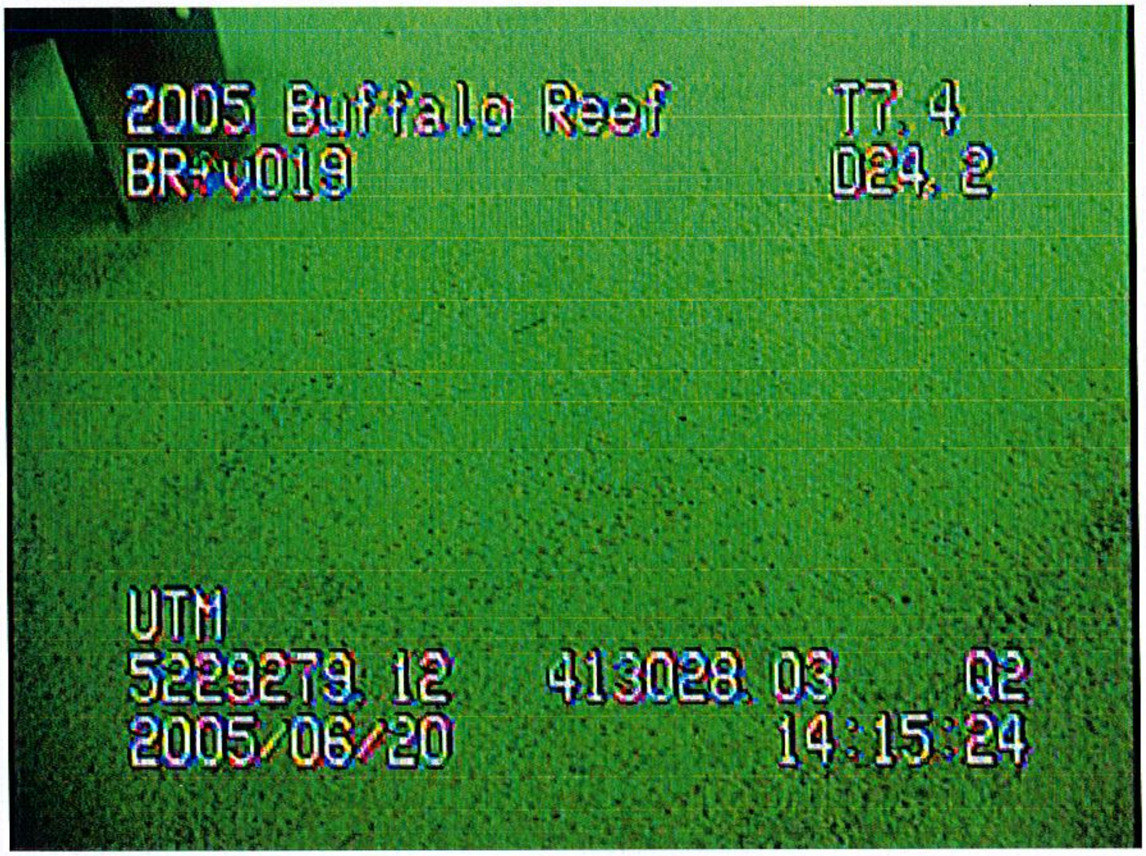

2005 Buffalo Reef
T9.5
BR-v016
D4.1
UTM
5230014.00
412411.06
Q2
2005/06/20
14:08:25


2005 Buffalo Reef T10.8
BR-v017 D3.6
UTM
5229426.05 412918.36 Q
2005/06/20 13:50:10


2005 Buffalo Reef T9.4
BR-v017 transit to harD
UTM
9518.10 411898.72 Q2
2005/06/20 13:53:57


2005 Buffalo Reef T9.7
BR-v017 transit to har03.3
UTM
5229646.78 411897.06 02
2005/06/20 13:57:53


2005 Buffalo Reef T9.1
BR-v018 07.5
UTM
5229342.29 412105.02 02
2005/06/20 14:02:28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T7.4
BR-v019
D24.2
UTM
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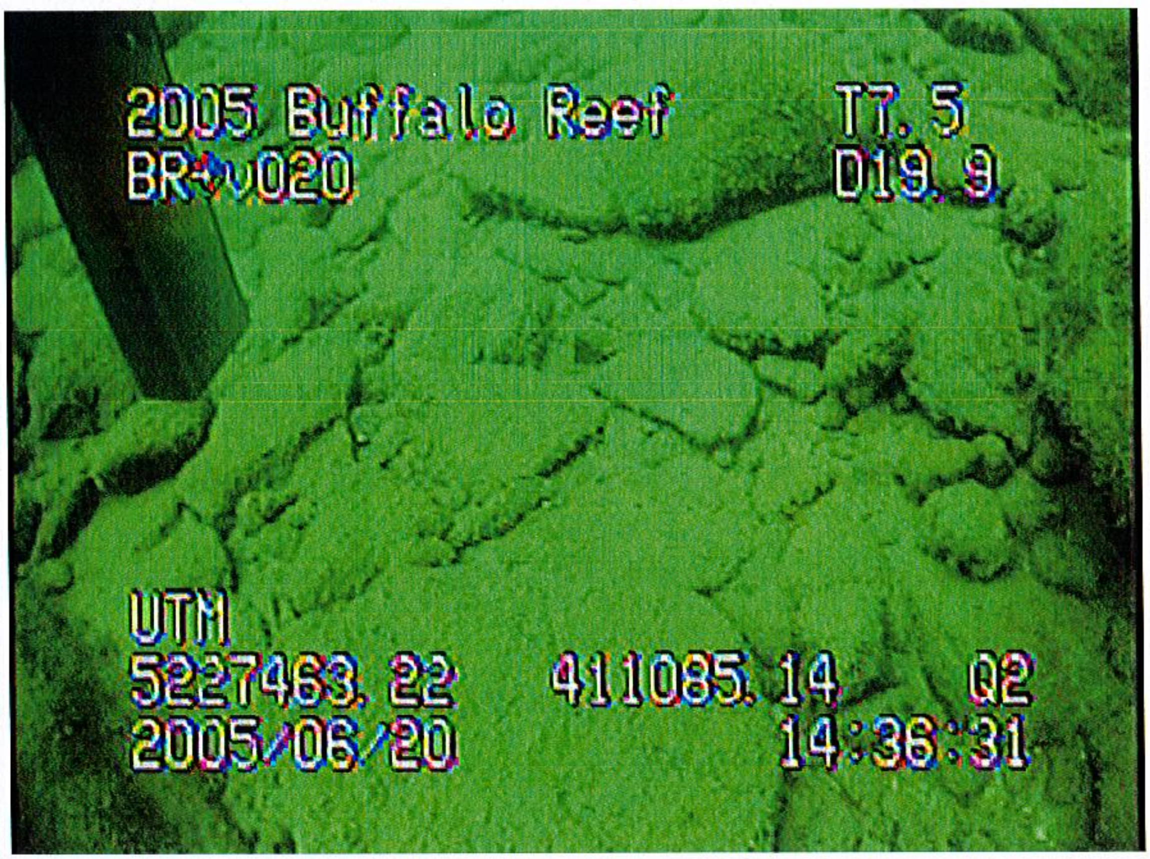
413028.03
Q2
2005/06/20
14:15:24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T7.5
BR-v020
D19.9
UTM
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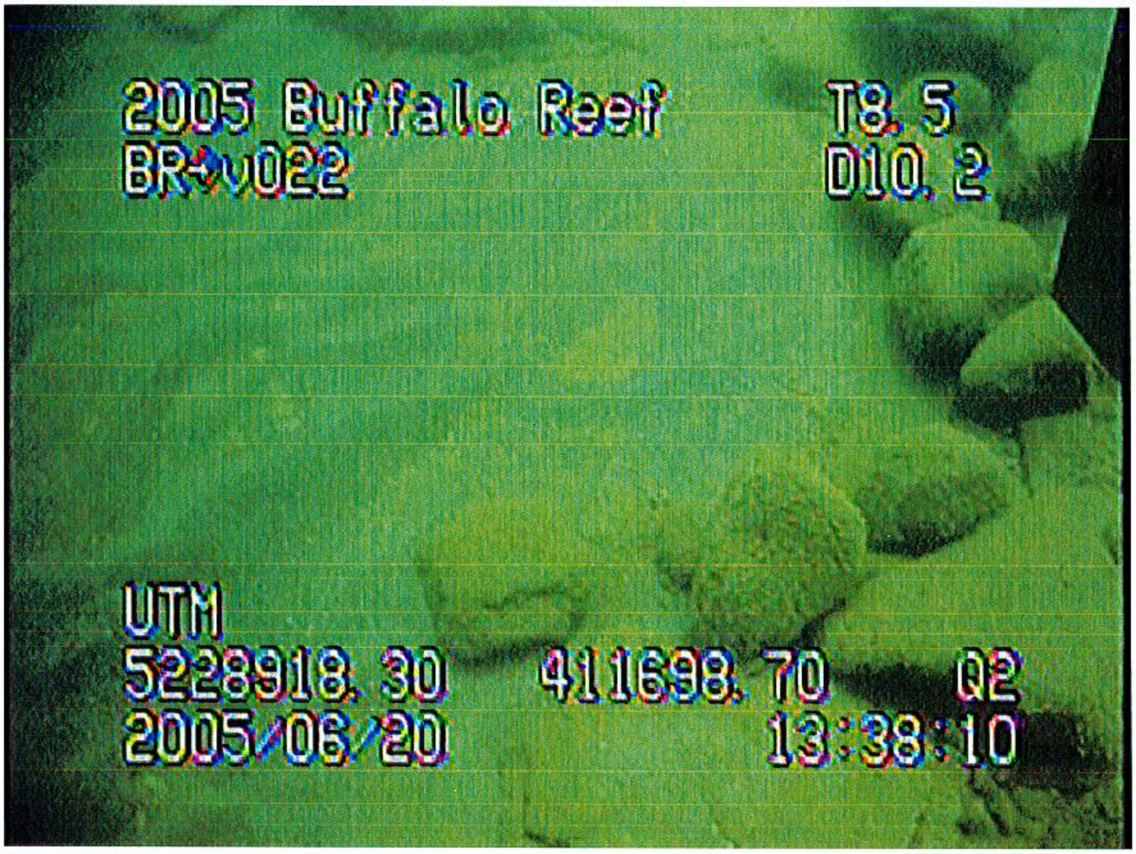
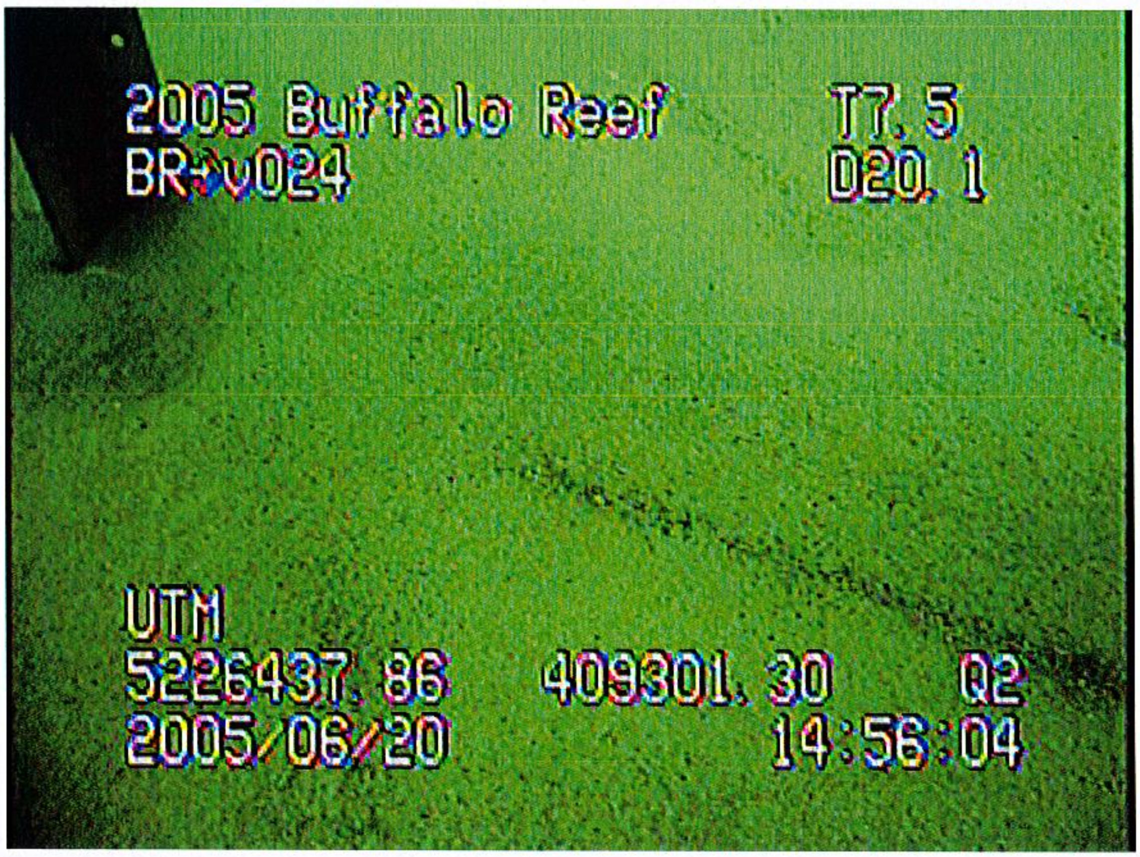
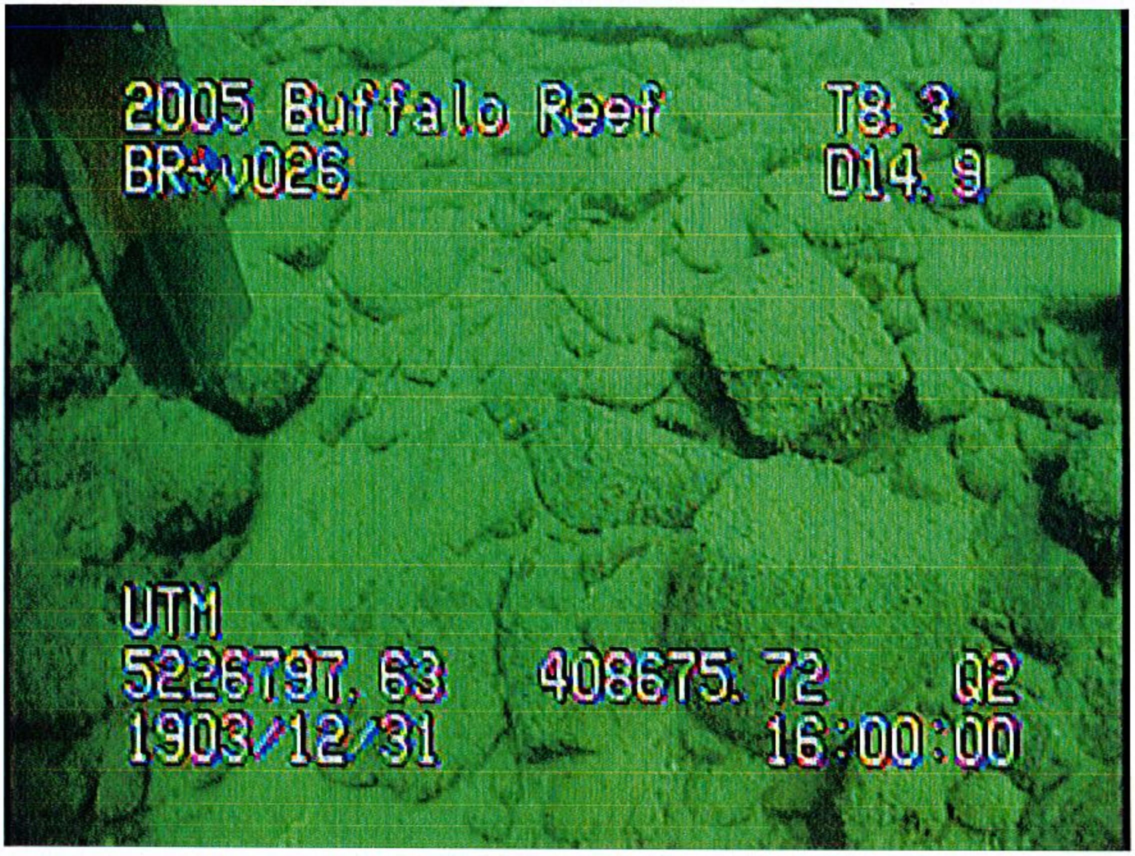
411085.14
Q2
2005/06/20
14:36:31

