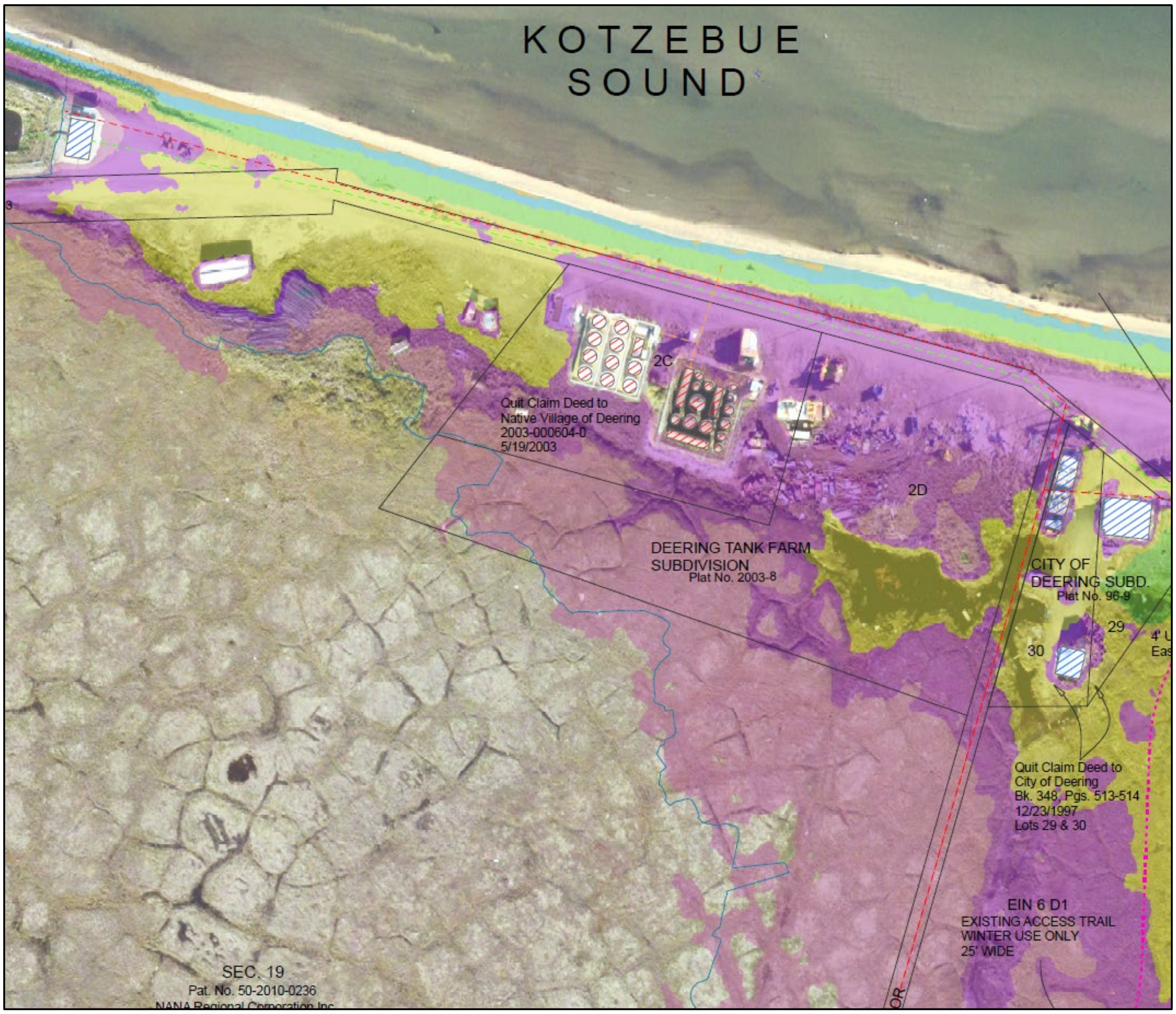
COLOR INDEXED ELEVATION MAPS FOR FLOOD-VULNERABLE COASTAL COMMUNITIES IN WESTERN ALASKA

Roberta Glenn, Jacquelyn Overbeck, and Rebecca Heim

Miscellaneous Publication 154, version 3



Screen shot of color-indexed map at Deering, Alaska.

2019
STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

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This is the third version of Miscellaneous Publication 154. For convenience, all three versions of this report are combined in one pdf. Versions one and two can be found following this report.

Version 2 begins on page 10 of this document.

Version 1 begins on page 18 of this document.

COLOR INDEXED ELEVATION MAPS FOR FLOOD-VULNERABLE COASTAL COMMUNITIES IN WESTERN ALASKA

Roberta Glenn[1], Jacquelyn Overbeck[1], and Rebecca Heim[2]

UPDATE SUMMARY

This publication serves as an update to previous versions of Miscellaneous Publication 154 (http://dggs.alaska.gov/pubs/id/29719) and covers four western Alaska communities—Kotzebue, Deering, Quinhagak, and Goodnews Bay (fig. 1). Elevation data collected between 2015 and 2016 were used to create color-indexed maps for the first time at these communities. Tschetter and others (2014) outlines the original methodology used to create color-indexed maps, while Overbeck and others (2017) discusses similar datasets to those used in this update and show useful schematics of the terminology used in this series.

Color-Indexed maps show elevation intervals at individual communities that might be used to communicate forecasted storm surge elevations. Each map sheet is associated with a tide staff reference page used to convert between local land and tidal datums, as well as to show the elevation interval corresponding to modeled water level elevations or low elevation infrastructure. Community infrastructure, boundary, and land-use delineations used in the color-indexed maps were provided by the Alaska Department of Community and Regional Affairs (DCRA), which were originally published in the community profile map series (DCRA, 2017). Other data sources and the accuracy of data used to create the color-indexed maps and tide staffs are referenced throughout this document.

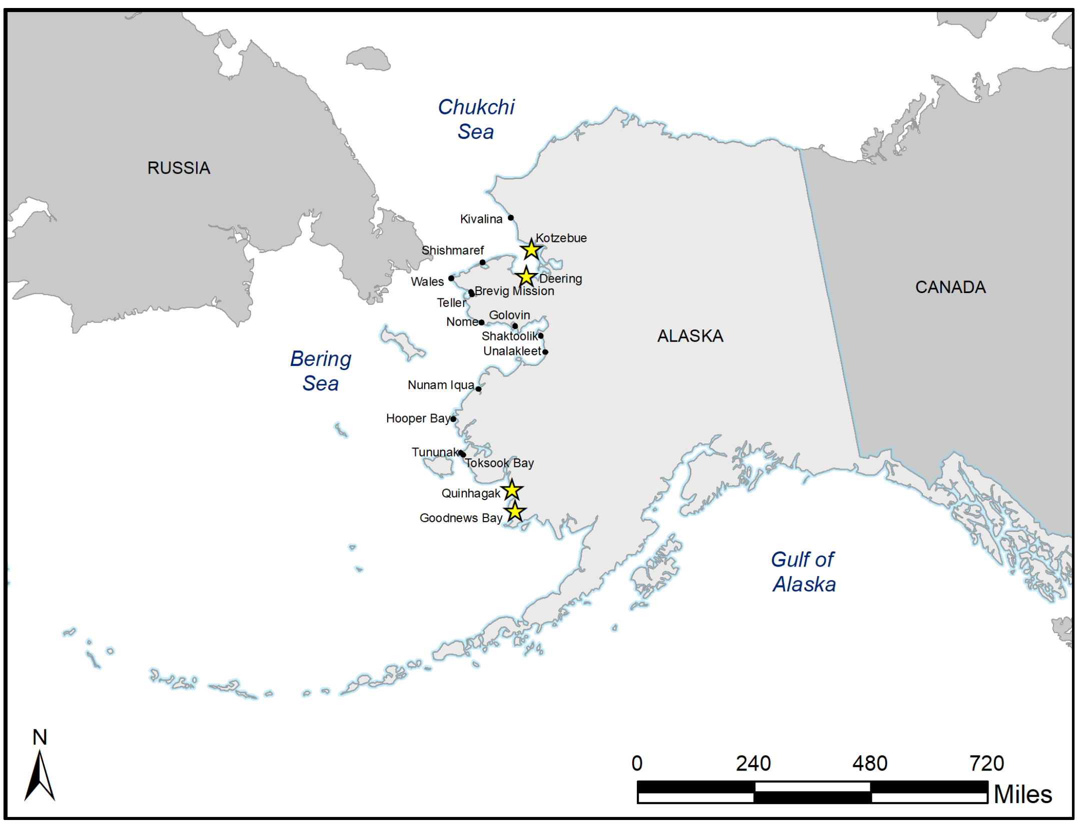

Figure 1. Map of MP 154 color indexed map coverage for Versions 1 and 2 communities (black circles) and Version 3 (current version, yellow stars).

[1] Alaska Division of Geological & Geophysical Surveys
[2] National Oceanic & Atmospheric Administration National Weather Service Alaska Region

DATA SOURCES

Elevations and orthophotos

Elevation data (digital surface models; DSMs) and orthophotos used in this map series were created using Structure-from-Motion (SfM) photogrammetric methods on aerial photographs collected in 2015 and 2016 over western Alaska. Elevation and orthophoto data shown in this map series have not been published but will be released in Overbeck and others (2017) at a later date. Data were not included in Overbeck and others (2016) due to accessibility to ground control and check points during the time of publication.

