Sites@Risk a Sea-Level Rise Vulnerability Assessment Tool: User Guide Development and Pilot Study

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1. Introduction

Throughout Newfoundland and Labrador (NL), many key archaeological resources are located on the coast. Recent reports have projected climate induced sea-level rise throughout the province over coming decades (James et al., 2014). Coastal archaeological resources may therefore be susceptible to inundation from higher sea levels (Westley, Bell, Renouf, and Tarasov, 2011). In addition, high water levels may result from storm surges, temporarily inundating the coast above the highest tide level.

In order to assess the vulnerability of coastal archaeological sites to sea-level rise and storm surges, a geographic information system (GIS) based assessment tool called *Sites@Risk* has been developed at Memorial University of Newfoundland (MUN) as part of the Coastal Archaeological Resources Risk Assessment (*CARRA*) project. This tool enables users to employ multiple geospatial data sets to assess the risk to coastal archaeological sites from projected higher water levels.

In order to disseminate this tool, a *Sites@Risk* user guide has been developed. The guide is intended to instruct users on collecting and formatting sea-level and archaeological data, and completing the *Sites@Risk* analysis. This guide was piloted with four partner organizations throughout Newfoundland and Labrador in order to gather feedback to assist in refining the user guide.

Although the original focus of the project was on archaeological data, the tool can also be used for assessing other coastal sites. The archaeological location data can easily be replaced with data for other types of sites.

2. Background

The *CARRA* project has assessed the risk of several coastal archaeological sites in Newfoundland and Labrador to projected higher water levels:

- Coastal flooding currently affects 30% of archaeological sites in areas of NL surveyed through the *CARRA* project (Bonavista Bay, Strait of Belle Isle, L'Anse aux Meadows, Port au Choix)
- By 2025, the number of affected sites in these areas is projected to increase on average to 43% due to rising water levels
- Among the sites at risk, approximately 10% are in protected National Historic Sites, including the UNESCO World Heritage Site of L'Anse aux Meadows

Given the high percentage of sites identified as at risk of inundation by 2025 in the *CARRA* study areas, there is a need to identify which sites are at risk elsewhere along the coast (the *CARRA* project examined less than 5% of the archaeological sites in the province). *CARRA* also demonstrated that there is regional variability in the percentage of at-risk sites, in part related to differential vertical land motion and to the elevational stratification of archaeological sites.

Consequently, certain coastal regions are of greater concern. Heritage managers can use the information provided by the *Sites@Risk* tool to target coastal regions that are more vulnerable to higher water levels.

3. Purpose and objectives

The overarching objective of this project is the development of a piloted user guide for the *Sites@Risk* tool. The availability of a user guide will assist in disseminating the tool and enable those involved in managing archaeological sites to operate it effectively. Identifying highly vulnerable sites is the first step in managing climate change impacts on coastal archaeology. Although designed with a focus on archaeological sites, the tool can be used with data for other types of coastal locations that may be at risk to sea-level change.

The creation of the *Sites@Risk* user guide was divided into three phases: 1) initial development of a draft guide; 2) piloting of the draft guide; and 3) refinement of the guide based on pilot operation and feedback.

The *Sites@Risk* draft user guide provided target users with comprehensive step-by-step instructions for using the tool. In addition to an overall introduction to the project, the user guide contains three key sections: Data Collection, Data Processing, and Data Analysis.

During the second phase of the project, the guide was piloted with four partner organizations to allow MUN researchers to gather feedback from a range of users. Guide developers worked with these users while they operated the tool to assess the vulnerability of coastal archaeology in their selected areas of interest. The pilot testers provided feedback on the usability of the guide and highlighted any sections where instructions were unclear or missing. They identified sections that they skipped because they were already familiar with the associated steps, and they tracked how long they took to complete the assessment process.

The third phase involved the completion of the *Sites@Risk* user guide. Feedback from pilot users and developers was integrated into a final version of the guide (attached).

4. Summary of the *Sites@Risk* User Guide

The *Sites@Risk* guide takes the user through a series of steps in a GIS environment to identify coastal archaeological sites with high, moderate, or low vulnerability to higher water levels. Sites classified as highly vulnerable are likely to be inundated by 2025, sites identified as moderately vulnerable are at risk between 2025 and 2100, and sites with low vulnerability would only be at risk after 2100. These time intervals mirror the projection periods in James et al. (2014), but can be user defined.

The guide is structured in three sections: Introduction and Data Requirements, Data Processing, and Data Analysis (Figure 1). In order to make use of the guide, the user needs to have experience working in a GIS environment and some understanding of archaeological data. The

software package ArcGIS (©Esri) is used throughout the guide. In order to make it available to a wider audience some workflows for the open source GIS software QGIS (www.qgis.org) are available as a supplement to the guide.

Part 1: Gather required data sets	→	Part 2: Process and format data sets	→	Part 3: Complete analysis and classify sites
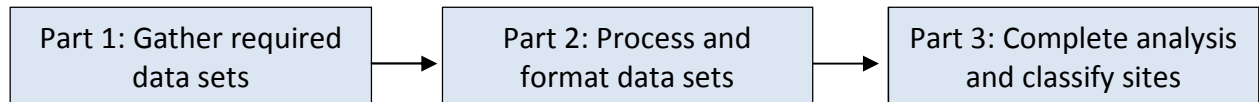
Figure 1. The Sites*@Risk* User Guide generalized workflow.

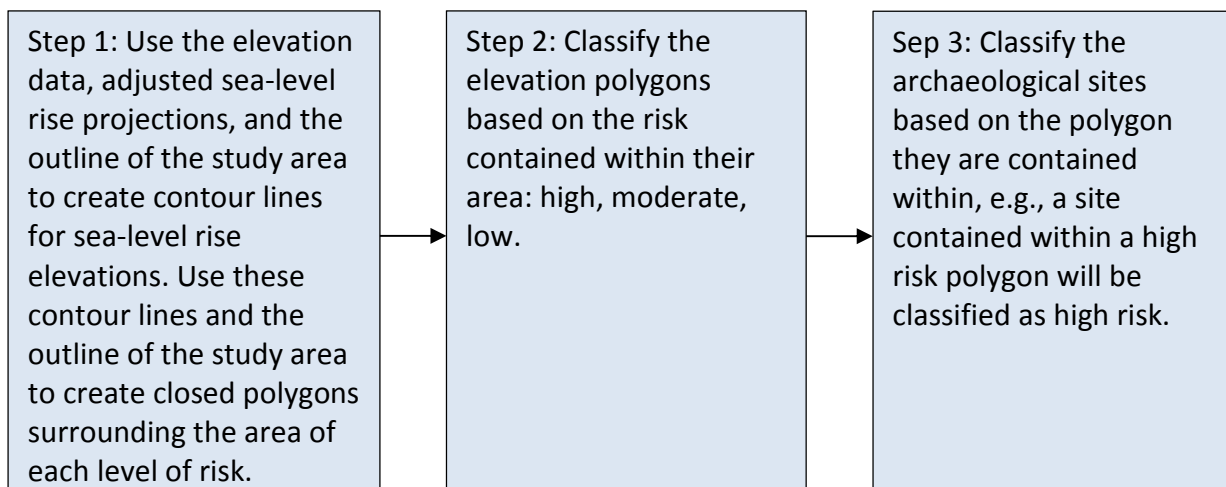The Introduction and Data Requirements section provides an overall introduction to the classification process and details regarding the main data sets required for using the *Sites@Risk* tool. This section specifies the data types required and provides recommendations on how to obtain these data. The required data sets are digital elevation data for the study area, geographic locations for the archaeological sites of interest, and sea level change projections. Guide users may already have the first two data sets. If not, they are directed to various online sources or provincial government departments to locate them. An Open File report released by the Geological Survey of Canada (James et al., 2014) provides sea-level projections for coastal Canada and users are directed to use these data for their sea-level change projections.

The section on Data Processing outlines the appropriate data formats to conduct the analysis and any data adjustments that are required. The length of time to complete this section will vary depending on the degree of data processing required, which is conditional on individual data sets. All users, however, will complete the section with their data layers properly configured and aligned in a GIS. At this stage, users will also adjust their sea-level projections relative to the highest high water large tide (HHWLT) level and also incorporate water level estimates for storm surge.

The section on Data Analysis provides step-by-step instructions for running the *Sites@Risk* analysis (Figure 2). This is the most complex part of the process. The *Sites@Risk* classification is

Step 1: Use the elevation data, adjusted sea-level rise projections, and the outline of the study area to create contour lines for sea-level rise elevations. Use these contour lines and the outline of the study area to create closed polygons surrounding the area of each level of risk.	→	Step 2: Classify the elevation polygons based on the risk contained within their area: high, moderate, low.	→	Sep 3: Classify the archaeological sites based on the polygon they are contained within, e.g., a site contained within a high risk polygon will be classified as high risk.

Figure 2. A generalized workflow for the *Sites@Risk* analysis.

based on the elevation of an archaeological site relative to projected water levels for the assessment area. In summary, polygons are drawn around coastal topography that will be inundated by projected higher water levels for selected time intervals (e.g. present to 2025, 2025–2100). The polygons are then designated as high, moderate, or low vulnerability according to the lowest to highest elevation range and archaeological sites that fall within them are assigned the corresponding vulnerability class. Those sites that straddle two polygons are assigned the higher vulnerability class.

With completion of the analysis, each site will be classified as High, Moderate, or Low risk for inundation. The information can be displayed either in tabular or map format (Figure 3).
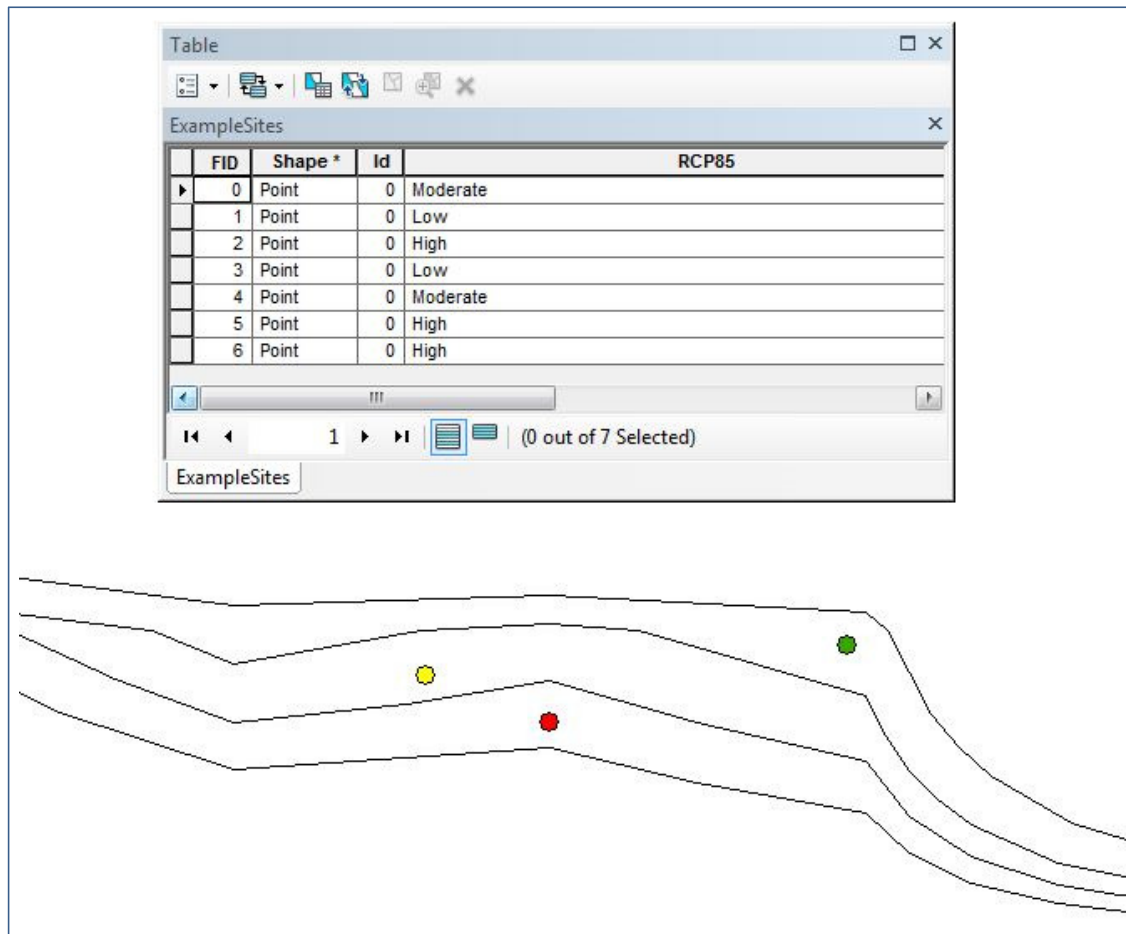
Figure 3. Top: an example of a table of classified sites. Bottom: colour-coded sites within designated elevation polygons based on their vulnerability classification.

5. Piloting the user guide

The *Sites@Risk* guide was piloted with target users in four heritage offices throughout NL. The piloting was conducted to identify and remedy any issues with the guide before a public release. The participants were provided with the guide and instructions to follow the steps sequentially. If at any point they encountered a barrier such that progress was halted, they

were given assistance to help them move forward and the guide developer documented the issue. If participants identified other issues through the piloting process they were able to describe them in a questionnaire that was completed at the end of the pilot.

5.1. Partner organizations

The guide was piloted with: the Provincial Archaeology Office, Government of Newfoundland and Labrador; the Nunatsiavut Archaeology Office, Nunatsiavut Government; and Parks Canada field units in Gros Morne National Park, Western Newfoundland and Labrador Field Unit and Terra Nova National Park, Newfoundland East Field Unit. These offices were considered to be potential users of the *Sites@Risk* tool and guide, representing federal, provincial, and Aboriginal heritage management in NL.

