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Guide to Projected Shoreline Positions in the Alaska Shoreline Change Tool

by

Alexander I. Gould, Nicole E.M. Kinsman, and Michael D. Hendricks



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STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
Division of Geological & Geophysical Surveys
3354 College Rd. ♦ Fairbanks, Alaska 99709-3707 ♦ 907-451-5010
dggs.alaska.gov; dggspubs@alaska.gov



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GUIDE TO PROJECTED SHORELINE POSITIONS IN THE ALASKA SHORELINE CHANGE TOOL

by

Alexander I. Gould¹, Nicole E.M. Kinsman², and Michael D. Hendricks²

This is a companion document designed to accompany the online, interactive DGGS shoreline change mapping tool (<http://dx.doi.org/10.14509/shoreline>). This reference is intended to help people from a range of backgrounds understand how a shoreline position is defined, how a rate of shoreline change is affected by the availability of data and type of calculation that is used, and how rates of change are presented in the DGGS map tool. The provided text defines terms, explains some of the uses and limitations of projected shoreline positions in Alaska, and makes recommendations for improving calculations of this type in the future.

INTRODUCTION

Coastlines are dynamic features that change shape and position on a range of timescales. As a result of this variability, many coastal communities in Alaska must carefully consider patterns of coastal erosion and/or accretion to appropriately plan for the future. Until now, a lack of available information and resources related to shoreline positional data has created challenges in assessing and planning for coastal hazards such as erosion. To address this identified data need, the Alaska Division of Geological & Geophysical Surveys (DGGS) has created the Alaska Shoreline Change Tool (<http://dx.doi.org/10.14509/shoreline>), an interactive map that displays historical and projected shoreline positions. This new tool will improve hazard assessments and aid in local management decisions.

The Alaska Shoreline Change Tool contains the best available information for shoreline change analysis in Alaska. These data come from many sources and include contributions from shoreline mapping projects conducted by numerous investigators. The variability in sources of these data, the limitations of historical records in Alaska, and the numerous options available for data analysis makes it critical for users of this information to have a sound understanding of how shoreline change assessments differ and how to assess the reliability of a projected shoreline position in their area of interest.

This guide will present users with an overview of:

1. Definitions for types of shorelines
2. Types of shoreline change calculations
3. Projected shoreline uncertainties
4. Considerations for coastal planning

TYPES OF SHORELINES

The shoreline is broadly defined as the interface between land and water; however, many approaches have been developed to define this linear feature as a physical position in space (for example, see the methods summarized by Moore [2000] and Boak and Turner [2005]). To evaluate how the position of the shoreline is changing, coastal investigators must define the position of the shoreline in a reliable and consistent way that is appropriate to the coastal setting.

¹ Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, Alaska 99709-3707; alexander.gould@alaska.gov

² Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, Alaska 99709-3707

The two most common ways to delineate a shoreline position are: (1) find the mathematical intersection of a water level with the land surface or (2) visually interpret a representative feature that can serve as a proxy shoreline indicator.

The mathematical intersection approach results in a “datum-derived” shoreline position, which is highly reproducible and is the preferred method of obtaining a shoreline position for navigational or regulatory purposes (fig. 1; Stockdon and others, 2002). Commonly used datum-derived shoreline positions are Mean High Water (MHW), Mean Lower Low Water (MLLW), and Highest Astronomical Tide (HAT), which are locally measured, standard elevations defined by a certain phase of the tide averaged over the National Tidal Datum Epoch (for comprehensive definitions of tidal datums, refer to the NOAA Tidal Datums website). This approach relies on a detailed map of the coastal geometry and long-term measurement of relevant local water levels. For much of Alaska, these types of information are lacking or inadequate, making datum-derived shoreline mapping of limited use for shoreline change studies.