DSMs represent the surface of vegetation, buildings, vehicles, etc., that are on the ground. Traditionally, maps showing the potential for inundation use a bare earth model, which removes these surface features. DSMs, however, are the only elevation data available for the communities in this study, and therefore give the best estimate of the potential for flood events to impact certain elevations. Vertical accuracies of the DSMs have been assessed using vertical check points surveyed by Division of Geological & Geophysical Surveys (DGGS) and University of Alaska Fairbanks (UAF) researchers, not by licensed surveyors. Vertical check points were collected on various flat surfaces around the communities with relatively uniform elevation using Global Navigation Satellite Systems (GNSS) Global Positioning Systems (GPS) survey equipment (table 1). Elevation values from the GNSS GPS survey were compared to the elevation model collected in the aerial survey to compute vertical accuracy statistics according to the American Society for Photogrammetry and Remote Sensing (ASPRS) (2014; table 1) standards. Some of the DSMs have been vertically shifted to better represent NAVD88 elevations of the GPS survey. Average offset values were either added or subtracted from the entire DSM to minimize the vertical root mean square error (RMSE) from NAVD88.

DSMs were processed to reduce noise and down-sampled to 2-meter resolution to streamline processing time. Water bodies and wet areas were delineated and removed from the elevation datasets to reduce elevation errors common to SfM DSMs (Overbeck and others, 2016). Culverts and bridges were manually edited to maintain flow through these known lower-elevation points. A fill was performed on the elevation models to ensure low-lying areas protected by landforms or infrastructure were shown as higher elevations. For example, if a sewage lagoon was surrounded by a higher elevation berm, the entire sewage lagoon would be shown at the higher elevation. The final elevation models are the best estimate of where water would flow in the event of a coastal flood.

Since the orthophotos were created as part of the SfM processing workflow, they are co-registered to the DSMs. These images have a 20-cm ground sample distance, and are the most up-to-date high resolution imagery dataset for the region. These images are more up-to-date than the infrastructure line work and cartography, so some buildings may not be labelled or may no longer exist.

Table 1. DSM and GPS data descriptions and accuracy assessment.

	Community Location			
	Kotzebue	**Deering**	**Quinhagak**	**Goodnews Bay**
DSM Acquisition Date	August 2016	August 2016	May 2016	May 2016
Ground survey conducted by	DGGS (R. Glenn and J. Overbeck)	DGGS (R. Glenn and J. Overbeck)	DGGS (L. Southerland and J. Overbeck)	UAF (C. Maio and R. Buzard)
GNSS Survey Date	July 2018	July 2018	June 2015	August 2017
Survey equipment	Trimble R8s + R10 + R2	Trimble R8s + R10	TopCon HiPerII (s)	Trimble R8s(s)
Number of Vertical Control	27	10	9	16
Average Vertical Difference	0.732 ft (0.223 m)	1.888 ft (0.575 m)	-0.157 ft (-0.048 m)	0.154 ft (0.047 m)
Vertical RMSE after shifting	1.050 ft (0.320 m)	0.002 ft (0.000 m)	0.932 ft (0.284 m)	0.692 ft (0.211 m)
Vertical Shift	DSM + 0.72 ft (0.220 m)	DSM + 1.88 ft (0.575 m)	None applied	None applied

Infrastructure and boundary cartography

Building locations and names, as well as land-use boundaries and local subsistence use areas are delineated at each community. These data were created for DCRA in their community profile map series, between 2004 and 2013. For ease of use and familiarity of local residents with the DCRA maps, formatting between the DCRA maps and this map series have been kept as similar as possible. Cartographic representations of mapped features were updated where the conversion between AutoCAD and ArcGIS was not congruent.

Reference datums

Conversions between land and tidal datums are available via the Alaska Tidal Datum Portal (DGGS, 2017), which uses verified and freely available source data from NOAA CO-OPS or NOAA NGS (table 2). In addition to datum conversions, tide staffs show modelled or observed elevations of water levels from storm events (labelled by the year in which they occurred), or elevations of infrastructure that might be of interest. For example, a modeled storm event that is expected to occur once every 20 years is referenced as a 20 year return interval storm. At Quinhagak, a local flood staff was installed and surveyed by DGGS in 2018 on a power pole. The staff is referenced to NAVD88 and color-indexed elevations (table 2; figure 2) that give a real-life representation of what the color intervals mean relative to structures.

Table 2. Source data by community map.

Community	Tidal Datum	Models/ Observations		
		Elevation (ft NAVD88)	**Description**	**Source**
Kotzebue	Kotzebue Station ID 9490424	13.85 +/- 3.62 ft	100 year return interval storm event	Chapman and others (2009)
		12.47 ft	November 1970 storm event	Glenn Gray and Associates (2013)
		9.75 +/- 0.92 ft	20 year return interval storm event	Chapman and others (2009)
		8.50 ft +/- 0.03 ft	Lower section of primary runway, Kotzebue airport	Elevation model used in color-indexed map
		6.02 +/- 0.05 ft	July 2018 storm event	DGGS survey 2018 of flooding at Air Force road
Deering	Deering Station ID 9469751	16.05 +/- 0.16 ft	Recommended building elevation on power pole	DGGS survey 2018
		4.90 ft +/- 0.26 ft	Low section of road to Deering airport	Elevation model used in color-indexed map
Quinhagak	Quinhagak (Kwinak), Kuskokwim River Station ID 9465831	17.00 +/- 1.50 ft	City of Quinhagak water pump	Elevation model used in color-indexed map
		14.31 +/- 0.10 ft	Flood staff elevation (0 ft)	DGGS survey 2018
		12.62 ft	November 1978 storm event	9 feet above sea level, *assumed mean sea level* (City of Quinhagak Mitigation Planning Team, 2012)
Goodnews Bay	Platinum Station ID 9465396	19.84 ft	November 2011 storm event	Buzard and others (in prep)
		17.55 ft	November 1979 storm event and recommended building elevation	Buzard and others (in prep)
		16.56 ft	August 1989 and 1969 storm events	Buzard and others (in prep)
		16.20 +/- 0.30 ft	Low section of runway Goodnews Bay airport	Elevation model used in color-indexed map
		11.24 +/- 0.96 ft	October 2017 storm event	Determined by R. Buzard from photographs collected by Alice Julius, using methods from Overbeck (2017)

Figure 2. Color indices relative to flood staff installed at Quinhagak in 2018. The flood staff is higher than both the orange and blue color indices.

ACKNOWLEDGMENTS

This work was funded by the Alaska Ocean Observing Systems. Special thanks to Chris Maio and Richard Buzard with the University of Alaska Fairbanks Arctic Coastal Geoscience Lab for sharing GPS data to determine the accuracy of the elevation models and for performing the analysis of photos taken during a storm at Goodnews Bay.

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Alaska Division of Geological & Geophysical Surveys

Miscellaneous Publication 154, *version 2*

COLOR-INDEXED ELEVATION MAPS FOR FLOOD-VULNERABLE COASTAL COMMUNITIES IN WESTERN ALASKA

by
Jacquelyn Overbeck, Katrina Kennedy, and Rebecca Heim

Example area of color-indexed map of Teller

July 2017

Released by:
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Note: *This report, including all digital data, explanations, and tables, is available in digital format from the DGGS website (http://dggs.alaska.gov).*

COLOR-INDEXED ELEVATION MAPS FOR FLOOD-VULNERABLE COASTAL COMMUNITIES IN WESTERN ALASKA

Jacquelyn Overbeck[1], Katrina Kennedy[1], and Rebecca Heim[2]

UPDATE SUMMARY

Version 2 of MP 154 is an update to 3 of the original 5 communities; in addition, color-indexed maps have been created for the first time at 8 communities (fig. 1). For the original documentation of methods used to create the color-indexed maps, please reference Tschetter and others (2014). Similar to the original map series, version 2 maps are accompanied by a tide staff reference sheet that is a separate but associated legend for maps from each community. These reference sheets are separate so they can be updated more frequently than the mapped datasets. The map and tide staff show elevations and conversions necessary to project forecasted flood events at individual communities and to communicate potential for flooding.

Recently collected elevation data over a large region of western Alaska were utilized to modify this map series (Overbeck and others, 2016). As with the original map series, all infrastructure, boundary, and land-use delineations have been provided by the Alaska Department of Community and Regional Affairs