5.2. Background of participants

The backgrounds of pilot participants varied in experience working with archaeological data and geomatics (Table 1). Two of the participants were trained archaeologists and two had training in GIS (one of the GIS users also had input from an archaeologist in their organization). Although most participants had some GIS experience, those less qualified primarily used it for data visualization and were less familiar with the range of tools used for GIS analysis. More experienced GIS users were cognizant of the underlying issues in the tool application, such as data quality, as they followed instructions and completed the analysis.

Table 1. Self-assessed experience of pilot participants with GIS and archaeological data.

Organization	Title	Self Assessed Experience with Archaeological data	Self Assessed Experience with GIS
Provincial Archaeology Office	Archaeologist	Very Experienced (approximately 20 years experience)	Somewhat Experienced (approximately 15 years experience)
Nunatsiavut Archaeology Office	Archaeologist	Experienced (approximately 6 years experience)	No Experience to Somewhat Experienced (approximately 6 months experience)
Parks Canada, Terra Nova National Park	Geomatics Technician	Somewhat Experienced	Experienced
Parks Canada, Gros Morne National Park*	Geomatics Coordinator (P1), Archaeologist (P2)	No experience (P1), Very Experienced (P2)	Very Experienced (P1), Experienced (P2)

*A Geomatics Coordinator (P1) primarily completed the pilot with assistance from an Archaeologist (P2).

5.3. Pilot study areas and data sources
The pilot study areas were all located in Newfoundland and Labrador and ranged from Trinity Bay in the south to Torngat Mountains National Park in the north (Figure 4).
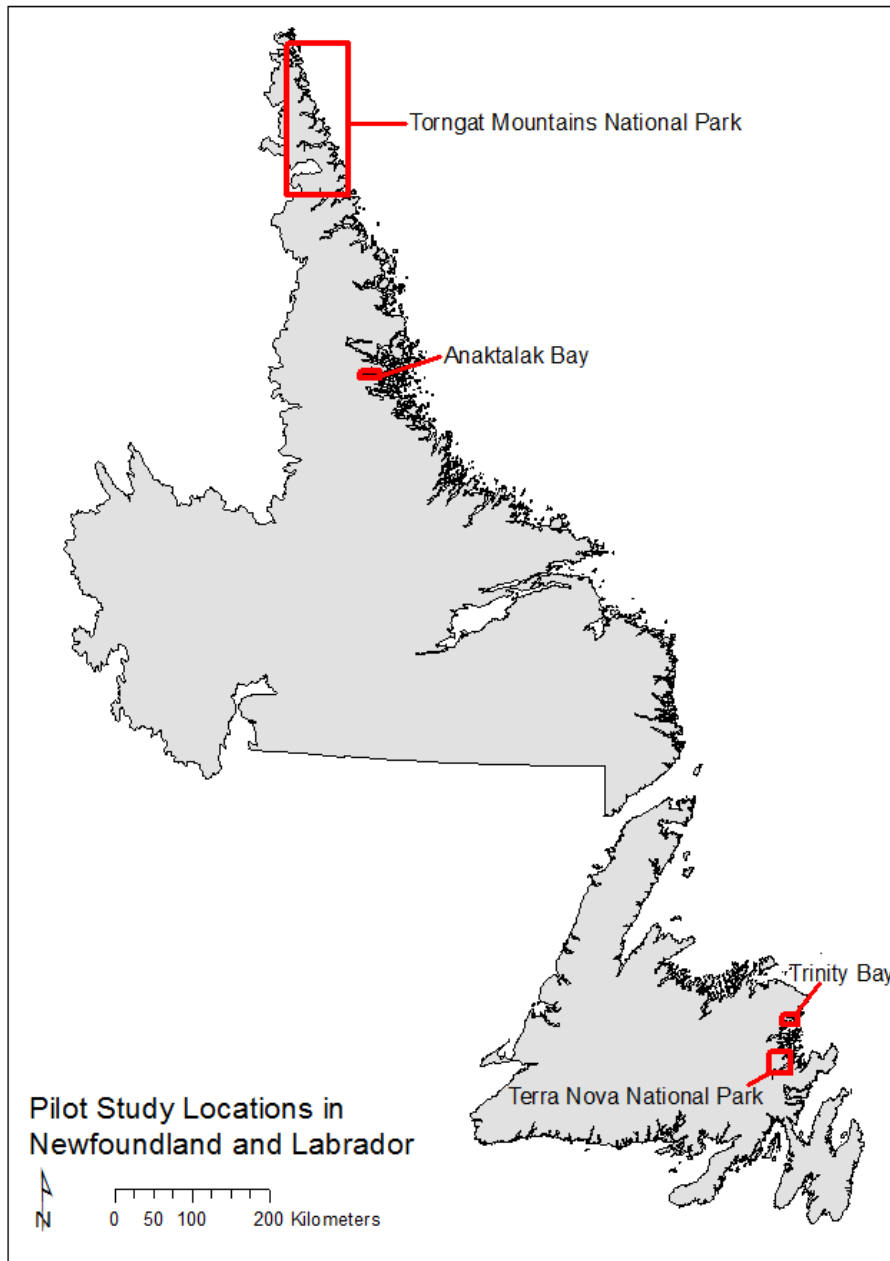
Figure 4. Pilot testing locations.

The participants gathered data from a variety of sources including online databases and local institutional data sets (Table 2). All of the participants used the James et al. (2014) report for their sea-level projections. No one was able to collect new data specifically for this project.

Table 2. Data sources used in each of the pilot regions.

Participant	Study Area	Site Location Data Source	Elevation Data Type/Source
Provincial Archaeology Office	Trinity Bay	Provincial Archaeology Database	Canadian Digital Elevation Model Mosaic – GeoGratis
Nunatsiavut Archaeology Office	Anaktalak Bay	Provincial Archaeology Database	Canadian Digital Elevation Model Mosaic – GeoGratis
Parks Canada, Terra Nova National Park	Terra Nova National Park	Parks Canada Data	LiDAR – Already in possession
Parks Canada, Gros Morne National Park	Torngat Mountains National Park	Parks Canada Data	Canadian Digital Elevation Model Mosaic - GeoGratis

5.4. Software used

Three of the four participants used Esri ArcGIS for their analysis. This is the software that is referenced throughout the guide. One user did not have access to this software and used the open-access GIS software QGIS. This created some issues for the participant, as it was difficult to translate instructions from one software package to another. This issue is discussed in Section 6.3.2.

5.5. Progress, performance, and user experience

The Provincial Archaeology Office pilot was completed without major issue. In contrast, the Nunatsiavut Government archaeologist, who is using QGIS, is still in the process of completing the analysis. In order to assist with this issue, a supplement to the user guide has been created with QGIS instructions for the most complicated part of the analysis (please see section 6.3.2. for further information). The vulnerability assessment conducted by Parks Canada in Torngat Mountains National Park encountered two issues. First, sea level is projected to fall in parts of northern Labrador under some sea-level change projection scenarios and therefore some scenarios were not completed. Second, several sites were incorrectly located in the sea and therefore, without better quality site records, they were unable to incorporate these sites into the assessment. A similar data quality issue was experienced during the site assessment in Terra Nova National Park.

Several of the pilot participants were quite satisfied with the tool performance and commented that it would be useful to them and their organizations for archaeological site management. Data quality was identified as a major obstacle for accurate and reliable site vulnerability assessment, especially where site management was concerned. One participant pointed out

that site vulnerability classification was only one part of the process and that a tool for at-risk site prioritization is also needed.

The user experience appeared to be highly influenced by the users' experience with using GIS for data analysis and the accuracy and resolution of available data for the users' study sites.

Users that were familiar with GIS analysis and tools were more likely to be able to work through technical issues on their own. They were also able to identify when they had identified an issue with the guide itself that needed to be corrected or if it was something they had done incorrectly. The piloting process has been used to correct issues with guide and make it as simple as possible. Since GIS can be complicated systems, experienced users will have an advantage and will be able to use their knowledge to complete the process and work through any issues that may arise more easily than inexperienced users.

The accuracy of available data was a major factor in the determination of the usefulness of the tool. Users with inaccurate data thought the tool might be useful in other circumstances but did not necessarily find it useful in their own. This is to be expected and is part of an overall issue with spatial data quality rather than an issue specific to the tool itself.

6. Summary of recommendations

The following recommendations for changes to and refinement of the *Sites@Risk* user guide were derived from questionnaires completed by participants after finishing their analysis, from interactions and conversations with participants throughout the piloting process, and from further review of the guide by its developers. Recommendations are arranged by guide section with general recommendations listed at the end. Each recommendation is divided into two parts: identified issue and appropriate response.

6.1. Section 1: Introduction and Data Requirements

6.1.1. Completion time estimates

Issue: Before beginning the pilot study, all of the participants wished to know how long it would take them to work through the *Sites@Risk* user guide. Only a very rough estimate could be provided at the time. This information is important to the users as they need the ability to plan and schedule their tasks at work.

Solution: During the pilot study, each of the participants was asked to track how long it took them to complete each section of the guide. Although there was a wide variation in completion times depending on data processing requirements and GIS competency, we now have a more accurate estimate based on the responses of participants. We have added an anticipated completion time to the introductory section of the guide.

6.1.2. Detailed descriptions of required skills and GIS processes used

Issue: Although the general skills required to use the *Sites@Risk* tool are referenced in the introduction, some participants suggested that a more detailed summary of specific skills and GIS competency would have given them a better idea of what to expect.

Solution: A detailed summary of required knowledge and skills (e.g., data formats and selection tools) and a list of the GIS processes used throughout the analysis have been added to the introduction.

6.2. Section 2: Data Processing and Formatting

6.2.1. Sea-level change scenarios

Issue: One of the key data sets required to complete the *Sites@Risk* analysis is a series of projections for sea-level rise. The *Sites@Risk* user guide recommends obtaining these sea-level projections from the James et al. (2014) report. It provides a range of projections based on different Representative Concentration Pathways (RCPs). RCPs describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. Each RCP projection by James et al. (2014) also provides a set of values based on confidence intervals. This wide selection of possible projections resulted in confusion for users.

Solution: In order to streamline the selection of a relevant sea-level projection from the James et al. (2014) report, users are now recommended to select the sea-level projection scenario that shows the highest amount of sea-level rise (RCP8.5, 95%CI). The guide therefore recommends a conservative and precautionary approach to site vulnerability assessment. Users are of course welcome to experiment with other sea-level projections once they feel confident in their selection and input.

6.2.2. Storm surge estimates

Issue: During the initial development of the guide, storm surge was not integrated into the higher water level calculation. A storm surge is an abnormal water level rise that results from atmospheric pressure changes and wind associated with a storm, over and above the predicted astronomical tide. Such storm surges can inundate archaeological sites well above the highest high water tide level. The frequency and magnitude of storm surge flooding is projected to increase in the future.

Solution: Users from NL are now instructed to add 2 m for 2025 and 3 m for 2100 water-level projections, approximating previous estimates (Vasseur and Catto, 2008; Westley et al., 2011). While storm surges may vary by storm and coastal exposure, these values will generate conservative water-level projections for the NL region. Application of the guide in other coastal regions should adopt local storm surge estimates and projections.

6.2.3. Water line adjustment

Issue: Projected water level increases need to be measured from a common datum and although this is typically taken to be mean sea level, for the purposes of archaeological site

vulnerability assessment, it makes more sense to use the high tide water level to encompass full inundation potential. The guide originally recommended using mean sea level but we have now incorporated this new recommendation. The conversion from mean sea level to high tide water level is region specific and the calculation must now also incorporate a new revision of mean sea level, introduced by the Canadian Hydrographic Service (CHS; Robin et al., 2015). CHS is currently working on an adjustment – the Hydrographic Vertical Separation Surfaces (HyVSEPs) – that will provide the necessary correction and conversion, but it is not complete or publicly available.

Solution: CHS has released a beta version of the HySVEPs for Newfoundland and southern Labrador for application in the *CARRA* project. These are used to estimate the Highest High Water Large Tide (HHWLT) for a region. A search box is being added to the *CARRA* website to allow users to search for their location and find the closest value for the HHWLT. We expect that these corrections will be available for the entire province in due course.

6.3. Section 3: Data Analysis

6.3.1. Additional illustrations for section three

Issue: Section three contains the analysis procedure and is the most complicated portion of the guide. While the guide contains screen shots showing the tools and sequential steps, it does not always show anticipated results of each step. Some pilot participants requested additional images throughout this section.

Solution: Additional screen shots are now added to this section to illustrate the outcomes of each step in addition to the completion procedure.

6.3.2. QGIS instructions

Issue: The user guide has been written for ArcGIS, as it is the GIS software that is commonly available in federal and provincial government departments, educational institutions and organizations that frequently use GIS. Unfortunately, the software is expensive and may not be affordable for small organizations with a limited budget or infrequent GIS needs. One of the participants in the pilot study did not have access to ArcGIS and used QGIS, an open access alternative. The participant had limited GIS experience and therefore had difficulty translating the instructions for one program to the other.

Solution: While it is not within the scope of this project to create full guides for each GIS software program available, a basic QGIS workflow for section three of the guide (the most complicated section) has been developed and will be available on the *CARRA* website as a supplement to the guide. This should assist in making *Sites@Risk* more accessible for a wider audience.

6.4. General

6.4.1. General GIS help
Issue: Several users had general technical issues with GIS or instances where they missed part of a step and did not have the skills to figure out what went wrong.

