Cooperator Project Completion Report Submitted to the Legislative-Citizen Commission on Minnesota Natural Resources

Mapping of Two Minnesota Lakes Using Commercial Side-scanning Sonar to Characterize Substrate Hardness and Vegetated Habitat

By Richard L. Kiesling

Open-File Report 2016-XXX

U.S. Department of the Interior
U. S. Geological Survey
Minnesota Water Science Center
2280 Woodale Drive
Mounds View MN 55112

U.S. Department of the Interior
SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

U.S. Geological Survey, Reston, Virginia: 201X

Suggested citation:
Kiesling, R.L., Mapping of two Minnesota lakes using Side-scanning Sonar to Characterize Substrate Hardness and Vegetated Habitat. U.S. Geological Survey Open-File Report 2016–XXXX, XX p.,

Contents

Figures

Abbreviations

eDNA	Environmental DNA
ft	feet
GIS	Geographic Information System
GPS	Global Positioning System
SD	Secure digital
Sonar	Sound Navigation and Ranging
USGS	United States Geological Survey

Acknowledgments

The U.S. Geological Survey gratefully acknowledges funding for this work from the Environment and Natural Resources Trust Fund of the State of Minnesota. The author also thanks Scott Adolphson of the U.S. Geological Survey for his verification of the sonar survey results using independent testing of the geospatial data sets.

Mapping of Two Minnesota lakes Using Commercial Side-scanning Sonar to Characterize Substrate Hardness and Vegetated Habitat

By Richard L. Kiesling

Abstract:

Sonar surveys of two Minnesota lakes were conducted in July and August of 2014 to provide bathymetric maps of relative substrate hardness and vegetation height and biovolume. The two lakes were chosen based on reported levels of zebra mussel (*Dreissena polymorpha*) infestation, and data were collected as part of a larger project to investigate potential management methods for control of zebra mussel infestations. Sonar data from surveys were processed using a commercially available post-processing software tool that produced same-day processing of transect data from the field using client software accessing a remote server. Processed data were used to produce geo-referenced maps by spatial analysis of the data using the kriging geo-statistical tool.

Description of Study Objective:

The objective of the study was to develop detailed bathymetric maps for selected areas of two Minnesota lakes with different levels of zebra mussel infestation. The objective was to complete a sonar survey of a high-density lake with a well-documented larval dispersal period, and then select a recently colonized, low density lake suitable for testing the limits of biochemical identification and detection assays. Both lakes were to be surveyed with a commercial sonar system in common use by State of Minnesota personnel, and the signal returns from the sonar unit were to be processed to and evaluated by a commercial software product capable of processing and analyzing the dual-beam transducer data. The overall goal of the project was to generate maps of bottom substrate hardness and vegetation height and density.

Approach and Scope:

Data were collected using a commercial sonar platform from Lowrance™ High Definition System (HDS®). An HDS® 10 unit equipped with a 200 kHz transducer operating with a 20 degree beam angle and a 455kHz side-scanning transducer for shallow vegetation characterization was used to cover predefined sampling grids. Raw data were saved on the sonar unit during collection and then processed using a commercial software product. The integrated software product combined a client software application with a remote server geo-spatial statistical program. Data were transmitted from the field for data processing wireless internet communication through a cellular communication port. The entire process followed is outlined in the following steps which led to the production of the final product

Bathymetric Mapping

1. Zebra mussel habitat mapping surveys were conducted using a commercial sonar unit equipped with high-resolution side-scanning sonar linked with real-time differential GPS data collection.
2. Data from each mapping area in Lake Le Homme Dieu, Alexandria, MN, or in Maple Lake, Forada, MN, were collected in transects spaced thirty meters apart on a rectangular grid. A single survey was conducted for each lake during mid-summer (July-August) to determine the substrate type, depth and vegetative cover during the zebra mussel larval (i.e. veliger) settling period.
3. Data from surveys were uploaded to a cloud server and processed using a commercially available post-processing software tool that allowed for near real-time uploading and concatenation of transect data from the field.
4. Processed data were to generate bathymetric maps of depth, relative substrate hardness, vegetation height above the recorded substrate, and plant volume as a percentage of the water column. Maps were generated using the kriging geo-statistical method.
5. Processed data from surveys for relative substrate hardness, vegetation height above the recorded substrate, and plant volume were imported into an ArcGIS geo-spatial database and subjected to kriging analysis to provide for an independent assessment of the methods used by the commercial software product.

The geo-spatial analysis using ArcGIS formed the basis of the USGS model archive for this data product.

Methods

Data Collection Platform Configuration

Data were collected using a commercial sonar platform from Lowrance™ High Definition System (HDS®) consumer echo-sounder (Contour Innovations LLC 2013). Transect data were collected using an HDS® 10 unit equipped with a 200 kHz transducer operating with a 20 degree beam angle and a 455kHz side-scanning transducer for vegetation characterization. The HDS® unit was configured using the shallow water setting which provides a constant 75% ping speed or 15 pings per second. Ping speed is the rate at which the transducer transmits a sound pulse into the water column and receives the response echo, controlling the along-transect coverage. During data collection, pings are combined into data ensembles, and ping values within an ensemble are averaged to produce a reported data value.

Data density in the field was controlled by the velocity of the boat as it traveled along the sampling transect during data collection. During sampling for this project, boat speed was maintained at five miles per hour providing a forward velocity of approximately seven feet per second. An estimate of the average sonar data density used for this project can be calculated by combining the forward velocity estimate with ping speed, resulting in an average sonar data density of approximately one sample every two feet of linear distance along a sampling transect.

Pulse width (i.e., band width) is not user controlled with the Lowrance™ system but is dynamic and varies depending on depth. Software algorithms for the ciBioBase application are optimized at 3200 bytes per second with a range window set to Auto on the HDS®-10 unit. This configuration of the unit provided the optimal range resolution of the sonar return signal for the range of depths available to the system.

Data Acquisition

Data were collected along transects spaced 30 meters apart using an eighteen-foot aluminum-hulled boat with a modified V hull configuration. Sonar transducers were mounted on opposite sides of the transom of the boat approximately 20 centimeters below the water line. Tracks for data collection were laid-out in the navigation display and followed at five miles per hour during data acquisition. The data feed from the transducers were continuously monitored on the heads-up display for signs of signal interference between the transducers or for problems with turbulence in the vicinity of the transducer mounts. In some instances, boat speed was reduced three miles per hour to reduce the frequency of sonar signal degradation.

Data ensembles were acquired at one second intervals. Feature data from pings that occurred between position reports were reported as an average value for each GPS geo-referenced data point. As a result, attribute data for a specific feature class including depth, bottom hardness, and plant height represents the average of 15 values from sonar returns during the sampling interval.

During acquisition, sonar data were simultaneously paired with global position (GPS) data using a built-in, time-referenced GPS unit on the HDS®-10. The GPS unit for the HDS®-10 was set to differentially correct the GPS satellite data using the Wide Area Augmentation System (WAAS) navigation system. Acoustic signal data and GPS position data were logged to SD data storage cards using the (.sl2) format for later upload to the Contour Innovations cloud server for post processing using the ciBioBase software tool.