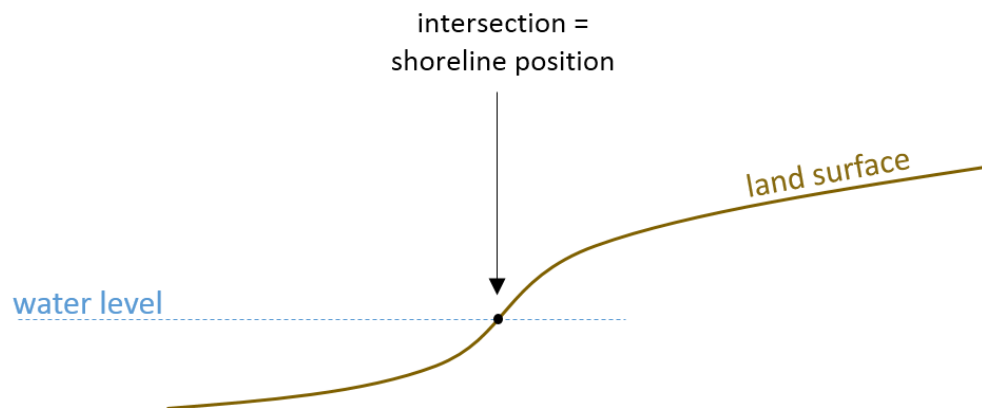


Figure 1. Illustration of a shoreline position that is mathematically defined at the intersection of some known water level with the land surface.

Visually discernible physical features in the field or in aerial/oblique imagery that represent various types of shoreline positions are commonly used by coastal investigators as proxies for the shoreline (Moore, 2000; Boak and Turner, 2005). These features, or shoreline indicators, range from landscape features such as a bluff top or the extent of stable vegetation, to ephemeral markers such as a wet/dry transition in the sand left behind from the previous high tide (fig. 2). Estimates of shoreline change can be generated by comparing these positions at different points in time and applying our knowledge of the processes involved in shoreline change.

Each shoreline indicator has unique advantages and disadvantages; factors such as the purpose, timescale, and coastal setting of the investigation are considered to determine which indicator is most appropriate to use. Some of the most commonly used shoreline indicators in Alaska are illustrated in figure 3. When assessing shoreline change for coastal management purposes, the type of coastal setting is often the determining factor for selecting an appropriate shoreline indicator. It is important to choose a feature that adapts to natural processes that alter the developable portion of a coastal area on a planning timescale. For example, along a bluffed coast where there is unidirectional retreat of the shoreline, the migration of the bluff edge is an appropriate indicator for shoreline change. In a coastal setting characterized by active sand dunes, bi-directional movement of the shoreline is common and the seaward extent of stable vegetation is a more appropriate indicator. For a project in the intertidal zone, such as the migration of an inlet used for navigation, changes in the position of the wet/dry line would be most useful for understanding critical rates and patterns.



Figure 2. Aerial image of a coastal segment near Unalakleet, Alaska. Shoreline indicators such as the wet/dry line (or high water line, in blue) and the vegetation limit (in red) are easily distinguishable.

In many circumstances the vegetation limit is a practical indicator for a variety of reasons. It is a readily identifiable feature both from the ground and from satellite and aerial imagery; it usually coincides with the bluff edge, allowing the use of a single indicator along a coast that has multiple coastal setting types; it generally marks the seasonal extreme water level along duned shorelines; and it is an excellent indicator for evaluating long-term shoreline retreat or advance because it is of greatest interest to many local planners. Caution should be exercised in using the vegetation line as a shoreline indicator around population centers, where its position can be significantly altered by human disturbances. For all downloadable historical shoreline position data included in the Alaska Shoreline Change Tool, the indicator used is given in the shoreline indicator field.