Solution: References to general online help resources have been added to the introduction. There are many online forums available and ArcGIS has an extensive online help site. Possible technical issues based on the participants' questions will be identified in the guide along with potential solutions.

6.4.2. Provide further discussion of accuracy of data
Issue: Some participants had several sites incorrectly classified because their coordinates placed them in the sea.

Solution: Further discussion has been added regarding specific issues that may occur as a result of inaccurate data and poor data quality.

7. Challenges in creating a generalized user guide
The *Sites@Risk* guide aims to be accessible to as many users as possible. These users will likely have a wide range of skills, knowledge, and data access in both archaeology and GIS. This can create substantial challenges in anticipating all of the issues users may face. For example, users may be gathering their data in many formats from different sources and will need to process them in a way that renders them compatible with their software package. While the user guide attempts to indicate typical data sources and formats, it does not assume to be all encompassing and users may need to rely on other supporting materials to prepare their data for tool input.

Data quality is a recurring issue for geospatial information from remote regions and when acquired over many decades (e.g., archaeological site information). For example, some of the older, pre-GPS recorded archaeological sites locate in the sea or many hundreds of metres away from their actual locations. Also, area boundaries are poorly recorded or unknown for some sites. These issues were also identified by the *CARRA* project and their resolution was deemed critical for accurate vulnerability assessments. Although collection of new site survey data, for example, would be preferable, this topic lies outside the scope of the *Sites@Risk* tool but it is important for the user to be aware of these data gaps and data quality issues in general.

8. Refinement and Enhancement of the *Sites@Risk* tool
The *Sites@Risk* tool currently uses projected sea-level rise and storm surge estimates in combination with the elevation of a site to assess a site's risk to sea-level rise. There are additional factors that can affect the vulnerability of a coastal site.

Loosely packed sediments such as sand or gravel are at greater risk of erosion from wave action than surfaces such as bedrock. Maps of the surficial land cover are often available from organizations such as provincial or federal geological surveys and may be able to provide the data required to incorporate surficial land cover into the *Sites@Risk* tool. Before this functionality could be added to the tool, it would have to be determined if the maps that are available are of a high enough resolution to provide an accurate description of the subsurface at individual archaeological sites or if conducting field work would be necessary. More research would also have to be done to determine a method to measure the influence of each substrate on the level of risk to a site. Catto (2012) has produced a Shoreline Classification System and Coastal Erosion Index for Newfoundland and it may be possible to incorporate this methodology.

Future changes in aspects of hydrodynamics, sea ice regimes, infrastructure and development, and human use could also potentially influence the risk level of a site but these factors are currently difficult to quantify.

9. Additional uses for the *Sites@Risk* tool and user guide

In addition to archaeological sites, the *Sites@Risk* tool and user guide could also be used with other types of coastal sites. While the tool was developed with archaeological sites in mind, it is not specific to archaeological data and could be used with any coastal location data. The system considers sites to be either points or polygons and what these points or polygons represent does not affect the analysis. When collecting data and conducting the analysis, the archaeological site locations can be replaced with location data for the sites the user is interested in. This requires no changes to the way the analysis is conducted.

The *Sites@Risk* tool could be used by many types of organizations for assessing a variety of features. For example:

- Coastal municipalities could use the tool to assess the vulnerability of local infrastructure located close to the coast, such as building footprints, drainage networks, water sources, and distribution or recreational facilities.
- Environmental and conservations groups could use the tool to assess risk to natural coastal features (e.g., dunes) and land types (e.g., wetlands) that protect the coast from flooding and host important ecosystems.
- The tourism industry could employ the tool to assess both hard and soft infrastructure along the coast, such as campgrounds or boardwalks and access trails or viewpoints, respectively.
- Transport authorities responsible for roads, bridges, and harbours could use the tool in a general vulnerability assessment of coastal transportation infrastructure.
- Energy utility companies could assess the risk of high water levels impacting transmission lines.

Note that some of these applications may require additional data, such as feature heights or elevation (e.g., bridges), in addition to the elevation of the surrounding landscape.

While the steps to complete the analysis will be the same, it may be useful to make some adjustments to the guide for non-archaeological users. The pilot users found the example images in the step-by-step instructions helpful. Adding non-archaeological examples may be useful for other users by illustrating the range of coastal sites that may be examined and by showing how data from different location types will look similar throughout the analysis.

One of the limitations that the archaeological pilot users had during the piloting process was the accuracy of available data. Some of their data placed sites in incorrect locations. This may be an issue with other kinds of sites as well. Depending on the types of sites the user wishes to examine, data availability could also be an issue.

Since the guide currently focusses on archaeological data, it was possible to list potential sources for archaeological data. Due to the wide range of possibilities of types of locations that may be assessed, it would not be realistic to provide a reference list of potential data sources for all possible site types as has been done for archaeological sites.

To determine changes to the guide that would be helpful for users other than heritage managers, the guide could be piloted with users from a variety of potential groups. Piloting the original guide with four users from the field of archaeology provided important revisions that enabled it to be tailored to user needs. Piloting the guide with users from other applications would meet the needs of a wider audience.

The *Sites@Risk* tool is intended to be part of the prioritization process and to indicate which sites may be most at risk. The results should be regarded as a first stage desktop assessment. Ultimately, critical and vulnerable infrastructure should be assessed by a licenced risk assessment professional.

10. Dissemination

The *Sites@Risk* guide will be distributed in both online and print formats. The online version will be made available on the *CARRA* website (http://carra-nl.com/). Other provincial heritage websites, such as the Association of Heritage Industries NL, will be contacted about providing links to the guide on their sites.

The guide will be promoted at the Adaptation Canada 2016 conference in mid-April. If a CARRA team member is accepted to the conference, the guide will also be promoted at the Canadian Association of Geographers Conference in June 2016.

The guide may also be distributed at additional targeted conferences and annual meetings as the opportunities arise.

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Sites@Risk:
A sea-level rise vulnerability assessment tool

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March, 2016

Version 1

Table of Contents

Introduction

Sites@Risk is a climate change adaptation tool designed to assist users in identifying archaeological sites that may be at risk of inundation due to sea level change. It was created for archaeologists and others who may be involved in assessing, managing, and maintaining coastal heritage but can also support assessments of other types of at-risk coastal resources and infrastructure.

After completing this analysis, each archaeological site will be classified by its risk to sea level rise (i.e. High, Moderate, or Low). This is a simple classification based on whether the elevation of an archaeological site is higher or lower than sea level is expected to rise above its current level. It is intended for an initial identification of sites that may be at risk and does not take into account other potential factors such as erosion, shoreline displacement, etc.

Identifying which sites are at highest risk to sea level rise can be one element in prioritizing which archaeological sites are in need of conservation. Heritage managers can integrate this information along with their knowledge of each individual site to enhance the decision making process.

While it has been developed with archaeological sites in mind, this tool can also be used in the assessment of non-archaeological coastal sites. For example, municipal parks infrastructure, such as playgrounds, public art, seating areas, etc. or natural features such as dunes, grasses, etc.

This is a geographic information systems (GIS) based tool and the software required for this analysis is ESRI ArcGIS with either the Spatial Analyst or 3D Analyst extension. Version 10 has been used in this guide. Advanced users may be able to adapt the methodology to their chosen software. A supplement to this guide with instructions for completing Section 3 using QGIS is available at the CARRA website http://carra-nl.com/. Spreadsheet software such as Microsoft Excel or OpenOffice will also be required.

In order to conduct this assessment, the following three data sets are required:

1. Geographic locations of the archaeological sites of interest
2. Elevation data for the area of interest
3. Projections of the amount of sea level change in the area of interest

The analysis cannot be completed without all three of these data sets. The data sets must be of sufficient accuracy for completing the analysis (e.g. if the data show that an archaeological site is located 50 m out to sea when it is know that the site is not currently submerged you will not be able to assess the risk to that site). Full details regarding data requirements are provided in Section 1.

The accuracy and reliability of this analysis will vary depending on the data sets being used.

How to Use This Guide

This guide is divided into three main sections:

1. Data Requirements
2. Data Processing
3. Data Analysis

Data Requirements provides details on the main data sets required for using the *Sites@Risk* tool. This section specifies the types of data required, provides recommendations on how to obtain these data, and discusses data quality.

Data Processing details the steps that must be taken to convert the data to the appropriate formats for analysis.

Data Analysis provides step-by-step instructions for running the *Sites@Risk* analysis.

Data collection and preparation may take a considerable amount of time. The total time taken will vary depending on the state of the data when they are received, the experience level of the user, whether the data sets are readily available or have to be collected or ordered, and the total number of sites that are being examined within an area.

Section 1 will take approximately 1 to 3 hours if the

data are available. If data need to be collected or ordered for the project then this will obviously add significant time to this section. Section 2 may take as little as 2 to 3 hours if the data are in usable formats or up to 2 - 3 days or more if the data need to be processed from a raw format. Section three will vary depending on the number of sites and the user's experience with GIS analysis. It will likely take anywhere from 3 hours to one day.

While we go through the processes step-by-step in this guide, it is strongly advised that the user has previous experience using GIS or an assistant that is an experienced user. Since every user will have different data sets, it is impossible to cover every technical issue that may arise. There are also several basic processes involved in using GIS that would not be feasible to cover here.

Throughout the guide, an asterisk* beside a word or phrase indicates that this term is listed in the section FAQ and Definitions.

If you are having trouble at any point in your analysis ESRI provides an extensive online help site for ArcGIS doc.arcgis.com/en/arcgis-online/ (link active as of March 2016). There are also many unofficial help sites that can be found by typing your problem into your preferred search engine.

Required Skills

The following list identifies general GIS skills used in this analysis:
- Adding data to a project
- Formatting, projecting, and editing data
- Creating new blank layers
- Using tools to make selections
- Using tools to create new data layers

The specific GIS tools and toolbars used in this analysis:
- Select by Attributes
- Select by Location
- Spatial Analyst Tools
- Data Management Tools
- Editor

1. Data Requirements

In This Section

This section will guide you through data acquisition and assessment. A key point to keep in mind is that the quality of your analysis will only be as high as the quality of you lowest quality input dataset. For each dataset it is exceptionally important to be aware of both the accuracy[*] and resolution[*] of the data. During this analysis you will be working with raster[*] and vector[*] data formats.

Archaeological Site Locations

Coordinates of the archaeological sites are required to determine whether the site will be located in a future area of inundation.

Some archaeological sites may already have ArcGIS layers available that have been collected using a GPS or that have been digitized from maps, remotely sensed imagery, or written location data. For example, the Provincial Archaeology Office in Newfoundland and Labrador has a digital database of all recorded archaeological sites

If you are unable to access a digital copy of the site location and are able to access the site, the data can be collected with GPS surveying. If you are unable to access the site or do not have access to a GPS the archaeological site location should be available on the

Points Vs. Polygons
As GIS layers these sites may be formatted as points or polygons[*] (see 'Vector' in FAQ). If only one set of coordinates was collected to represent the entire site then it will be a point layer. If coordinates for the entire outline of the site were collected to form an enclosed shape then it will be a polygon layer.
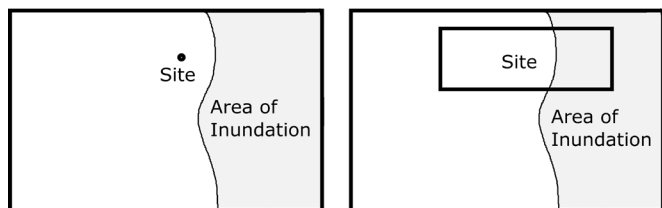
A polygon is a more realistic representation of the site and will provide better results. For example, a point taken at the centre of a site will not be classified as at risk if only the seaward side of the site is going to be inundated.

site record form (this may vary by region). These locations will have varying levels of accuracy depending on the original collection method. Instructions for how to create a point layer from written coordinates are included in the section on Data Processing.

The accuracy of the site locations is very important for this analysis. If your data do not represent the actual locations of your sites then your final results will not be accurate. Data in the provincial database may vary in accuracy depending on how they were collected. Ideally, the site locations will be verified through field work and GPS surveying to provide the highest accuracy data.

Elevation Data

Elevation data are required to determine the elevation of your site above sea level and potential areas of inundation.

Ideally, the data will come in a raster format. The highest resolution data available should be used. Vector contour lines[*] may be converted to a raster format during processing if they are the only data format available.

There are a many different data types available and the availability and cost varies widely between provinces and territories and within the provinces and territories themselves. We recommend contacting your provincial or territorial mapping and survey division and asking them what they have available. Please specify that you need the highest resolution data available and will need it in a raster format.

A list of potential sources for topographic data by province or territory is located in Appendix A. These are suggestions and starting points only and may not have data available at the resolution required for your

analysis.

> *Why Do I Want High Resolution Elevation Data?*
> A higher resolution raster has more data points over a given area than a lower resolution raster. For example, if you have a raster with a resolution of 1 m then each cell in the raster represents 1 m x 1 m on the ground while a cell in a raster with a resolution of 25 m represents 25 m x 25 m on the ground.

Sea Level Change

Projections for sea level change at the site of interest are required to determine whether relative sea level will increase beyond the elevation of the site and cause inundation. The most recent report for relative sea level change projections across Canada is:

James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., and Craymer, M., 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States; Geological Survey of Canada, Open File 7737, 72 p. doi: 10.4095/295574

This report provides sea level change estimates for 59 locations across Canada as well as 10 locations in the United States and is available from the Natural Resources Canada GEOSCAN Database (http://geoscan.nrcan.gc.ca/starweb/geoscan/servlet.starweb?path=geoscan/geoscan_e.web link active as of March 2016). These estimates are based on Representative Concentration Pathways (RCP) scenarios. The estimates for each scenario are based on different projections for the concentration of greenhouse gases in the atmosphere. Sections 2.1 Scenarios of Global Sea-level Rise and 3. Projections of Sea-level Change are of particular use in determining how the scenarios and projections in this report were developed.