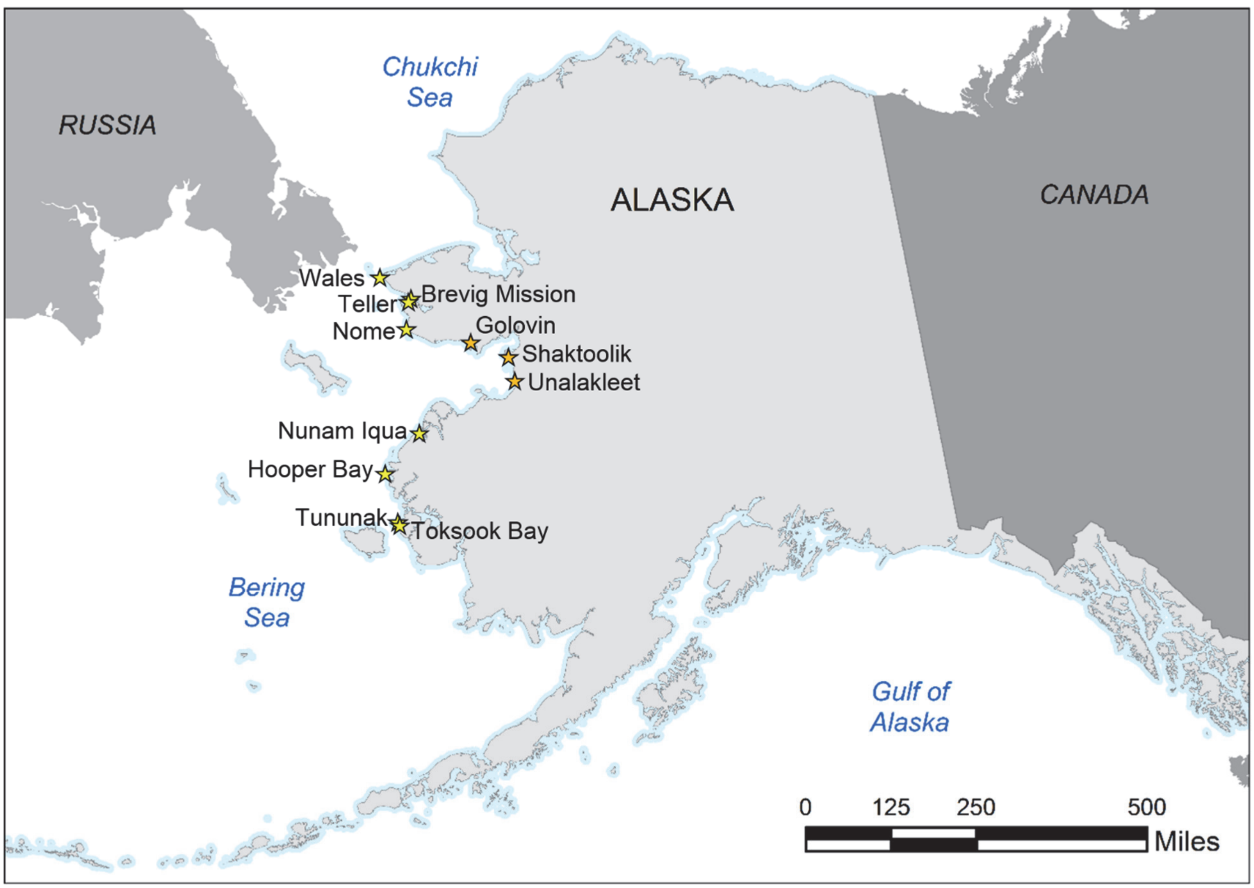

Figure 1. Map of updated (orange) and new (yellow) locations with color-indexed maps (star).

[1]Alaska Division of Geological & Geophysical Surveys

[2]National Oceanic & Atmospheric Administration National Weather Service Alaska Region

(DCRA) via the community profile map series (DCRA, 2017) along with Bristol Engineering Services for the community of Nome. Individual datasets used to create maps and their accompanying elevation conversion tables are listed throughout this document. Information on the accuracy and original source data are also referenced.

DATA SOURCES

ELEVATIONS AND ORTHOPHOTOS

Base elevations were processed from aerial photographs collected over western Alaska in 2015 (Overbeck and others, 2016). These data are digital surface models, which represent the surface of vegetation, buildings, vehicles, etc. Common elevation datasets used for flood mapping are usually bare earth models, which represent the ground surface beneath vegetation or buildings. Because a surface model was used to update this map series, there are inherent errors where flood waters are expected to flow over a bare earth surface rather than on top of vegetation. These elevation datasets, however, are the first of their kind for most of western Alaska and therefore give the best estimate for communicating about floods at individual community sites. The elevation datasets are also co-registered to orthophotos. Orthophotos are aerial images geospatially corrected to represent the earth's surface and collected in a true color composite (i.e. what you would see with your eye). The updated orthophotos are used as background images in this map series. The elevation and orthophoto datasets are more recent than other datasets used to create this map series. In some areas buildings have been moved, however, most of the delineated infrastructure are still relevant.

Elevation data were processed from their raw format to remove noise and down-sampled to streamline data processing. The raw digital surface elevations included erroneous data over water bodies and wet areas. These areas were hand delineated and removed from the dataset. The ground sample distance of the raw elevation data ranged from 8-20 cm. These high resolution datasets were down-sampled to improve data processing time resulting in ground point resolution of approximately two meters. Culverts and bridges

Figure 2. Schematic of color indices over topographic surface.

were manually edited as low elevation data points to maintain flow through these areas. A fill was then performed on the elevation data so that low-lying areas protected from floods by levee-type landforms or infrastructure would be correctly mapped. The resulting elevation models are the best estimate of where water would flow with increasing water levels.

Elevation data are represented as color indices with discrete ranges. For example, orange represents the lowest two meters of elevation data, while blue may represent the next one meter higher (fig. 2). Elevation ranges were selected based on local information, so are different for each community. Since the elevation data used to create the color indices are digital surface models rather than bare earth models, the top of a house may be a different elevation range than the floor (fig. 2). Flood waters, however, inundate the base of a building regardless of roof height, and can cause damage within an area which may be shown at a high elevation indices. Elevations near buildings may also be skewed, due to the processing method used to create them. Because the elevations are derived from aerial photographs, the sharp changes in elevation at building edges are somewhat smooth. Caution must be used when interpreting potential flood elevations relative to color-indexed elevations, particularly around buildings.

LINE WORK AND CARTOGRAPHY

Building locations and names, as well as land-use boundaries and local subsistence use areas are delineated at each community. These data were created for DCRA in their community profile map series, between 2004 and 2007. For ease of use and familiarity of local residents with the DCRA maps, formatting between the DCRA maps and this map series have been kept as similar as possible. Cartographic representations of mapped features were updated where the conversion between AutoCAD and ArcGIS was not congruent.

REFERENCE DATUMS

A datum is a base elevation used as a reference from which to measure heights or depths (NOAA, 2017a). In the case of this map series, a datum is important to relate relevant elevations of infrastructure (e.g. sewage lagoon) and the elevations of storm events (e.g. 100 year storm). For flood mapping, a conversion is necessary between a datum relative to tidal fluctuations (tidal datum) and local land elevations (land-based datums; e.g. North American Vertical Datum of 1988; NAVD88). The tidal datums represented by this map series are commonly used by coastal modelers and engineers (NOAA, 2017a):

> "*MLLW*—Mean Lower Low Water—The average of the lower low water height of each tidal day observed over the national Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the national Tidal Datum Epoch.
>
> *MSL*—Mean Sea Level—The arithmetic mean of hourly heights observed over the national Tidal Datum Epoch. Shorter series are specified in the name, e.g., monthly mean sea level and yearly mean sea level.
>
> *MHHW*—Mean Higher High Water—The average of the higer high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch." (NOAA, 2017a; fig. 3)

Elevation datasets used in this map series were referenced to NAVD88 using ground control elevation points (Overbeck and others, 2016). Tidal datums were verified by the National Oceanic and Atmospheric

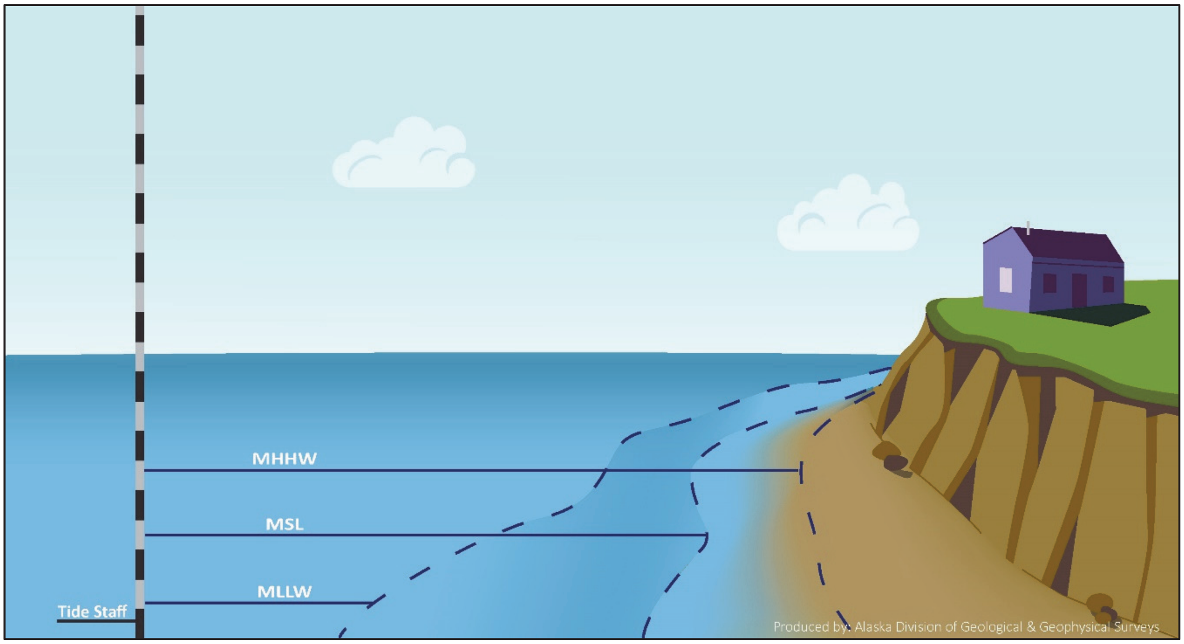

Figure 3. Schematic of alongshore tidal datum position over topographic surface.