Post Collection Data Processing

Unprocessed data files were uploaded to the Contour Innovations centralized servers using a client software program supplied as part of the ciBioBase GIS software system. Raw data files for GPS positional data and quality-assured sonar response data were processed using proprietary algorithms into estimates of bottom depth, plant height, plant bio-volume, and bottom hardness features. Within the ciBioBase software package, each data ensemble goes through a quality-assurance test to determine whether the feature data for the sampling period can be extracted and used for further analysis. If the data pass the internal data filters, values are sent on to the respective feature detection algorithms. Data failing to meet the quality assurance tests are removed from consideration for summarization

Map Development

Processed data were used to generate geo-referenced, surface response maps for each feature class using kriging to generate a grid of equal-area cells referred to as a raster grid. Kriging is a geo-spatial analysis method that uses the actual statistical relationship of neighboring data points to make predictions in un-sampled locations. The following explanation from the ArcGIS online help manual helps explain the kriging process:

> “Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. The Kriging tool fits a mathematical function to a specified number of points, or all points within a specified radius, to determine the output value for each location. Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and (optionally) exploring a variance surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data.” (http://desktop.arcgis.com/)

Once kriging had produced x,y,z grids of raster cells for each feature class, the data were used to project the data in three dimensions, producing a map of each attribute class for each survey. Maps were used to choose potential eDNA sampling sites prior to preliminary field data collection.

In order to be able to reproduce the statistical analysis used in the ciBioBase software, processed data files from the cloud server were incorporated into an ArcGIS project and subjected to kriging analysis following the reported analysis criteria from ciBioBase. This independent analysis of the feature class and GPS location data confirmed the proprietary mapping program included in the ciBioBase processing software. Once data were geo-referenced in ArcGIS, the results were combined with existing Minnesota DNR GIS base layers for lake bathymetry and satellite imagery to generate ArcGIS geo-spatial databases and map products. The ArcMap data platform provides the end user with the option of changing the parameters used to generate the feature maps. For example, the buffer width surrounding the transect data can be changed during kriging analysis, providing for a more narrow or a wider map footprint.

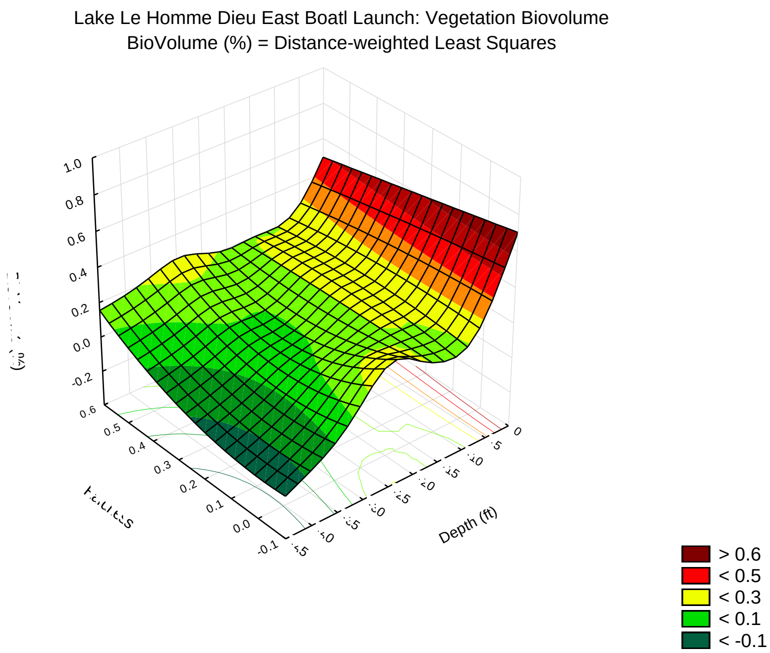
Results and Discussion

Bathymetry from the data collection effort provided one-foot contour resolution within the survey areas. This level of resolution was more than three times the available bathymetry resolution from MN DNR historical mapping efforts conducted prior to their use of the ciBioBase software (fig. 5). In addition to higher-resolution bathymetry, the data for substrate hardness and vegetation bio-volume in the water column provided important data on habitat quality for zebra mussels (figs. 6-13). Zebra mussels in Lake Le Homme Dieu and in the connected Lake Carlos have been observed to preferentially colonize hard substrates (Kiesling, unpublished video surveys). In addition to substrate hardness, observed zebra mussel density (> 10 individuals per plant) in vertical (>40centimeters) vegetation stands in Lake Le Homme Dieu suggest that vegetation biomass in the water column is a potential axis of zebra mussel distribution in the study lakes (fig. 1). The amount of plant biovolume at the survey sites is significant (e.g., figs. 2 - 4), accounting for more than half of the water column in many location in Lake Le Homme Dieu. The distribution of vegetation biovolume also varies between the sites within Lake Le Homme Dieu, as well as between the two lakes.

Maps generated by the ciBioBase software identify both Maple Lake and Lake Le Homme Dieu as having a wide range of available depths, substrate types, and vegetation height and biovolume cover (figs. 2-4). This range of feature-class values provided the eDNA sampling teams with a broad choice of habitat class combinations to guide their sampling plans. Sampling transects were located in or very near to sonar survey data collection areas. Maps from multiple areas in Lake Le Homme Dieu have also made it clear that feature characteristics such as vegetation bio-volume do not track depth or substrate hardness directly (e.g., east launch area maps) suggesting a need for follow-up analyses of the factors controlling the vegetation distribution. However, it is possible to construct generalized response surfaces for understanding how more than one feature at a time can influence vegetation biovolume (fig. 1).

Development of an ArcGIS geo-spatial data product provides a common platform for future spatial analysis of the mapping datasets from this project. In addition to the GIS database, the ability to generate the same maps in ArcMap as were produced by the commercial software product (e.g., figs. 1-9) provides an important statistical data archive for the results of the kriging analysis in ciBioBase. Data from the project are also available through the Contour Innovation cloud server and can be incorporated into future map enhancements for the lakes by requesting permission to use the data.

a.



b.

