A Geographic Information Systems (GIS) Hazard Assessment Application for Recreational Diving within Lake Superior Shipwrecks

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Abstract

The popularity of recreational diving is increasing rapidly and one of the main contributors to this popularity is the exploration of shipwrecks. The simple thought of getting in the water and going into a sunken ship seems deceptively easy, but what many divers do not understand is that there are many hidden hazards involved with shipwreck diving. The use of Geographic Information Systems (GIS) can help inform divers of the hazard levels associated with shipwrecks in Lake Superior. This study uses geographic data supporting a web-based hazard assessment application. The resulting web application created in this case study provides users the ability to view hazard levels associated with recreational diving in Lake Superior shipwrecks. Using methodology content following Sauro (2011), a user experience survey was conducted on the web application. Survey results provided insight into end user needs and preferences which will be used for future application enhancements.

Introduction

Lake Superior offers many recreational activities including fishing, kayaking, and surfing. One of the most popular activities is the exploration of historic shipwrecks. Participation in recreational diving increased dramatically during the 1980's and continued to rise in the 1990's, prompting authors to claim that recreational diving was the fastest growing recreational activity in the world (Stolk and Markwell, 2007).

The attraction of wrecks regardless of whether they sank accidentally or were sunk intentionally meets the demands of recreational divers (Van Treeck and Schumacher, 1998). With thousands of recreational divers taking to the water each year to explore the underwater mystery of shipwrecks, many do not understand the hazards involved. Although there are many text-based resources available to recreational divers, there is insufficient use of spatial web based technologies to provide adequate recreational diving hazard information.

The purpose of this study was to analyze hazards associated with recreational diving in Lake Superior shipwrecks, to assign hazard levels to each location, and to assess the effectiveness of a user interface web application.

Methods

Software Used

GIS software used to perform tasks in the hazard assessment web application consisted of ESRI ArcGIS Desktop 10.1,

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ESRI Spatial Analyst extension, Microsoft Excel for and ArcGIS Online.

Data Acquisition

Geographic data used in this project were acquired from many different sources. To complete the necessary hazard assessment, bathymetry data were vital. The Great Lakes Information Network (2013) provided a Lake Superior Bathymetry shapefile. This data set was crucial in determining the depth of shipwrecks which contributed to the overall hazard ranking.

The next data set acquired were Lake Superior shipwreck locations. This data set was the primary focus of this project. Data were acquired through multiple Lake Superior shipwreck lists provided by the following: (a) Michigan Underwater Preserves (2011), (b) Minnesota Historical Society (2014), and the (c) Wisconsin Historical Society (2014).

Lake Superior Shipping Lanes were essential to the hazard assessment for the purpose of recreational diver safety. The Shipping Lanes data were derived from the Great Lake and Seaway Online Vessel Passage Chart Maps provided by the National Ocean and Atmospheric Administration (NOAA, 2014). These chart maps were obtained as a Tagged Image File Format (TIFF) image.

Health Care Facility locations were another data set that was important to the hazard assessment. This data included hospitals, clinics and other medical facilities that could provide emergency care. These data were difficult to obtain due to the multiple jurisdictions Lake Superior encompasses. It was acquired through a combination of sources including the American Hospital Association (2014), Minnesota Geospatial Office (2014), Ontario Hospital Association (2014), and the Wisconsin Hospital Association (2014).

Information regarding the sunken vessels hull material was required in addition. Rusting iron and steel contribute to the accumulation of silt. The kicking of a diver’s fin and the exhaust bubbles can stir the silt resulting in low visibility. Information was gathered through the following sources: (a) Michigan Underwater Preserves (2011), (b) Minnesota Historical Society (2014), and the (c) Wisconsin Historical Society (2014).

An additional live feed of current water conditions at each shipwreck location was captured using a Geo Rich Site Summary (GEORSS) service. This information was acquired through the Great Lakes Observing System (2014) which works to provide new tools and forecasts to improve safety, enhance the economy, and to protect the environment.

Live radar was acquired to provide an up-to-date view of the current weather conditions. This live feed was provided by ArcGIS Online (2014).

The last data acquired consisted of base map data. These data were critical to the presentation of the final web application. The use of ESRI’s ArcGIS Online application provided the needed base map information which included: (a) administrative boundaries, (b) aerial photography, (c) hydrography, (d) and road centerlines.