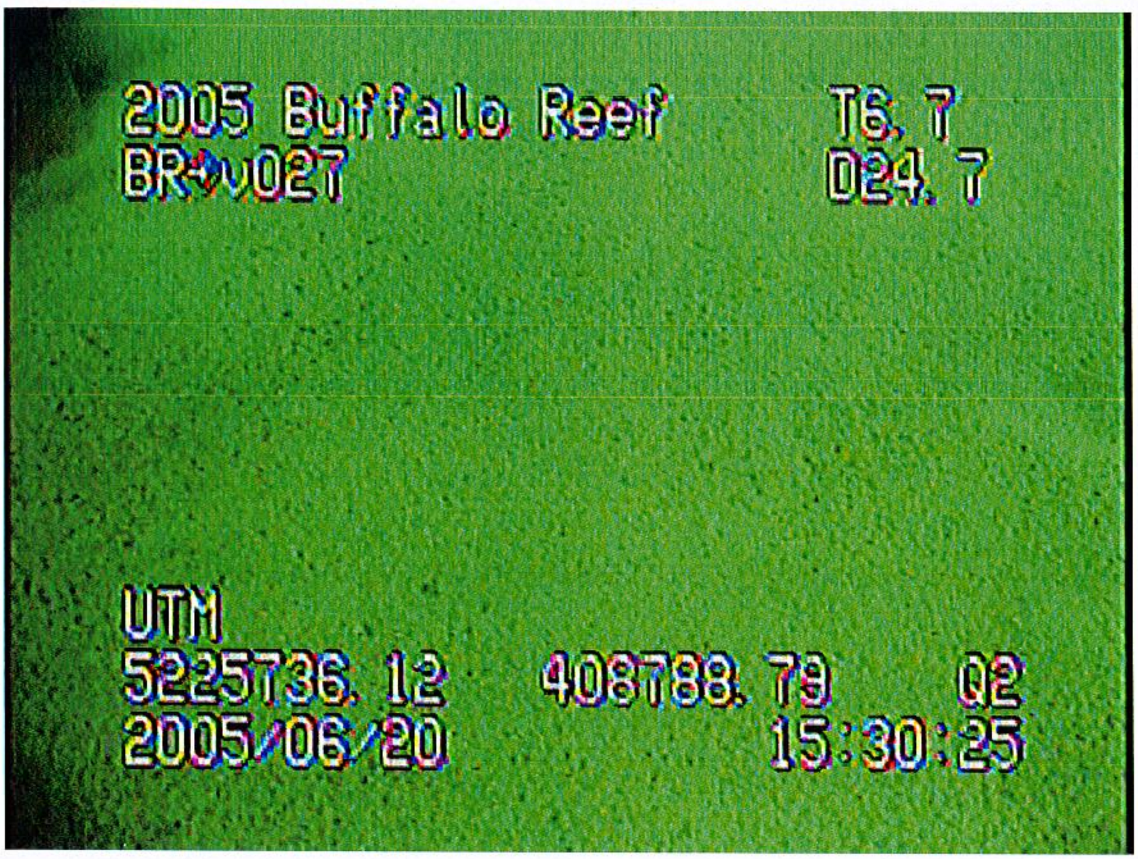

2005 Buffalo Reef
T8.5
BR-v022
D10.2
UTM
5228918.30
411698.70
Q2
2005/06/20
13:38:10

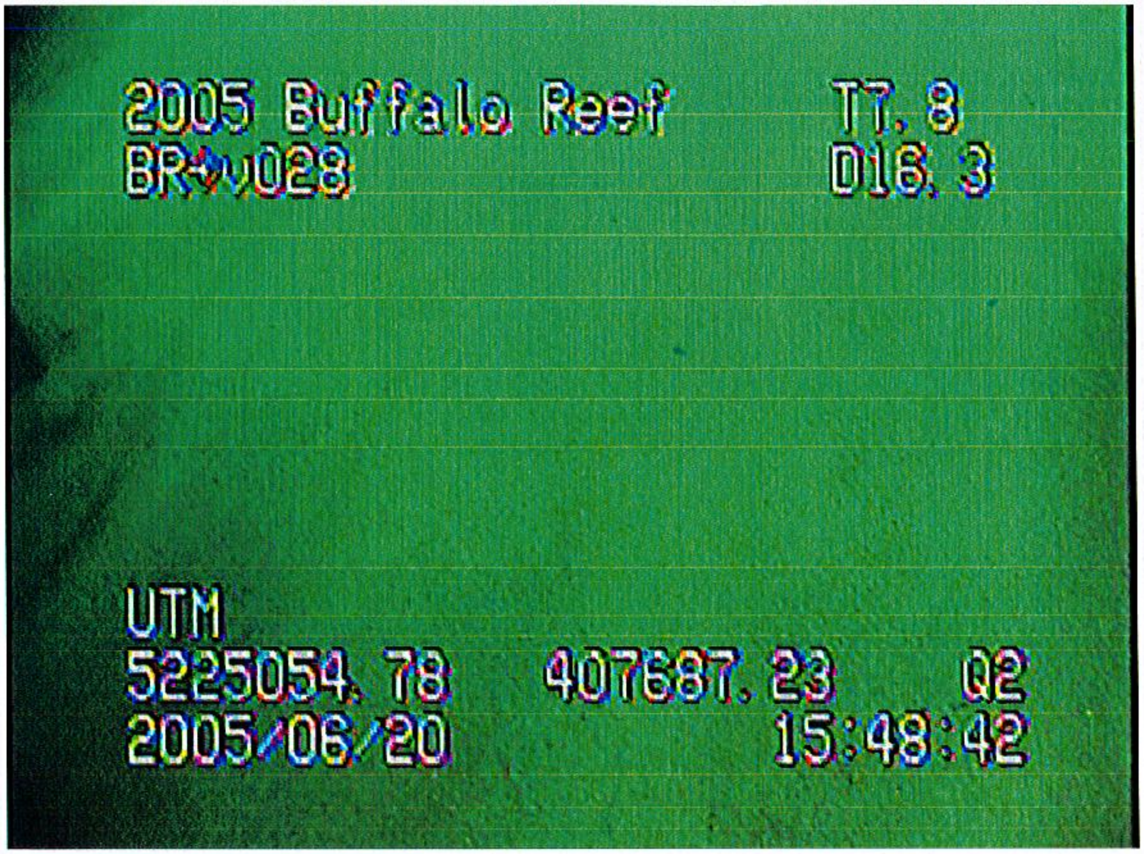

2005 Buffalo Reef
T7.5
BR-v024
D20.1
UTM
5226437.86
409301.30
Q2
2005/06/20
14:56:04

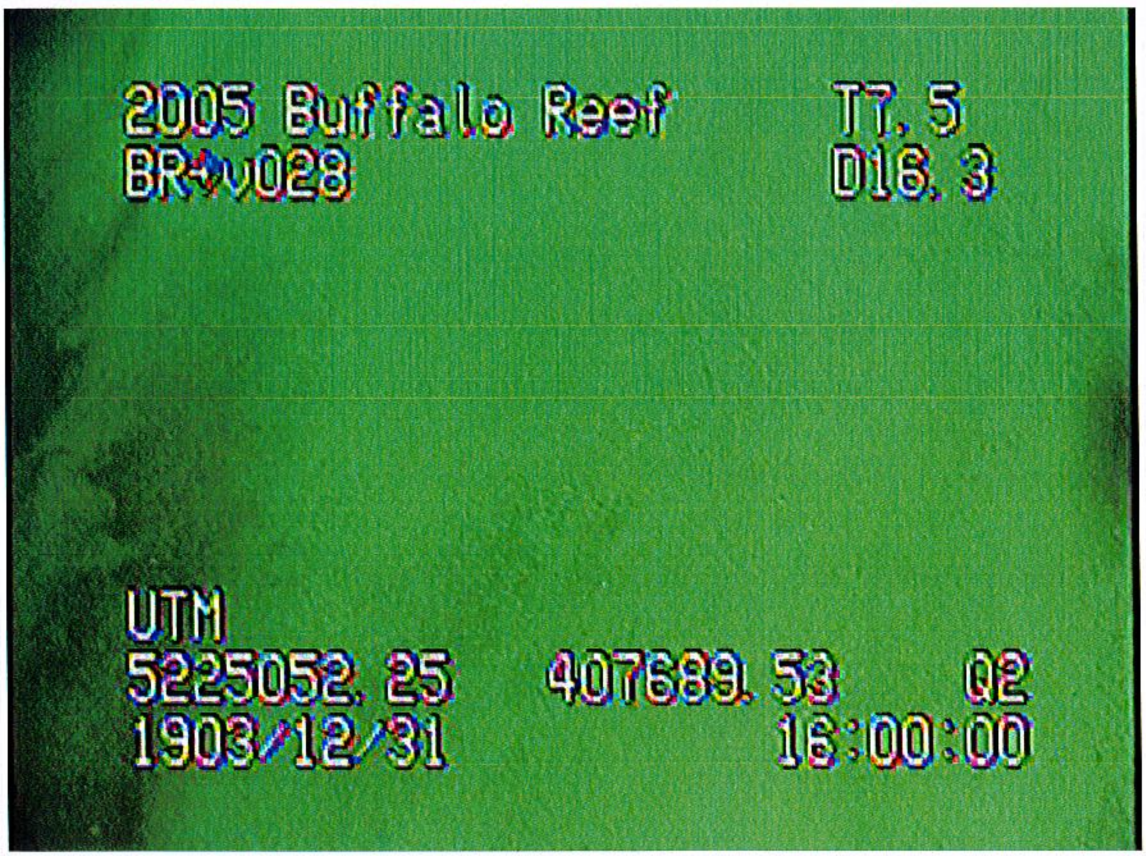

2005 Buffalo Reef
T7.8
BR-v025
D19.6
UTM
5226081.16
408687.31
Q2
2005/06/20
15:23:23


2005 Buffalo Reef
T8.7
BR-v026
D13.5
UTM
5226797.51
408674.14
Q2
2005/06/20
15:09:45


2005 Buffalo Reef
T8.3
BR-v026
D14.9
UTM
5226797.63
408675.72
Q2
1903/12/31
16:00:00


2005 Buffalo Reef
T6.7
BR-v027
D24.7
UTM
5225736.12
408788.79
Q2
2005/06/20
15:30:25


2005 Buffalo Reef
T7.8
BR-v028
D16.3
UTM
5225054.78
407687.23
Q2
2005/06/20
15:48:42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BR-v028
D16.3
UTM