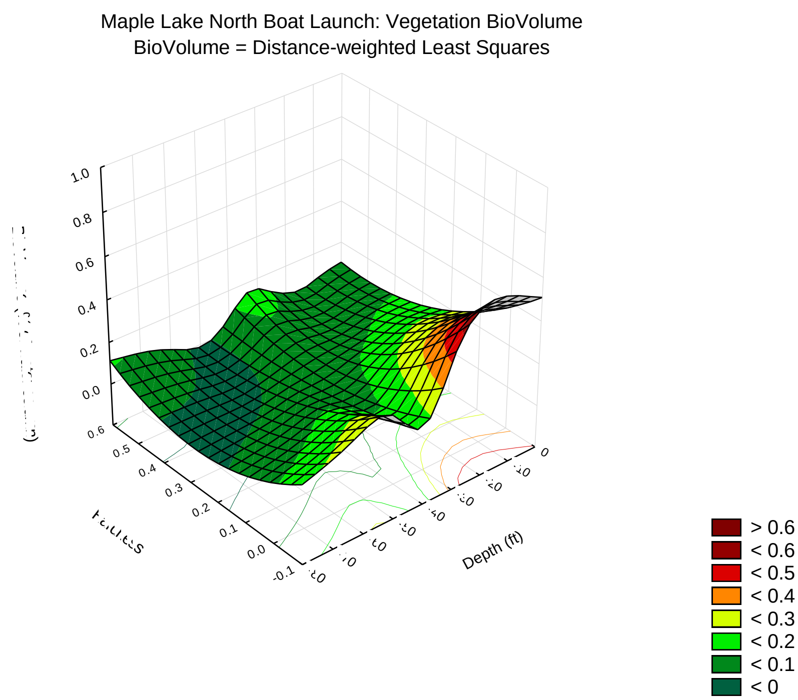
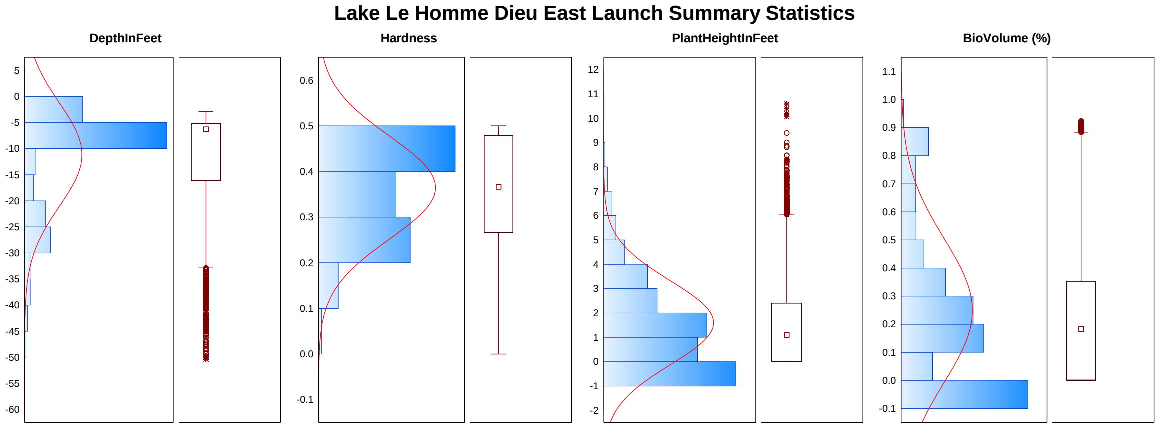


Figure 1. Plant biovolume as a function of water depth (ft) and hardness from (a) Lake Le Homme Dieu East Boat Launch site and (b) Maple Lake North Boat Launch site

a.



	DepthInFeet	Hardness	PlantHeightInFeet	BioVolume (%)
N:	5724	4960	5599	5599
Mean:	-11.40	0.362	1.579	0.247
Median:	-6.291	0.366	1.095	0.183
Min:	-50.33	0	0	0
Max:	-2.875	0.500	10.58	0.923
L-Qrt:	-16.17	0.266	0	0
U-Qrt:	-5.110	0.479	2.414	0.354
Variance:	97.41	0.0126	2.945	0.0645
SD:	9.870	0.112	1.716	0.254
Std.Err:	0.130	0.00159	0.0229	0.00339
Skw:	-1.503	-0.332	1.377	1.077
Kurt:	1.230	-0.830	1.814	0.225
95% Conf SD				
Lower:	9.692	0.110	1.685	0.249
Upper:	10.05	0.115	1.749	0.259
95% Conf Mean				
Lower:	-11.66	0.359	1.534	0.240
Upper:	-11.14	0.365	1.624	0.253

b. c. d.

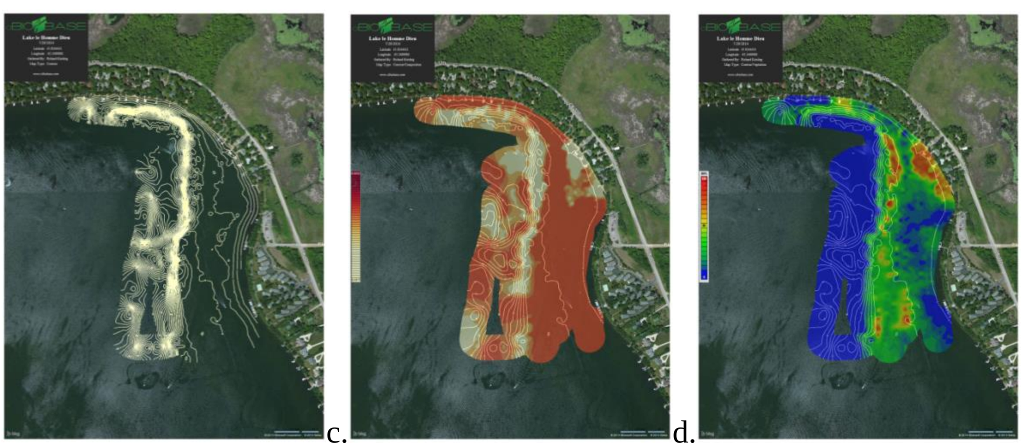
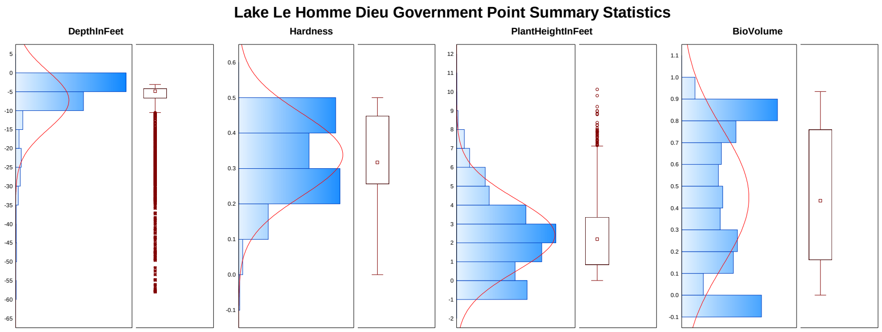


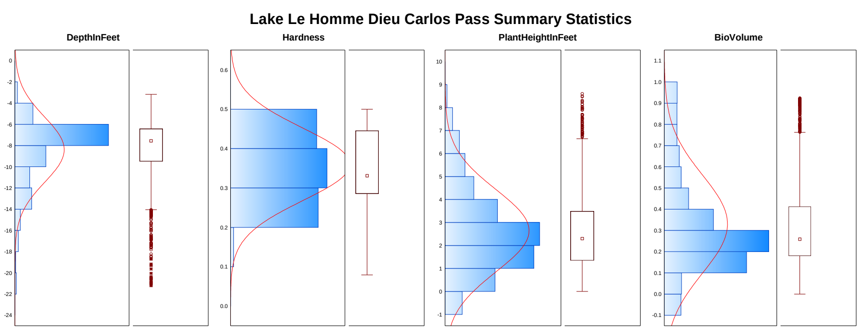
Figure 2. Statistical summary (a) for feature class data collected for East Boat Launch site from Lake Le Homme Dieu. Raster class data for depth (b), hardness (c) and plant biovolume (d) are displayed as color scale maps

a.