Data Preparation

In order to properly assess hazard levels for each shipwreck, data organization and preparation were needed. A File Geodatabase was created to provide a central location for all data.

Shipwreck Locations

Microsoft Excel was used to collect shipwreck locations. Information obtained included: (a) ship name, (b) sunken date, (c) notes, (d) latitude of shipwreck, and (e) longitude of shipwreck.

The latitude and longitude data from the shipwreck locations spreadsheet were converted from Degrees, Minutes, and Seconds to Decimal Degrees. This process was performed by using the following formula:

$$\mathrm{DD} = \mathrm{D} + \frac{\mathrm{M}}{60} + \frac{\mathrm{S}}{3600}$$

DD = decimal degrees
D = degreed
M = minutes
S = seconds
60 = constant; number of minutes in an hour
3600 = constant; number of seconds in an hour

Once coordinate values were generated, shipwreck sites were then spatially located. This process created a new point feature class layer of the shipwreck locations. New fields were added to the shipwreck location feature class. These new fields included: (a) Image, (b) Contour, (c) Ship Material, (d) Depth, (e) Nearest Health Care Facility, (f) Nearest Shipping Lane, (g) Rank of Depth, (h) Rank of Health Care Facility, (i) Rank of Shipping Lane, (j) Rank of Material, (k) Total Rank, and (l) Hazard Level.

Lake Superior Shipping Lanes

Lake Superior Shipping Lanes data were acquired in a TIFF image format. This was georeferenced using the Shipping Lane data.

Health Care Facility Locations

Health Care Facility locations were obtained in two different formats: (a) shapefile, and (b) a Microsoft Excel spreadsheet. The Health Care Facilities that were not spatially located were geocoded using ESRI's World Address Locator and then combined into the shapefile. These locations provided value in the overall analysis along with a visual representation within the web application.

Current Water Conditions

The Current Water Conditions feed provided by the Great Lake Observing System needed to be extracted into a usable format for use. This process consisted of manually entering the coordinates of each shipwreck into the Great Lakes Observing System query tool. The output of the query tool provided a GEORSS link for each shipwreck location which was used in the final web application.

Analysis

Analysis of the data produced a hazard assessment for shipwreck areas. Key hazards included the following variables: (a) water depth, (b) proximity to shipping lanes, (c) material of wrecks hull, and (d) proximity to a health care facility. Ranking values were the assigned to the variables illustrated in Table 1.

Lake Superior Bathymetry Analysis

Bathymetry data provided water depth at each shipwreck. In order to extract depth information, the vector data set was converted to a Triangulated Irregular Network (TIN) using an ArcGIS interpolation tool (Figure1). Data was derived to create an interpolated surface of Lake Superior (Figure 2).

Table 1. Assigned rank values by hazard variable.

Hazard Variable	Rank Value (1)	Rank Value (2)	Rank Value (3)
Water Depth	0 to 49 Ft.	50 to 99 Ft.	> 100 Ft.
Closest Shipping Lane	> 2,640 Ft.	1,321 to 2,640 Ft.	< 1,320 Ft.
Hull Material	Wood		Steel
Closest Hospital	< 15 Miles	16 to 30 Miles	> 30 Miles

Once the TIN was created, depth values needed to be linked to shipwreck locations layer. ArcGIS surface tools created “z” values for water depth at each location.

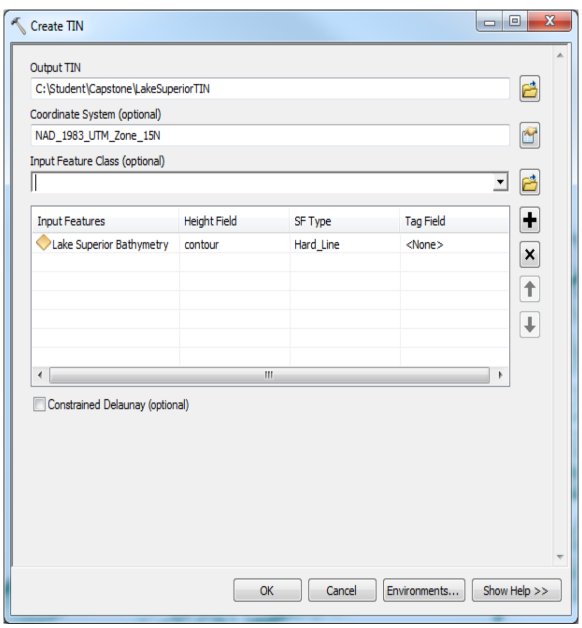


Figure 1. Create TIN dialog properties.