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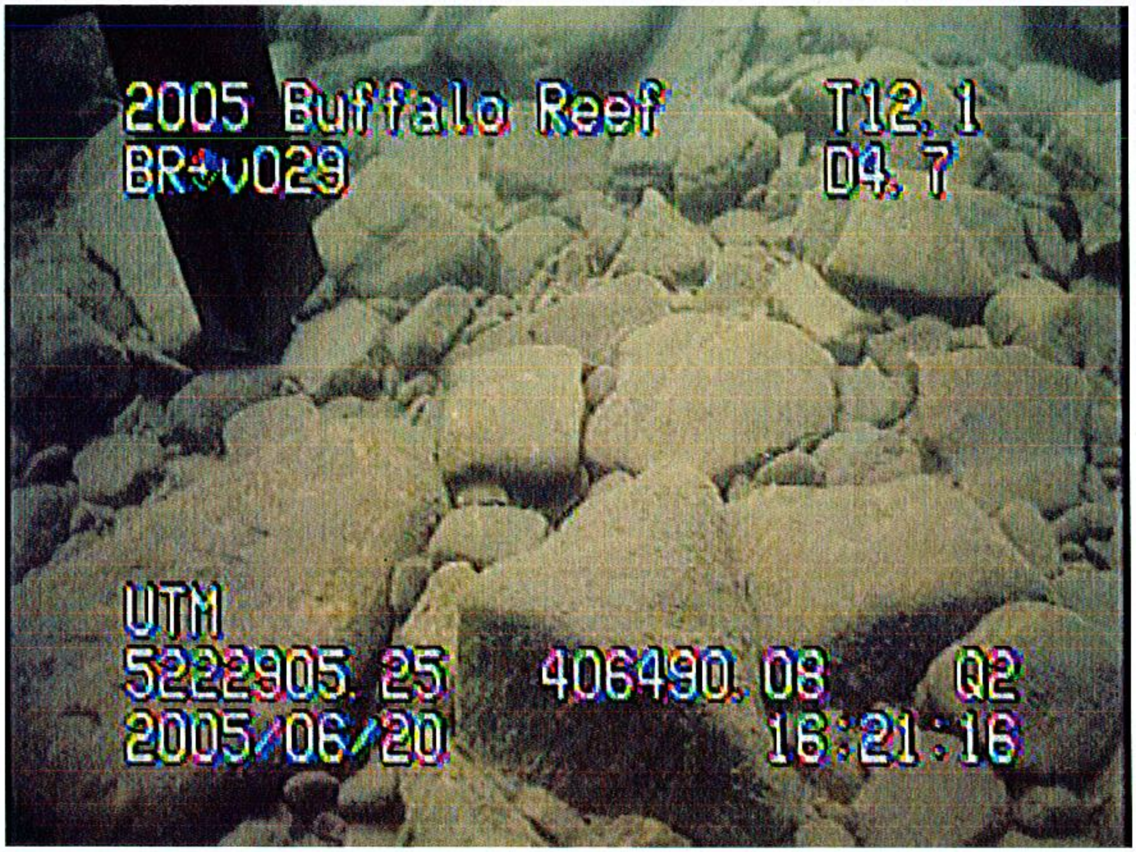
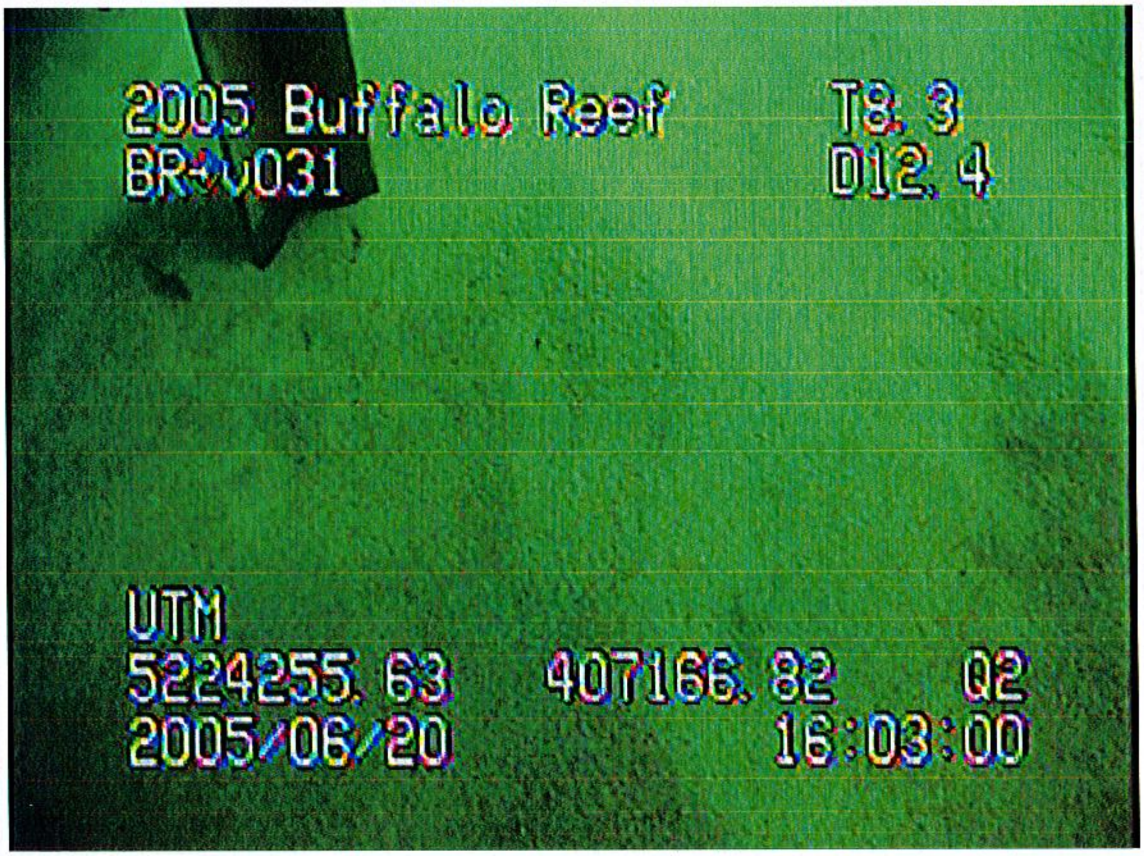
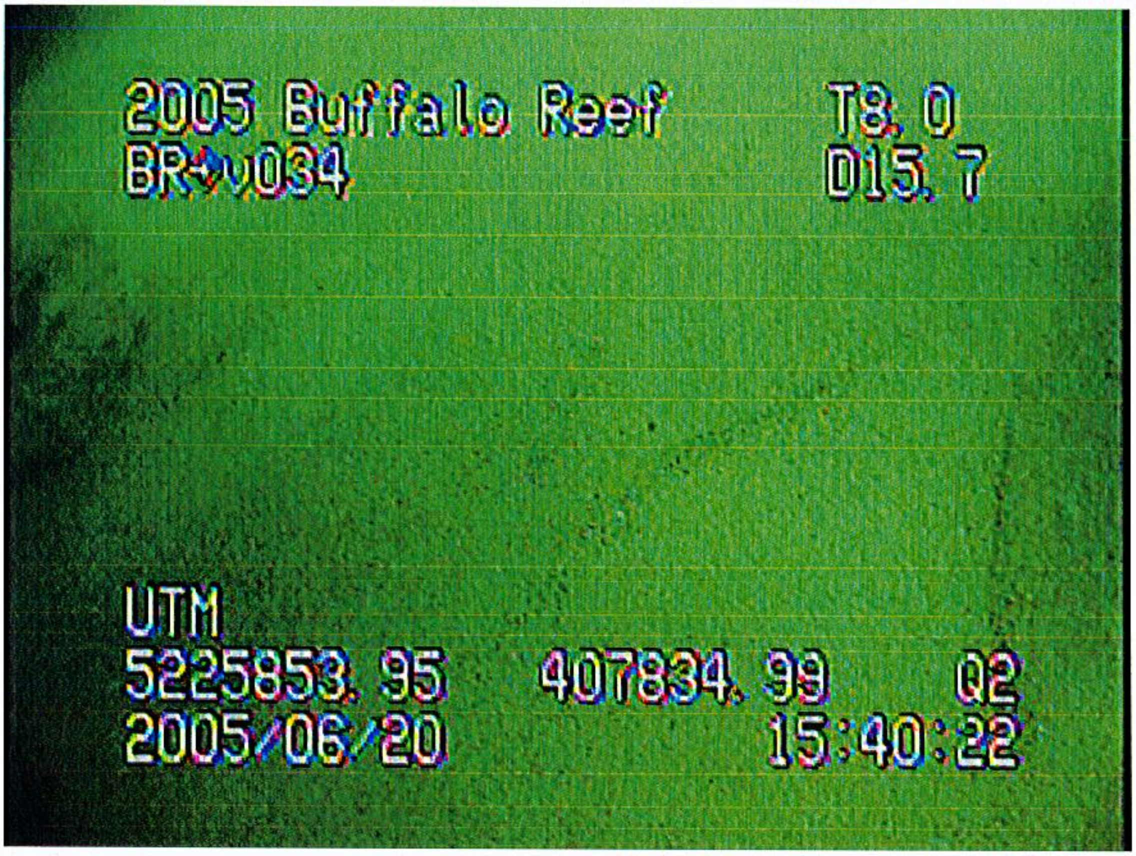
407689.53
Q2
1903/12/31
16:00:00


2005 Buffalo Reef
T12.1
BR-v029
D4.7
UTM
5222905.25
406490.08
Q2
2005/06/20
16:21:16


2005 Buffalo Reef
T8.5
BR-v030
D13.1
UTM
5222853.98
407297.79
Q2
2005/06/20
16:12:56


2005 Buffalo Reef
T8.3
BR-v031
D12.4
UTM
5224255.63
407166.82
02
2005/06/20
16:03:00


2005 Buffalo Reef
T9.5
BR-v032
D9.4
UTM
5224490.42
406490.38
02
2005/06/20
16:34:45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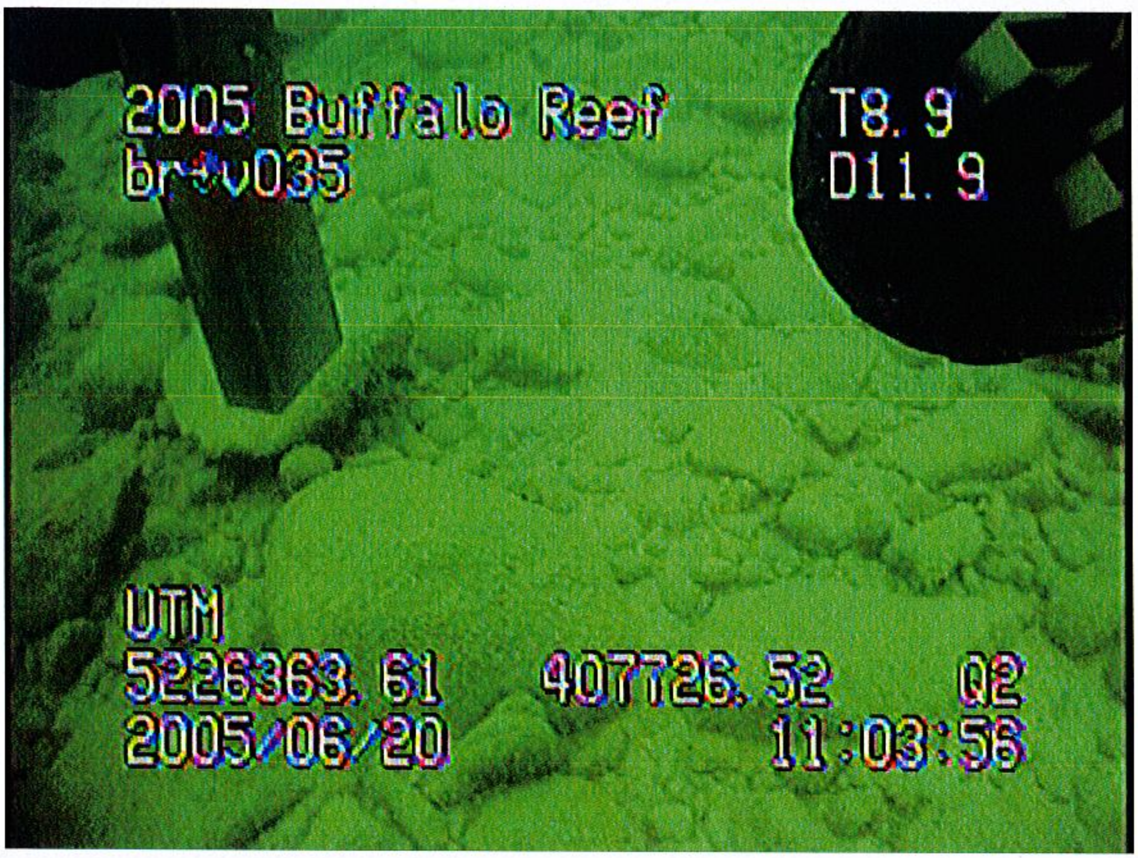
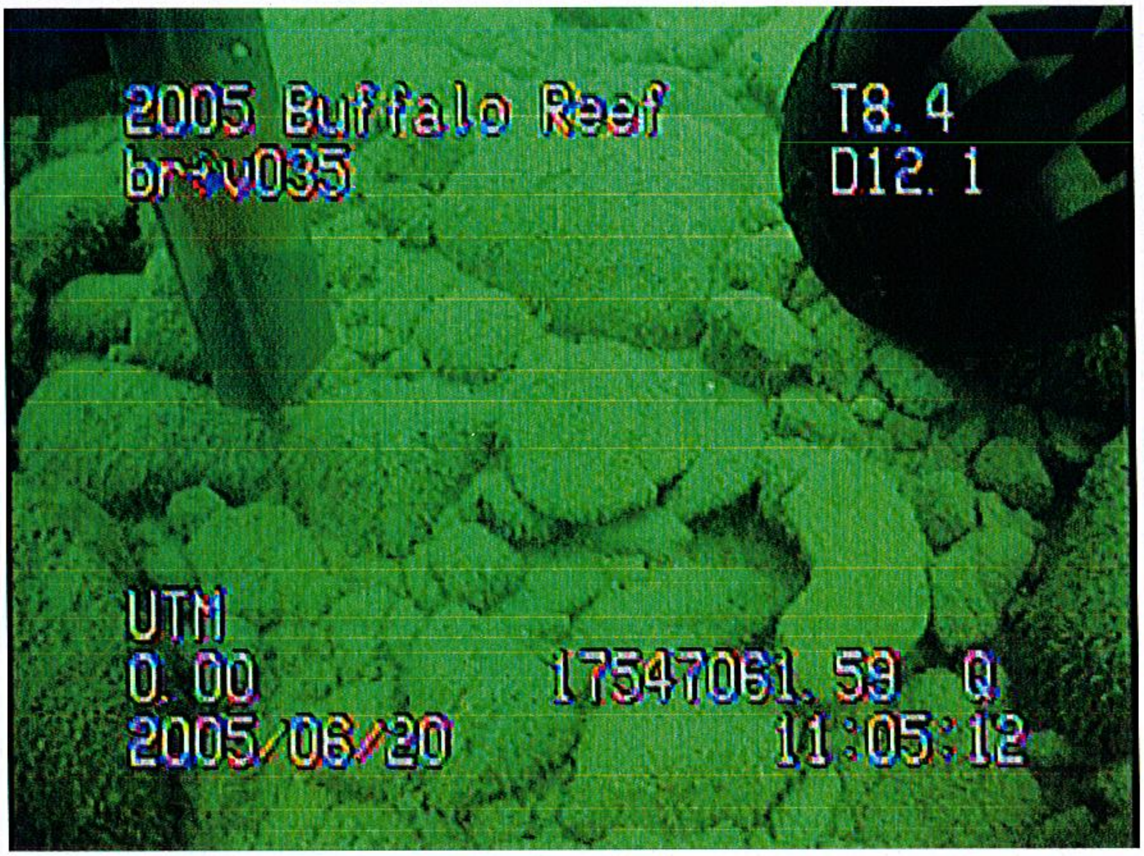
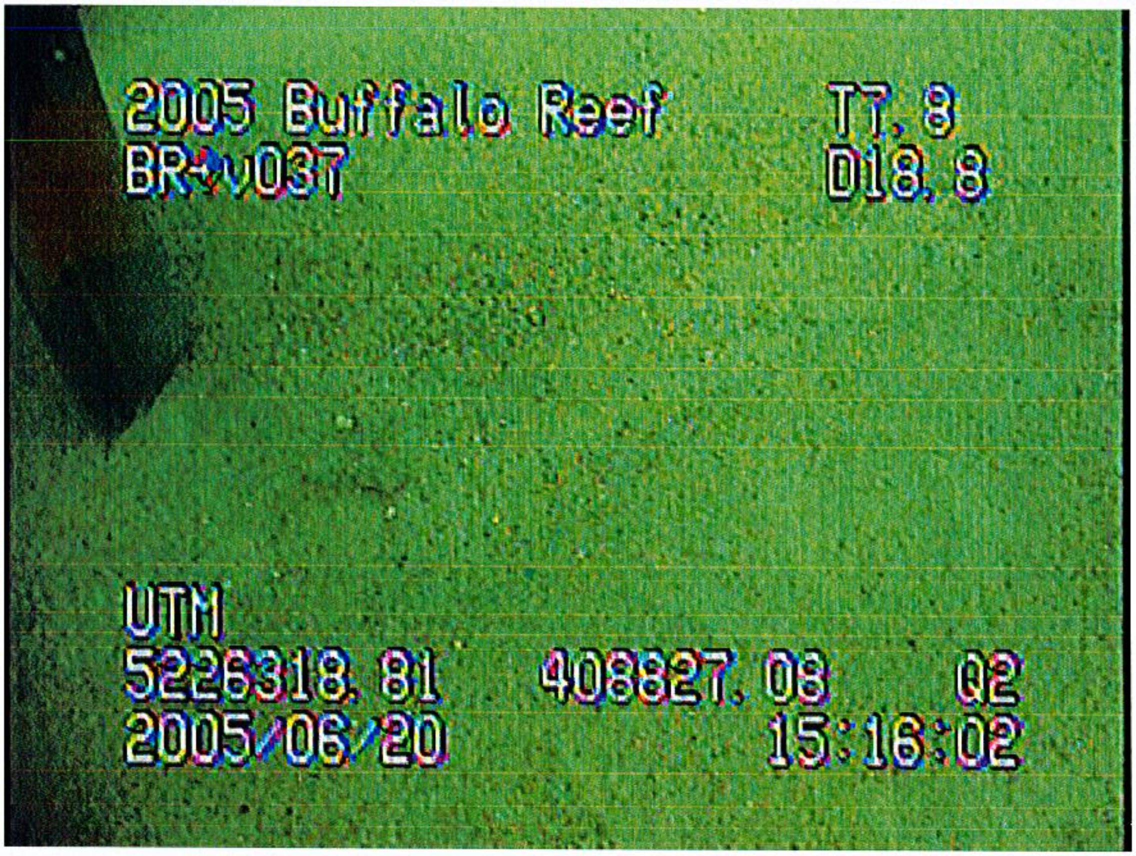
T8.0
BR-v034
D15.7
UTM
5225853.95
407834.99
Q2
2005/06/20
15:40:22