	DepthInFeet	Hardness	PlantHeightInFeet	BioVolume
N:	2821	1582	2759	2759
Mean:	-7.571	0.336	2.386	0.445
Median:	-4.861	0.317	2.191	0.433
Min:	-57.99	0	0	0
Max:	-3.070	0.500	10.12	0.935
L-Qrt:	-6.729	0.256	0.843	0.162
U-Qrt:	-4.187	0.448	3.355	0.759
Variance:	58.95	0.0135	3.589	0.0981
SD:	7.678	0.116	1.895	0.313
Std.Err:	0.145	0.00292	0.0361	0.00596
Skw:	-3.464	-0.104	0.758	-0.0178
Kurt:	13.37	-0.767	0.228	-1.452
95% Conf SD				
Lower:	7.482	0.112	1.846	0.305
Upper:	7.883	0.120	1.946	0.322
95% Conf Mean				
Lower:	-7.855	0.331	2.315	0.433
Upper:	-7.288	0.342	2.457	0.457

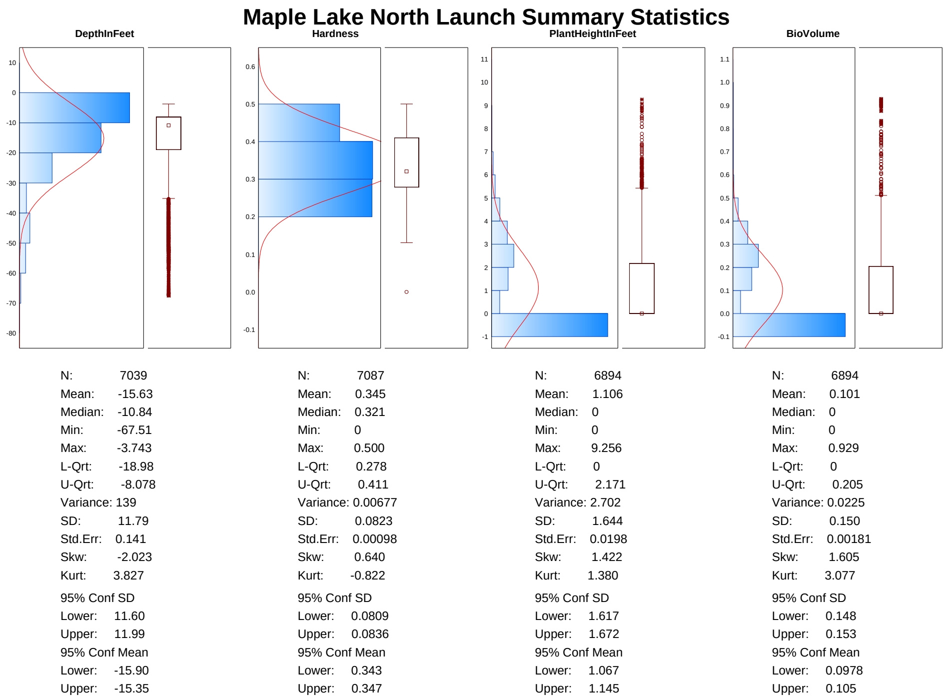
b.



	DepthInFeet	Hardness	PlantHeightInFeet	BioVolume
N:	1985	1676	1944	1944
Mean:	-8.468	0.358	2.622	0.327
Median:	-7.545	0.331	2.299	0.259
Min:	-21.21	0.0794	0	0
Max:	-3.167	0.500	8.603	0.924
L-Qrt:	-9.477	0.286	1.347	0.180
U-Qrt:	-6.429	0.445	3.481	0.413
Variance:	9.312	0.00838	3.180	0.0528
SD:	3.051	0.0915	1.783	0.230
Std.Err:	0.0685	0.00224	0.0404	0.00521
Skw:	-1.455	0.331	0.912	1.111
Kurt:	2.219	-1.035	0.498	0.493
95% Conf SD				
Lower:	2.959	0.0885	1.729	0.223
Upper:	3.149	0.0947	1.841	0.237
95% Conf Mean				
Lower:	-8.602	0.354	2.543	0.317
Upper:	-8.333	0.362	2.701	0.338

Figure 3. Statistical summary for feature class data collected for (a) Government Point site and (b) for Carlos Pass site from Lake Le Homme Dieu

a.



b.

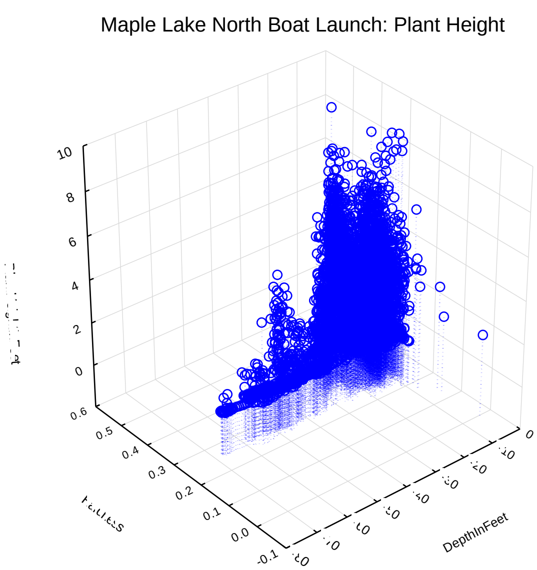


Figure 4. Statistical summary for (a) Maple Lake North Launch feature class data and (b) plant height data as a function of depth and substrate hardness