Administration (NOAA) at 10 locations where tidal predictions are currently available (NOAA, 2017b; DGGS, 2017). The tidal datum information at Golovin was computed using an online datum calculation tool (https://www.tidaldatumtool.com/) from water level data collected in 2012 (Overbeck and others, 2015).

MODELED AND OBSERVED WATER LEVELS

There are currently no consistent standards for flood modeling in Alaska. From one community to another, different flood reporting may be available in a variety of formats. This map series uses consistent language regarding modelled and observed water levels. Inundation, or Marine Total Water Level, is defined as the sum of water levels from tides, non-tidal residuals, and wave-induced components (Moritz and others, 2016). Common model outputs for coastal inundation take into account different water level components. For the model reports used in this map series there are two main types of models, which are defined below:

Storm Surge—tides and storm surge

Wave Runup—tides, storm surge, and wave-induced water levels

Storm elevations are also often reported as return interval flooding events. A storm with a return interval of 100 years is expected to occur once in a 100 year record.

Since there is minimal observational equipment in the nearshore zone of Alaska (AOOS, 2016), many of the observed water levels were referenced to historical information about flooding collected by the U.S. Army Corps of Engineers (USACE, 2017). Floods are often reported as heights above ground elevations at well-known locations (e.g. post office). For these observations, where the location could be identified, the reported height was converted to the datum used in this map series, resulting in a generalized term for observed water levels:

Flooding—unknown water level components, where standing water was observed

Specific infrastructure elevations have been extracted and used to fill in the tide staff sheet. For example, infrastructure vulnerable to flooding, such as a sewage lagoon located near a beach front, has a minimum elevation before it is inundated. This elevation is important for community leaders, emergency managers, and forecasters to know and communicate flood risks for a given event. It also provides a path of communication to better convey peak water levels during post-event assessments.

Table 1. Source data by community map.

Community	Tidal Datum	Line work	Models/Observations
Brevig Mission	Port Clarence Station ID 9469239	DCRA (2017)	USACE Data Sheet Brevig Mission
Golovin	2012 DGGS occupation	DCRA (2017)	Chapman and others (2009); Overbeck and others (2015); USACE Data Sheet Golovin; Kinsman and DeRaps (2012)
Hooper Bay	Dall Point Station ID 9466931	DCRA (2017)	Chapman and others (2009); USACE Data Sheet Hooper Bay
Nome	Nome, Norton Sound Station ID 9468756	BEESC (2009)	Chapman and others (2009); BEESC (2009); Kinsman and DeRaps (2012)
Nunam Iqua	Nunam Iqua (Sheldon Point) Station ID 9467551	DCRA (2017)	Chapman and others (2009); USACE Data Sheet Sheldon Point
Shaktoolik	Shaktoolik Station ID 9468691	DCRA (2017)	Chapman and others (2009); USACE Data Sheet Shaktoolik; Kinsman and DeRaps (2012)
Teller	Port Clarence Station ID 9469239	DCRA (2017)	USACE Data Sheet Teller
Toksook Bay	Nelson Island, Toksook Bay Station ID 9466298	DCRA (2017)	Chapman and others (2009)
Tununak	Nelson Island, Toksook Bay Station ID 9466298	DCRA (2017)	None available
Unalakleet	Unalakleet Station ID 9468333	DCRA (2017)	Chapman and others (2009); Erikson and others (2015); USACE Data Sheet Unalakleet; Kinsman and DeRaps (2012)
Wales	Tin City, Bering Sea Station ID 9469439	DCRA (2017)	Chapman and others (2009)

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Alaska Division of Geological & Geophysical Surveys

MISCELLANEOUS PUBLICATION 154

COLOR-INDEXED ELEVATION MAPS FOR FLOOD-VULNERABLE COASTAL COMMUNITIES IN WESTERN ALASKA

by
Timothy Tschetter, Nicole Kinsman, and Aimee Fish

Coastal flooding along the Tagoomenik River in Shaktoolik, Alaska, in November 2011 (photograph by Elmer Bekoalok).

October 2014

Released by

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$2.00

Overview

This map series is a joint effort by the Alaska Division of Geological & Geophysical Surveys (DGGS) and the National Weather Service (NWS) to merge best-available datasets into a tool that can streamline communication about forecasted water levels, local elevations, and potentially impacted infrastructure during storm events that may cause coastal flooding (fig. 1). These maps are not designed to function as flood inundation maps, but to serve as a temporary tool to communicate about elevations in at-risk coastal communities until true inundation mapping can be completed. Pilot work to test the usefulness of this map format is presented for five communities: Kivalina, Shishmaref, Golovin, Shaktoolik, and Unalakleet.

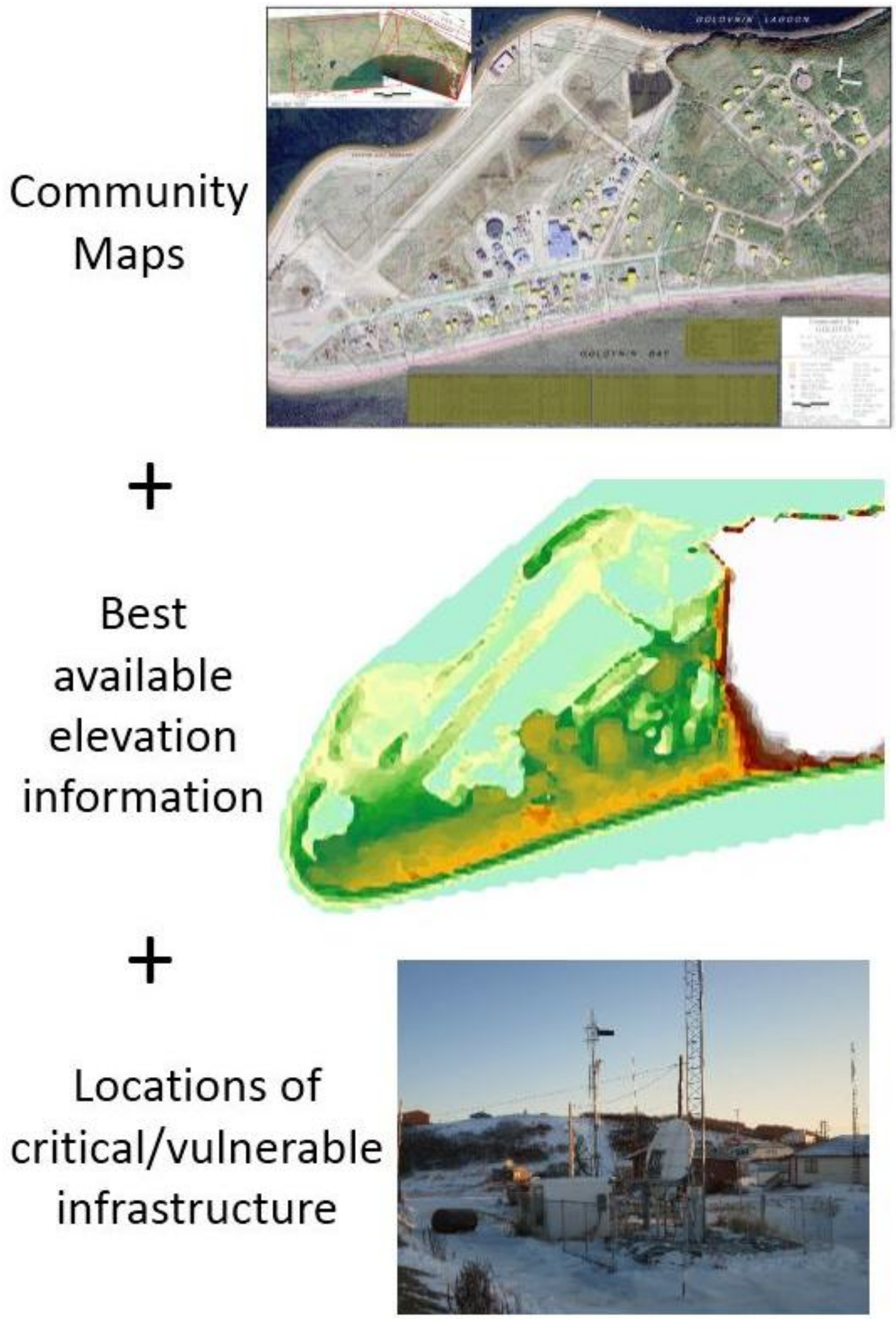

Figure 1. Graphical summary of the compilation of best available data sets to produce community-specific, color-indexed elevation maps.

Purpose/Need

When an extreme storm event is forecast, it is imperative for local community leaders and emergency managers to quickly and effectively communicate with the NWS regarding:

- How high floodwater may reach
- From what direction(s) flooding may be most severe
- Where impacts are most likely to occur
- Which critical infrastructure is potentially at risk
- How this event will differ from past storms at a local level

Unfortunately, there are challenges that can impede this dialog. An emergency manager in Anchorage may not be familiar with the location of a village's power supply; a community leader may not know the elevation of the evacuation road; a forecaster may use unfamiliar language that is confusing in an emergency context. For some simplified definitions of some common terms, please see Appendix 1.

During the 2011 and 2013 fall storm seasons, Alaska NWS staff struggled to convey relevant coastal storm impacts to communities along the west coast of Alaska. Forecast water levels were expressed in units above local tide or above Mean Lower Low Water (MLLW); this did not effectively convey the threat to local decision makers. Staff with the State of Alaska Emergency Operations Center challenged the NWS to use language that community members could understand, suggesting forecasters describe potential impacts to critical infrastructure as a more effective approach.