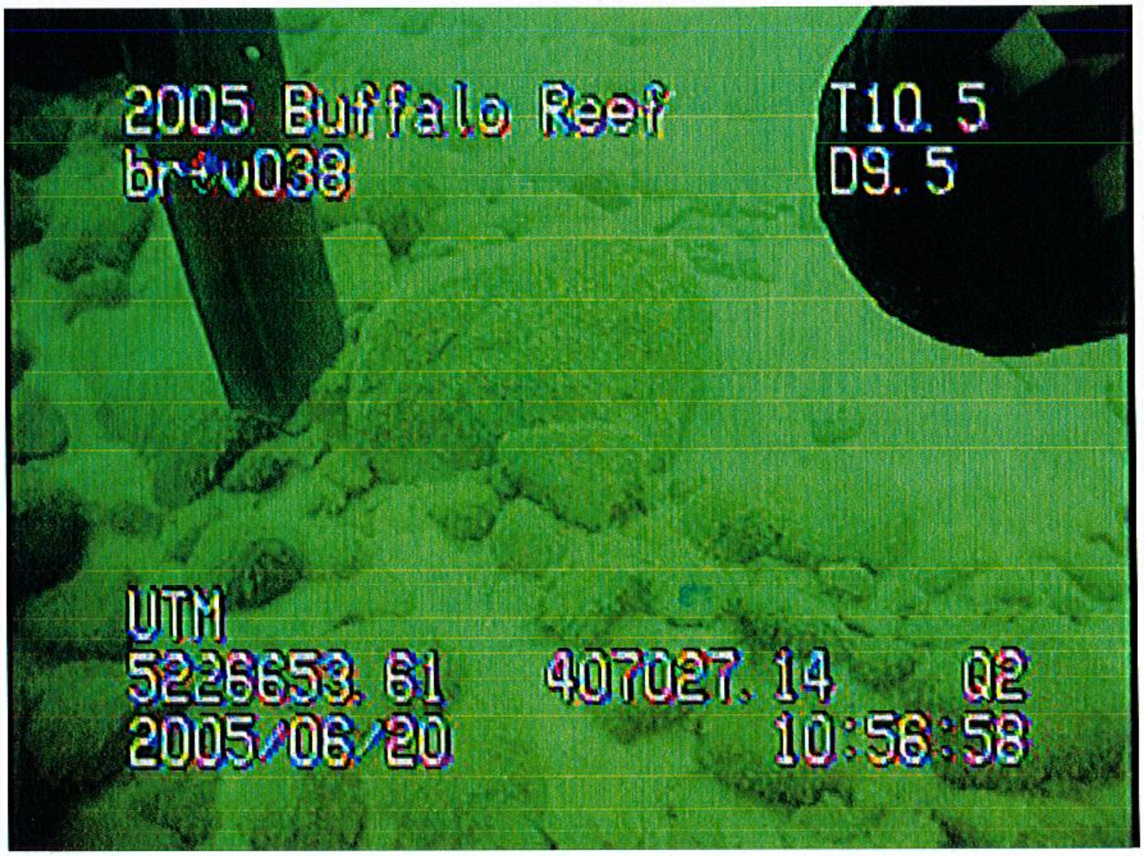

2005 Buffalo Reef
T8.9
br-v035
D11.9
UTM
5226363.61
407726.52
Q2
2005/06/20
11:03:56


2005 Buffalo Reef
br-v035
T8.4
D12.1
UTM
0.00
17547061.59
Q
2005/06/20
11:05:12


2005 Buffalo Reef
BR-v036
T8.2
D11.7
UTM
5225464.42
406860.92
Q2
2005/06/20
16:49:48

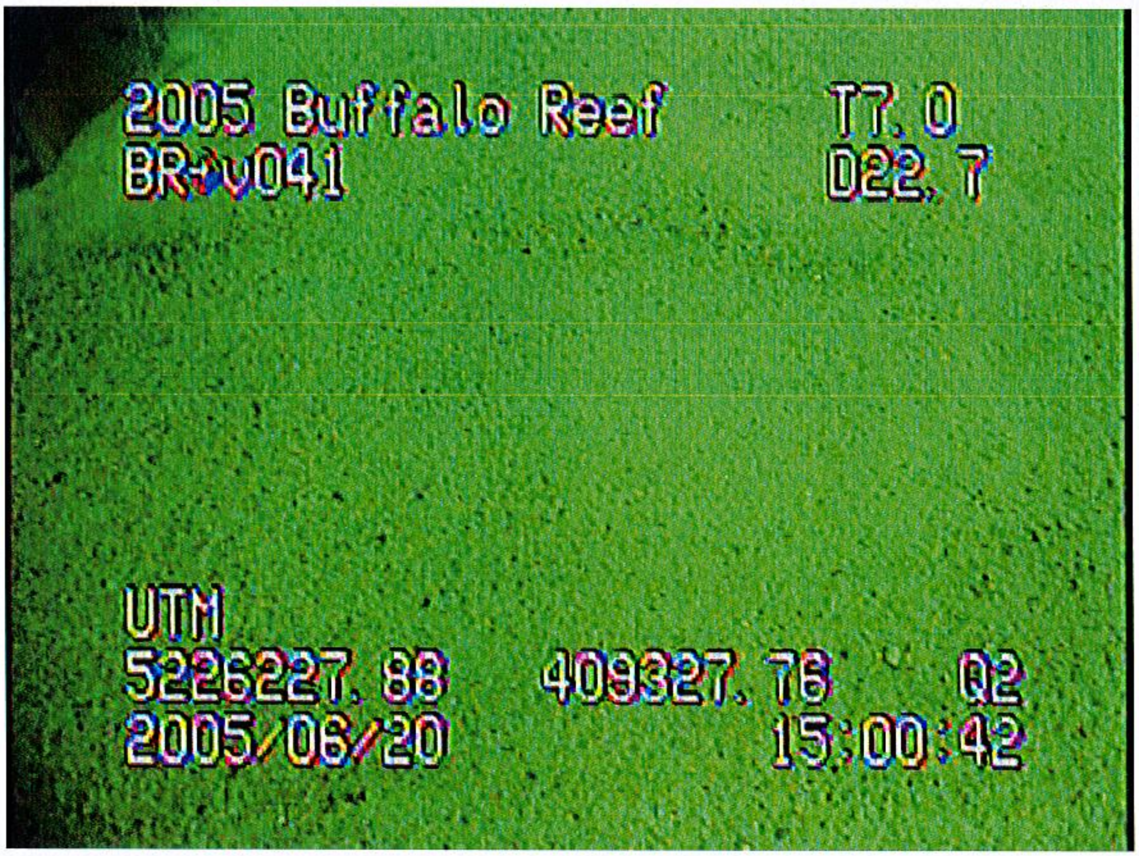

2005 Buffalo Reef
T7.8
BR-v037
D18.8
UTM
5226318.81
408827.08
Q2
2005/06/20
15:16:02


2005 Buffalo Reef
T10.9
br-v038
D9.0
UTM
5226654.07
407016.03
Q2
2005/06/20
10:56:01

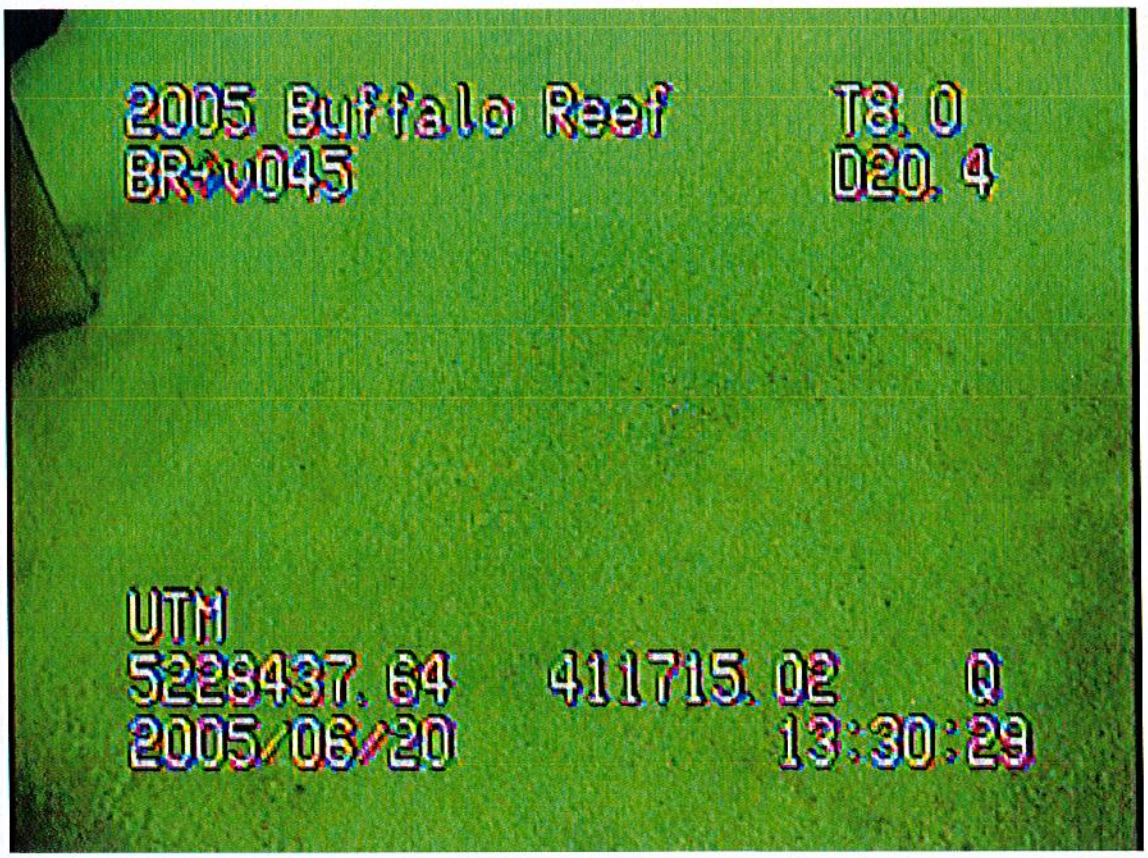

2005 Buffalo Reef
br+v038
T10.5
D9.5
UTM
5226653.61
407027.14
Q2
2005/06/20
10:56:58

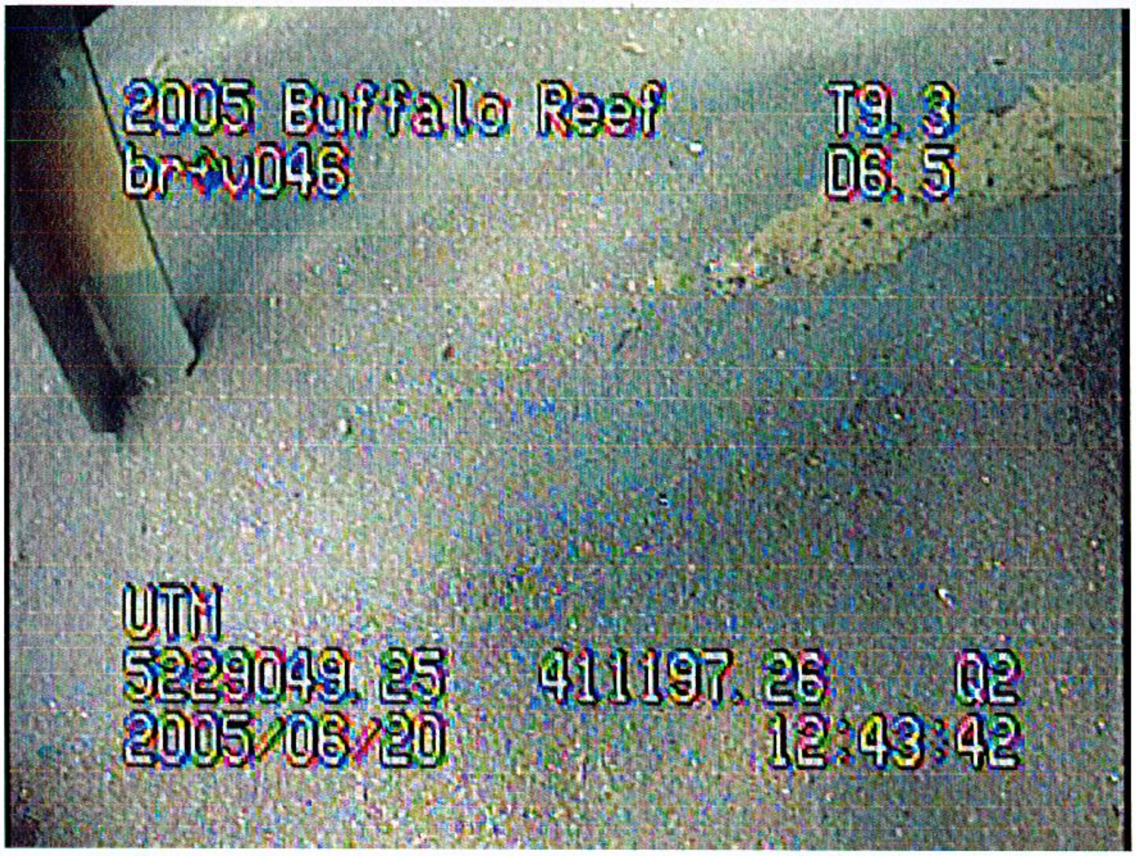

2005 Buffalo Reef
br+v038a
T8.2
D15.1
UTM
5227449.93
410139.37
Q
2005/06/20
12:19:26


2005 Buffalo Reef
T12.5
br-v040
D1.8
UTM
5228117.29
407815.79
Q2
2005/06/20
11:22:16

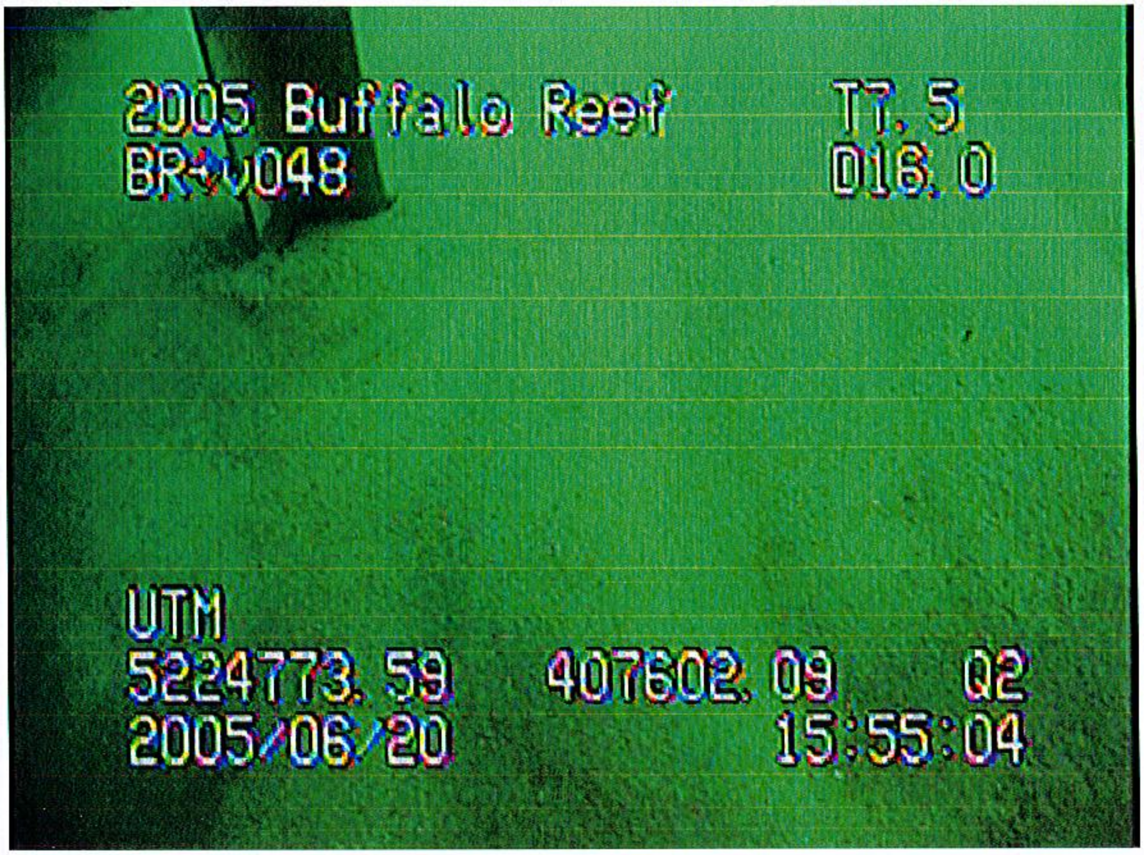

2005 Buffalo Reef
T7.0
BR-v041
