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METHODS FOR EVALUATING COASTAL FLOOD IMPACTS IN ALASKA COMMUNITIES

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Alaska Division of Geological & Geophysical Surveys
3354 College Rd., Fairbanks, Alaska 99709-3707
Phone: (907) 451-5010 Fax (907) 451-5050
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METHODS FOR EVALUATING COASTAL FLOOD IMPACTS IN ALASKA COMMUNITIES

Keith C. Horen[1], Autumn C. Poisson[1*], Jessica E. Christian[2], and Nora M. Nieminski[1]

INTRODUCTION

This report provides a standardized methodology for coastal flood height estimation and flood impact assessment in Alaska. It is a necessary supplemental that clarifies and expands upon the State of Alaska Division of Geological & Geophysical Surveys (DGGS) Report of Investigation (RI) 2021-1 (Buzard and others, 2021). These evaluations utilize community-specific, high-quality baseline data, and although the availability of these data varies by community, the methods described here provide a generalized analysis that accounts for data quality. This publication supersedes the Methods section and modifies the Community-Specific Products section of RI 2021-1 (Buzard and others, 2021) to provide greater consistency among future reports.

INFORMATION AND DATASETS

Coastal flood height estimation and flood impact assessment in Alaska require a variety of geospatial, quantitative, and qualitative information. Prior to this update, first-floor (or finished floor) height data were not available in most rural Alaska communities. The Alaska Native Tribal Health Consortium (ANTHC) and DGGS have recently collected these data in multiple communities, making it possible to use these data for flood height estimate and flood impact category analysis. The following list includes an expanded description of this new dataset, as well as information and datasets previously mentioned in RI 2021-1 (Buzard and others, 2021).

Data requirements include:

- First-floor height data: the surveyed heights of community infrastructure, including residential structures, schools, community buildings, power facilities, drinking water sources, and waste sites.
- High-resolution elevation datasets: digital elevation models (DEM), in the form of digital surface models (DSM) or digital terrain models (DTM), derived from data collected using uncrewed aerial system (UAS) or light detection and ranging (lidar) instruments.
- High-resolution orthoimagery: orthometrically corrected images, derived from high-resolution elevation data and photogrammetry, ideally spanning the time period that corresponds to a given flood event.
- Written, oral, and/or measured documentation of flood events: accounts from community members; reports from the National Weather service (NWS) or other agencies; and/or high-water mark (HWM), water level sensor, flood staff, and/or photographic data. These data are most useful if they describe or depict inundation as it relates to identifiable infrastructure.
- Tidal datums: data describing the tidal range and characteristics specific to each community geodetically tied to the North American Vertical Datum 1988 with Geoid 12B applied (NAVD88 [GEOID12B]) orthometric height.

HISTORICAL FLOOD HEIGHT ESTIMATES

Historical flood heights may be estimated from a variety of sources and observation types. Some observations can be difficult to interpret and convert to quantifiable flood heights and impacts, so all details used to create estimates and their associated uncertainties are recorded in the Histor-

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[1] Alaska Division of Geological & Geophysical Surveys, 3651 Penland Pkwy, Alaska 99508

[2] Alaska Division of Geological & Geophysical Surveys, 3354 College Rd., Fairbanks, Alaska 99709

* *Now at Dewberry, 8401 Arlington Blvd., Fairfax, Virginia 22031*

ical Flood Record section of community-specific reports, with additional information provided, when necessary, as an appendix. To be quantifiable for these assessments, an observation must describe or depict flooding in a way that can be measured using ground or infrastructure heights. For example, if a source reported the height of water at a road intersection, the height of that intersection may be measured from a DEM or through a Global Navigation Satellite System (GNSS) survey observation. If there are not enough specific details or data available to estimate a flood height for a particular event, a flood impact categorization may still be possible based on narrative information alone.

Calculating Flood Height Estimates

Multiple sources of data may be available for a given flood event; when this is the case, we rank flood height evidence by confidence level based on the source data type. We use these rankings to identify the single best available data type from which to generate an estimate. These data rankings, listed from most to least confidence, are as follows:

1. Data from a water level sensor or surveyed observations of physical HWM evidence as described by Koenig and others (2016).
2. Photographs, written accounts, or verbal accounts that correspond to specific infrastructure that can be related to first-floor height data or a GNSS observation and describe or depict an identifiable water height.
3. Photographs, written accounts, or verbal accounts that describe or depict a water height unrelated to specific infrastructure but identifiable from a DEM.
4. Written or verbal accounts that correspond to specific infrastructure impacts but lack an identifiable water height.

Photographic, written, or verbal evidence of flooding that describes or depicts an identifiable water height as it relates to specific infrastructure can be estimated using first-floor height data or GNSS observations collected during field investigations (confidence rank 2). If a field visit to collect GNSS observations is not possible, we use the bathtub method described by Poulter and Halpin (2008) to make estimates using photographic evidence or an account that describes an identifiable water height without a corresponding first-floor height (confidence rank 3). This method is commonly used to simulate inundation extent (Moorhead and Brinson, 1995; Titus and Richman, 2001) and uses a high-resolution DEM to model water heights to match the identifiable water height described or depicted. In the absence of an identifiable water height, written or verbal accounts of impacts to infrastructure may be used, in conjunction with first-floor height data, to estimate a flood event (confidence rank 4).