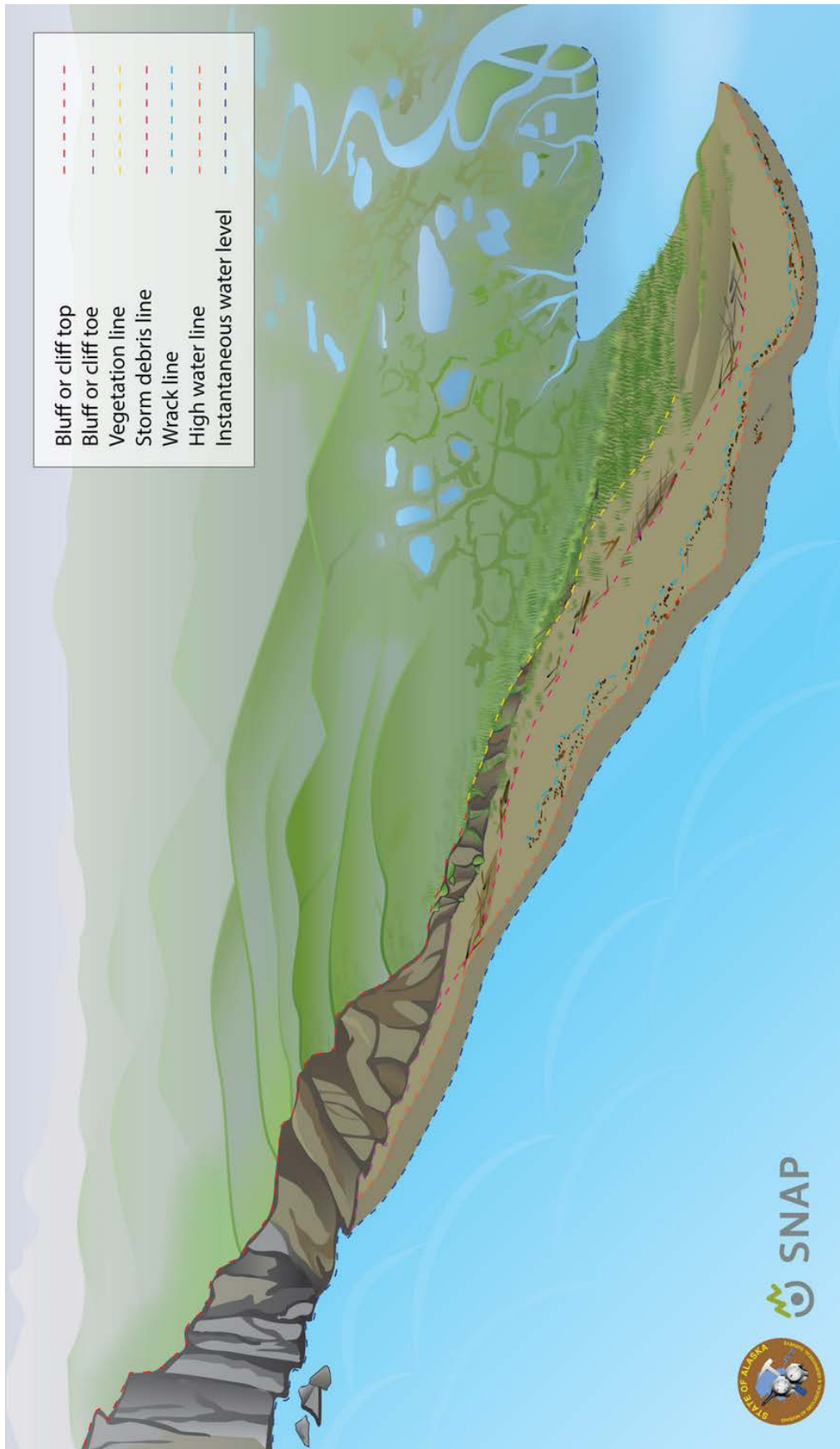


Figure 3. Representative drawing reflecting a diversity of Alaska coastal environments with common shoreline indicators illustrated by different colors of dashed line.

Table 1 Summary of definitions for the most commonly used shoreline indicators, along with the most analogous (not exact) water level or datum that corresponds to each.