D22.7
UTM
5226227.88
409327.76
Q2
2005/06/20
15:00:42


2005 Buffalo Reef
T9.2
BR-v044
D7.3
UTM
5229186.43
411636.31
Q2
2005/06/20
13:45:14


2005 Buffalo Reef
T8.0
BR-v045
D20.4
UTM
5228437.64
411715.02
Q
2005/06/20
13:30:29

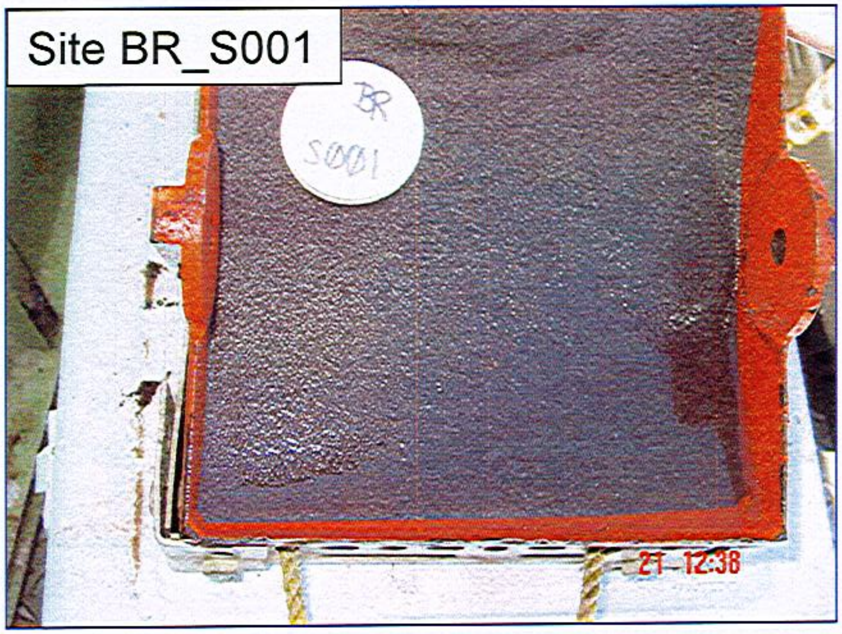

2005 Buffalo Reef T9.3
br-v046 D6.5
UTM
5229049.25 411197.26 Q2
2005/06/20 12:43:42

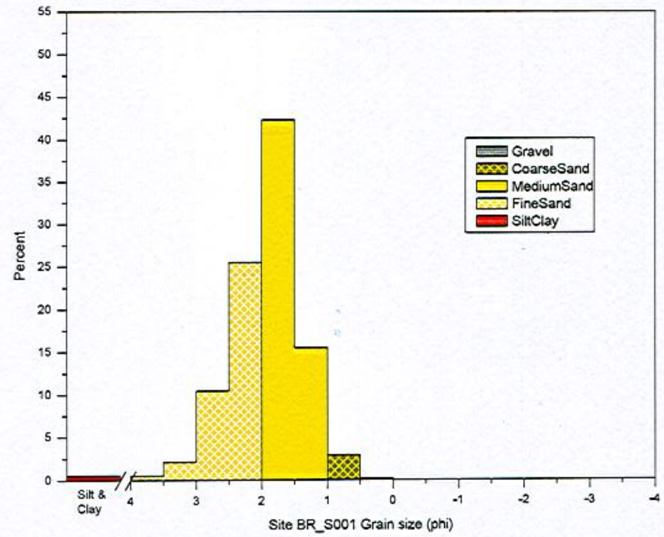

2005 Buffalo Reef T10.2
br-v047 D4.2
UTM
5228858.98 410346.02 Q
2005/06/20 12:33:19


2005 Buffalo Reef
T7.5
BR-v048
D16.0
UTM
5224773.59
407602.09
Q2
2005/06/20
15:55:04

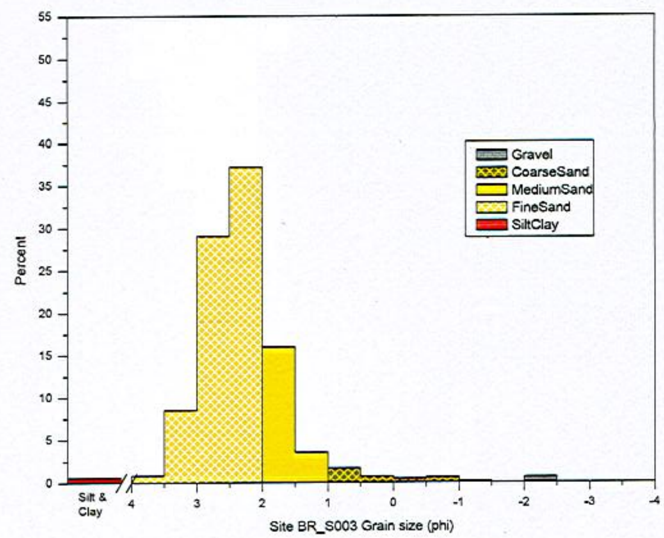

2005 Buffalo Reef
T10.7
BR-v049
D7.4
UTM
5225175.19
406230.28
Q2
2005/06/20
16:41:08

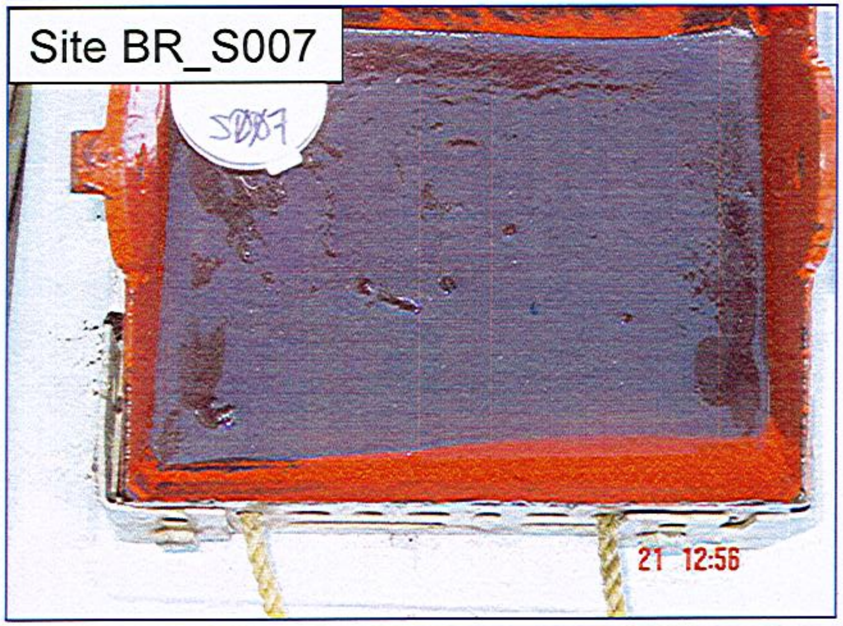
Appendix 2: Sediment sample images


Site BR_S001
BR
S001
21 12:38

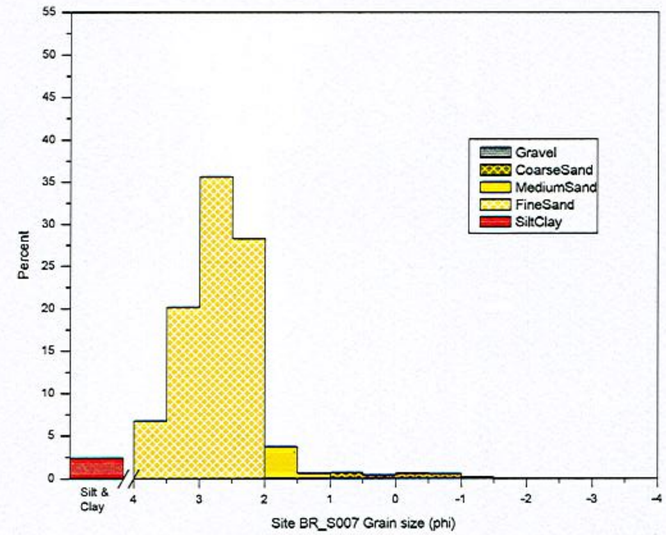

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S001 Grain size (phi)