At this point you need only locate and write down the sea level change numbers for your location for the different climate change scenarios. We looked at the scenarios RCP 4.5 and RCP 8.5. You will be prompted to enter these numbers later during the analysis.

Values for RCP 4.5 can be located in Table C6 on pages 64 - 65. Values for RCP 8.5 can be located in Table C7 on pages 66 - 67. Locate the station closest to your study area (look in Table C1 to identify the GPS station codes). Write down the RCP Projection at 2010 and

2100 for each scenario, we used the median values for RCP 4.5 and the 95% values for RCP 8.5 to identify the worst case scenario.

If a local study has been completed for your area then, at your discretion, it may be used instead of, or in addition to, the James et al. report. You may wish to complete the analysis using the James report first to see how the analysis works.

Recommended Data: Satellite Imagery or Digitized Aerial Photography

Satellite imagery or digitized aerial photography can be useful in visualizing your study area and for creating maps once you are finished your analysis. It is not required to complete the analysis.

If you do not have access to imagery through your organization you may be able to obtain some through Natural Resources Canada, Canada Centre for Mapping and Earth Observation (CCMEO) (link as of March 2016 http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/10782). This is the home of the National Air Photo Library and there is also some satellite imagery available. You may also be able to obtain imagery from your provincial or territorial organization in charge of surveys and mapping.

Data Sets Checklist

Required

☐ Archaeological site locations in digitized or written format

☐ Topographic data with the highest resolution obtainable

☐ Sea level change scenarios from James et al. 2014 or local report

Please ensure you have all of these datasets before proceeding to the next steps.

Recommended

☐ Satellite imagery or digitized aerial photography of your study area

2. Data Processing and Formatting

In This Section

Data may need to be processed or converted to another format or projection[*] before analysis can be completed. This section will guide you through getting your data sets into the formats required to complete your site classification.

In addition to processing and formating the layers you have collected, you will also need to create a GIS layer that outlines your study area.

Checking and Converting Map Projections

All data sets must be in the same map projection and coordinate system. Check each layer and convert if necessary. Steps for beginners are included below or proceed to Site Location Data if you are comfortable with this process.

Map projections tell ArcGIS how to draw features from the world's three dimensional surface onto your flat computer screen. There are many different projections which may be used and all of the layers in your project must have the same projection in order line up properly for analysis. If you are unfamiliar with this concept please refer to an introductory GIS textbook or ArcGIS help for more information as this is a fundamental concept for using GIS.

To check the projection:
1. Open a new instance of ArcGIS

2. Add your data layer (there are multiple ways to do this: Click on 'File', hover over 'Add Data', select 'Add Data…'; Click on the plus symbol in the orange triangle; Right click on the 'Layers' menu item in the table of contents sidebar, select 'Add Data…')

3. Right click on the layer in the 'Table of Contents' sidebar

4. Select 'Properties…'

5. Click on 'Source' tab

6. The projection and coordinate system will be listed in the 'Data Source' display box

To convert the projection:
1. Open ArcToolbox → 'Data Management' tools → 'Projections and Transformations' → 'Feature' (for a vector layer) or 'Raster' (for a raster layer) → 'Project' (for a vector layer) or 'Project Raster' (for a raster layer)

For a Vector or Feature Layer:
2. Select the file you wish to re-project in 'Input Dataset or Feature Class'

3. Name and select the location for the output dataset in 'Output Dataset or Feature Class'

4. Select the coordinate system you wish to convert to

5. Click 'OK'
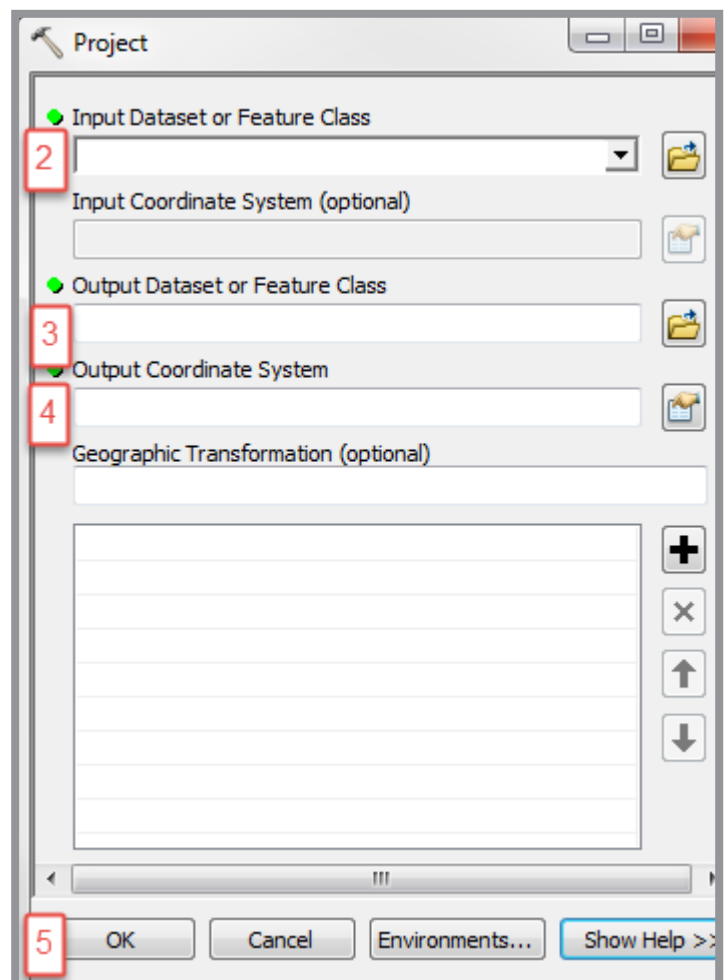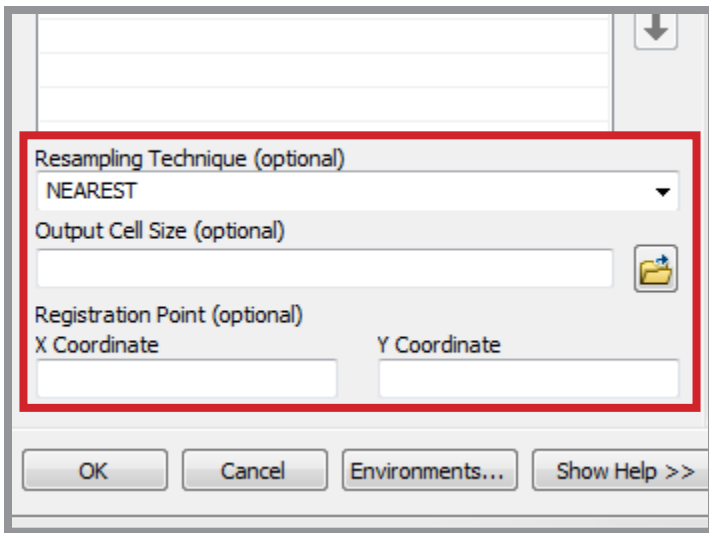
For a Raster Layer:
Follow steps as for vector and leave additional options as defaults.

Site Location Data

If your site locations are already in a GIS format then you do not need to do any further processing. If you have written point locations, these will need to be converted to a point layer. Steps for beginners are included below or you can proceed to Sea Level Rise if you are comfortable with this process.

Creating a point layer:

1. Enter data into a spreadsheet (such as Excel) with a minimum of the following information in separate columns Easting, and Northing or Latitude and Longitude and save your spreadsheet

2. Click 'File' on the menu bar in ArcMap

3. Select 'Add XY Data'

4. Browse for and select the table containing your data

5. For the X Field select your Easting or Longitude, for the Y field select your Northing or Latitude. If you have elevation data this will be selected for the Z field

6. Click on 'Edit' button

7. Select desired projection and coordinate system

8. Click 'OK'

Elevation Data

If your elevation data are in a raster format, also referred to as a digital elevation model or DEM, then they should not require any processing.
Some data sets may be available as raw data which means they are in the format they have been collected in and may require additional processing to be used in ArcGIS. This may be a simple task or may be quite complex and require specialized software. Please discuss this with your data provider.

If your data are in the form of contour lines they will have to be converted to a raster format. This can be done using the Topo to Raster tool in ArcGIS.

1. Open 'ArcToolbox' → 'Spatial Analyst Tools' → 'Topo to Raster'

2. Enter your 'Input feature data' (the layer you want to convert)

3. Enter your 'Output surface raster' (the name and file
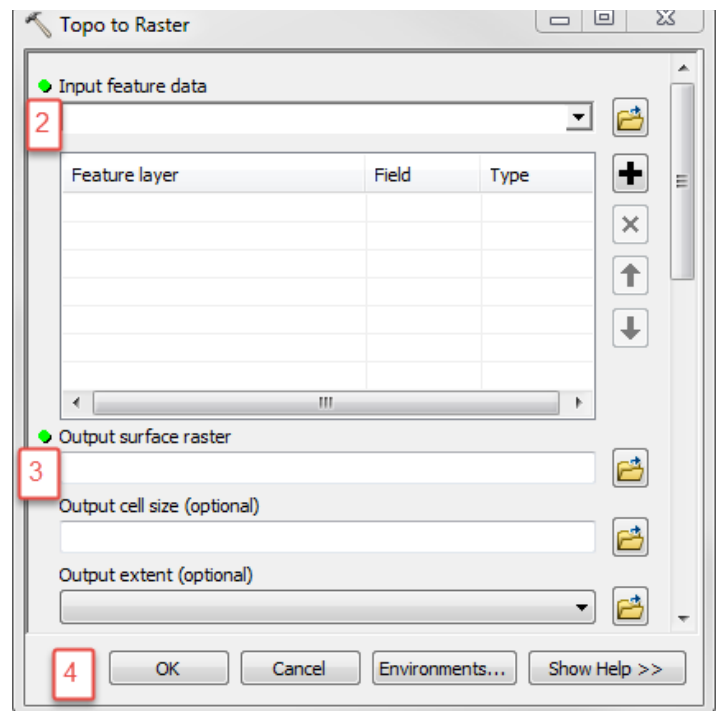
location of your final layer)

4. Click 'OK'

Sea Level Rise

The James et al. (2014) report provided sea level projections for 2010 and 2100. In order to identify which

sites are at the most immediate risk, the FORECAST function in OpenOffice or Microsoft Excel will be used to interpolate values for the years 2025 and 2050. This will enable the identification of the sites that are at high, moderate, and low risk within each sea level change scenario. Although the actual projection for sea level change is not linear, this linear approximation using the available data will allow the assessment of which sites are at more immediate risk.

To use the Forecast function:
1. Open an Excel or Open Office spreadsheet.

2. Create a column for the Year and a column for the sea level change scenario (e.g. RCP 8.5 median)

3. Enter the values for the know years and the year you wish to calculate values for in the year column (i.e. 2010, 2100, 2025, 2050)

3. Enter the known RCP values in the sea level change scenario column

4. In the RCP Scenario column for the year 2025 enter the following formula into the function bar:

=FORECAST(x, known_y's, known_x's)
where x = the year you wish to make the calculation for; known_y's = the known RCP projections; known_x's = the known year

5. Repeat for 2050

In addition to the predictions for 2010 and 2100 you should now have estimates for 2025 and 2050. Keep in mind that these numbers are in centimetres and will need to be converted to the same units as your elevation data before they can be used.

Storm Surge

Storm surge is a rise in the water level above the predicted tide that is caused by a storm. This can cause the water level to be much higher than would otherwise be estimated. To take this into account we will now add an estimated storm surge estimate. These numbers are for Newfoundland and Labrador, if you are in another location you will need to locate estimates for your area. For the years 2025 and 2050 please add on 2 m (200 cm) and for the year 2100 please add on 3 m (300 cm) to your sea level rise projections.

Vertical Datum
For many elevation data sets, mean sea level is used as the vertical datum[*] and elevation is measured as the height above mean sea level. This does not take into account the level of the water at high tide and can cause an underestimate the extent of the study area that is susceptible to inundation.

The Canadian Hydrographic Service (CHS) is developing a series of Hydrographic Vertical Separation Surfaces (HyVSEPs) that will allow the conversion of mean sea level to the Highest High Water Large Tide (HHWLT) (Robin et al, 2015). While these data are not yet publicly available, data have been obtained for most of Newfoundland and southern Labrador.

To access these data, please visit the CARRA website at http://carra-nl.com/. Once you are there you will enter the coordinates of one of your sites into the search box and you will be provided with an elevation. This elevation will be used as your datum instead of mean sea level. This value will also need to be added to all of your sea-level projections.

If this correction is not available for your study area, please be aware that using mean sea level for your analysis will underestimate the risk of inundation.

Create a Polygon of the Study Area

During some parts of the analysis you may need to contain your data to your study area. This is the area containing your archaeological sites, the coast with part of the ocean, and a buffer area.

To create this layer:

1. Load your data and imagery (if available) into Arc-Map.

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2. Create a new polygon layer by going to ArcCatalog → right click on the folder in which you wish to put your new layer → 'New' → 'Shapefile...'

3.a. Name your shapefile,
b. select 'Polygon' from the dropdown menu
c. Click on 'Edit' and select 'Coordinate System'
d. Click 'OK'

The layer you just created should have been added to your map. If it was not, add the layer.