Health Care Facility Locations Analysis

Another important variable included identified distances from each shipwreck to the nearest health care facility. This was important because it contributed to the overall hazard ranking of each shipwreck location and provided a visualization of its location within the final web application.

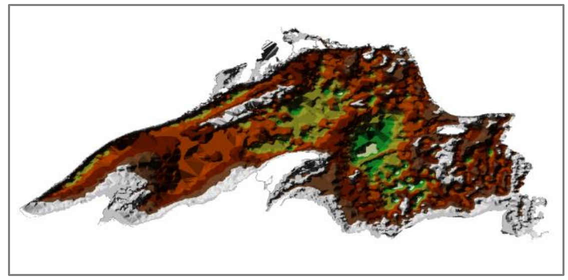


Figure 2. Output TIN interpolation of Lake Superior.

In order to obtain the closest health care facility for each shipwreck location, ESRI’s Near tool was used. The importance of obtaining this distance was to assess the amount of time it would take for recreational divers to seek advanced medical assistance in the case of a diving accident (Kirkbride-Smith, Wheeler, and Johnson, 2013). Once calculated, these values were incorporated into the final hazard assessment.

Shipping Lanes Analysis

Shipping lanes pose a great threat to the safety of recreational divers due to the suction of large ship’s propellers when passing overhead. Extraction of distances to the nearest shipping lanes were derived providing value to the final hazard assessment.

Lake Superior Shipwreck Location Analysis

Ranked values were allocated to each shipwreck location based on results of the prior analysis. These values were significant because they provided the foundation of the overall hazard level for each shipwreck location. A combination of VB Script and Python code (shown below) were used to calculate the value for each variable.

Lake Superior Bathymetry

```
def Reclass(DepthRank):
  if (DepthRank > 0 and DepthRank <= 49):
    return 1
  elif (DepthRank > 50 and DepthRank <= 99):
    return 2
  elif (DepthRank >= 100):
    return 3
```

Health Care Facility Locations

```
def Reclass():
  if (Hospital_Near_FT < 79200):
    return 1
  elif (Hospital_Near_FT >= 79200 and Hospital_Near_FT <=158400):
    return 2
  elif (Hospital_Near_FT > 158400):
    return 3
```

Shipping Lanes

```
def Reclass(TEMP1):
  if (ShippingLanes_Near_FT > 2640):
    return 1
  elif (ShippingLanes_Near_FT >= 1321 and ShippingLanes_Near_FT <=2640):
    return 2
  elif (ShippingLanes_Near_FT < 1320):
    return 3
```

Ship Hull Material

```
Dim density
If [MATERIALRANK] = "WOOD" Then
density = "1"
elseif [MATERIALRANK] = "STEEL" Then
density = "3"
end if
```

Once these values were assigned, the variables were ranked into a summative rank. The rank totals were classified into 3 hazard levels: Low (5-6), Medium (7-8), and High (9-10). These classifications were based on criteria derived from Kirkbride-Smith *et al*. (2013).The equation below illustrates the summation process.

[Depth_Rank] + [Hospital_Rank] + [ShippingLane_Rank] + [Material_Rank]

Web Application Development

ArcGIS Online was utilized to create a web application deliverable. The usability and content requirements for the development of the application were based on prior research of recreational diving safety and web application development. ArcGIS Online is a platform provided by ESRI where users can create, manage, and store their maps and applications.

The purpose of the web application was to provide recreational divers a user friendly platform to access hazard information pertaining to Lake Superior shipwrecks. Usability, functionality, and content were the main priorities in the creation of the web application. Data was imported into the ArcGIS Online application and configured into a map (Figure 3). This included the following data sets: (a) Lake Superior Shipwreck Locations, (b) Shipping Lanes, and (c) Health Care Facility Locations. The most important map rendering was applying custom symbols based on the hazard level assigned to each location. This allows the user to easily identify where the Low, Medium, and High hazard shipwrecks are located.

Another important enhancement involved customizing pop-up display properties of the viewer window. GeoRSS feeds of current water conditions provided by Great Lakes Observing System were then added to the web map. Figure 5 illustrates an example of the pop-up display of the current water conditions in the web map for a shipwreck site.