Site BR_S003
21 12:48

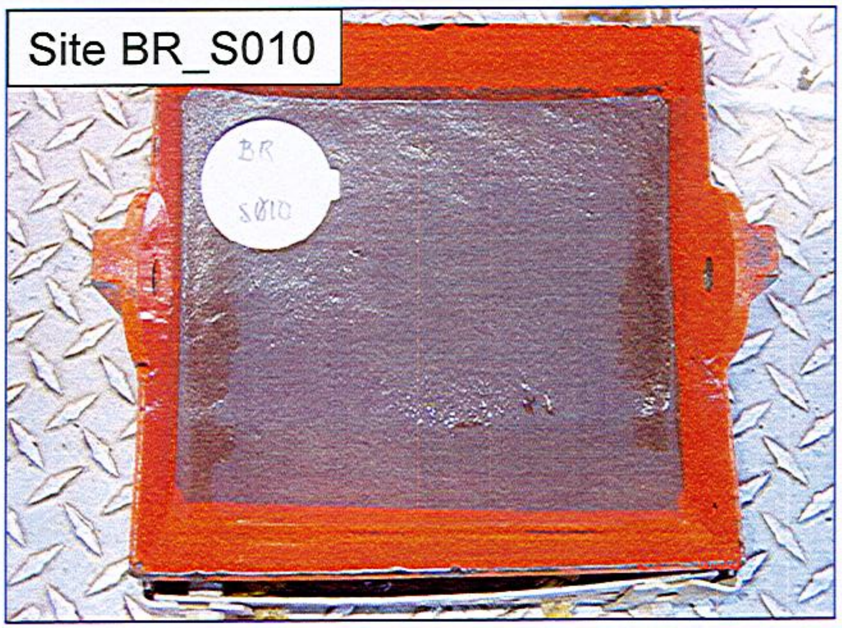

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S003 Grain size (phi)



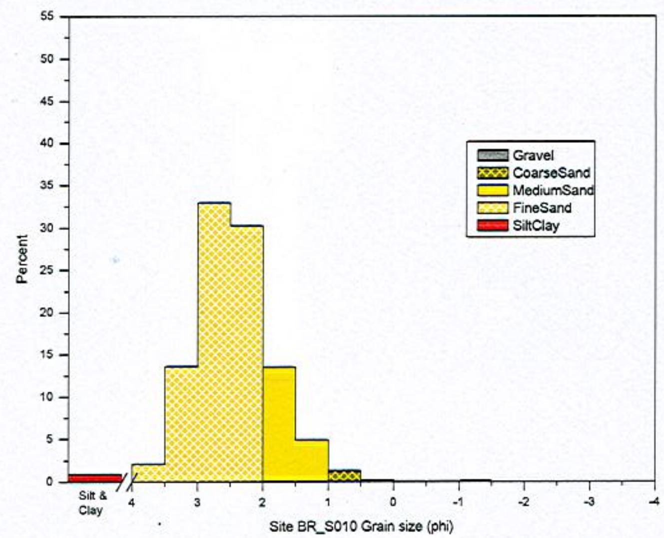
Site BR_S007
21 12:56



Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S007 Grain size (phi)

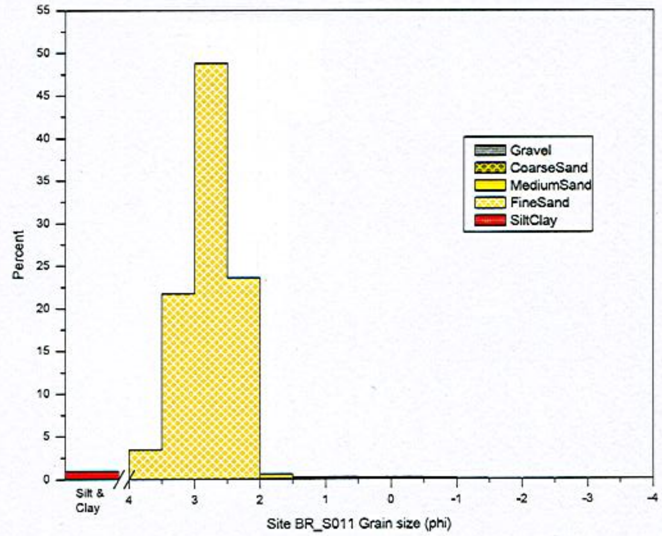


Site BR_S010

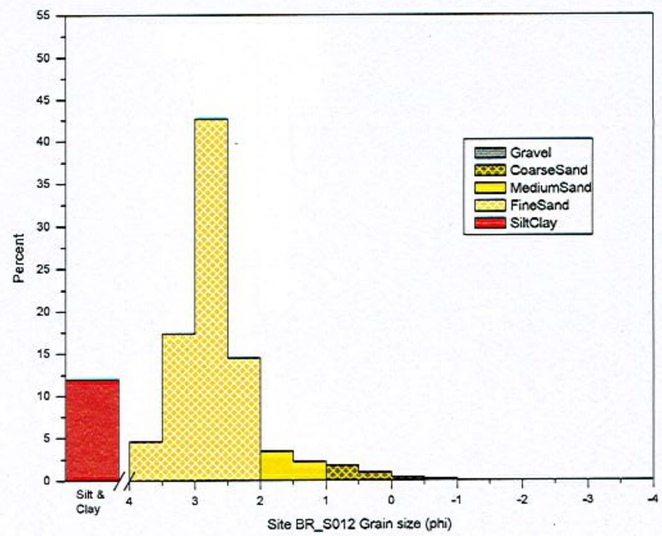


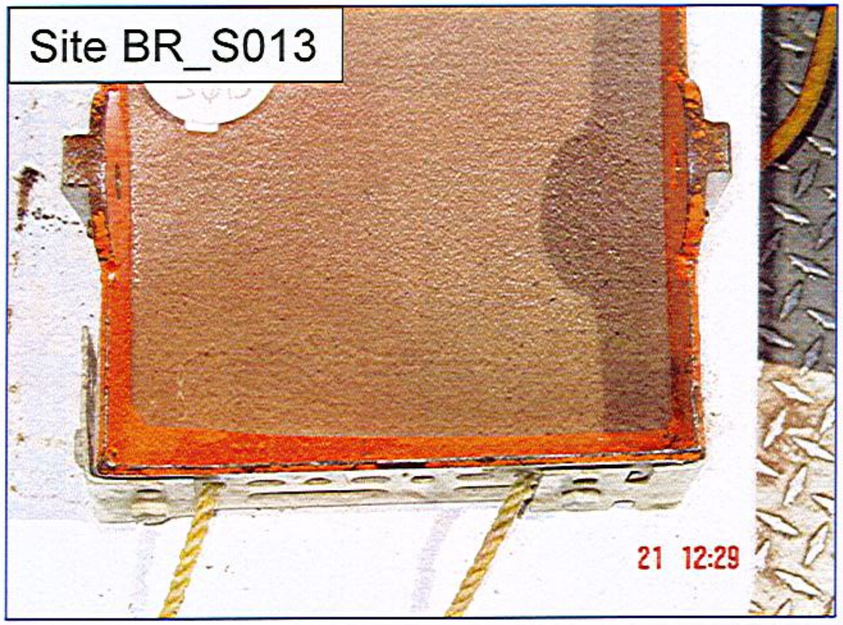
Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S010 Grain size (phi)

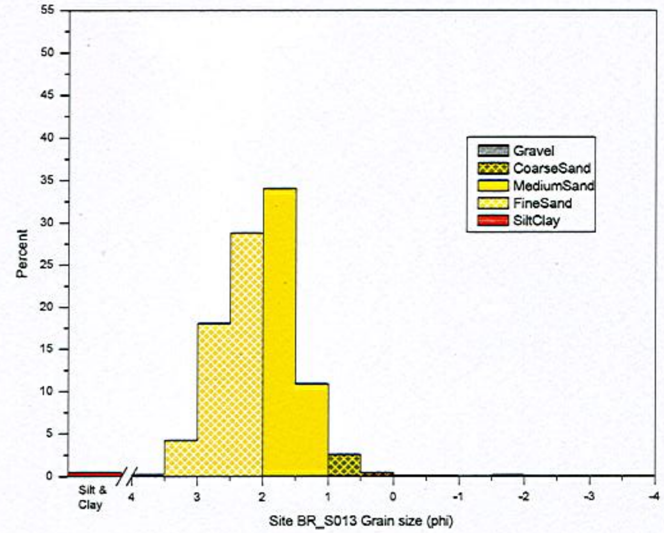

Site BR_S011



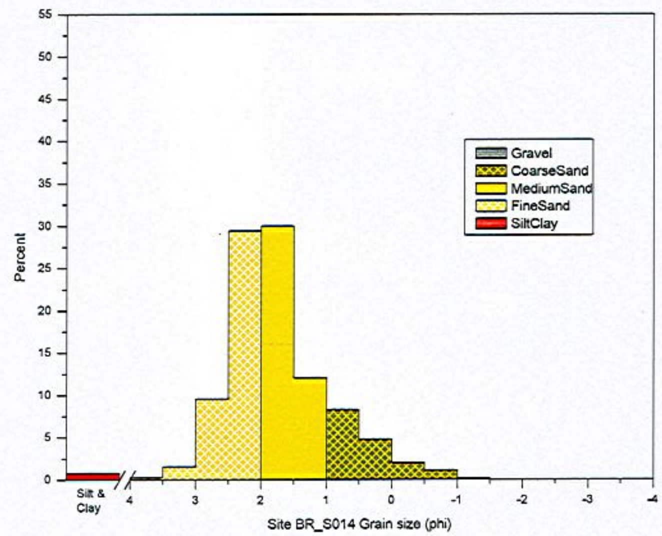

Site BR_S012



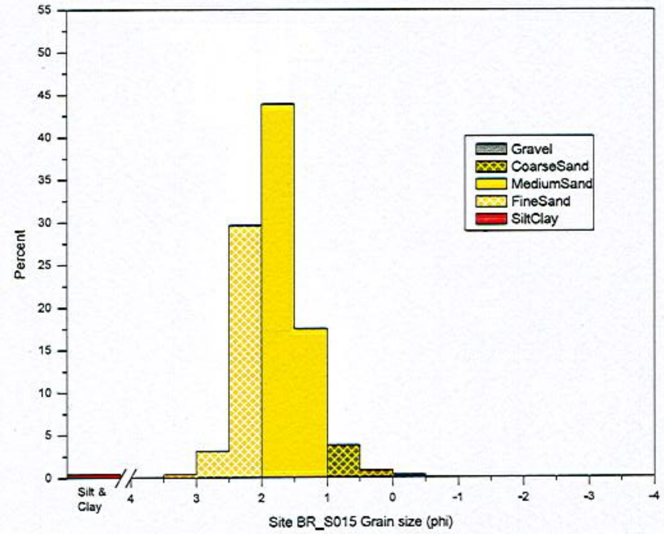

Site BR_S013
21 12:29


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site BR_S013 Grain size (phi)

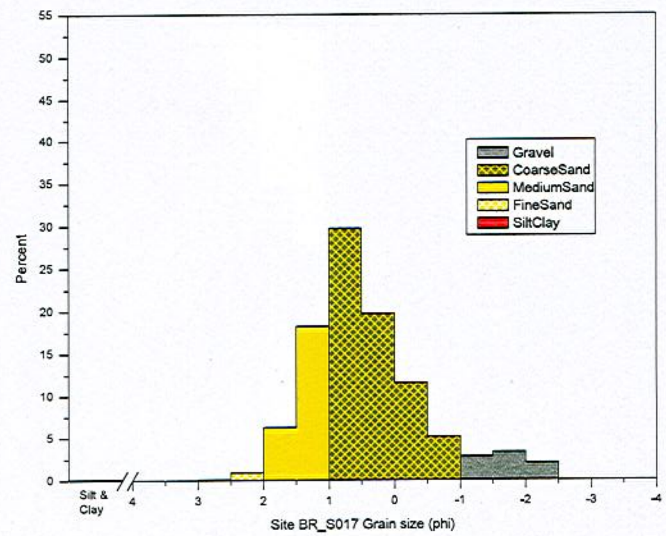

Site BR_S014
S014


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site BR_S014 Grain size (phi)

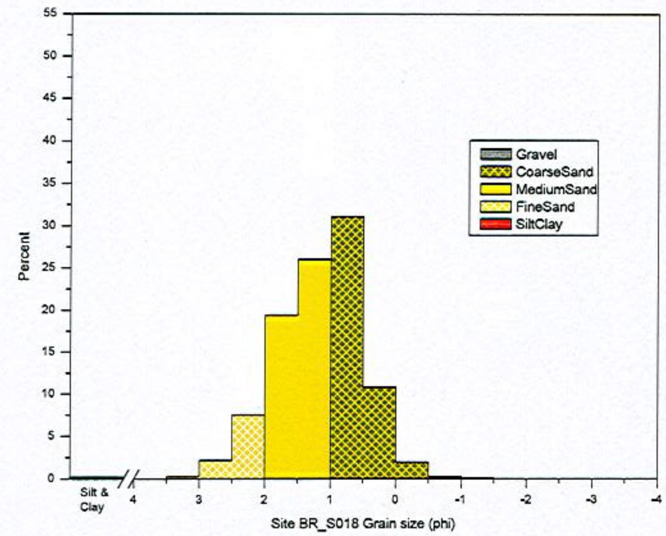

Site BR_S015
S015
21 11:48


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S015 Grain size (phi)

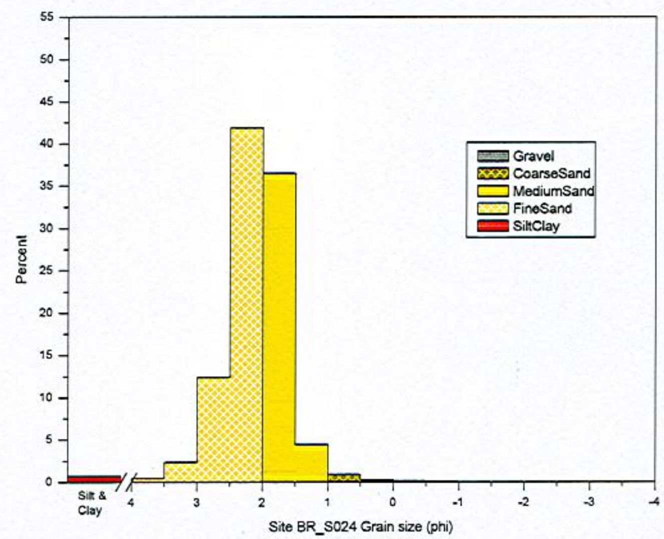

Site BR_S017
S017
21 12:03


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S017 Grain size (phi)