4. Click on the Editor toolbar and select 'Start Editing' (if you do not see the Editor toolbar you can add it by clicking on 'Customize' → 'Toolbars' → 'Editor' to add it to your toolbars)

5. Use polygon drawing tool to draw a polygon around study area

6. Click on Editor toolbar and select 'Save Edits'

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3. Data Analysis

In This Section

This section provides step-by-step instructions for classifying archaeological sites according to their risk of inundation due to sea level change.

The first step in this process is to use elevation data to create polygons around areas of equal risk to inundation for each scenario.

The second step is to assign a classification to these polygons of high, moderate, or low risk to sea level change in that scenario.

The final step is to classify each archaeological site based on which polygon they are located within.
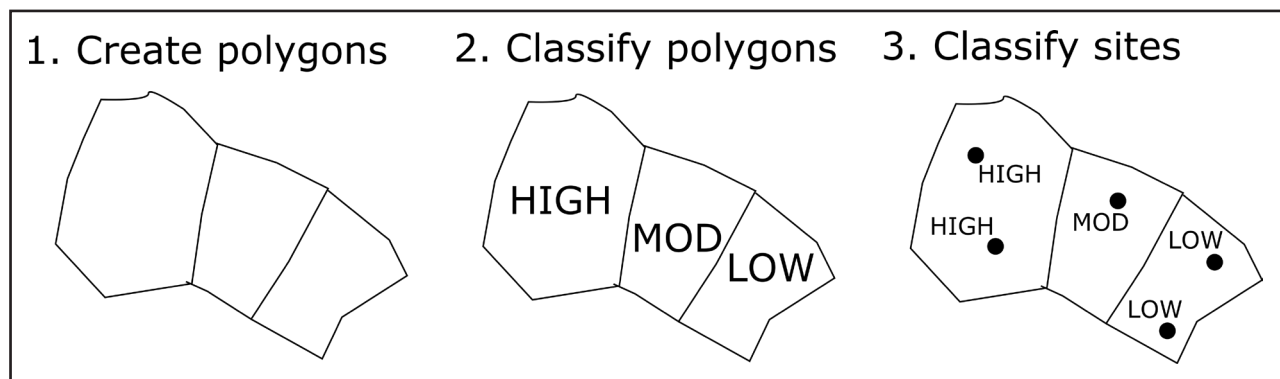
A series of detailed flowcharts outlining each step is located in Appendix B.

If you are using QGIS for your analysis, please visit our website http://carra-nl.com/ to download a supplement to this guide containing QGIS specific instructions for this section.

Part 1: Create Polygon Contour Shapefiles

The result of this step will be a layer with polygons representing areas that may be inundated in each sea level change scenario (e.g. RCP 4.5 or RCP 8.5). You will start by creating polylines from your elevation raster using the adjusted elevation values from the James et al. report (or your own data) and will then use these polylines to create enclosed polygons.

1. Add the elevation raster and the polygon(s) of your study area to a new project in ArcMAP

2. Use 'Contour with Barriers' to create polylines.

a. Open – 'Catalog' → 'System Toolboxes' → '3D Analyst Tools' → 'Raster Surface' → 'Contour with Barriers'
(You can also find this tool in 'Spatial Analyst' if you do not have access to '3D Analyst')

b. 'Input Raster' – Input your elevation raster
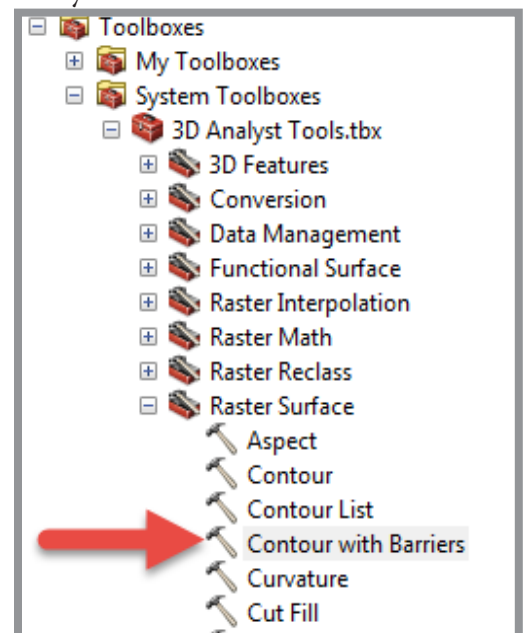
c. 'Input Barrier Features' – Input the polygon for your study area

d. 'Output Contour Features' – Save to a known location

e. 'Type of Contours (optional)' – Select 'POLYLINES' from dropdown menu options

f. 'Enter Explicit Contour Values Only (optional)' – Tick this box

g. 'Explicit Contour Values (optional)' – Enter the value for potential sea level rise derived from the James et al. report for 2100, your estimated values for 2025 and 2050, as well as the sea level datum. (these numbers may have been adjusted as discussed in the section on Data Processing). The RCP values are in centimeters in the report and will have to be converted to the same units as your elevation data.

h. Click 'OK'

You should now have a layer of polylines representing the contour values you specified.
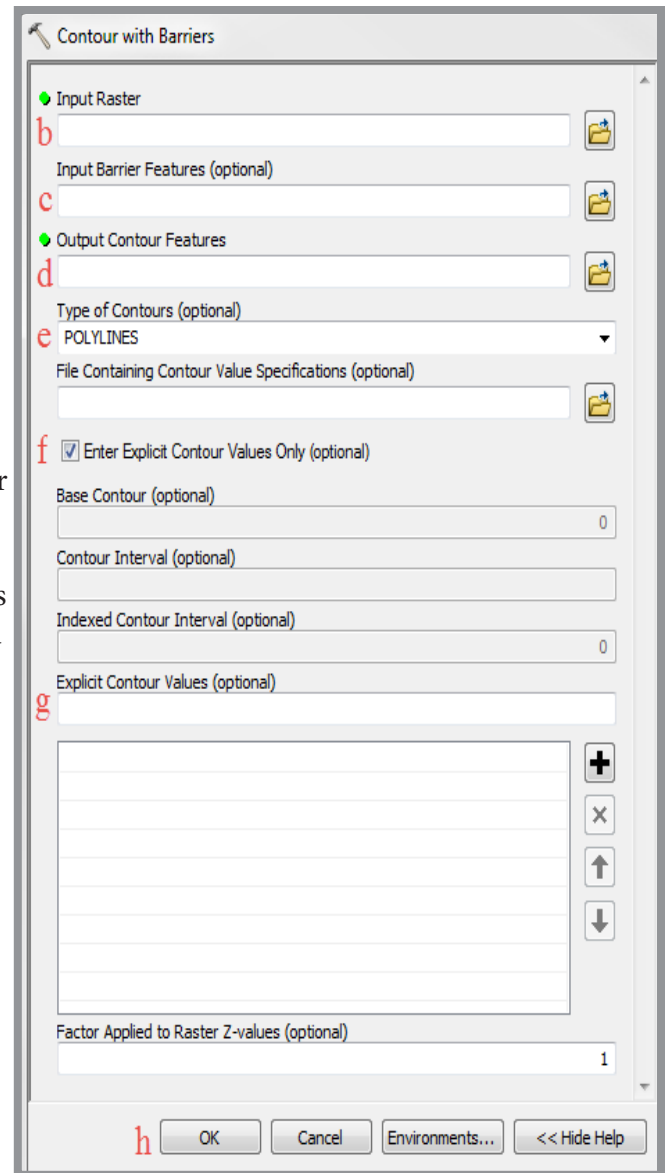
The green lines in the image below are the contour lines and the purple box is the extent of the study area. The base image is the elevation layer.
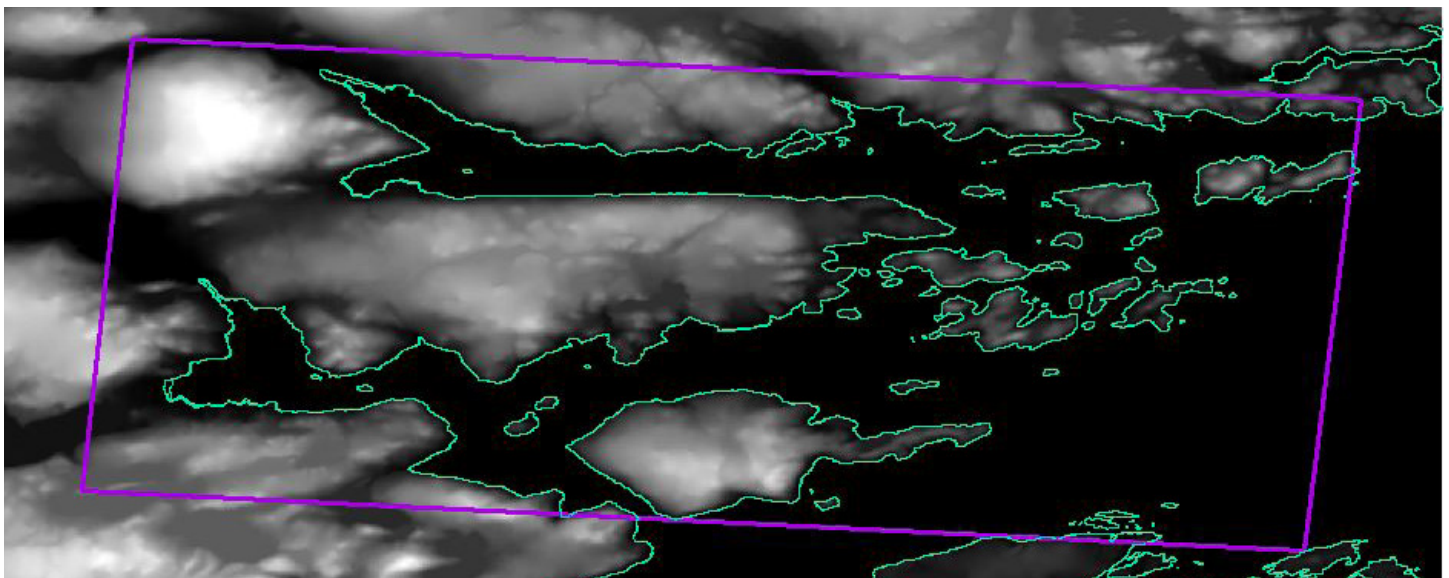
When the contour lines within the study area are selected (highlighted in blue), it is apparent that there is a break in the line at the edge of the study area. Select one of your contour lines to make sure that it has been contained to your study area.
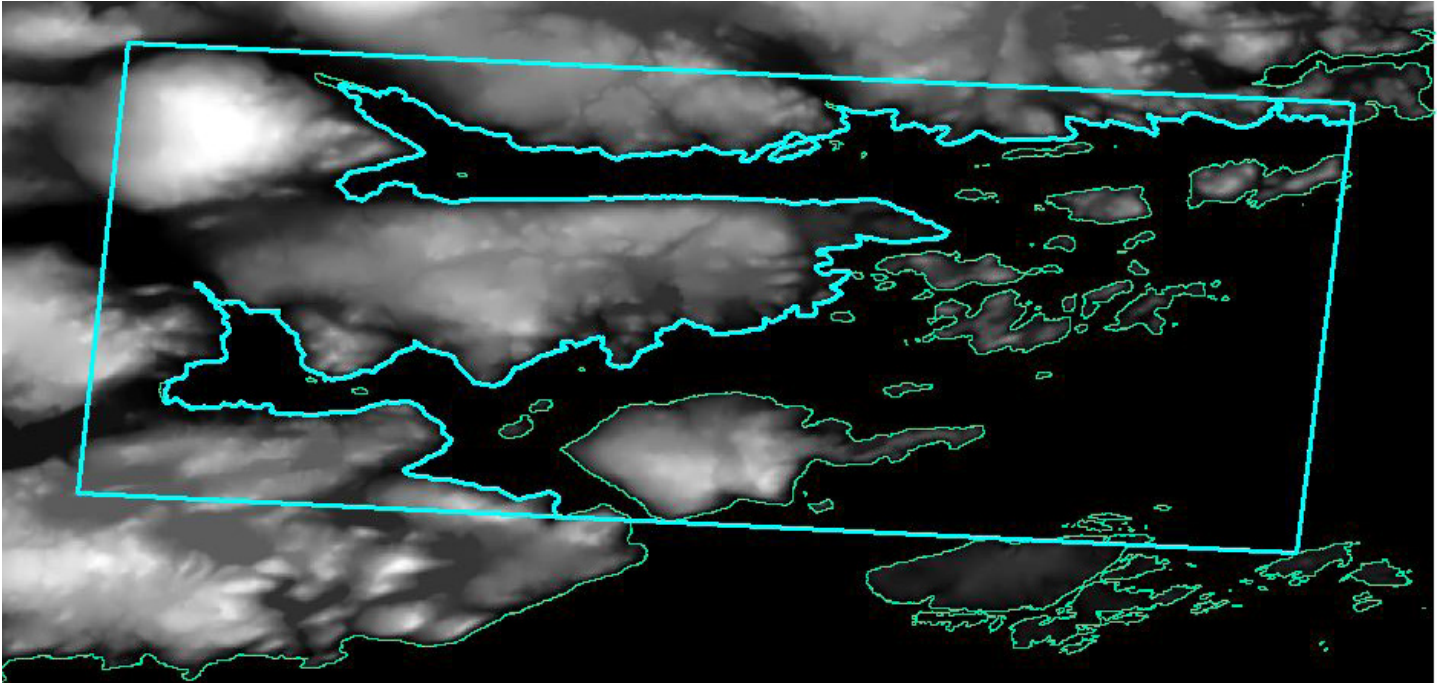
Since the distance between contour lines will likely be quite small, the contour lines may appear to be one line when the image is zoomed out. Zoom in to see that there are actually three lines, like in the image below.
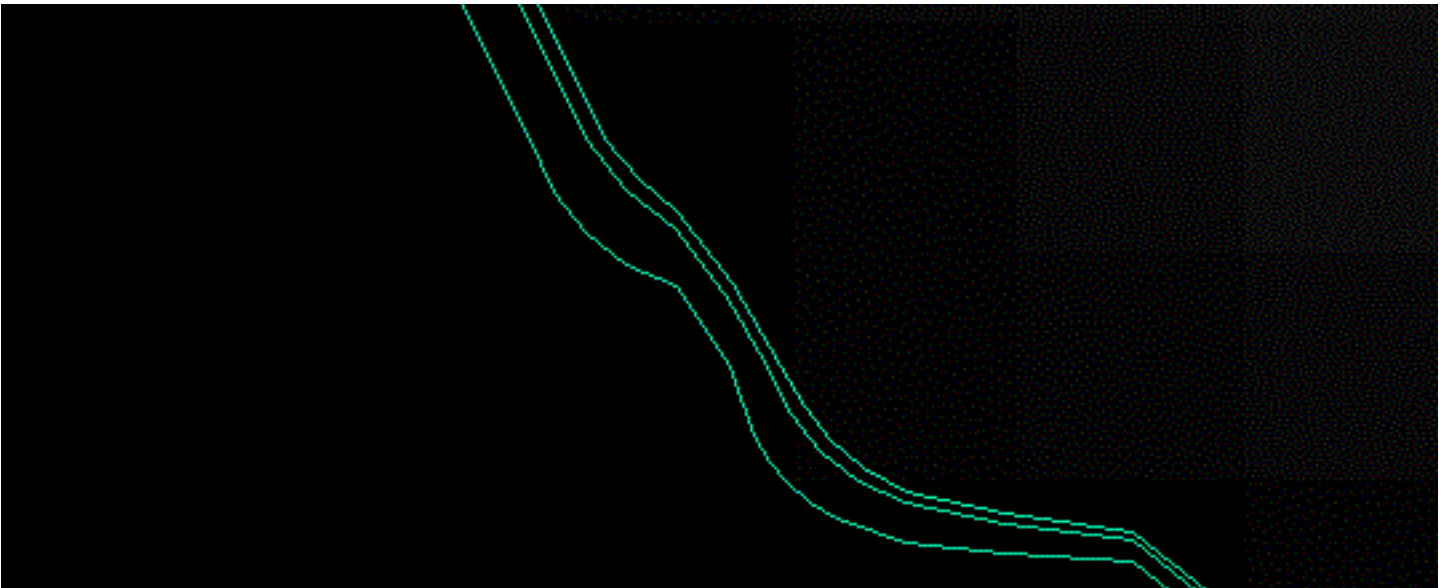
3. To contain the polylines to your study area use the selection tool to select the polylines within your study area then right click on the polyline layer in your Table of Contents and Select 'Data'→ 'Export Data' to save a new layer with only your selected features.