Shoreline Indicator	Definition	Most analogous water level/datum
Bluff/cliff top	Convex break in slope at seaward edge of bluff or cliff	none
Bluff/cliff toe	Concave break in slope near base of bluff or cliff	none
Salt-tolerant vegetation line	Inland limit of halophytes, such as salt marsh grasses, in a low-lying environment	HAT ¹
Vegetation line	Seaward edge of stable, long-term vegetation	none
Storm debris line	High-water line from a storm as identified by residual debris, such as driftwood	TWL ²
Wrack line	Line of debris, such as seaweed, stranded on beach during a recent high tide, or other elevated water	MHHW ³ ; TWL ²
High water line	Wet/dry line from previous high tide; visible in imagery as a change in color tone on the beach and caused by differences in water content of the sediment	MHW ⁴
Instantaneous water line	Position of the land–water interface at one instant in time	Any tidal datum if tide level is known; MSL ⁵ \pm GT ⁶ /2 under low-energy sea state

¹ Highest Astronomical Tide = elevation of the highest predicted astronomical tide expected to occur

² Total Water Level = actual elevation of water during an extreme event resulting from tides, surge, setup, or runup

³ Mean Higher High Water = average of the higher high water height over a tidal epoch

⁴ Mean High Water = average of all the high water heights over a tidal epoch; for additional information on the High Water Line to MHW relationship, see Moore and others (2006).

⁵ Mean Sea Level = average hourly water level as calculated over a tidal epoch

⁶ Great Diurnal Range = difference in height between mean higher high water and mean lower low water

RATES OF SHORELINE CHANGE

Shoreline positions are highly dynamic. They may move either landward (erosion), seaward (accretion), or remain stationary (stable). These movements may occur at a steady pace, speed up, slow down, or change directions in response to changing coastal conditions (for example, winds, waves, tides, sediment supply). Informed coastal management requires an understanding of these changes. To increase their understanding of how shorelines evolve, coastal scientists calculate rates of shoreline change. A shoreline change rate quantifies how much, and in which direction, movement has occurred over a period of time. For example, if a shoreline has migrated landward 10 feet over a period of 10 years, this change may be described as erosion at a rate of 1 foot per year (1 ft/yr).

A rate of shoreline change represents an average value of how much the shoreline has moved over a given period of time. The time period may be event-specific (hours to days), seasonal (<1 year), short-term (inter-annual), or long-term (decadal; for example, 50 years), and the measurement interval has a strong influence on the calculated rate of change. While presented as a single rate of change, these average changes do not typically occur at the same rate all the time; shoreline change is generally episodic. For example, if a shoreline is stationary for 10 years and then moves landward during a single large storm, a rate of change based on the entire time period would indicate gradual retreat because the rate represents an average over that

time period. Shoreline positions may also shift with the seasons, moving back and forth between summer and winter, but returning to a similar starting position. In these cases, if the shoreline position is measured at similar times in the year, the measured rate of shoreline change would be zero even though there is seasonal variation. Coastlines that exhibit this type of trend are described as dynamically stable.

Different calculations may be used to present rates of shoreline change in a way that most accurately describes the changes based on the best available data (fig. 4). One of the most common methods used to calculate a rate of change is with an ordinary linear regression fit to all known historical shoreline positions. This widely applied statistical technique provides a general estimate of long-term shoreline change, particularly where shoreline movement is only in one direction. However, it does not incorporate the uncertainties associated with each shoreline position into the calculated rate of change. Other types of long-term rates of change, such as a weighted linear regression or least median of squares method, may employ various weighting factors that address the quality of the underlying data. These include calculations where more-accurately-measured shorelines are given greater emphasis, or where the influence of an outlier shoreline position is minimized. A weighted linear regression approach is useful when there is a high degree of uncertainty associated with some shoreline positions (perhaps they were derived from low-resolution imagery or historical data sources that are poorly georeferenced). An end-point rate of change is a very basic calculation that utilizes only two (usually the oldest and the most recent) shoreline positions. End-point calculations are typically used when there is a very limited number of shoreline positions (for example, National Assessment of Shoreline Change for the North Coast of Alaska, by Gibbs and others [2015]), and are often used to compute short-term rates of change. For more details on the specific formulas used to calculate these rates, see Thieler and others (2009).