At this time, the full suite of data necessary for coastal flood inundation mapping is not yet available in many parts of Alaska. To meet the identified need for an interim tool, a widely-used map series that is color-indexed by elevation and linked to a table of relevant reference frames (surveyed elevations and tidal datums such as MLLW) may facilitate real-time discussions during storm events. In combination with community dialog, this work will contribute toward enhancing an 'Impacts Catalog' to assist the NWS in their decisions to issue warnings and further the goals of NOAA's Weather-Ready Nation initiative.

What are the differences between a Flood Inundation Map and a Color-Indexed Elevation Map?

The color-indexed elevation maps in this series are not a substitute for flood inundation maps; the colored areas on these maps do not directly correspond to flood warning zones, but to pure elevations. When a storm surge impacts a community, local currents, wind, and waves will lead to different peak water levels in different areas. For example:

- A low area in the middle of town may not flood if it is surrounded by higher elevation
- Elevated ocean water levels may prevent drainage from a nearby river, leading to overflow flooding along the riverbanks
- Large waves may break and run high up on one portion of a beach, while farther down the same beach a protective sandbar causes the waves to break offshore

Unlike color-indexed elevation maps, flood inundation maps will account for these variables in local conditions by incorporating advanced models of where water will flow in a range of scenarios. Flood zones are established based on the likelihood that an event will occur in any given year (a 2-year flood zone has a 50/50 chance of flooding each year, like flipping a coin). The creation of flood inundation maps is a lengthy process that requires a detailed record of local conditions—data not yet available in many of Alaska's small communities.

Approach and Community Selection

To evaluate this new type of tool, DGGS worked with NWS to select five communities to include in this pilot project (fig. 2). The selection process was based on need (documented flood events), the possession of an established Local Hazard Mitigation Plan, and the availability of existing data required to compile these maps in a timely fashion. Minimal data needs include:

1. Imagery and Linework
   Alaska Division of Community and Regional Affairs Community Profile Maps (DCRA, 2014)
2. Detailed Surface Elevations
   Most recent lidar or photogrammetrically-derived digital elevation model
3. A conversion factor between local water levels and elevations on land
   NOAA tidal datum with a tidal benchmark of known elevation (NGS-published height)
4. Storm Surge Guidance
   NWS guidance location points with both storm surge and tidal prediction capabilities

Figure 2. Location map of the five communities included in the pilot project.

The production of color-indexed elevation maps and associated conversion tables varied based on the quality and format of the data listed above. Details about this process, including the specific source data and production steps, are provided for each community in Appendix 2 and summarized in table 1. A community feedback meeting was held on September 9, 2013, to identify critical infrastructure and ensure a useful format for the final publication.

Intended Use

The maps in this series are intended to facilitate two-way communication about situational storm surge impacts. Each map has highlighted elevation intervals in developed, low-lying areas; maps also highlight any critical infrastructure. The map sheets are all maintained separately to allow for re-versioning as vertical datums are refined in western Alaska.

Table 1. Summary of data sets used in the preparation of each color-indexed map.

Community	Shishmaref	Kivalina	Unalakleet	Shaktoolik	Golovin
DCRA Map	2004	1999	2004	2004	2004
Imagery	2004 (DCRA)	2013 (DCRA)	2014	2014	2004
Elevation Model	2004 lidar	2004 lidar	2014 model	2014 model	2013 lidar
Tidal Predictions	Yes	Yes	Yes	Yes	No
Tidal Datum	Est. 2003	Est. 1985–86	Est. 2011	Est. 2010	Approx. 2012
Surge Guidance	Yes	Limited	Yes	Yes	Yes
Local Hazard Mitigation Plan	2010	2007	2008	2009	2008
Existing flood map tools	FEMA Flood Insurance Study (2009)	No	NRCS Floodplain Management Map (2003)	USACE Coastal Flooding Analysis Maps (2011a)	No

Elevations can be defined relative to various reference frames, which can cause confusion when information is transmitted between different users. By supplying a conversion table with each map, users from different backgrounds can determine which colors correspond to the reference frame they are most comfortable with and communication can occur with a simplified color-based scheme (for example, see fig. 3). Each conversion table is accompanied by a graphic of significant infrastructure elevations as well as documented and modeled water levels in each community (compiled from U.S. Army Corps of Engineers [USACE], 2011b; Chapman and others, 2009; Kinsman and DeRaps, 2012). Combining this information with knowledge of local flood patterns, storm track, and considerations such as the absence or presence of ice in the nearshore, local planners can use these calculations to make immediate decisions for storm-response needs. NWS forecasters can also speak directly to local planners about at-risk infrastructure with a shared reference frame and visual aid by using these maps as a discussion platform.

Please note the following disclosures/use limitations:

- These maps illustrate elevations and are not intended for use in the definition of flood zones. Flood levels are not perfectly flat and will not directly correspond to specific elevations.
- Vertical and horizontal accuracies vary by location.
- Best available data sets in Alaska are not always up-to-date. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

  Examples: ◊ Houses or infrastructure may have moved since DCRA linework was completed

  ◊ Local engineering projects might raise a road or add a seawall

  ◊ Beaches and sand spit change shape regularly
- Colors are restricted to areas of known elevation; in some cases the best available elevation model does not cover the entire DCRA Community Map area.

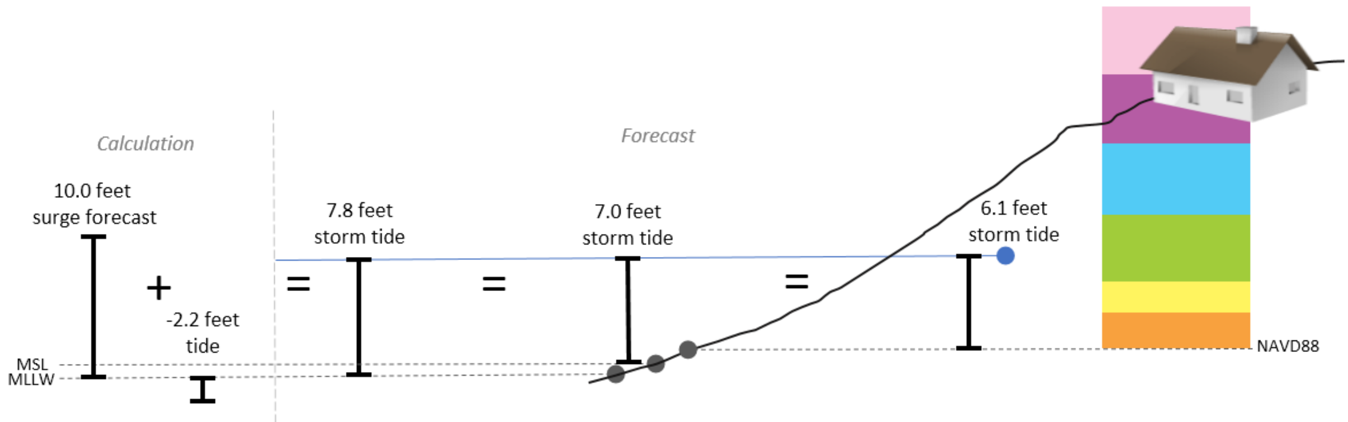

Figure 3. A storm tide level is the sum of the surge forecast and the local tide prediction. For example, a storm surge forecast (10.0 feet MLLW) may be added to the local tide prediction at the projected time of landfall (2.2 feet below MLLW) to calculate the storm tide at peak surge (7.8 feet above MLLW). This same storm tide value may be reported in many ways: 7.8 feet above MLLW, 7.0 feet above MSL or 6.1 feet above NAVD88. With the table in this report, these calculations (or additional setup/wave runup factors) can be simplified to "water levels that correspond to local elevations highlighted in green."

Recommendations

This pilot work will be available in time for the peak of the 2014 coastal storm season. If used, feedback from local leaders and NWS staff will determine if this work is appropriate to extend to additional communities in Alaska. If this approach is continued, maps may be updated as existing datasets are improved and new products become available.

An additional use for these maps is to share knowledge about what colors corresponded to the peak water levels in different parts of a community if a flood event does occur. This could provide valuable information to NWS to improve local impact catalogs and verify coastal flood forecasts and warnings.

Ultimately, flood inundation maps can be developed that will replace these stopgap elevation tools. To promote the eventual development of flood inundation products throughout Alaska, an emphasis must be placed on collecting high-resolution (< 1 m ground spacing) elevation and bathymetry measurements in the coastal zone (vertical accuracies of <25 cm are recommended), enhancing tidal predictions and tidal datums, and improving storm surge models with descriptive storm surge recurrence intervals.

Additional Resources

Up-to-date storm surge information may be obtained from NWS advisories, warnings, and situational awareness bulletins (http://www.arh.noaa.gov/). For more technical users, storm surge and storm tide guidance is available for selected parts of Alaska from the NWS Meteorological Development Laboratory's Extra-tropical Water Level website (http://www.nws.noaa.gov/mdl/etsurge/).

We strongly encourage residents in small coastal communities to adopt and update a FEMA-approved Local Hazard Mitigation Plan and to review the Alaska Division of Homeland Security & Emergency Management (DHS&EM)'s 2013 *Alaska Emergency Response Guide for Small Communities*, which includes checklists, recommendations, and resources for local emergency managers. An additional way to prepare your community for future storm events is to adopt a Small Community Emergency Response Plan (SCERP). For additional information or to obtain a SCERP toolkit, please contact the Alaska DHS&EM.