Water level sensor and flood reporting data density can be sparse throughout rural Alaska, often resulting in a single sensor reading or reported infrastructure impact (such as a reading from a water level sensor on a bridge), but whenever possible, we seek to compile multiple instances of evidence for each flood event. If more than one data point of the same source data type is available, we use the average of these data as the basis for our flood height estimate. For example, we would average the measured heights of multiple HWM from a given flood event. In the case of estimates generated through the bathtub method, a model is created from each photograph or account, the results of which are averaged (confidence rank 3).

If data points of different source data types are available, we use only the data of the highest ranked source data type during estimating but may use additional evidence to corroborate results. For example, if water level sensor data (confidence rank 1) and photographic evidence are both available for a flood event, the water level sensor data would be used for estimation, though the photographic evidence may be used to verify the estimate using a bathtub model (confidence rank 3).

It is possible for a description or depiction of flooding to necessitate the use of more than one source data type; in such cases we provide a detailed explanation in the Historical Flood Record section of community-specific reports describing why and how these source data types were used. For example, an event narrative might state, "flood waters reached the Post Office," but not specify how water height relates, if at all, to the first-floor height of the building affected. For this flood event, we might use the first-floor height of the Post Office as an upper bound and the average ground height beneath the building extracted from a DTM as a lower bound for the estimated flood height (confidence level 4).

Final flood height estimates are reported in the local Mean Higher High Water (MHHW) vertical datum, where available, in both feet (ft) to the nearest tenth of a foot and meters (m) to the nearest hundredth of a meter. In most locations in Alaska, data collected or reported in a non-tidal datum other than NAVD88 (GEOID12B) must first be converted to this orthometric datum before being converted to a tidal datum. This is due to a lack of tidal datum model coverage for much of Alaska in the National Oceanic and Atmospheric Administration (NOAA) Vertical Datum Transformation (VDatum) software. Once data are converted to the NAVD88 (GEOID12B) datum, the specific tidal datum offsets for the local tide station, provided by the NOAA Center for Operational Oceanographic Products and Services (CO-OPS), where available, are used to convert data to the local MHHW datum. Some locations may have established tidal datums not tied to the NAVD88 (GEOID12B) datum; in such cases, the Alaska Tidal Datum Portal (dggs.alaska.gov/hazards/coastal/ak-tidal-datum-portal.html) may be used for conversions.

Calculating Confidence

Estimate confidence is derived from potential methodological and systemic sources of error. These errors manifest from the accuracies, precisions, and uncertainties of data.

Terminology

For the purposes of flood height estimation, DGGS uses the following definitions for common terms related to error and confidence:

- **Confidence** is the assessed reliability of a measured or calculated value.
- **Error** is any deviation from a true or calculated value.
- **Accuracy** is the degree to which a measurement or set of measurements conforms to a true or calculated value.
- **Precision** is the degree of reported exactness among measured or calculated values.
- **Uncertainty** is the range of potential values of a measured or calculated value.

DGGS calculates flood height estimate uncertainty in one of two ways depending on the number of measurements or observations used during estimation. For an estimate derived from a single data point, the accuracy and, if applicable and available, the precision of the source data serves as the estimate uncertainty. For an estimate derived from two or more data points, the upper--lower bounds method (UNC, 2018) is used to calculate the estimate uncertainty. This process uses the highest and lowest reasonable values of a dataset to define the total potential range within which an estimate might fall, with the uncertainty being the maximum difference between the average of all values and the bounds of the range.

Error should be assessed only as it becomes relevant to the process being performed. The way in which errors contribute to the confidence of an estimate is reliant on their relationality to each other. For the purposes of calculating estimate confidence, DGGS uses the following definitions of error types, presented in the order in which they should be applied:

- **Cumulative Errors** are exclusive to only one data point but are either not of the same type or not from the same source. For example, when two measurements must be added together to produce a single value, their individual errors must also be added together.
- **Interdependent Errors** apply to separate data points but are of the same type, related to each

other through procedure. For example, when averaging a set of values, the individual errors associated with each of those values must also be averaged.

- **Discrete Errors** are independent from other sources of error but are equally applicable to the full dataset. For example, when applying a datum conversion using an offset value, the conversion error would be the same for the entire dataset.

Estimate Confidence

To account for other sources of potential error, DGGS combines the estimate uncertainty with the discrete errors associated with the type of data source(s) used during estimation by applying the root-sum-square (RSS) method as described by the National Aeronautics and Space Administration (NASA, 2010). The errors considered for each data source type are as follows:

- Water level sensor data include the manufacturer-reported accuracy and precision of the sensor, the survey accuracy achieved during installation, and, if applicable and available, the accuracy of observations taken during installation.
- HWM include the survey accuracy achieved during collection and, if applicable and available, the accuracy of the observations collected. This may include data based on matching written, verbal, or photographic evidence during field investigations.
- First-floor height surveys include the survey accuracy achieved during collection and, if applicable and available, the accuracy of the observations collected.
- Data extracted from a DEM include the reported accuracy of the model from which the DEM is derived, the survey accuracy achieved during model data collection, and, if applicable and available, the accuracy of the observations gathered during model data collection.