The above calculations assume that rates of shoreline change are constant over long periods of time, or that past rates are similar to those occurring today. In some instances, though, historical rates of change may be significantly different than those of the present day. A prime example of this case in Alaska is coastlines that are experiencing a net decline in the duration of landfast sea ice and are increasingly exposed to high-energy storm events each fall. In these evolving environments it is useful for planning purposes to adopt a calculation that addresses this trend and places more importance on recent shoreline positions. One method is to average multiple end-point rates, each one based on a pair of shoreline positions consisting of the most recent position and some position from the past (modified from Foster and Savage, 1989). An “average of rates” value calculated in this manner may better predict future trends in settings where environmental factors have shifted and historical rates of change no longer reflect what is happening today. However, this type of calculation may place more emphasis on end-point rates of shorter timespans, which could result in potentially misleading values (Genz and others, 2007). Calculations can be improved by weighting an average of rates by the component end-point rate durations; estimates obtained using this approach are best confirmed by evaluating against other long-term rate of change calculations.

Rates of shoreline change in the DGGS Shoreline Change Tool interactive map database (DDS-9; <http://dx.doi.org/10.14509/shoreline>) are calculated using the Digital Shoreline Assessment System (DSAS), an ArcGIS extension developed by the U.S. Geological Survey (USGS; Thieler and others, 2009). Shore-normal transects are created at 50 m intervals and an ordinary linear regression approach is used that incorporates all shorelines to calculate a rate of change at each transect; the slope of the linear regression is the reported rate of change (in distance/year). The earliest shorelines included in Alaska shoreline change calculations typically date to the 1940s, and each DSAS transect in this tool requires a minimum of three shoreline years for the calculation. Breaks in projected shoreline position appear on isolated coastal segments where fewer than the minimum three shorelines exist; this may arise in locations where the selected shoreline indicator is not present or identifiable, or where a coastal structure (such as a rock revetment) has obscured the position of at least one of the shorelines.