Acknowledgments

This publication has been prepared on an expedited timeline so that it may be an available resource in the 2014 fall storm season. Development and production of the color-indexed maps was completed by Timothy Tschetter (DGGS/UAF). Accompanying text and figures were prepared by Nicole Kinsman (DGGS), Timothy Tschetter, and Aimee Fish (NWS).

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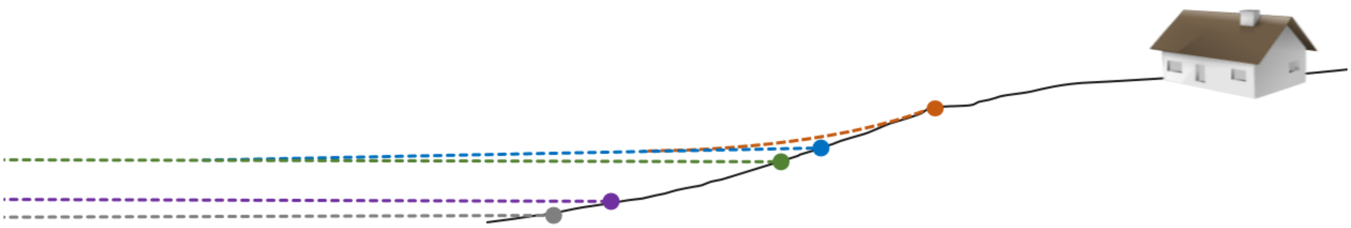
The authors extend their gratitude to participants in the community outreach meeting on September 9, 2014: Steve Ivanoff (Unalakleet); Zena Barr, Howard Weyiouanna, and Willard P. Jones (Shishmaref); Toby Anungazuk, Jr., Carol Oliver, and Jack Fagerstrom (Golovin); Isabelle Jackson, Edgar Jackson, and Edna Savetilik (Shaktoolik); and Millie Hawley (Kivalina). We also appreciated input from the NWS Fairbanks Weather Forecast Office. Matt Nolan (Fairbanks Fodar) expedited data collection, processing, and delivery for updated DEM and imagery needs over Unalakleet and Shaktoolik. John Lingaas (NWS) and David Williams (U.S. Army Corps of Engineers) generously provided their time to review this publication and their comments have greatly improved the final content.

Appendix 1. Useful Definitions

Types of Water Levels

Many factors, including tides, atmospheric pressure, waves, and wind combine during an extreme storm to elevate water levels at the coast. Forecasters and scientists have specific names to describe each component that elevates the water level, and some components are more difficult to calculate than others. When all of these components are added together, the result is a prediction of the total water level at a particular location.



<table>
<tr><th colspan="3">COASTAL STORM WATER LEVEL COMPONENTS</th><th>Full Definition</th><th>How Determined</th><th>Easy Explanation</th></tr>
<tr><td colspan="3">Mean Sea Level</td><td>The average height of all water levels in a local area under normal conditions</td><td>Tide gauge</td><td>This is where the water level is usually located</td></tr>
<tr><td>Tide Level</td><td rowspan="2">Storm Tide Level</td><td rowspan="3">Total Water Level</td><td>Regular variation in the water level caused by sun/moon gravitational forces and the earth’s rotation</td><td>Tidal predictions modeled by NOAA</td><td>This includes both high and low tide levels under normal weather conditions</td></tr>
<tr><td>Storm Surge</td><td>Elevated ocean levels that arise from a combination of onshore-directed wind stresses and reduced atmospheric pressure</td><td>Forecasted by regional NWS ocean models</td><td>This is the overall rise in the open ocean water level due to storm conditions</td></tr>
<tr><td colspan="2">Nearshore Setup</td><td>An increase in water level due to waves and the shoreward transport of water</td><td>Calculated or modeled based on local conditions and typical storm characteristics</td><td>An additional rise in the water level along open coastlines during a storm as waves ‘pile up’ against the shore</td></tr>
<tr><td colspan="3">Wave Runup</td><td>The maximum height breaking waves can reach on a shoreface</td><td>Calculated or modeled based on local conditions and typical storm characteristics</td><td>Breaking waves have extra energy that can cause the water to rush up even higher in some locations. This is an elevation where your feet may be splashed but you are not standing in water.</td></tr>
</table>

Vertical Reference Frames (Datums)

Vertical reference frames that are included on the conversion table have been selected based on their applicability to emergency response needs in the coastal zone. These datums, their primary uses, and definitions are summarized below.

<u>Mean Lower Low Water (MLLW) – in feet</u>

Commonly used:
- by NWS forecasters
- on NOAA nautical charts (depths)
- to define the landward edge of United States waters

Simple definition: The average height of the lowest water levels in a local area

Formal Definition: Average of the lower low water height of each tidal day observed at a tide station over a 19-Year National Tidal Datum Epoch or a Modified 5-Year Epoch. For stations with shorter series (1–3 months is common in Alaska), comparison of simultaneous observations with a control tide station is made in order to derive the equivalent Modified or National Tidal Datum Epoch.

<u>Mean Sea Level (MSL) – in feet and meters</u>

Commonly used:
- to report NOAA tide predictions
- by coastal scientists and modelers

Simple definition: The average height of all water levels in a local area

Formal Definition: The arithmetic mean of hourly heights observed over a 19-Year National Tidal Datum Epoch or a Modified 5-Year Epoch. Shorter series (1–3 months is common in Alaska) are specified in the name; for example, monthly mean sea level and yearly mean sea level.

<u>North American Vertical Datum of 1988 (NAVD88) – in feet and meters</u>

Commonly used:
- on topographic maps
- by land surveyors and engineers

Simple definition: The standard for land elevations in the United States

Formal Definition: A standardized geodetic datum based on orthometric height (a height above the geoid or equipotential gravitational reference surface that approximates an idealized global sea surface). Orthometric heights may be determined by combining a measured height above the ellipsoid surface with a model of the geoid. NAVD88 elevations are obtained in this manner by combining the vertical component of the NAD83 ellipsoid, which can be measured using a GPS receiver or though differential leveling, with GEOID12A (the best available geoid model).

Appendix 2. Technical Documentation on Map Preparation

Table of Color-Indexed Map Products (Sheets)

Shishmaref	Shishmaref Numerical Elevation Table 1 Color-Indexed Shishmaref Community Map Sheet 1 Color-Indexed Shishmaref Community Map Sheet 2 Color-Indexed Shishmaref Area Use Map Sheet 3
Kivalina	Kivalina Numerical Elevation Table 1 Color-Indexed Kivalina Community Map Sheet 1 Color-Indexed Kivalina Area Use Map Sheet 2
Unalakleet	Unalakleet Numerical Elevation Table 1 Color-Indexed Unalakleet Community Map Sheet 1 Color-Indexed Unalakleet Community Map Sheet 2 Color-Indexed Unalakleet Community Map Sheet 3 Color-Indexed Unalakleet Area Use Map Sheet 4
Shaktoolik	Shaktoolik Numerical Elevation Table 1 Color-Indexed Shaktoolik Community Map Sheet 1 Color-Indexed Shaktoolik Community Map Sheet 2 Color-Indexed Shaktoolik Area Use Map Sheet 3
Golovin	Golovin Numerical Elevation Table 1 Color-Indexed Golovin Community Map Sheet 1 Color-Indexed Golovin Community Map Sheet 2 Color-Indexed Golovin Area Use Map Sheet 3

Table of Best Available Data

Component	Format	Source	Date
SHISHMAREF			
Community and Area Maps (3)	Annotated aerial imagery	DCRA, 2014	2004
Digital Elevation Model	Interpolated lidar point-cloud	NOAA and others, 2004	2004
Tidal/Geodetic Datum Conversion	Measured offset	CO-OPS/NGS (NOAA, 2014)	2003
KIVALINA			
Community and Area Maps (2)	Annotated aerial imagery	DCRA, 2014	1999
Digital Elevation Model	Interpolated lidar point-cloud	NOAA and others, 2004	2004
Tidal/Geodetic Datum Conversion	Measured offset	CO-OPS/NGS (NOAA, 2014)	1986
UNALAKLEET			
Community and Area Maps (4)	Linework and annotations	DCRA, 2014	2004
Updated Imagery	Aerial imagery	DGGS (in production)	2014
Digital Elevation Model	Digital photogrammetry	DGGS (in production)	2014
Tidal/Geodetic Datum Conversion	Measured offset	CO-OPS/NGS (NOAA, 2014)	2011
SHAKTOOLIK			
Community and Area Maps (3)	Linework and annotations	DCRA, 2014	2004
Updated Imagery	Aerial imagery	DGGS (in production)	2014
Digital Elevation Model	Digital photogrammetry	DGGS (in production)	2014
Tidal/Geodetic Datum Conversion	Measured offset	CO-OPS/NGS (NOAA, 2014)	2010
GOLOVIN			
Community and Area Maps (3)	Annotated aerial imagery	DCRA, 2014	2004
Digital Elevation Model	Interpolated lidar point-cloud	DGGS (in production)	2013
Tidal/Geodetic Datum Conversion	Estimated offset	DGGS (unpublished)	2013

Vertical Datum Offset Calculations

The local transformations between the geodetic and tidal datums presented below have been calculated using shared orthometric heights of a tidal benchmark in combination with local tidal station datum elevations from the 1983–2001 National Tidal Datum Epoch (fig. 4; NOAA, 2014; DGGS, 2014).