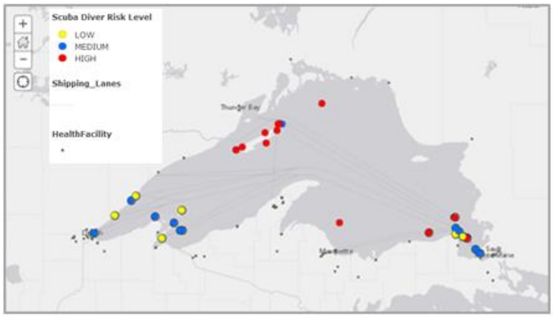


Figure 3. ArcGIS Online web map showing hazards renderings.

Web Application Usability Assessment

In order to properly assess the quality and usability of the web application, a user survey was created. The purpose of the assessment was to gain insight to end user needs and preference based on the three main categories of use: (a) usability, (b) functionality, and (c) content. Survey questions were created for each of the three categories and then submitted to a sample group of 10 people.

A purposive sample strategy was used for study to target individual characteristics ranging from expert recreational divers with knowledge of Lake Superior shipwrecks to GIS professionals with experience in using web-based applications but no diving experience. This sampling strategy was used to provide a diverse and purposeful sample specifically for the purpose of the study.

Results

Lake Superior Shipwreck Hazard Ranking

The shipwreck hazard ranking system used four variables: (a) water depth, (b) nearest health care facility, (c) nearest shipping lane, and (d) hull material. The results of the analysis show the majority of the 34 shipwreck locations fall in the medium hazard level (Table 2).

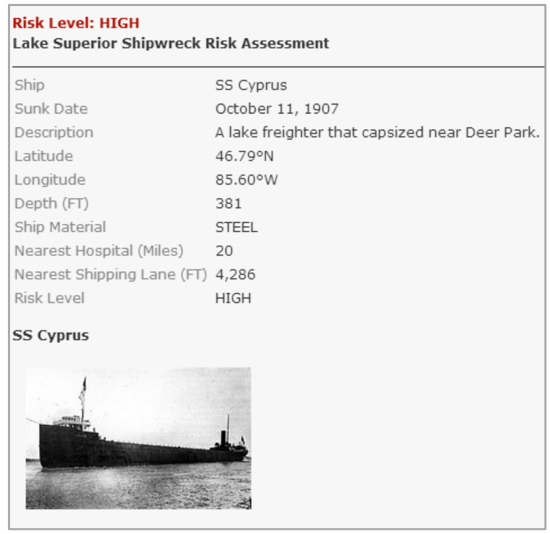


Figure 4. Pop-up display showing information on a shipwreck site. Information includes ship name, sunk date, description, latitude, longitude, depth, ship material, nearest hospital distance nearest shipping lane distance, recreational diving hazard level and an image of the sunken vessel.

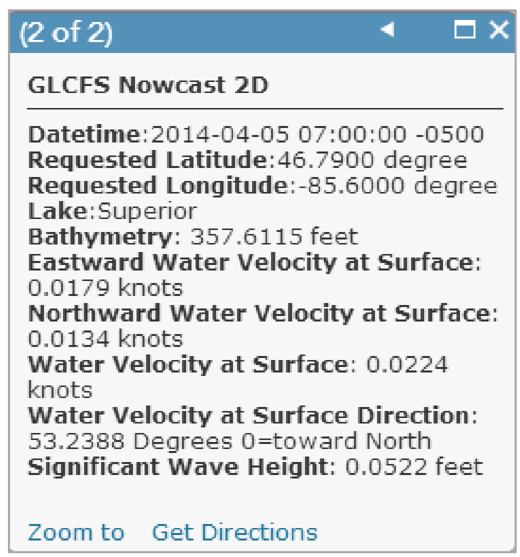


Figure 5. Pop-up display of current water conditions provided by the Great Lake Observing System.

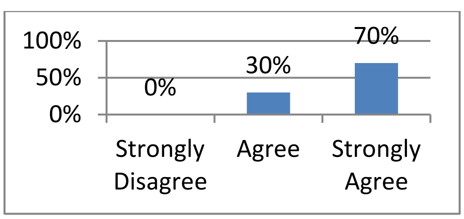
Table 2. Hazard ranking results of shipwrecks.