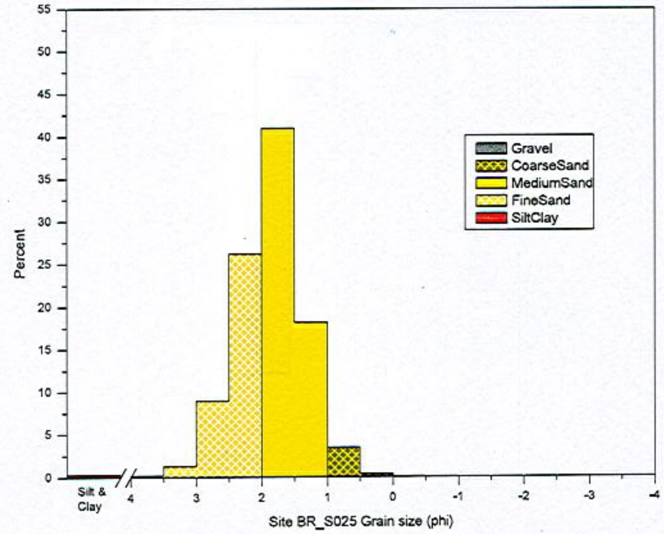

Site BR_S018
BR
S018
21 11:56


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S018 Grain size (phi)

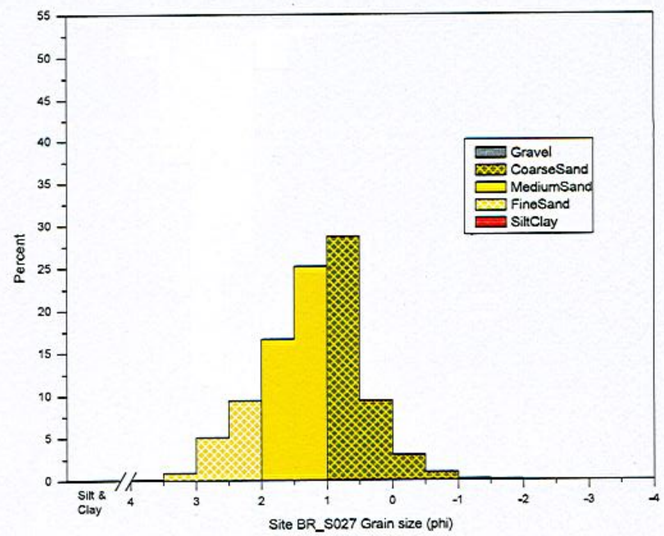

Site BR_S024
BR
21 10:59


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site BR_S024 Grain size (phi)


Site BR_S025
BR
SØ25
21 10:22


Percent
0
5
10
15
20
25
30
35
40
45
50
55
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S025 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay


Site BR_S027
SØ27
21 10:38


Percent
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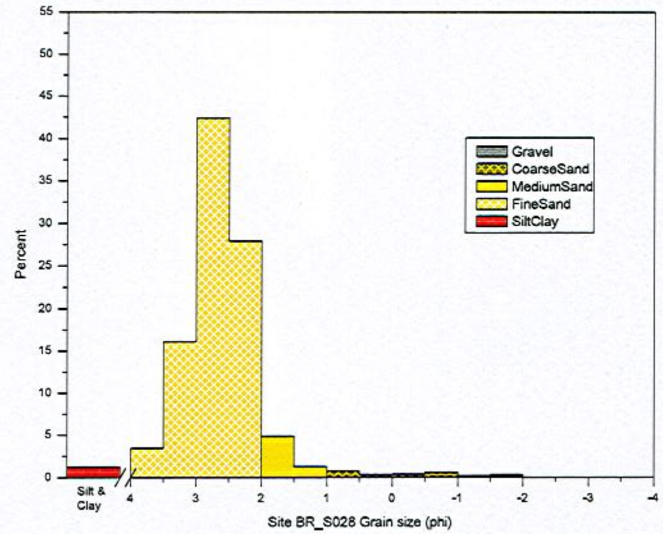
5
10
15
20
25
30
35
40
45
50
55
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S027 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay


Site BR_S028
21 13:33


Percent
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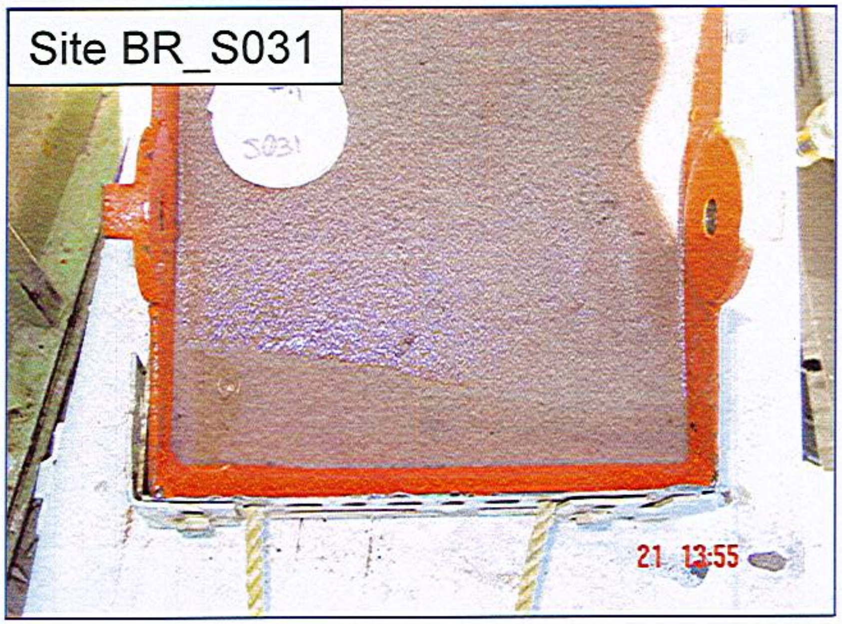
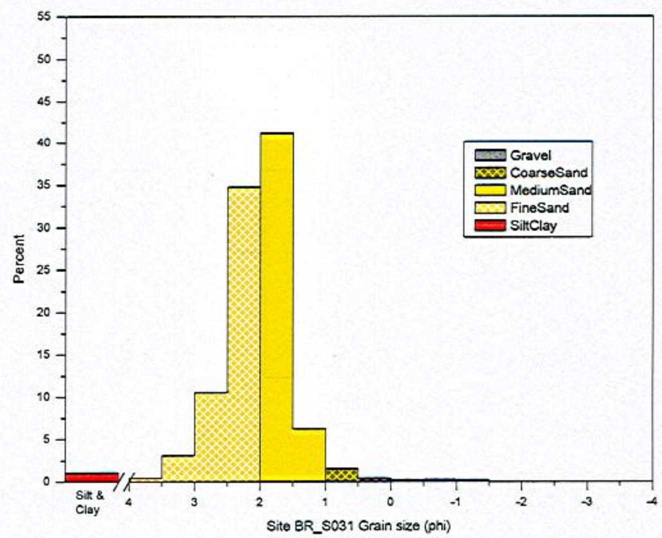
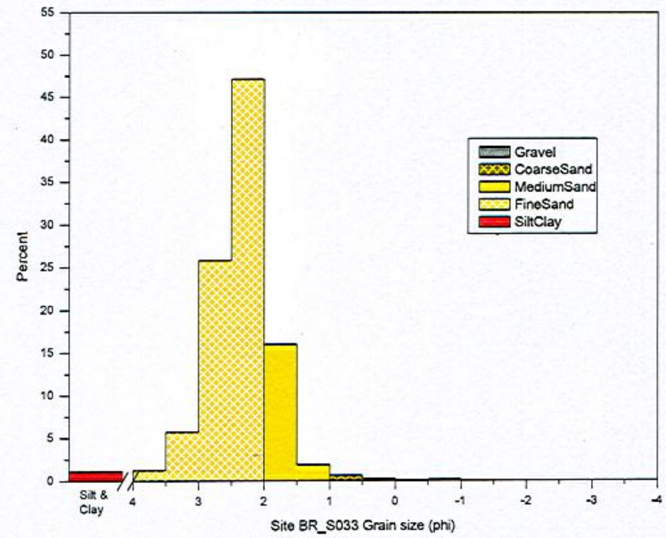
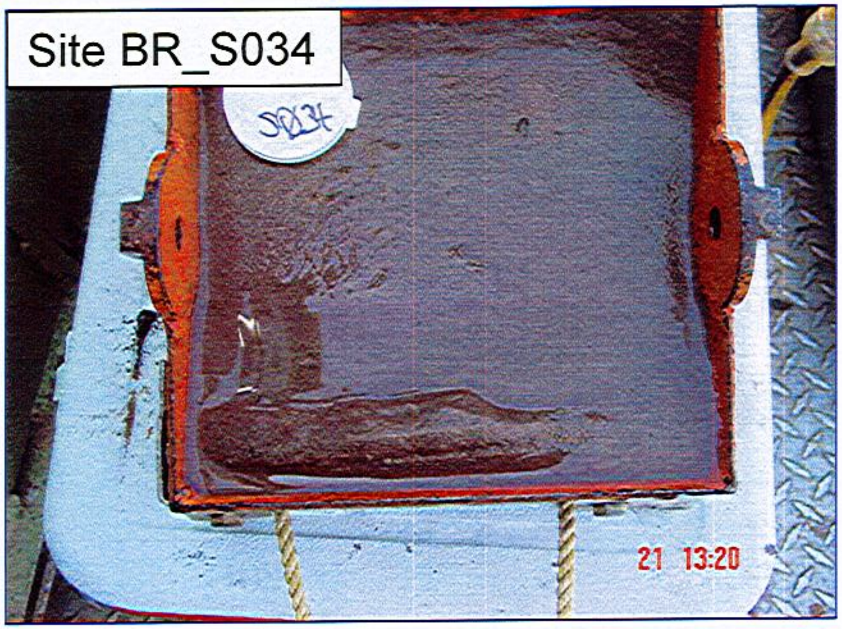
50
45
40
35
30
25
20
15
10
5
0
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S028 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

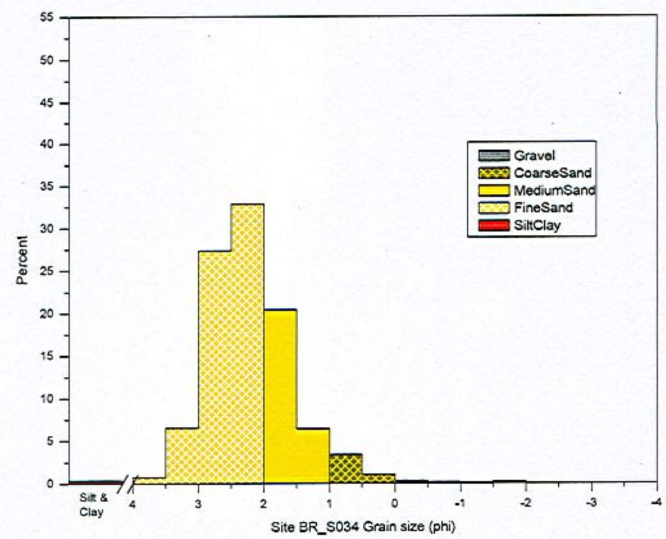

Site BR_S031
21 13:55


Percent
55
50
45
40
35
30
25
20
15
10
5
0
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S031 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

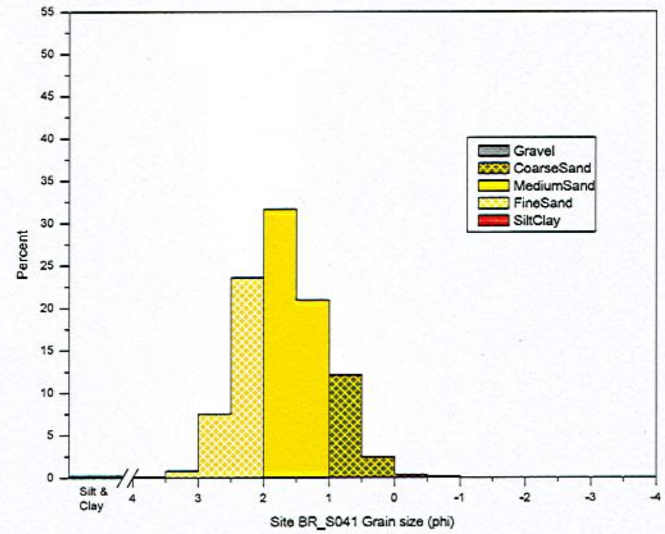

Site BR_S033
BR
S033
21 14:03


Percent
0
5
10
15
20
25
30
35
40
45
50
55
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S033 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

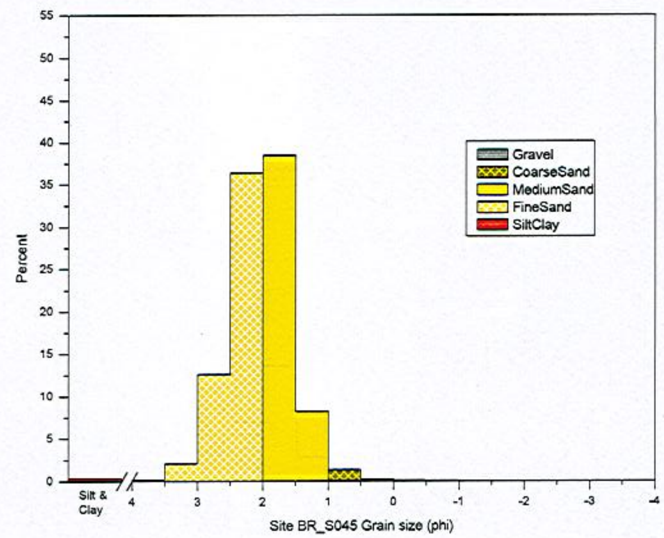

Site BR_S034
S034
21 13:20

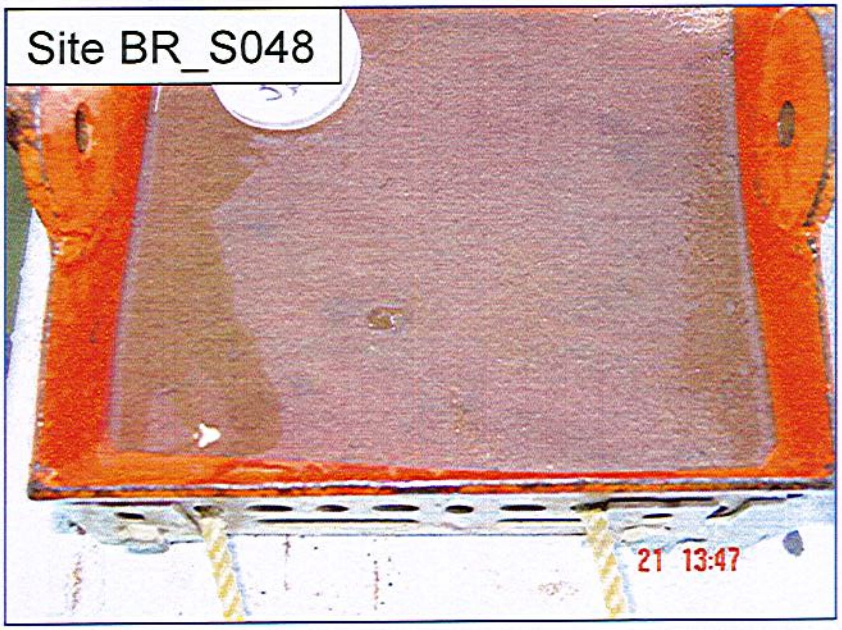

Percent
0
5
10
15
20
25
30
35
40
45
50
55
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S034 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