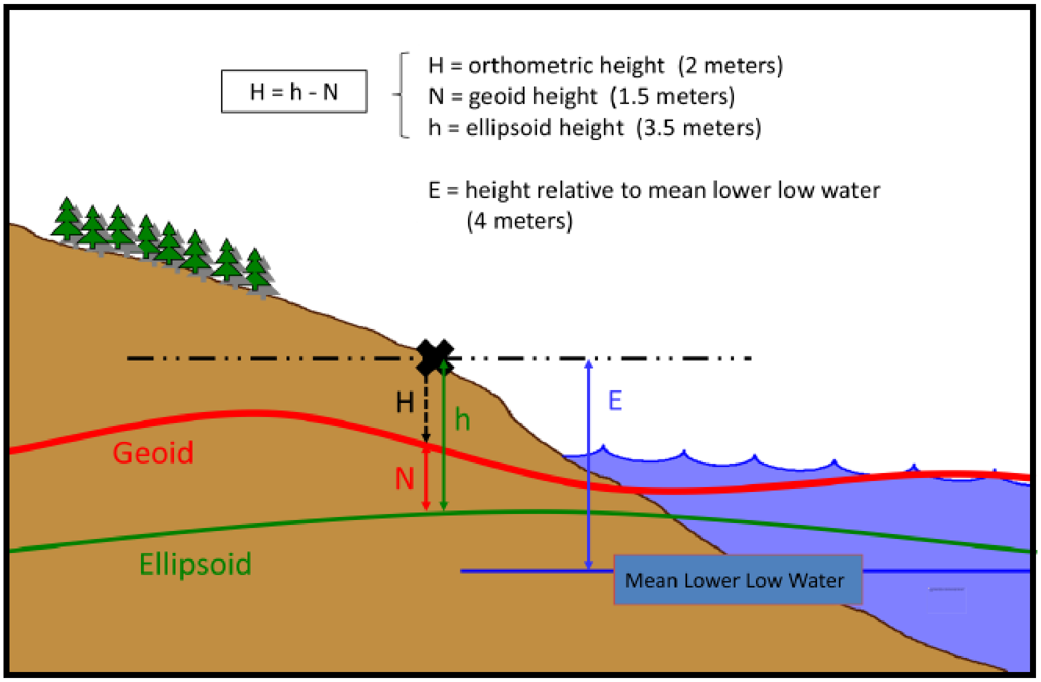


Figure 4. Graphical explanation of how sole-station offset transformations are calculated. Elevations obtained using this method are only valid in the immediate vicinity of the original tide station (Re-captioned illustration from NPS, 2011).

Tidal station and benchmark used to generate datum conversion values

Location Name	Tide Station ID	Tidal datum analysis period	Benchmark used for vertical control		NAVD88 orthometric height source
			Stamping	NGS Position ID (PID)	
Shishmaref Inlet 2	9469854	09/01/2003 – 09/30/2003	946 9854 B	BBBH56	Shared OPUS solution 9/20/2003
Kivalina	9491253	09/06/2003 - 09/27/2003	(unstamped)	BBBH52	Shared OPUS solution 10/5/2003
Unalakleet	9468333	07/01/2011 - 08/31/2011	8333 H 2011	BBCK34	Shared OPUS solution 6/22/2011
Shaktoolik	9468691	07/15/2010 - 08/23/2010	8691 A 2010	BBBZ37	Shared OPUS solution 7/16/2010
(Golovin)	n/a	07/07/2012- 08/07/2012	USLM 3651 1970	BBDJ67	Shared OPUS solution 7/27/2013

Sources and Accuracies of Component Data - Shishmaref

Community and Area Maps

The DCRA basemaps were prepared in 2004 using an orthorectified aerial photo taken June 11, 2004. Property and utility data information was generated by Kawerak Inc. from readily available sources that were current as of December 2004.

Digital Elevation Model

The best available DEM for this community was derived from a lidar survey conducted in July and August 2004 by the NOAA Coastal Services Center (NOAA, 2004). The native spatial reference system for this dataset is NAD83, with vertical coordinates defined by the GRS80 ellipsoid. The lidar point cloud contains only last returns with vertical point accuracies of 30 cm RMSE or better.

Confidence Comments

There is a spurious curvilinear offset in the lidar-derived DEM of less than 1 m in the vertical that runs approximately parallel to the open ocean coastline of Sarichef Island (see location in fig. 5). Colored elevations in close proximity to these blunders should be used with caution. The DEM coverage is incomplete over Sarichef Island on the DCRA maps; these gaps in coverage are shown as uncolored areas along the shoreline.

Elevation intervals on the map are derived from 2004 source data. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

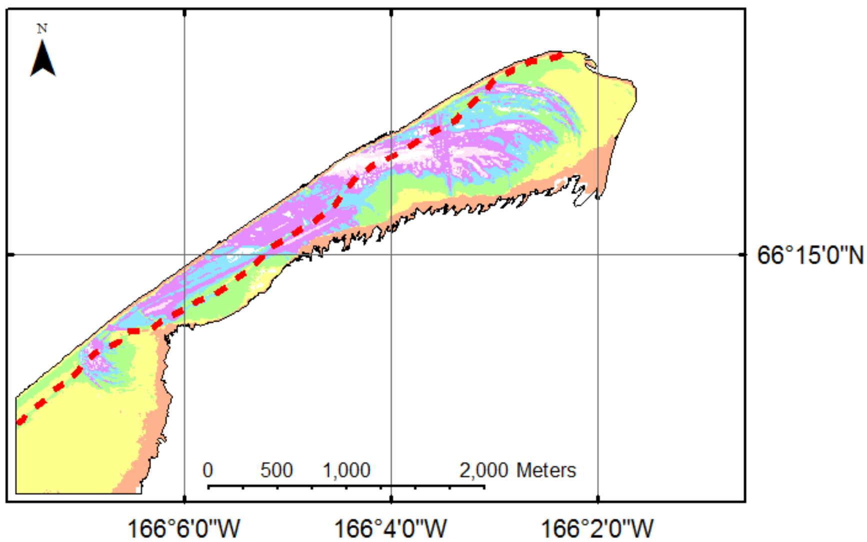


Figure 5. Dashed red line indicates location of a vertical offset error in the lidar data for this area.

Notable Recent Changes:

- An engineered rock revetment was constructed (from 2008 through 2010) along the open ocean side of Sarichef Island (see fig. 6).

Highlighted Infrastructure:

- Shishmaref High School
- Church evacuation center

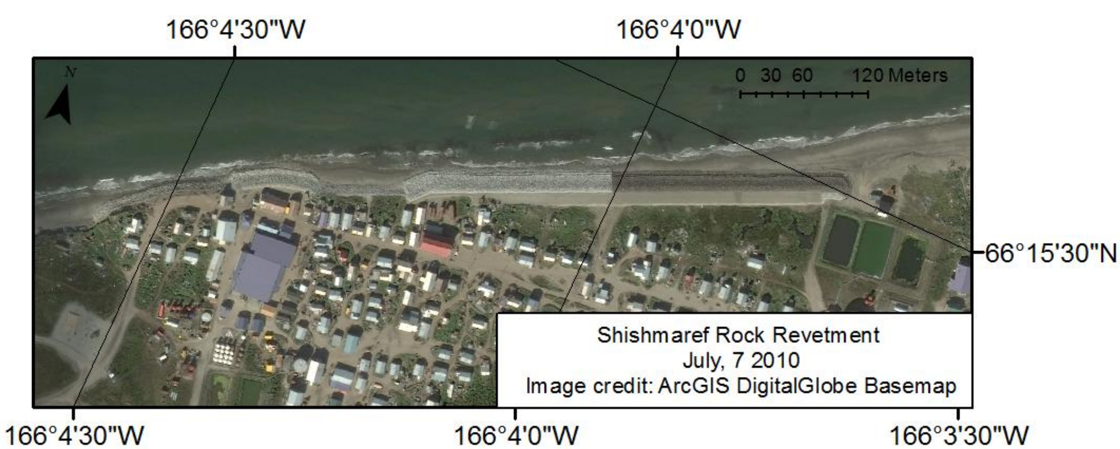


Figure 6. Aerial Image of the rock revetment that is not included in the DEM or basemap imagery.

Sources and Accuracies of Component Data — Kivalina

Community and Area Maps

The DCRA basemaps were prepared in 1999 and an update is currently underway. For this project, the maps have been updated with an orthorectified aerial photo taken in 2013. Property and utility data information was generated from readily available sources that were current as of November 1999.

Digital Elevation Model

The best available DEM for this community was derived from a lidar survey conducted in July and August 2004 by the NOAA Coastal Services Center (NOAA, 2004). The native spatial reference system for this dataset is NAD83, with vertical coordinates defined by the GRS80 ellipsoid. The lidar point cloud contains only last returns with vertical point accuracies of 30 cm RMSE or better.

Confidence Comments

There is a small offset in the lidar-derived DEM of less than 1 m in the vertical that runs approximately perpendicular to the open ocean coastline of Kivalina on the western edge of the Area Use figure (see location in fig. 7). Colored elevations in close proximity to these blunders should be used with caution. The DEM coverage is incomplete over the land area depicted on the DCRA maps; these gaps in coverage are shown as uncolored areas along the shoreline.