Figure 5. Lake Le Homme Dieu East Launch site one-foot contour data

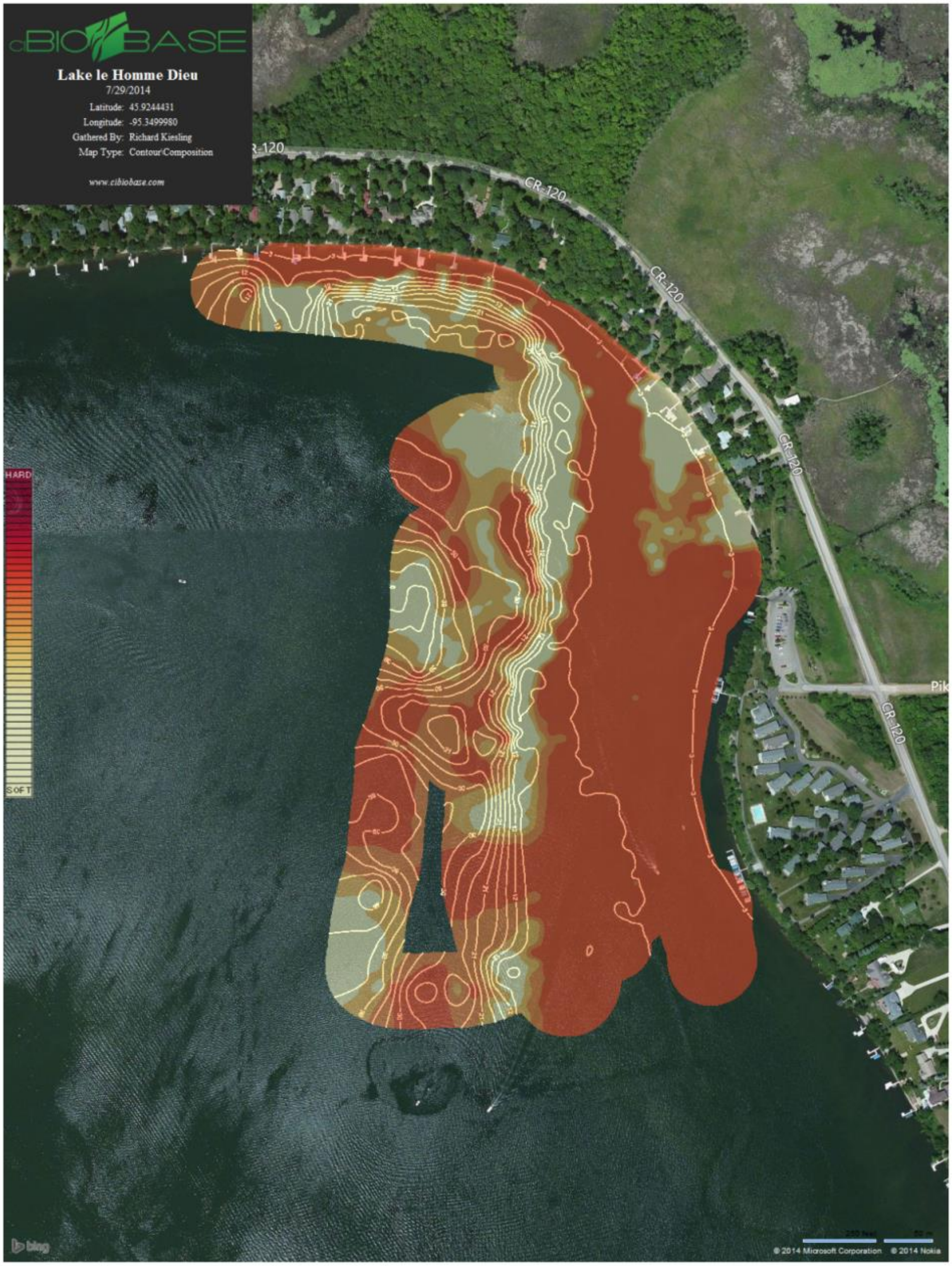


Figure 6. Lake Le Homme Dieu East Launch substrate hardness with three-foot depth contours

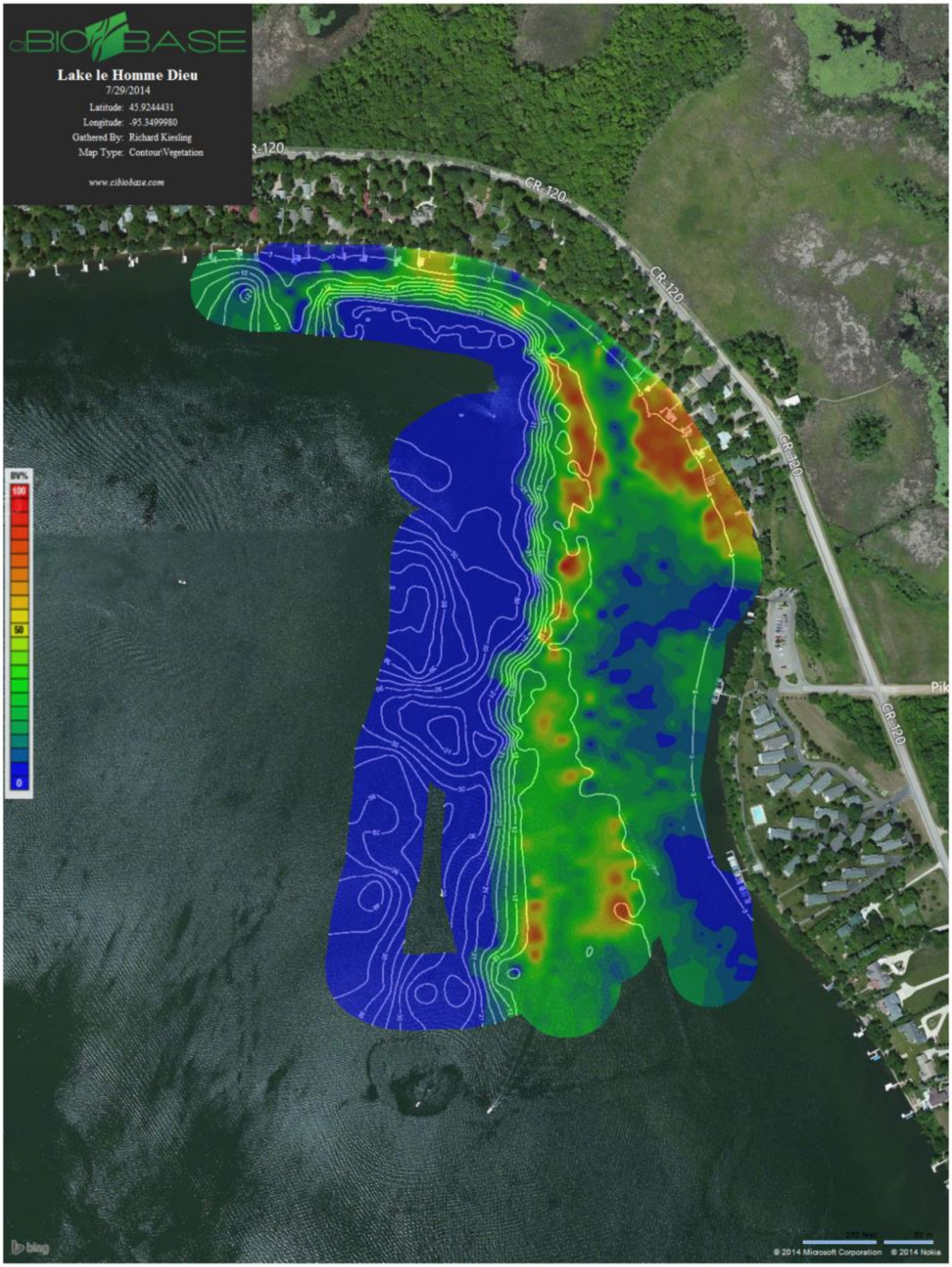


Figure 7. Lake Le Homme Dieu East Launch vegetation biovolume as % of water column