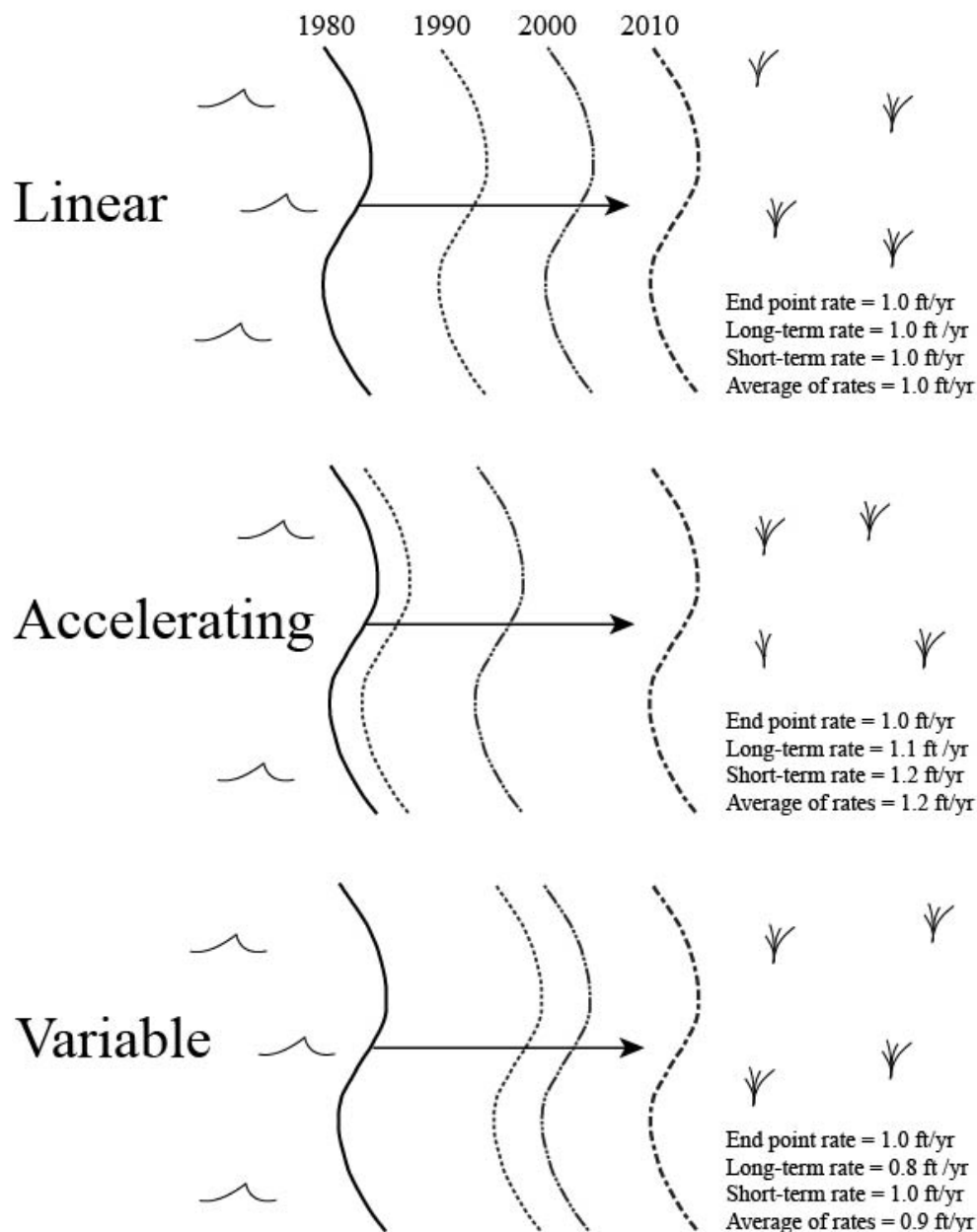


Figure 4. Diagram illustrating three different scenarios of shoreline movement with associated rates of shoreline change calculated with four different approaches. Long- and short-term rates were calculated using ordinary linear regression.

PROJECTED SHORELINES

A projected shoreline is an estimation of where the shoreline will be located at a certain time in the future. In the DGGS interactive shoreline change map (DDS-9; <http://dx.doi.org/10.14509/shoreline>), projected shoreline positions are determined by extrapolating the long-term linear regression rate along each transect. This method assumes that the long-term rate of change calculated from historical shoreline positions will remain constant into the future, which may or may not be correct. This method accommodates both eroding (projected position appears further inland) and accreting shorelines (projected position is seaward).

In the DGGS interactive map environment (fig. 5), each projected shoreline is displayed with a projected shoreline position (solid line), accompanied by a projected shoreline uncertainty (dashed collar) and DSAS

transects along which the calculations were made (shore-normal dashed lines). The uncertainty lines represent, with 90 percent confidence, the area in which the shoreline position will be located for the projected year. This uncertainty is based on the standard error of the statistical regression; therefore, non-linearity in the shoreline positional data results in greater uncertainty. For example, a shoreline that has experienced both periods of advance and retreat will have a larger uncertainty value, corresponding to lower confidence in the estimated shoreline locations. Because the projected shoreline uncertainty is compounded annually, the width of the collar expands for shorelines projected further in the future.