Elevation intervals on the map are derived from 2004 source data. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

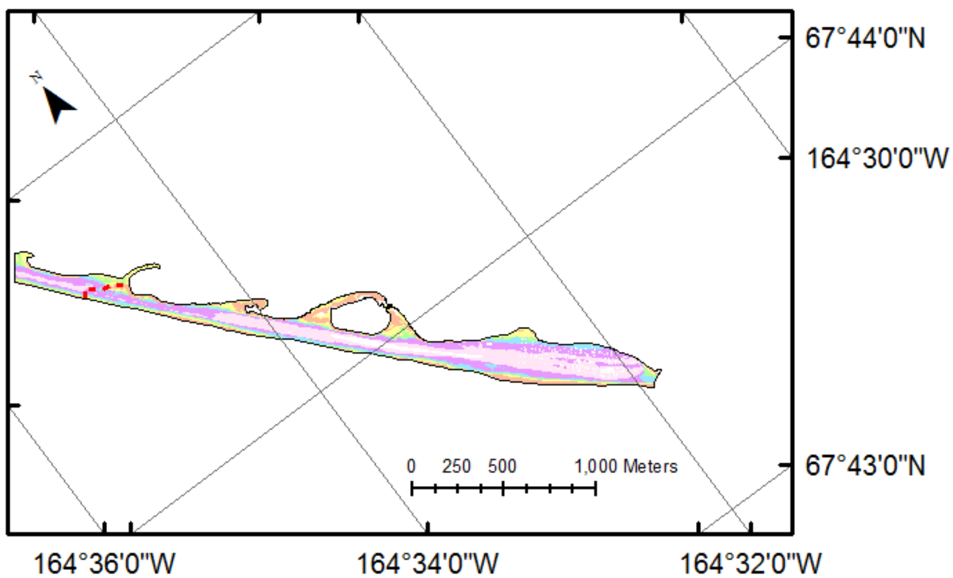


Figure 7. Dashed red line indicates location of a vertical offset error in the lidar data for this area.

Notable Recent Changes:

- An engineered rock revetment was constructed beginning in 2006 on the southeastern end of the island. This structure is visible in the 2013 basemap imagery but is not included in the best available elevation dataset.
- Ongoing coastal processes have reshaped the sand spit at the eastern end of the island.

Highlighted Infrastructure:

- McQueen School
- School tank farm
- AVEC tank farm

Sources and Accuracies of Component Data — Unalakleet

Community and Area Maps
The DCRA basemaps were prepared in 2004 using an orthorectified aerial photo taken June 27, 2004. For this project, the maps have been updated with an orthorectified aerial photo taken September 21, 2014. Property and utility data information was generated by Kawerak Inc. from readily available sources, and was current as of December 2004.

Digital Elevation Model
The best available DEM for this community was derived from an aerial survey contracted in September 2014 by DGGS. The elevation data was generated by Fairbanks Fodar using a Structure from Motion photogrammetric approach. The native spatial reference system for this dataset is WGS84, with vertical coordinates in NAVD88. The vertical accuracy is estimated to be 25 cm RMSE or better in areas without dense vegetation.

Confidence Comments
The photogrammetric technique used to generate this DEM is in an experimental phase at DGGS; it is being tested for a range of applications in the coastal zone. Preliminary assessment of the DEM surface showed good agreement with 2011 DGGS ground control and with known past flood levels. This DEM is a significant improvement over a 2005 lidar-derived surface that predated the construction of an engineered rock revetment (2010; fig. 8) at the Unalakleet River inlet and the raising (+3 feet or 0.9 meters; 2005) of Beach Front Road.

Elevation intervals on the map are derived from 2014 source data. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

Figure 8. 3-dimensional model view of the Unalakleet revetment looking north from the inlet. (2014 aerial image draped over DEM provided by Fairbanks Fodar, 2014).

Notable Recent Changes:

- None identified in map area at this time.

Highlighted Infrastructure:

- None highlighted at this time.

Sources and Accuracies of Component Data — Shaktoolik

Community and Area Maps

The DCRA basemaps were prepared in 2004 using an orthorectified aerial photo taken June 27, 2004. For this project, the maps have been updated with an orthorectified aerial photo taken September 21, 2014. Property and utility data information was generated by Kawerak Inc. from readily available sources, and was current as of December 2004.

Digital Elevation Model

The best available DEM for this community was derived from an aerial survey contracted in September 2014 by DGGS. The elevation data were generated by Fairbanks Fodar using a Structure from Motion photogrammetric approach. The native spatial reference system for this dataset is WGS84, with vertical coordinates in NAVD88. The vertical accuracy is estimated to be 25 cm RMSE or better in areas without dense vegetation.

Confidence Comments

The photogrammetric technique used to generate this DEM is in an experimental phase at DGGS; it is being tested for a range of applications in the coastal zone. Preliminary assessment of the DEM surface showed good agreement with 2011 DGGS ground control and with known past flood levels. This DEM is a significant improvement over a 2004 photogrammetric DEM associated with the DCRA contour elevations that was very coarse, did not cover critical areas along the evacuation route, and did not reflect recent changes associated with erosion along the coast.

Figure 9. 3-dimensional model view of the berm project under construction in front of the Shaktoolik School (2014 aerial image draped over DEM provided by Fairbanks Fodar, 2014).

Elevation intervals on the map are derived from 2014 source data. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

Notable Recent Changes:

- The DEM includes a berm along the open-ocean coast that was constructed in 2014 as a locally-led project by Shaktoolik residents (fig. 9).

Highlighted Infrastructure:

- Shaktoolik School
- City fuel tank farm

Sources and Accuracies of Component Data — Golovin

Community and Area Maps
The DCRA basemaps were prepared in 2004 using an orthorectified aerial photo taken June 6, 2004. Property and utility data information was generated by Kawerak Inc. from readily available sources that were current as of December 2004.

Digital Elevation Model
The best available DEM for this community was derived from a lidar survey that was conducted in November 2013 and was acquired for release by DGGS in September 2014. The native spatial reference system for this dataset is NAD83 (CORS96), with vertical coordinates in NAVD88 (GEOID09). The vertical point accuracies of the last returns are 35 cm RMSE or better.

Confidence Comments
The DEM coverage is incomplete over the area shown in the Golovin Area Use Map Sheet 1. The areas without elevation data are shown as uncolored areas of the map. There is no DEM coverage over the area shown in the Golovin Area Use Map Sheet 2.

There is no published tidal datum for Golovin, Alaska. The presented tidal elevations are an approximation based on water level measurements conducted by DGGS in 2012.

Elevation intervals on the map are derived from 2013 source data. Temporal changes, human or naturally induced, could have occurred that would cause the elevations depicted on these map figures to no longer represent actual surface conditions.

Notable Recent Changes:

- Prior to the 2013 storm season, a local short-term project resulted in the construction of a temporary levee along Antone Street, which is frequently overtopped by flood waters (see fig. 10).

Figure 10. Temporary levee project from fall 2013 (photo by Carol Oliver, 2013).

Highlighted Infrastructure:

- M.L. Olson School
- Power plant
- City fuel tank farm
- Health clinic

Production Process Steps

Adapted from the methods presented in the Coastal Inundation Mapping Guidebook and other inundation map recommendations (NOAA, 2009; NOAA 2010).

1. Digital Elevation Model
   A. Lidar-derived DEM source lidar processed during acquisition with automated tools available from the NOAA Digital Coast Data Access Viewer
      i. Output projection and/or datum transformation: NAD83, UTM (horizontal), NAVD88 (vertical)
      ii. Output format: 2 m, 32-bit GeoTiff raster derived from a minimum interpolation of the raw point cloud with small gap filling
   B. Elevation data derived from Structure from Motion (SFM) approach (Unalakleet and Shaktoolik) are 18 to 19 cm raster products (WGS84)
      i. Datum transformation: NAD83, UTM (horizontal), NAVD88 (vertical)
   C. Raster DEM → Elevation-based polygon areas (ArcGIS processing)
      i. Reclassified continuous elevation raster into discrete elevation bins. Elevation bin spacing was selected to create evenly spaced colored intervals throughout the entire community, not just areas prone to inundation.
      ii. Smoothed edges of binned elevation raster using three iterations of the 'Majority Filter' function in ArcGIS. The input parameters (numbers of neighbors to use and replacement threshold) for the successive runs of the majority filter were eight and half, eight and half, and eight and majority.
      iii. Converted binned elevations to polygon layer.
      iv. Clipped elevation polygons to shoreline position.
      v. Clipped elevation polygons around buildings and infrastructure, and inland water bodies, as appropriate
2. Aerial Photographs (1:9,600 scale; 1:6,000 and 1:14,400 for Kivalina; 9 cm resolution for Unalakleet and Shaktoolik)
   A. Orthorectified aerial images acquired from DCRA (Alaska State Plane, NAD83)
   B. Reprojected to NAD83, UTM
3. DCRA Maps (source ungeoreferenced PDF)
   A. The community maps were produced using only a subset of DCRA text and linework to improve legibility. Text or linework not pertaining to buildings, utilities, landmarks, or prominent local features were removed when possible. Text and linework seen in the Area Use Map were not changed.
   B. Manually georeferenced DCRA text and linework were transferred to aerial photographs.

Note: The rasters used to generate the elevation polygons in this study are a derived lidar point-cloud product, therefore the vertical accuracy of this surface is not better than the vertical accuracy of the original point returns. Sparse, low vegetation combined with the low-relief terrain is a favorable environment for interpolated lidar DEMs and a 'minimum' interpolation was used to produce low-biased surfaces. A comparison of stable areas in Shishmaref (such as the runway surface) revealed vertical differences of no more than 60 cm when compared to the interpolated raster (n=5).

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