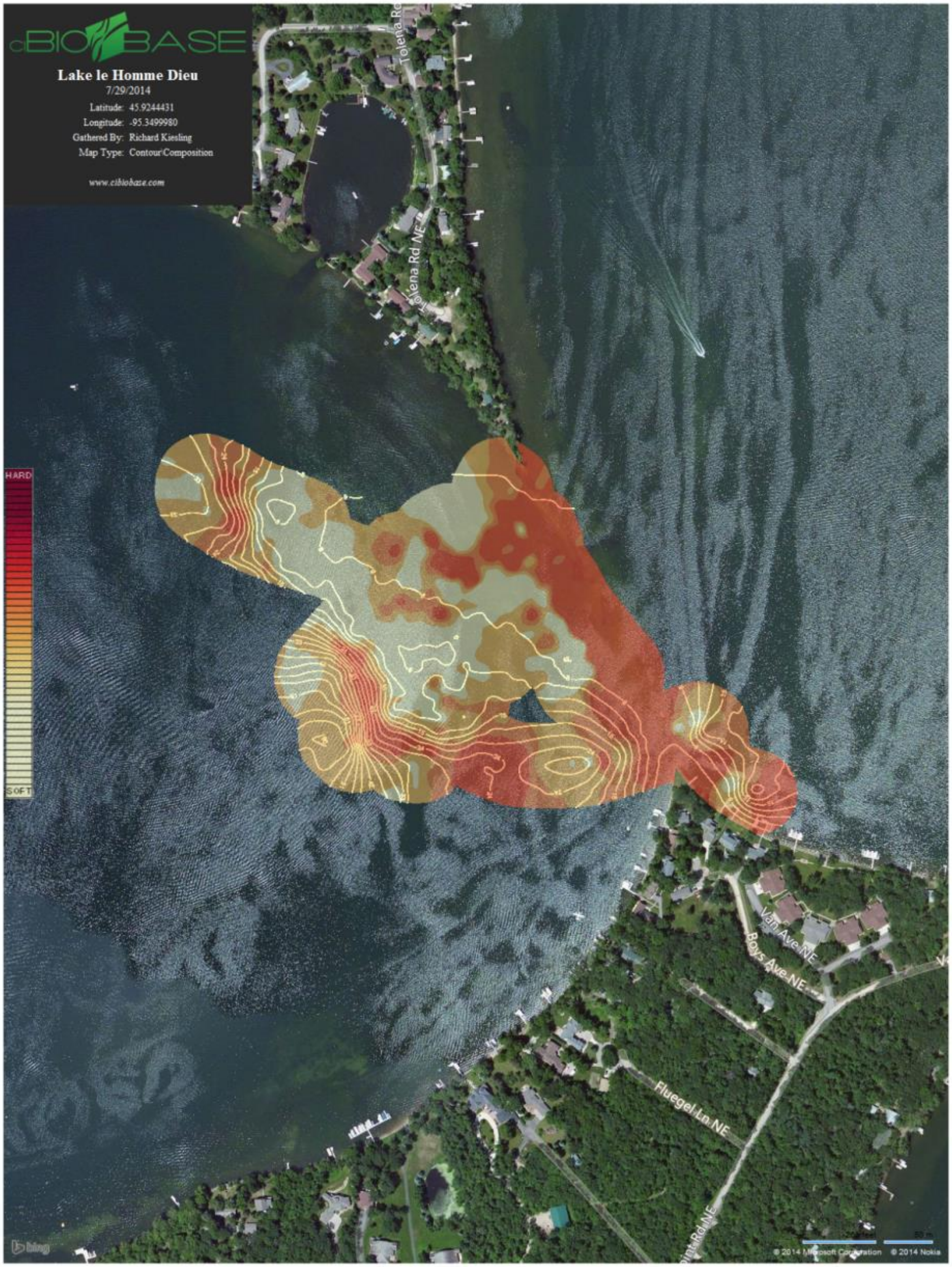


Figure 8. Lake Le Homme Dieu Government Point hardness with three-foot depth contours

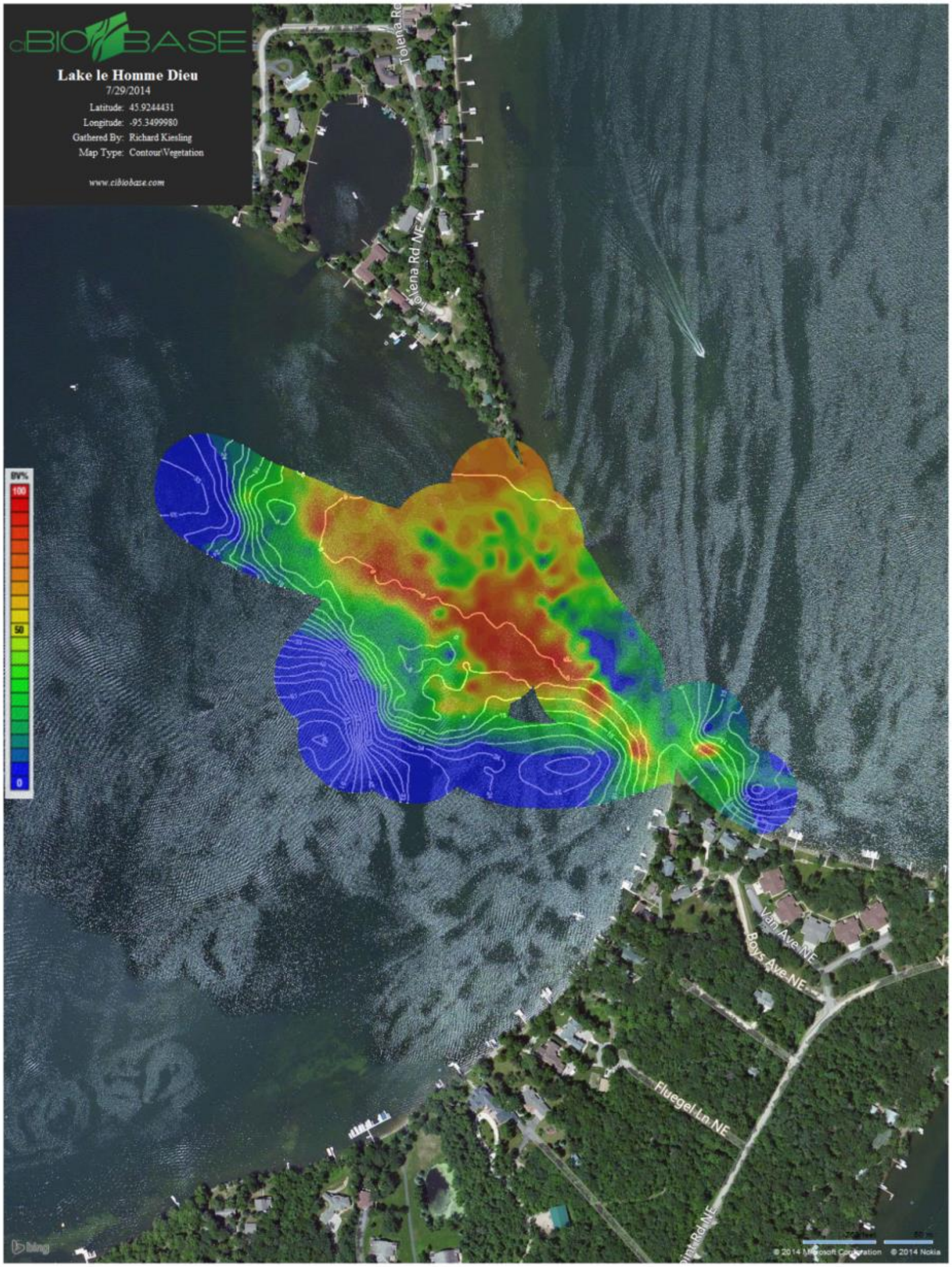


Figure 9. Lake Le Homme Dieu Government Point vegetation biovolume as % water column