4. The polylines created in step 3 that extend to the boundary of your study area may not actually touch the boundaries of your study area. In order to create closed polygons in future steps you must inspect your polylines and edit them so that they intersect with the edge of your study area polygon.

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a. Zoom in to examine each polyline that extends to the boundary of the study area. The polyline in the image below does not touch the boundary of the study area and needs to be extended.
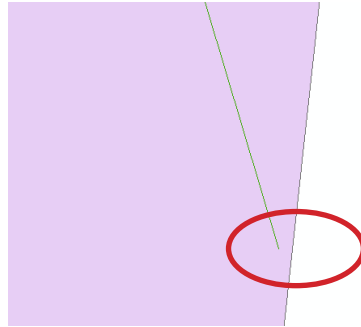
b. Use the 'Editor' toolbar to extend each border polyline past the extent of the study area.
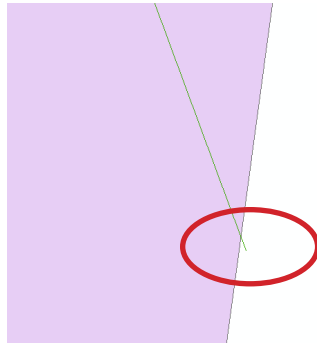
5. Create a new attribute field for 'SCENARIO' for the layer just created in Step 3. This will enable you to identify each of your sea level change scenarios throughout the analysis.

a. Right click on your new layer in 'Table of Contents' sidebar

b. Select 'Open Attribute Table'

c. Click dropdown arrow for Table Options in the top left corner of the attribute table and select 'Add Field … '
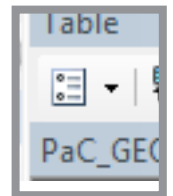
d. Name your field 'SCENARIO', select 'Text' from type dropdown menu, click 'OK'

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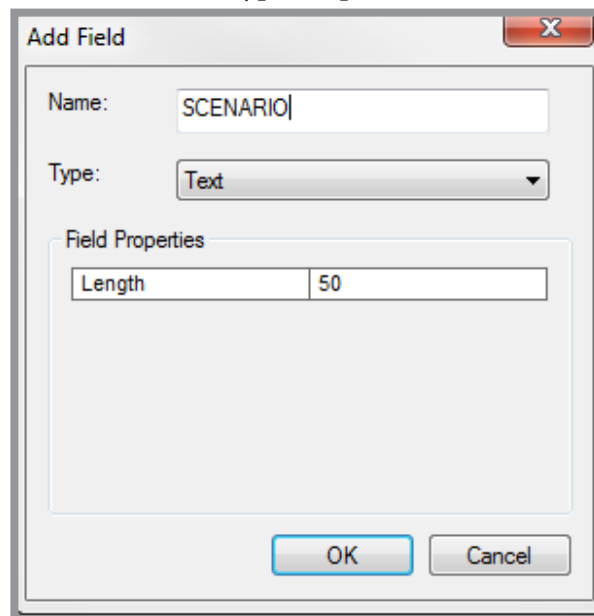
e. Click on 'Editor' toolbar and select 'Start Editing' to add text to the 'SCENARIO' field (if you do not see the 'Editor' toolbar you can add it by clicking on 'Customize' → 'Toolbars' → 'Editor' to add it to your toolbars)

f. Enter a scenario name/description for each data row. Each data row represents one contour line. You will need to name the lines representing your datum with the datum you are using (e.g. MWL if your datum is the Mean Water Level or HHWLT if your datum is Highest High Water Large Tide) and the lines that represent each sea level change scenario (e.g. RCP4.5 and RCP8.5). Refer to code list in the Appendix C for an example naming format. Depending on the size of your study area and how many scenarios you choose to look at this could take some time.

g. Click on 'Editor' toolbar and select 'Stop Editing'

Your polylines should now all have an attribute for the scenario they represent

6. Create polygons for each scenario being modeled

a. Use 'Select By Attributes' in the 'Selection' toolbar to select all contours for the scenario
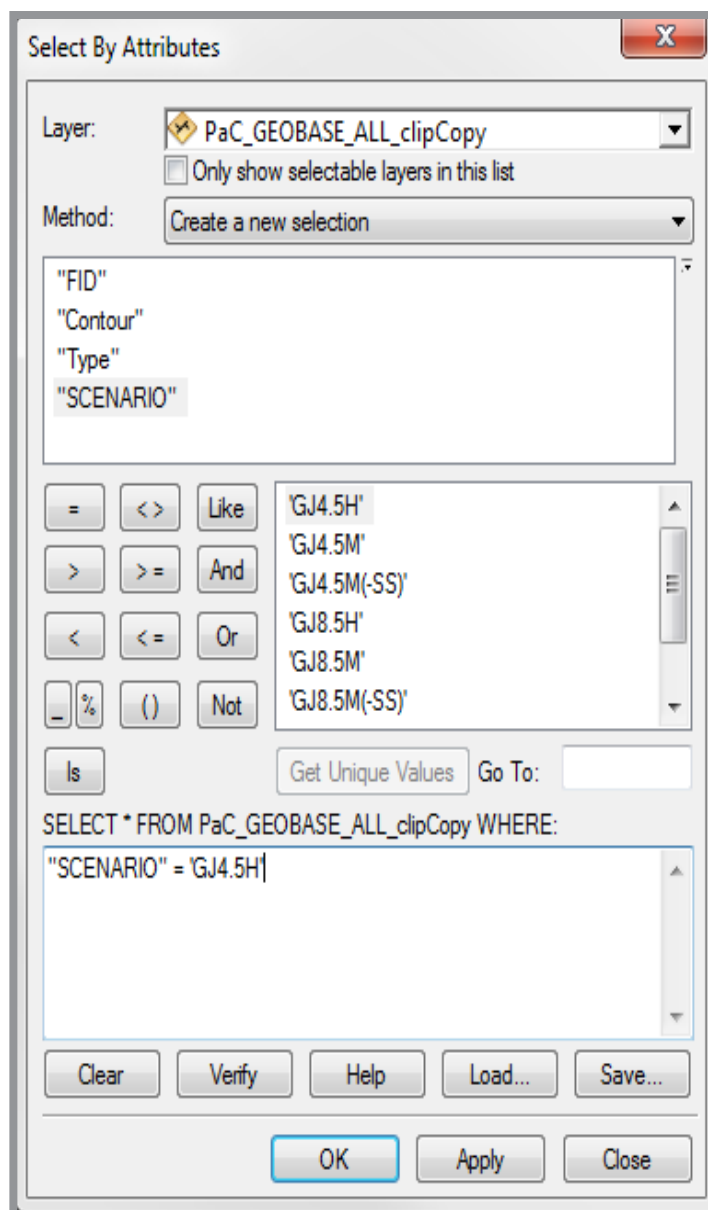
b. Save the selection as a new layer (right click on layer → 'Data' → 'Export Data')

c. Open ArcToolbox and select 'Data Management Tools' → 'Features' → 'Feature To Polygon'
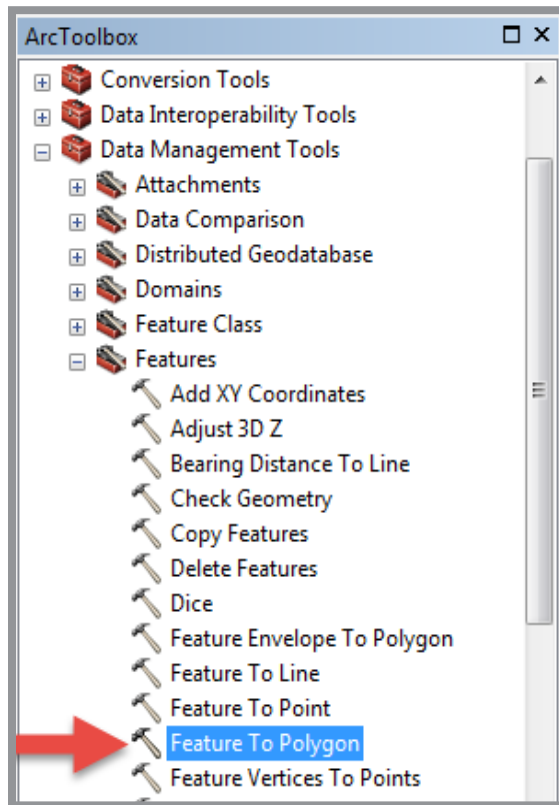
d. 'Input Features' – Select contour layer from step b and your study area

e. 'Output Feature Class' – Save with appropriate name and location

f. 'Preserve Attributes' – Tick box if not already ticked

g. Click 'OK'

h. Repeat steps for each scenario being modeled
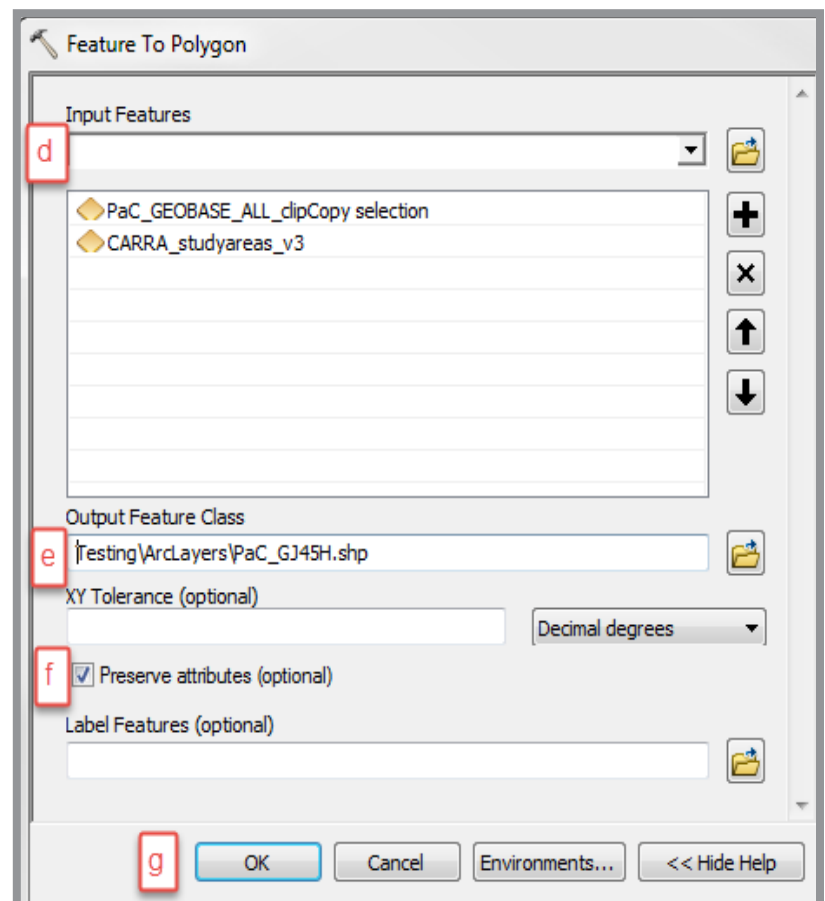
Part 2: Create Classified Polygon Contour Shapefiles

This step will classify the polygons created in the previous step according to the sea level change risk level to the area contained within the polygon.