Hazard Level	Shipwreck Count	Percentage
Low	7	21%
Medium	15	44%
High	12	35%

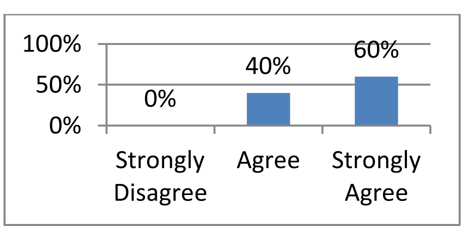
Web Application User Experience Survey

For each category (usability, functionality and content), two to three questions were designed to address each individual user experience component. The survey participants had three answer options (strongly disagree = 1, agree = 3, and strongly agree = 5). User needs of the application were not attainable prior to the development phase, therefore the methodology of the user experience was adopted and altered from content by Sauro (2011). The survey sample group was asked the same questions through a questionnaire document. The use of the term “understandable” in the survey questions was meant to assess if the user comprehended the information or functionality easily.

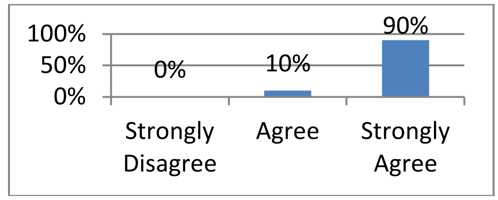
Question 1: Does the web application target the intended user needs?



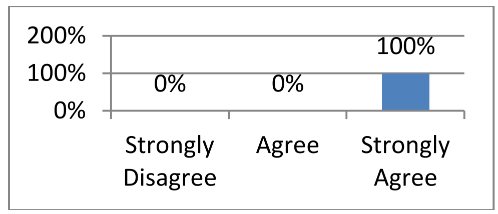
Question 2: Does the web application aid in the users’ goals and tasks?



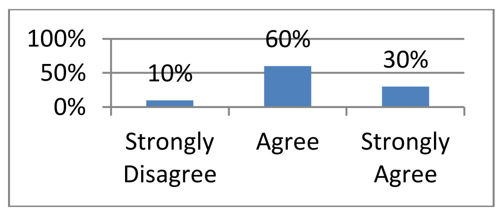
Question 3: Is the information easily understandable?



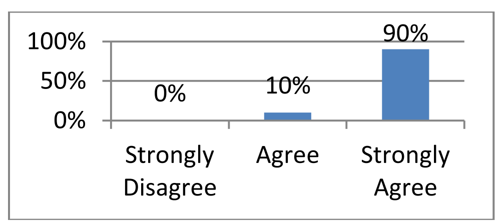
Question 4: Is the map display rendered quickly?



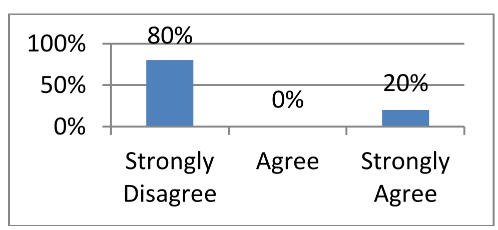
Question 5: Are the tools easily understandable?



Question 6: Is the map more useful than tabular data?



Question 7: Is there any additional information that might be helpful?



Discussion

Results from the user survey show the web application is an overall effective tool during its initial testing for the tested sample group. Of the seven questions asked, there was general consensus the map is more useful than tabular data and the information was understood in the web application. One user responded the tools were not easily understandable. The future course of action to improve an understanding of each tool would be a help document describing the functionality and use of each tool.

The largest limitation of the user experience survey was the limited number of users within the sample group. Since this web application is a prototype, collecting initial feedback from a smaller pilot sample group was deemed to be sufficient to evaluate and identify improvement areas for the web application. Results from the survey allow future usability assessments to be more specific to the user needs by directly focusing on the areas of concern.

Additional future phases for this web application would need to include a larger group of people surveyed before making the application available to the public. This project incorporated four main variables into the hazard assessment analysis. It would be beneficial in future enhancements to include additional variables, such as current water temperature, identified shipwreck entanglements, and high traffic fishing areas.

Conclusion

With enjoyment of recreational diving comes the need for awareness of the hazards involved. Availability of a web-based resource providing a hazard assessment for recreational divers can be a very important safety tool. Recreational diving hazards can vary from location to location, but having a systematic tool that provides a general hazard level is a good start. Future studies may entail exploring additional factors and variables impacting recreational shipwreck sites.

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