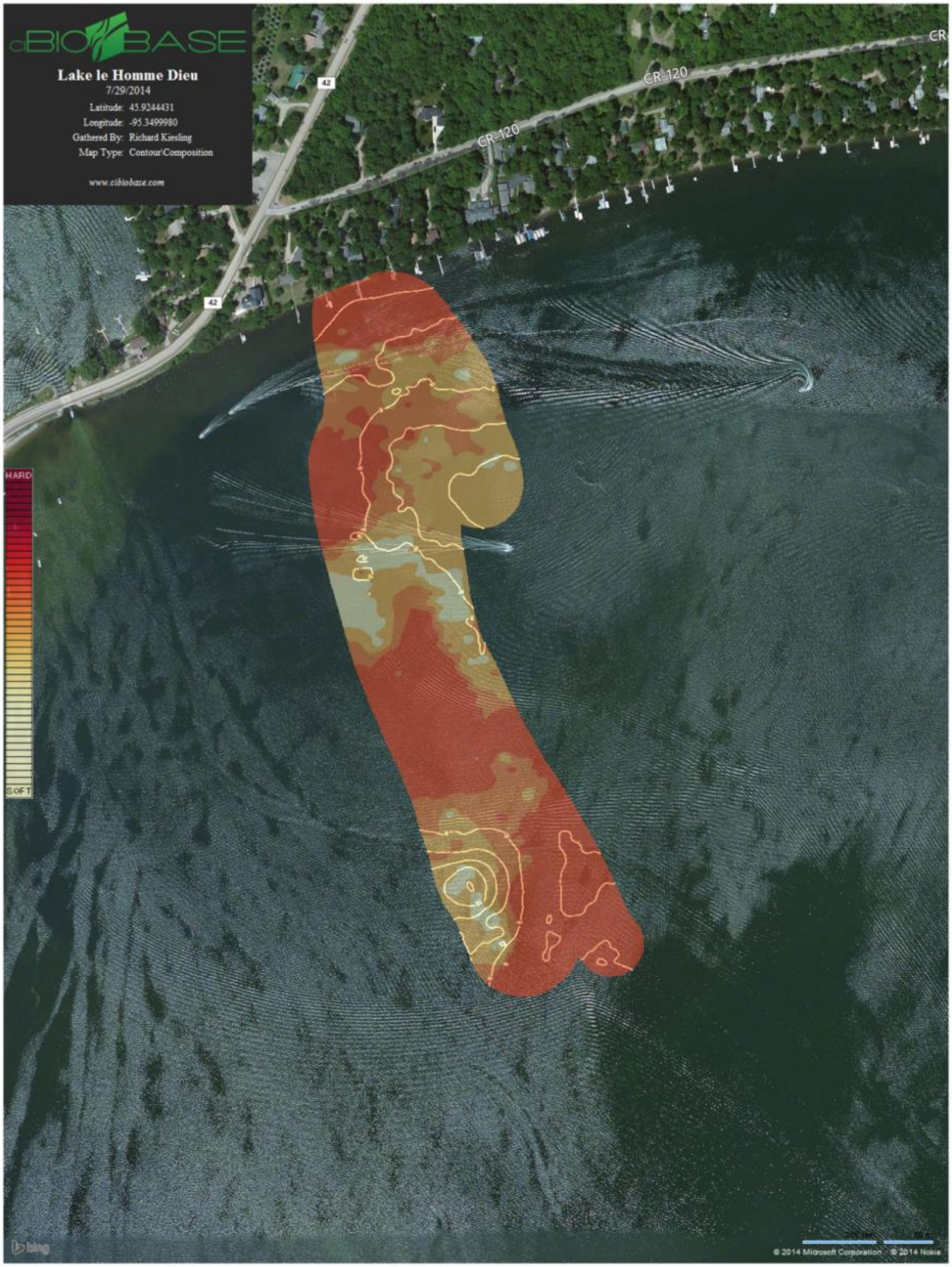


Figure 10. Lake Le Homme Dieu Carlos Pass hardness with three-foot depth contours