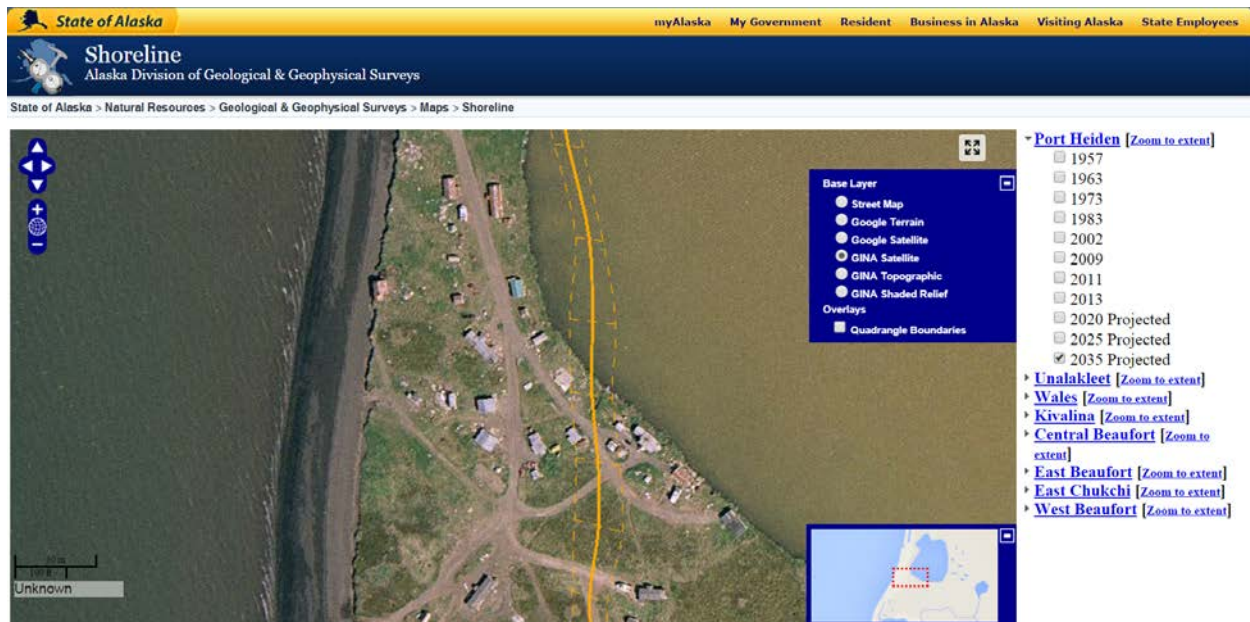


Figure 5. Screenshot of Alaska Shoreline Change Tool, showing projected shoreline position (solid line), accompanied by a projected shoreline uncertainty (dashed collar).

The projected shorelines and associated uncertainty polygons in the DGGS interactive map are generated using a custom ArcGIS 10 tool (built with ArcGIS model-builder and python) that incorporates rates of change values calculated with the Digital Shoreline Analysis System (DSAS) ArcGIS Extension version 4.3.4730 (Thieler and others, 2009). Projected shorelines can only be created where calculated rates of shoreline change exist. Data gaps exist where the minimum number of shorelines was not available or where the most recent shoreline was not identifiable. The procedure used to generate projected shorelines is as follows (fig. 6):

1. Historic shorelines and a baseline are digitized in ArcGIS or obtained from an external source.
2. Digitized features are formatted for use in the DSAS tool, which is used to produce a set of 50-m-spaced transects perpendicular to the baseline. Transects are manually inspected and edited, where necessary, to ensure adequate shoreline intersection.
3. At each transect, DSAS calculates standard rates of change and statistics based on historic shoreline data. Output is in the form of a Transect Feature Class, Transect Intersection Table, and Transect Rates Table.
4. The three datasets from Step 3 are used as inputs in the custom DGGS shoreline projection tool. The tool produces projected shoreline points at specified future intervals, and the 90 percent confidence error of these shoreline locations in both onshore and offshore directions along each transect.

5. Individual projected points are connected and smoothed using the Bezier smoothing algorithm to produce projected shorelines and associated uncertainty for visualization in the online map. All projected shorelines show the predicted location for July 1 of that year.