The classifications will be 'HIGH+' for polygons that represent currently submerged areas, 'HIGH' for areas at or below the level of the 2025 estimate, 'MOD' for areas above the 2025 estimate and at or below the RCP 2050 and 'LOW' for areas above the level of the 2050 estimate. These classifications will have to be adjusted to suit your data if you use numbers other than those from the James et al. (2014) report.

1. a. Add your newly created polygon shapefile to a new project in ArcMAP

b. Open attribute table and create a new text field named 'CLASS' (follow the steps in Part 1, Step 3)

c. In editing mode, select the polygon that represents area seaward of the contours describing sea-level datum. This polygon will generally be atop open ocean and (should the area of each polygon be calculated - which is recommended) be the largest polygon within the dataset

d. In selected field enter 'HIGH+'. The addition of the + , or similar symbol, is useful to differentiate between archaeological resources located on land and those offshore

2. Use 'Select by Location' tool to select polygons for each class

HIGH

a. With polygon 'HIGH+' selected, click on 'Selection' menu → 'Select By Location …'

b. 'Selection Method' – choose 'select features from' from dropdown menu

c. 'Target Layers' – select your polygon contour layer

d. 'Source Layer' – select your polygon contour layer

e. Tick 'Use selected features' box

f. 'Spatial Selection Method' – select 'share line segment with source layer' from dropdown menu

g. Click 'OK' to run selection

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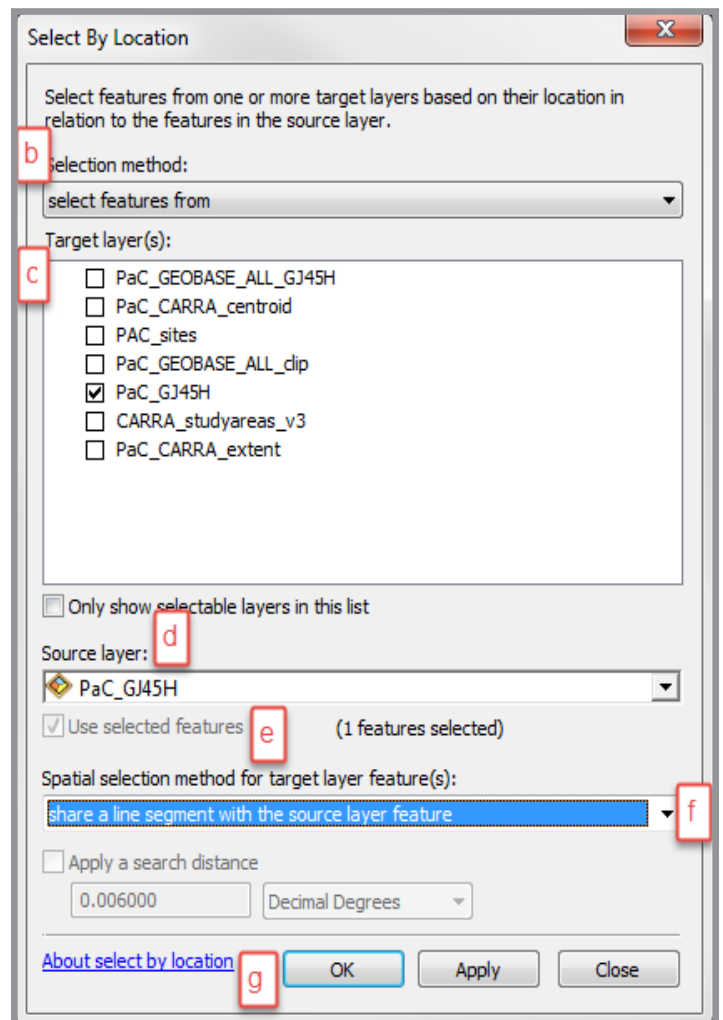
h. Open attribute table

i. Sort by selection

j. Remove 'HIGH+' data from selection set – right-click then unselect highlighted

k. Use field calculator to enter 'HIGH' into 'CLASS' field (Right click top of 'CLASS' column – select 'Field Calculator' – type in 'HIGH' – click OK) or enter manually in editing mode

MOD
With 'HIGH' polygons still selected, edit parameters of the 'Select By Location' tool

a. 'Selection Method' – choose 'select features from' from dropdown menu

b. 'Target Layers' – select your polygon contour layer

c. 'Source Layer' – select your polygon contour layer

d. Tick 'Use selected features' box

e. 'Spatial Selection Method' – select 'share line segment with source layer' from dropdown menu

f. Click 'OK' to run selection

g. Open attribute table

h. Sort by selection

i. Remove 'HIGH+' and 'HIGH' data from selection set – right-click then unselect highlighted

j. Use field calculator to enter 'MOD' into 'CLASS' field (Right click top of 'CLASS' column – select Field Calculator – type in 'MOD' – click OK) or enter manually in editing mode

LOW
With 'MOD' polygons still selected, edit parameters of the 'Select By Location' tool

a. 'Selection Method' – choose 'select features from' from dropdown menu

b. 'Target Layers' – select your polygon contour layer

c. 'Source Layer' – select your polygon contour layer

d. Tick 'Use selected features' box

e. 'Spatial Selection Method' – select 'share line segment with source layer' from dropdown menu

f. Click 'OK' to run selection

g. Open attribute table

h. Sort by selection

i. Remove 'HIGH+' and 'HIGH' and 'MOD' data from selection set – right-click then unselect highlighted

j. Use field calculator to enter 'LOW' into 'CLASS' field (Right click top of 'CLASS' column – select Field Calculator – type in 'LOW – click OK) or enter manually in editing mode

3. Inspect to ensure all polygons have been correctly classified. Correct manually if necessary.

4. Save classified polygon shapefile and backup data

All of your polygons should now be classified according to the scenario that they represent and are now ready to use for the classification of your archaeological sites.

Part 3a: Classify Archaeological Resources - Polygons

Use this method if your archaeological features are polygons.

1. Set up layers in a new instance of ArcMAP

a. Add classified polygon shapefile from step 3

b. Add archaeological site locations (polygons)

c. Open the attribute table for each layer and create new text fields for each flood extent scenario being modeled

2. Classify LOW risk features

a. With the 'LOW' polygons selected in the classified polygon shapefile, click on the 'Selection' menu and open 'Select By Location' tool

b. Click on selection method dropdown menu and choose 'select features from'

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' box

f. Click on spatial selection dropdown menu and select 'are completely within the source layer feature'

g. Click 'OK'

h. Open attribute table of archaeology polygon layer, sort by selection and use field calculator to enter 'LOW' into appropriate classification field (or enter manually in editing mode)

3. Classify MOD risk features

a. With the 'MOD' polygons selected in the classified polygon shapefile, click on the 'Selection' menu and open 'Select By Location' tool

b. Click on selection method dropdown menu and choose 'select features from'

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' Box

f. Click on spatial selection dropdown menu and select 'intersect the source layer feature'

Spatial selection method for target layer feature(s):

intersect (3d) the source layer feature

g. Click 'OK'

h. Open the attribute table of the archaeology polygon layer, sort by selection and use field calculator to enter 'MOD' into appropriate classification field (or enter manually in editing mode). Overwrite any polygons previously classified as 'LOW'

4. Classify HIGH and HIGH+ risk features

a. With the 'HIGH+' and 'HIGH' polygons selected in the classified polygon shapefile, click on the 'Selection' menu and open 'Select By Location' tool

b. Click on selection method dropdown menu and choose 'select features from'

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' box

f. Click on 'spatial selection' dropdown menu and select 'intersect the source layer feature'

g. Click 'OK'

h. Open the attribute table of the archaeology polygon layer, sort by selection and use the field calculator to enter 'HIGH' into appropriate classification field (or enter manually in editing mode). Overwrite any polygons previously classified as 'MOD'

5. Inspect archaeology polygons to ensure all have been correctly classified.

6. Save and repeat the process for each scenario being modeled.

Part 3b: Classify Archaeological Resources - Points

Use this method if your archaeological features are formatted as points.

1. Set up layers in a new instance of ArcMAP

a. Add classified polygon shapefile from step 3

b. Add archaeological site locations (points)

c. Open the attribute table for each layer and create new 'text' fields for each flood extent scenario being modeled

2. Classify LOW risk features

a. With the LOW polygons selected in the classified polygon shapefile, click on the 'Selection' menu and open 'Select By Location' tool

b. Click on selection method dropdown menu and choose 'select features from'

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' box

f. Click on spatial selection dropdown menu and select 'intersect the source layer feature'

g. Click 'OK'

h. Open attribute table of archaeology polygon layer, sort by selection and use field calculator to enter 'LOW' into appropriate classification field (or enter manually in editing mode)

3. Classify MOD risk features

a. With the MOD polygons selected in the classified polygon shapefile, click on the 'Selection' menu and open 'Select By Location' tool

b. Click on selection method dropdown menu and choose 'select features from'

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' box

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f. Click on spatial selection dropdown menu and select 'intersect the source layer feature'

g. Click 'OK'

h. Open attribute table of archaeology polygon layer, sort by selection and use field calculator to enter 'MOD' into appropriate classification field (or enter manually in editing mode). Overwrite any polygons previously classified as 'LOW'
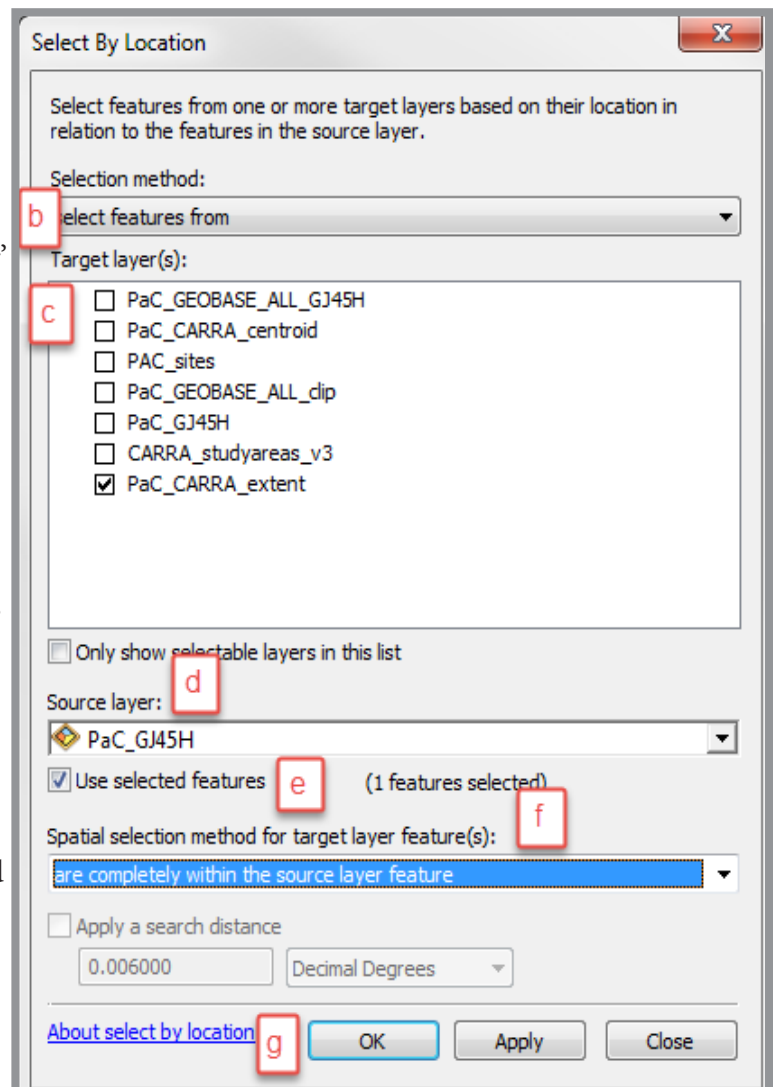
4. Classify HIGH+ and HIGH risk features

a. With the 'HIGH+' and 'HIGH' polygons selected in the classified polygon shapefile, click on the Selection menu and open Select By Location tool

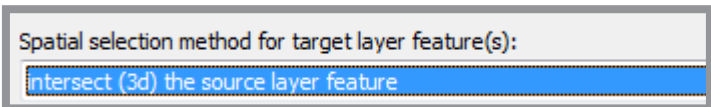b. Click on selection method dropdown menu and choose select features from

c. Select your archaeological site locations as the 'Target layer'

d. Select the classified polygons as your 'Source layer'

e. Tick 'Use selected features' box

f. Click on spatial selection dropdown menu and select 'intersect the source layer feature'

g. Click 'OK'

h. Open attribute table of archaeology polygon layer, sort by selection and use field calculator to enter 'HIGH' into appropriate classification field (or enter manually in editing mode). Overwrite any polygons previously classified as 'MOD'

5. Inspect archaeology points to ensure all have been correctly classified.

6. Save and repeat the process for each scenario being modeled.

After the sites are classified, they can be identified in the attribute table or on a map. One way this may be done is by colour coding the sites according to their risk level.

References

James, T.S., Henton, J.A., Leonard, L.J., Darlington, A., Forbes, D.L., and Craymer, M., 2014. Relative Sea-level Projections in Canada and the Adjacent Mainland United States; Geological Survey of Canada, Open File 7737, 72 p. doi: 10.4095/295574

Robin, C., Nudds, S., MacAuley, P., Godin, A., de Lange Boom, B., Bartlett, J., Maltais, L., Herron, T., Fadaie, K. Craymer, M., Véronneau, M., and Hains, D., 2015. HyVSEPs: Hydrographic vertical separation surfaces for Canadian waters; U.S. Hydro 2015; National Harbor, Maryland; US; March 16-19, 2015, p. 1-10.