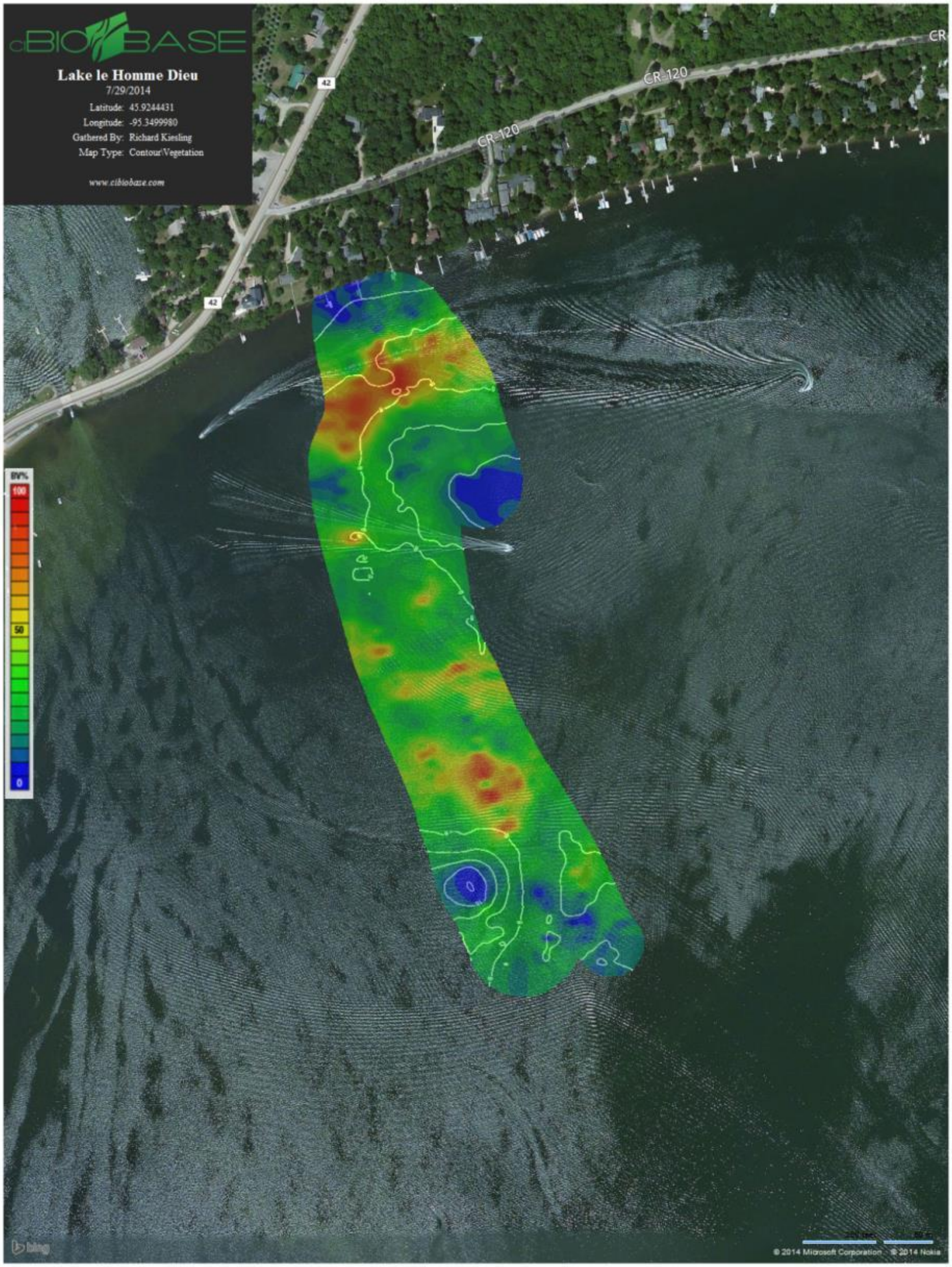


Figure 11. Lake Le Homme Dieu Carlos Pass vegetation biovolume as % water column

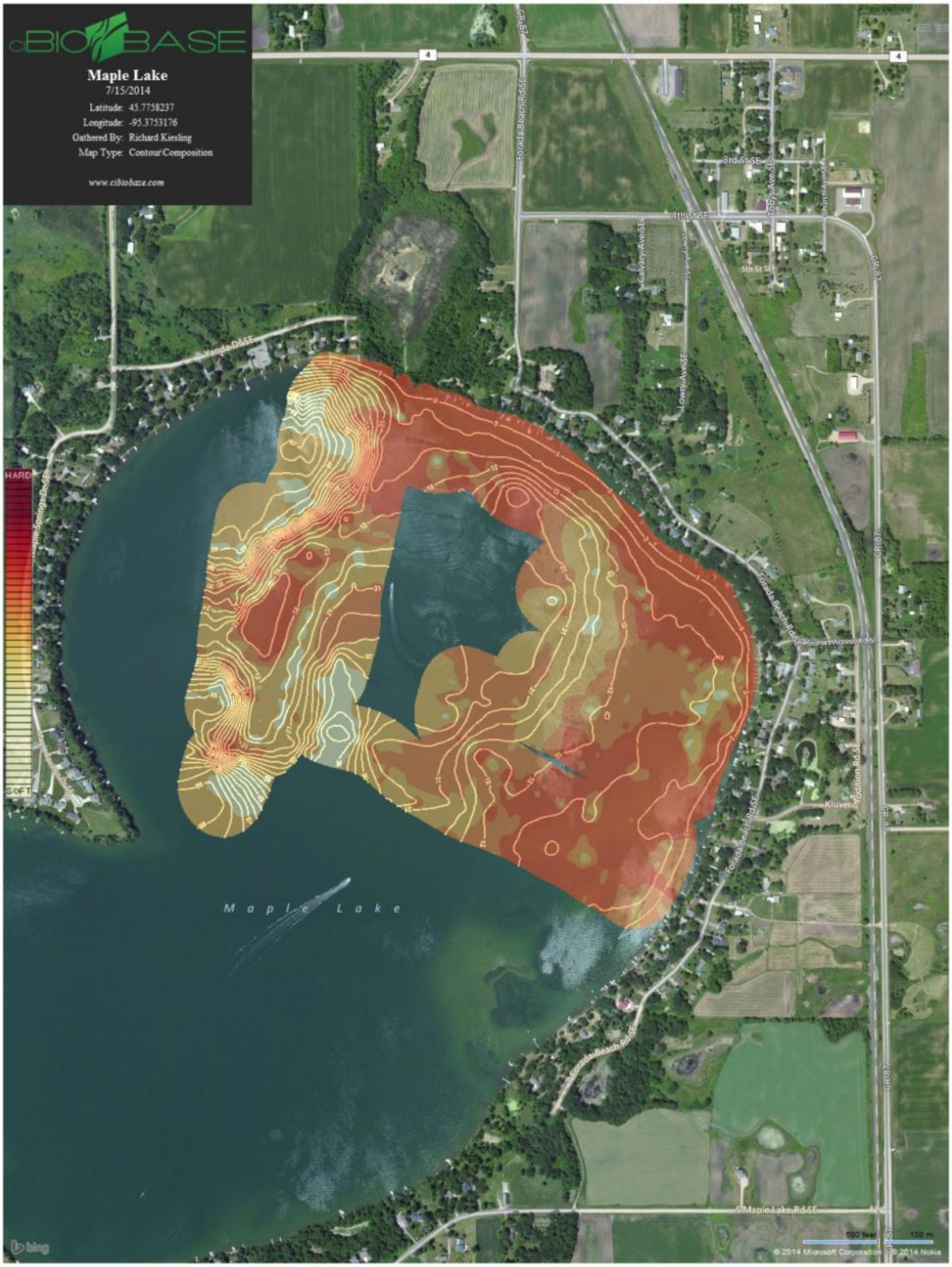


Figure 12. Maple Lake North Launch hardness with three-foot depth contours

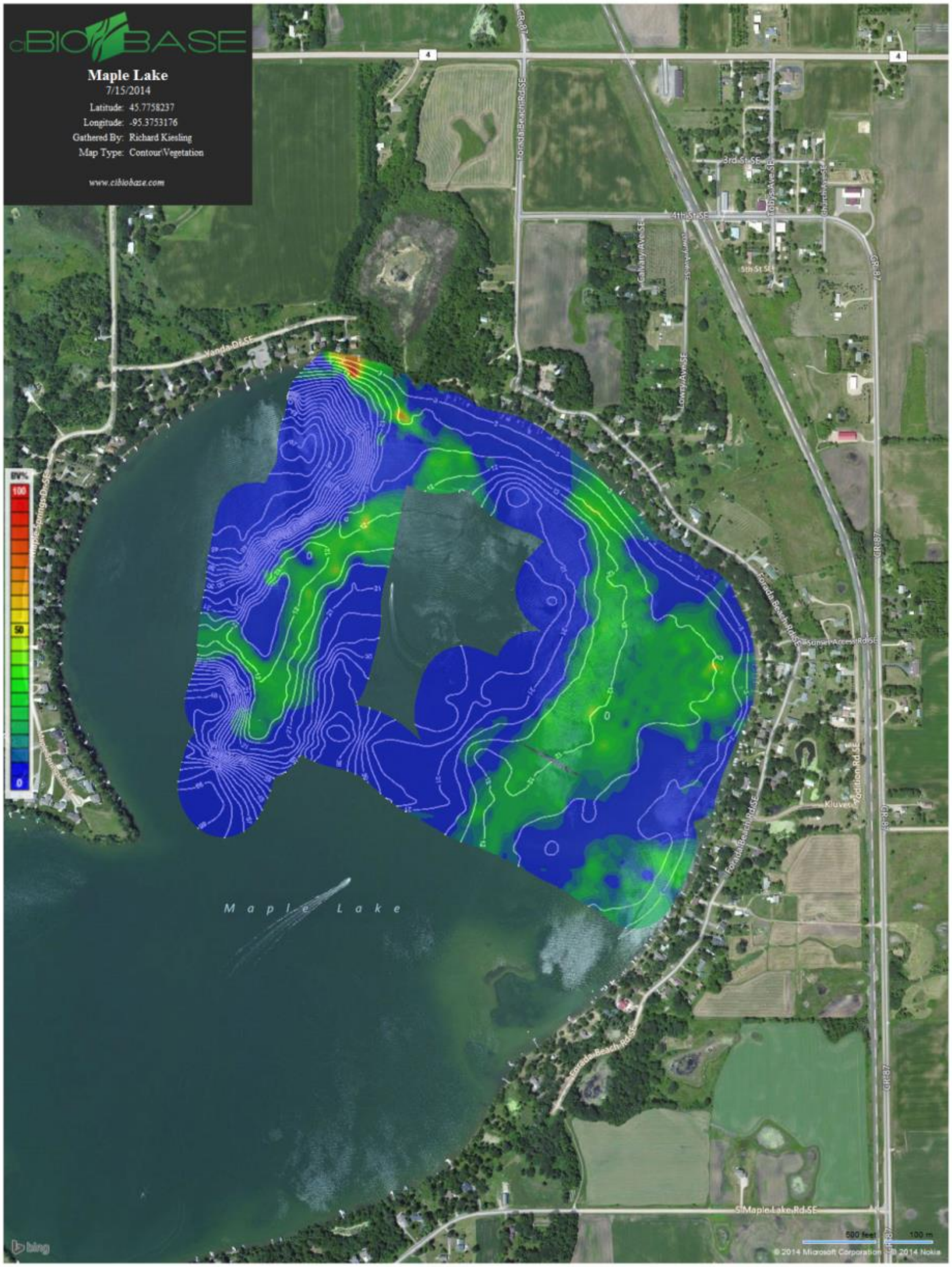


Figure 13. Maple Lake North Launch vegetation biovolume as % water column