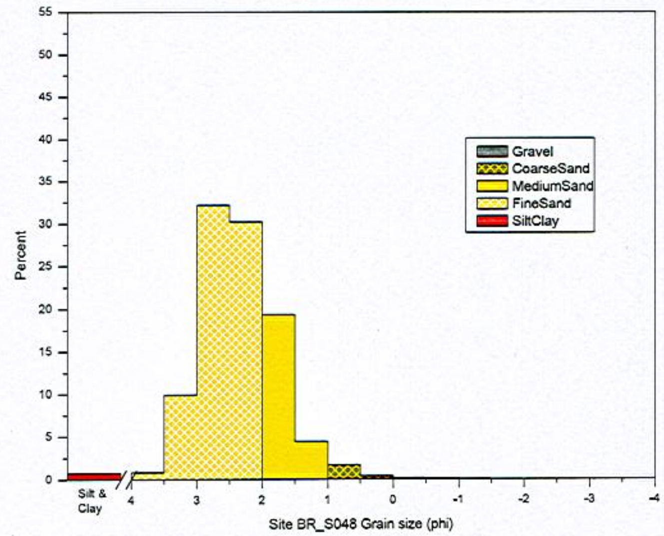
Site BR_S041



Site BR_S045



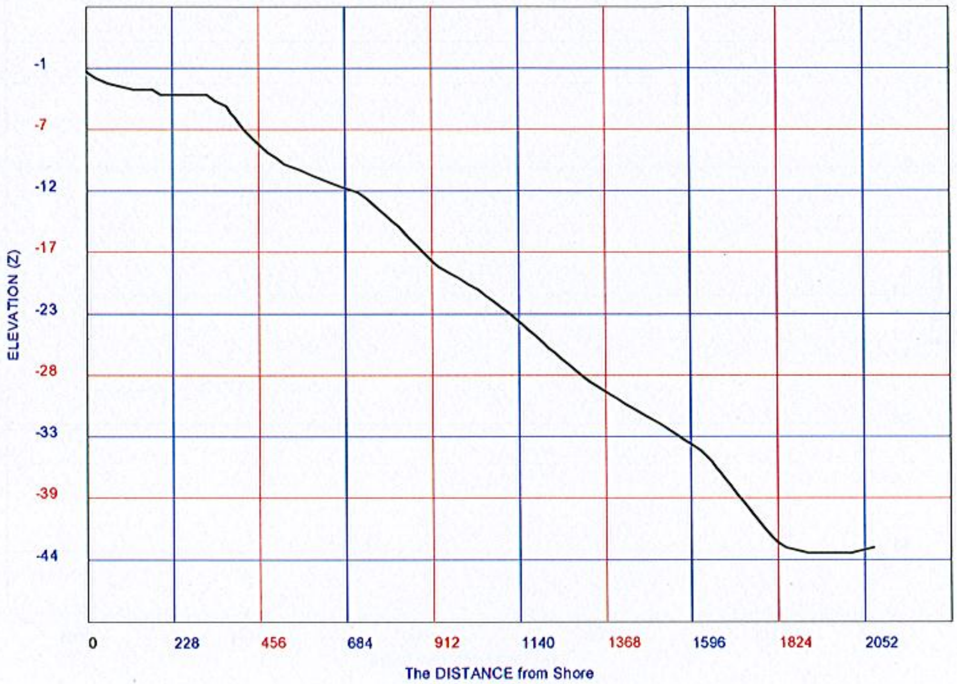

Site BR_S048
21 13:47


Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site BR_S048 Grain size (phi)

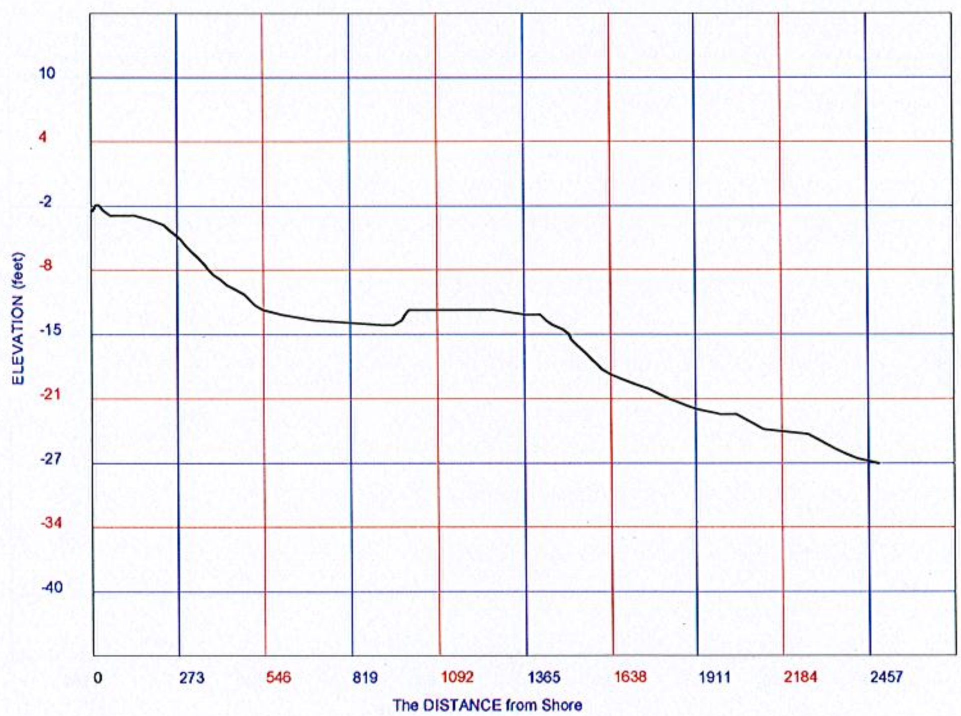
Appendix 3:

Lakebed Profiles

PROFILE 1



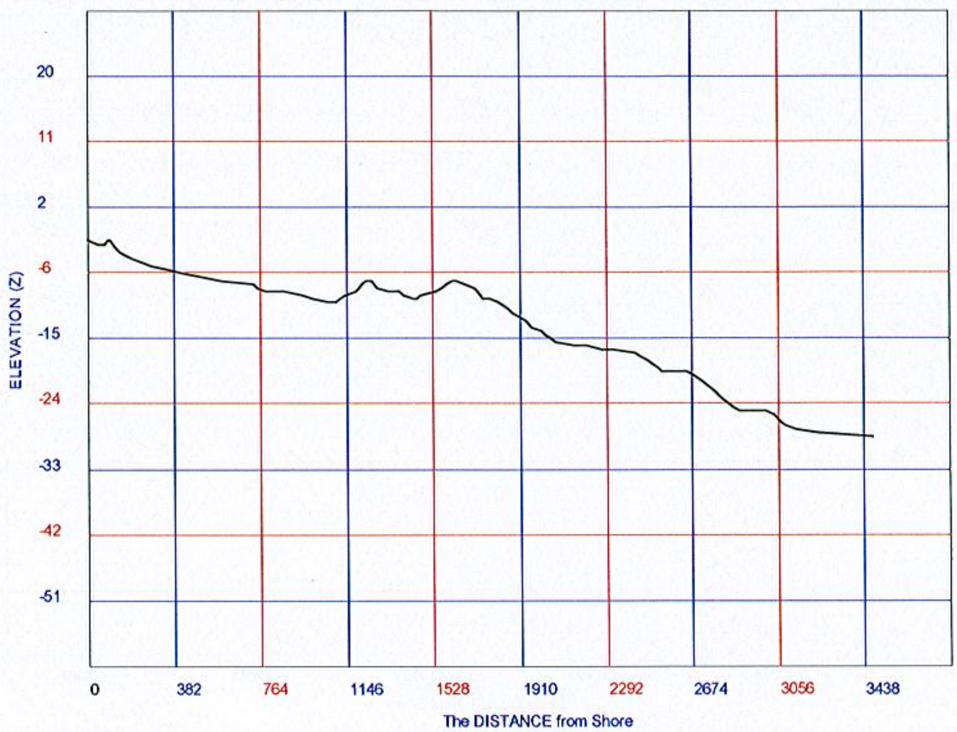
PROFILE 2



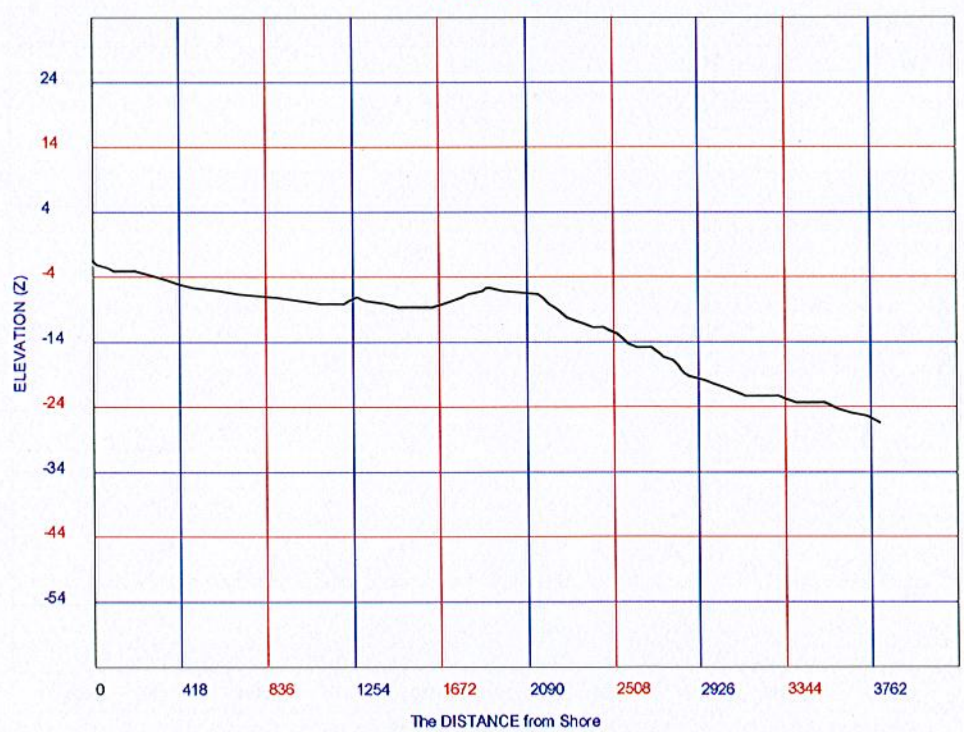

PROFILE 3
15
7
0
-6
-14
-21
-28
-36
-43
ELEVATION (Z)
0
312
624
936
1248
1560
1872
2184
2496
2808
The DISTANCE from Shore


PROFILE 4
15
7
0
-7
-14
-22
-29
-37
-45
ELEVATION (Z)
0
320
640
960
1280
1600
1920
2240
2560
2880
The DISTANCE from Shore

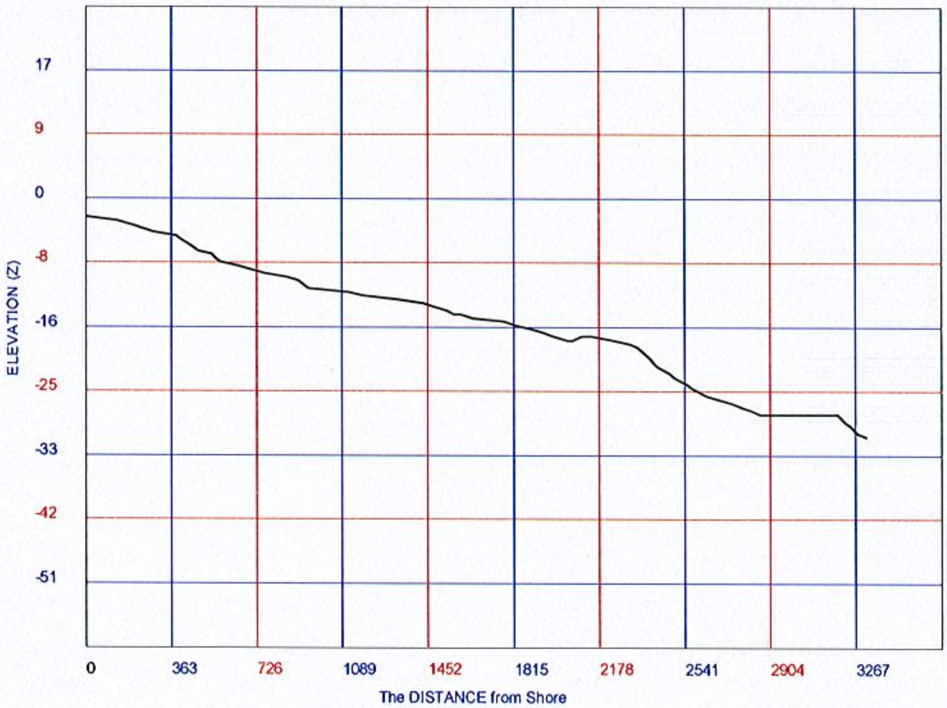
PROFILE 5



PROFILE 6



PROFILE 7



PROFILE 8