Definitions and Frequently Asked Questions

Accuracy
How close the data are to their actual value, e.g. are your sites located where your data say they are.

Contour lines
Lines on a map joining points of equal elevation. Elevation is usually height above mean sea level.

Datum
A reference system against which positional measurements are made.

Projection
A method for representing the three dimensional, curved surface of the earth on a two dimensional planar surface. Please see an introductory mapping or GIS textbook or ArcGIS help if you are unfamiliar with this concept.

Raster Data Sets
Raster data consist of continuous grids where each square on the grid represents a data value. For example, an elevation dataset will contain an elevation value for each square of the raster. The area represented in each cell is the resolution of the dataset.

9	10	8
9	9	7
7	8	6

Resolution
Spatial data resolution is the smallest discernible difference between adjacent positions. Raster resolution relates to the area that is represented by each cell. A raster where each cell represents 1 m x 1m on the ground would rave a resolution of 1 m while a cell that represents an area of 25 m x 25 m would have a resolution of 25 m.

Vector Data Sets
Vector data sets are made up of discreet points, lines, or polygons. These files consist of coordinates and instructions that tell ArcGIS where and how to draw the features. You can only have one type of feature in each layer, i.e. points must be in one layer, lines must be in another separate layer, and polygons must be in an additional layer.

Appendix A. Potential Elevation Data Sources

Canada

Name and Description	Scale	Cost	File formats	Link (if available)
Geogratis - Canadian Digital Elevation Model Mosaic (CDEM) - Raster data Released by Natural Resources Canada	Varies	Free	GeoTIFF	http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/C40ACFBA-C722-4BE1-862E-146B80BE738E.html
Geogratis - Canadian Digital Elevation Data (CDED) - Legacy product which is still available but has been replaced by CDEM	1:50 000	Free		http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/3A537B2D-7058-FCED-8D0B-76452EC9D01F.html
CanVec+ - Vector data released by Natural Resources canada	1:10,000 - 1:50,000	Free	GML/SHP/FGDB	http://geogratis.gc.ca/site/eng/whats-new/intro-canvec and http://geogratis.gc.ca/site/eng/whats-new/intro-canvec

Newfoundland and Labrador

Name and Description	Scale	Cost	File formats	Link (if available)
Orthometric	1:10,000	$25-$100	SHP/DXF	
Community mapping	1:5,000	$20	CARIS/DXF/SHP	http://miga.gov.nl.ca/lands/maps/topographic.html
Community mapping	1:2,500	$20	CARIS/DXF/SHP	http://miga.gov.nl.ca/lands/maps/topographic.html
LiDAR: By commission	Varies (high resolution)	$1000s	LAS/ACSI	
LiDAR: Department of Environment and Conservation		?	LAS/ACSI	
LiDAR: Private businesses/educational institutes - If interested in the same area, these organizations may be available for partnerships		?	LAS/ACSI	

Appendix B. Analysis Flowcharts

Step 1. Create polyline and polygon contour shapefiles

1.

RASTER

STUDY AREA (polygon)

3D Analyst > Raster Surface > Contour with Barriers

- Input Raster
  - input raster
- Input Barrier Features (optional)
  - input study area polygon
- Output Contour Features
  - save with appropriate name/location
- Type of Contours (optional)
  - POLYLINES
- File Containing Contour Value Specifications (optional)
- Enter Explicit Contour Values Only (optional) — Ensure this box is ticked
- Base Contour (optional)
- Contour Interval (optional) — 0
- Indexed Contour Interval (optional) — 0
- Explicit Contour Values (optional)
  - 0
  - 1.108
  - 0.516
  - 4.087
  - 0.959
  - 5.046
  - 3.067
- Factor Applied to Raster Z-values (optional) — 1

Enter all contour elevation values for all flood extent scenarios

2.

Open attribute table and create new TEXT field: 'SCENARIO'

Enter relevant scenario name/description for each data row. This may be the most time consuming phase of the process.

(Refer to accompanying code list for naming recommendations)

PaC_GEOBASE_ALL_clip

FID	Shape	Contour	Type	SCENARIO
0	Polyline ZM	0	3	MWH
1	Polyline ZM	0.108	3	GJ4.5M(-SS)
2	Polyline ZM	0.108	3	GJ4.5M(-SS)
3	Polyline ZM	0.516	3	GJ4.5M(-SS)
4	Polyline ZM	0.516	3	GJ4.5H
5	Polyline ZM	5.046	3	GJ4.5H
6	Polyline ZM	3.067	3	GJ4.5H
7	Polyline ZM	0.108	3	GJ4.5M(-SS)
8	Polyline ZM	0.108	3	GJ4.5M(-SS)
9	Polyline ZM	4.087	3	GJ0.5M
10	Polyline ZM	0.108	3	GJ4.5M(-SS)
11	Polyline ZM	0	3	MWH
12	Polyline ZM	4.475	3	GJ4.5H
13	Polyline ZM	5.046	3	GJ4.5H
14	Polyline ZM	0.196	3	GJ0.5M(-SS)
15	Polyline ZM	0.516	3	GJ4.5M(-SS)
16	Polyline ZM	0	3	MWH
17	Polyline ZM	0	3	MWH
18	Polyline ZM	4.475	3	GJ4.5H
19	Polyline ZM	2.196	3	GJ0.5M
20	Polyline ZM	0.196	3	GJ0.5M(-SS)
21	Polyline ZM	0.516	3	GJ4.5M(-SS)
22	Polyline ZM	0.959	3	HHWLT
23	Polyline ZM	0.959	3	HHWLT
24	Polyline ZM	0.108	3	GJ4.5M(-SS)
25	Polyline ZM	0.959	3	HHWLT

(0 out of 51 Selected)

Hint:

Inspect contours to ensure there are no discrete breaks in polylines which would interfere with creation of polygons.

If breaks are present, repair polyline segments with appropriate editing tools, e.g Continue Feature tool

3.

Data Management > Features > Feature To Polygon

Input Features
- PaC_GJ45H_export.shp
- Study_area.shp

Output Feature Class
- PaC_GJ45H.shp

XY Tolerance (optional) — Meters

☑ Preserve attributes (optional)

Label Features (optional)

Select by Attributes

Select all contours describing a single flood extent scenario & relevant sea-level datum e.g. "SCENARIO" = 'GJ4.5H' OR "SCENARIO" = 'HHWLT'

Save (not export) selection as new (temporary) layer and name appropriately

STUDY AREA (polygon)

REPEAT THESE STEP 3 FOR EACH SCENARIO BEING MODELLED

Hint:

Inspect attribute table to ensure all polygons have been created, i.e. study area is fully described with polygons

If polygon creation has failed:
1) double check selection parameters
2) re-check contour polylines and inspect for discrete breaks. Repeat STEP 3 as necessary

Step 2. Create classified polygon contour shapefiles

1.

Newly-created polygon contour shapefile
e.g. PaC_GI45H.shp

Open attribute table and create new TEXT field: 'CLASS'

In editing mode, select polygon that represents area seaward of contours describing sea-level datum. This polygon will generally be atop open ocean and (should the area of each polygon be calculated - which is recommended) be the largest polygon within the dataset.

In selected field enter 'HIGH+'. The addition of the '+', or similar symbol, is important for further automated classification and is useful to differentiate between archaeological resources located on land and those offshore

2.

Select by Location

With polygon 'HIGH+' selected, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = polygon shp, e.g. PaC_GI45H.shp

SOURCE LAYER = same as above

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'Share line segment with source layer'

- **RUN tool** -

In attribute table, sort by selection & remove 'HIGH+' data from selection set (right-click > Unselect Highlighted). Use field calculator to enter 'HIGH' into 'SCENARIO' field or enter manually in editing mode.

Select by Location

With polygons 'HIGH' still selected, edit parameters of open Select by Location tool.

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = polygon shp, e.g. PaC_GI45H.shp

SOURCE LAYER = same as above

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'Share line segment with source layer'

- **RUN tool** -

In attribute table, sort by selection & remove 'HIGH+' AND 'HIGH' data from selection set. Use field calculator to enter 'MOD' into 'SCENARIO' field or enter manually in editing mode.

Select by Location

With polygons 'MOD' still selected, edit parameters of open Select by Location tool.

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = polygon shp, e.g. PaC_GI45H.shp

SOURCE LAYER = same as above

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'Share line segment with source layer'

- **RUN tool** -

In attribute table, sort by selection & remove 'HIGH+' AND 'HIGH' AND 'MOD' data from selection set. Use field calculator to enter 'LOW' into 'SCENARIO' field or enter manually in editing mode.

Inspect to ensure all polygons have been correctly classified. If a few polygons have been mis-tagged, correct manually

If all polygons are correctly classified, categorise Each class within the symbology menu of the shapefile

Save classified polygon shapefile and backup data

Hint:

The selection process for 'LOW' classified polygons may be skipped. Once "HIGH+' and 'HIGH' and 'MOD' polygons have been classified, only those to be classified as 'LOW' should remain.

Step 3a. Classify archaeological resources - polygons

1.

Classified polygon shapefile (from Step 3) e.g. PaC_GJ45H.shp

Archaeological site locations (polygons) e.g. PaC_CARRA_extent.shp

Open attribute table and create new TEXT fields for each flood extent scenario being modelled. e.g GJ45H, GJ85H, etc..

Open attribute table and create new TEXT fields for each flood extent scenario being modelled. e.g GJ45H, GJ85H, etc..

2.

Select by Location

With polygons **'LOW'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology polygon shp, e.g. PaC_CARRA_extent.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GJ45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'are completely within the source layer feature'

- **RUN tool** -

In attribute table of archaeology polygon shapefile, sort by selection & use field calculator to enter **'LOW'** into relevant classification field or enter manually in editing mode.

3.

Select by Location

With polygons **'MOD'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology polygon shp, e.g. PaC_CARRA_extent.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GJ45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'intersect the source layer feature'

- **RUN tool** -

In attribute table of archaeology polygon shapefile, sort by selection & use field calculator to enter **'MOD'** into relevant classification field or enter manually in editing mode. Overwrite any polygons previously classified as **'LOW'**.

4.

Select by Location

With polygons **'HIGH+'** and **'HIGH'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology polygon shp, e.g. PaC_CARRA_extent.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GJ45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'intersect the source layer feature'

- **RUN tool** -

In attribute table of archaeology polygon shapefile, sort by selection & use field calculator to enter **'HIGH'** into relevant classification field or enter manually in editing mode. Overwrite any polygons previously classified as **'MOD'**.

Inspect archaeology polygons to ensure all have been correctly classified. Save and repeat process for each scenario being modelled.

Step 3b. Classify archaeological resources - points

1.

Classified polygon shapefile (from Step 3) e.g. PaC_GI45H.shp

Archaeological site locations (points) e.g. PaC_CARRA_centroid.shp

Open attribute table and create new TEXT fields for each flood extent scenario being modelled. e.g GI45H, GI85H, etc..

Open attribute table and create new TEXT fields for each flood extent scenario being modelled. e.g GI45H, GI85H, etc..

2.

Select by Location

With polygons **'LOW'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology points shp, e.g. PaC_CARRA_centroid.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GI45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'intersect the source layer feature'

- **RUN tool** -

In attribute table of archaeology points shapefile, sort by selection & use field calculator to enter **'LOW'** into relevant classification field or enter manually in editing mode.

3.

Select by Location

With polygons **'MOD'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology points shp, e.g. PaC_CARRA_centroid.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GI45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'intersect the source layer feature'

- **RUN tool** -

In attribute table of archaeology point shapefile, sort by selection & use field calculator to enter **'MOD'** into relevant classification field or enter manually in editing mode.

4.

Select by Location

With polygons **'HIGH+'** and **'HIGH'** selected in classified polygon shapefile, open Select by Location tool (Selection menu).

SELECTION METHOD = 'select features from'

TARGET LAYER(s) = archaeology points shp, e.g. PaC_CARRA_centroid.shp

SOURCE LAYER = classified polygon shp, e.g. PaC_GI45H.shp

- **TICK 'USE SELECTED FEATURES' BOX** -

SPATIAL SELECTION METHOD = 'intersect the source layer feature'

- **RUN tool** -

In attribute table of archaeology point shapefile, sort by selection & use field calculator to enter **'HIGH'** into relevant classification field or enter manually in editing mode.

Inspect archaeology point data to ensure all have been correctly classified. Save and repeat process for each scenario being modelled.

Appendix C. Suggested Scenario Code Formatting

TOPOGRAPHIC DATA

Geobase	Canvec / Canvec+	Orthometric Elevation Data	Community Mapping	Airborne Laser Survey (ALS)
G _ _	**C _ _**	**O _ _**	**M _ _**	**A _ _**

SEA LEVEL MODEL / SCENARIO

James at al. (2014) RCP **4.5**	James at al. (2014) RCP **8.5**
_ J 4.5 _	**_ J 8.5 _**

SEA LEVEL DATUM

Geodetic Datum - **M**ean Water Level (MWL)	**H**ighest High Water, Largest Tide (HHWLT)	Surveyed **S**eaweed limit
_ _ M	**_ _ H**	**_ _ S**

To track your scenarios throughout your analysis standardized naming should be used. The table above provides an example of the type of codes that may be used.

For example, GJ4.5M indicates that elevation data were taken from Geobase, RCP 4.5 from the James et al. (2014) report is being used, and the sea level datum is mean water level.

If you are on using one datum and one set of elevation data these variables do not need to be used in your codes.