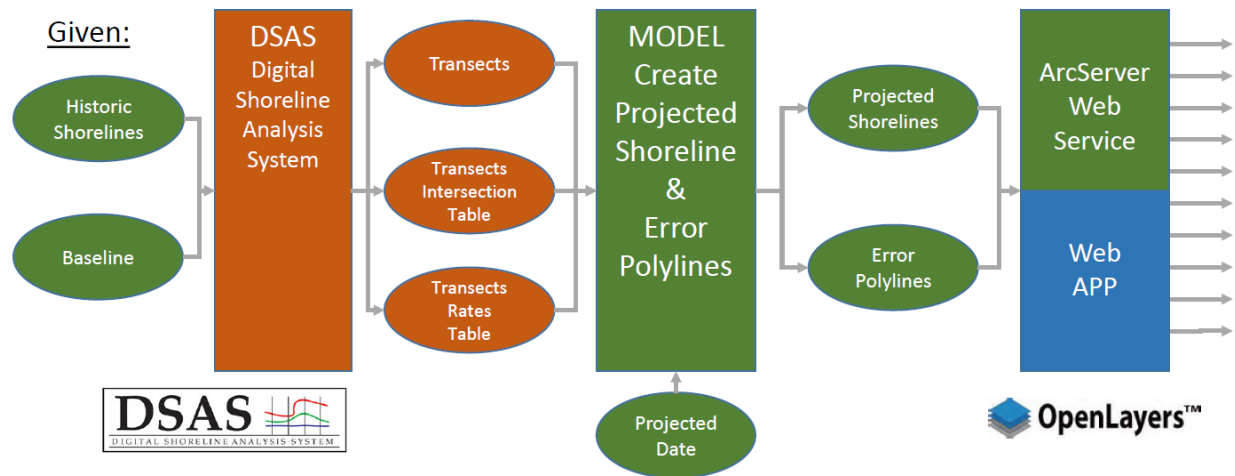


Figure 6. Schematic workflow for creating projected shorelines displayed in the DGGS interactive Alaska Shoreline Change Tool.

EXAMPLE APPLICATIONS AND LIMITATIONS OF PROJECTED SHORELINE POSITIONS

Local planners, as well as federal and state agencies, often rely on quantitative assessments of shoreline movement to make informed decisions about coastal land use or development. Long-term rates of shoreline change are used in many parts of the country to establish setback distances for coastal development, prioritize areas for mitigation, or aid in the design of erosion-control structures. Regardless of the application, it is critical to understand the limitations associated with any projected shoreline position; these features are estimations only and proper care must be exercised when using these projections as a guide for coastal management projects. Knowledge of local geology, patterns of coastal processes, different types of statistical rates of change, and other contributing factors must all be considered and assessed in depth before planning and decision-making occurs. When using a projected shoreline position, always consider:

1. *How long is the record of historical shoreline positions used in the calculation?*

An underlying dataset that extends across many decades is most likely to include a full range of environmental conditions and extremes. If the record is short, carefully evaluate whether it encompasses any time period with shoreline conditions known to be anomalous for the area.

2. *What type of shoreline indicator is used?*

The shoreline indicator should be consistent across all time periods for any given rate-of-change calculation.

3. *How accurate are the historical shoreline positions used in the analysis?*

Rates of change are only as accurate as the underlying errors associated with each shoreline vector included in the analysis (for additional information on calculating component uncertainties see Crowell and others, 1991; Hapke and others, 2006; Ruggiero and others, 2013; Del Río and Gracia, 2013). Errors in the historical shoreline positions may arise from geolocation issues or uncertainty in the identification/delineation of a shoreline indicator; an accuracy assessment should always be included in any reputable rate calculation.

4. *What type of calculation is used to project rates of change?*

Keep in mind that different types of rates of change calculations will influence projected shoreline positions. This is a particularly important consideration if the available shoreline positions are migrating in a nonlinear fashion or if the coastal area is known to be experiencing a change in local environmental conditions that could introduce a trend in the rate of shoreline change.

The projected shoreline positions displayed by the DGGs Shoreline Change Tool are presented as a convenience and are intended to be a visualization of a first-order estimation of shoreline change throughout the state. Because this database uses long-term linear regression rates, which do not account for individual shoreline uncertainties but give equal weight to each of the historical shorelines, the projected shoreline position is vulnerable to bias from outliers (Genz and others, 2007). These projected positions also include an assumption of linearity in shoreline evolution with no trend in shoreline migration rates; this is atypical of most coastal segments included in the database.

Additional shoreline position data is integral for the development of this database and to produce more accurate shoreline projections. Improved results are obtained in areas with longer records of shoreline positions and frequent remapping at different times of the year. As more imagery, particularly historical orthoimagery, becomes available, the collection of shoreline position data in the DGGs tool will grow. The addition of data will greatly improve the application's estimates of projected shoreline positions and will also provide essential information for comparing historical and contemporary rates of shoreline change to understand how shorelines and coastal processes are changing in response to environmental and climatic variations.

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