For datasets that include individual accuracies for each data point (e.g., post-processed GNSS observations), DGGS averages those accuracies to create a single relative accuracy for the dataset. Additionally, individual data points based on written or verbal accounts may be assigned added uncertainty corresponding to the precision of the measured and/or reported depth or height. This uncertainty should be considered a component of the cumulative accuracy of each individual data point and is applied before calculating the relative accuracy of a dataset. It is determined using the following guidelines and examples:

- A report of depth or height is considered confident to within one-half of the precision (i.e., the number of digits given) of the measured value provided in the reported units. For example, a data point derived from a report reading “water reached a depth of 3 feet” would have an added uncertainty of ± 0.5 ft, while a data point derived from a field measurement recorded to the tenth of a meter would have an added uncertainty of ± 0.05 m.
- A report of height directly related to a permanent, identifiable reference point would not be assigned additional uncertainty. For example, a data point derived from a report reading “water rose to the second step at the front of the school” would only be subject to the systemic errors of the source data type.

All analyses should be performed in the reported vertical datum and units of the data being analyzed unless the data have been measured or reported in more than one datum and/or unit, in which case all data should be converted to the datum and units of the data with the greatest reported precision to minimize errors due to rounding. Vertical datum and/or unit conversions for the purpose of reporting are only performed after the completion of analysis. For example, a mix of GNSS observations collected in the North American Datum 1983 (NAD83[2011]) in U.S. survey feet (USFT) recorded to the hundredth of a foot and the NAVD88 (GEOID12B) datum in meters recorded to the thousandth of a meter would be converted to the NAVD88 (GEOID12B) datum reported to the thousandth of a meter for the purposes of analysis. The results derived from these data would then be converted to the local MHHW datum in feet to the tenth of a foot and, separately, in meters to the hundredth of a meter for inclusion in the community-specific report.

Temporal Confidence

Finally, it is important to note ground surface elevation change from differential movement (thaw settlement and frost heave) is common in undisturbed permafrost environments (figs. 1 and 2; O'Neill, 2023; Streletskiy and others, 2016) and beneath infrastructure situated on permafrost (Golder Associates Inc., 2011; AECOM, 2016). Typical foundation types and the frequency of structural releveling prevalent in many rural Alaskan communities (Golder Associates Inc., 2011; AECOM, 2016) necessitates some form of time-dependent confidence be applied when evaluating the relationship of nonconcurrent height data.

Streletskiy and others (2016) found an average year-to-year vertical change of -0.008 m (-0.03 ft) across four study sites in Utqiagvik, Alaska, between 2003 and 2015. Though the average vertical change calculated by Streletskiy and others (2016) demonstrates a general negative trend in ground surface elevation over the course of the study, a broader look at the data reveals an average minimum and maximum vertical change of -0.127 m (-0.42 ft) and +0.070 m (+0.23 ft), respectively, over the 12-year period. The inconsistency of year-to-year averages and large overall range of those averages are illustrative of highly dynamic short-term vertical change in permafrost environments. This observation is bolstered by the findings of O'Neill and others (2023) who gath-

Figure 1. (Left) Photograph of local residents releveling a home in Kipnuk, Alaska. Photo: Golder Associates Inc.. (Right) Photograph of a structure's foundation footers affected by thaw settlement in Kipnuk, Alaska. Photo: AECOM.

Figure 2. (Left) Photograph of a boardwalk affected by frost heave in Chefornak, Alaska. Photo: DGGS. (Right) Photograph of a home affected by thaw settlement in Tuntutuliak, Alaska. Photo: DGGS.

ered ground surface elevation data across multiple locations characterized by extensive continuous and discontinuous permafrost in Northwest Canada from 1991 to 2018. These data are indicative of a similar year-to-year inconsistency in vertical change with results ranging from -0.261 m (-0.86 ft) to +0.131 m (+0.43 ft) across 49 study locations over the 27-year period.

Based on our interpretation of the results of Streletskiy and others (2016) and O'Neill and others (2023), we developed a time-dependent confidence metric. From Streletskiy and others (2016), who provided average elevations only, we divided the range of average year-to-year vertical change by the time-series length in years: 0.65/12 = 0.05 ft/yr (0.197/12 = 0.016 m/yr). From O'Neill and others (2023), who provided discrete elevation data points, we divided the overall range of year-to-year vertical change by the time-series length in years: 1.29/27 = 0.05 ft/yr (0.392/27 = 0.015 m/yr). To determine this temporal confidence, the following formula derived from the average of these two analyses is applied (equation 1):

$$\begin{array}{ll} c_t = \pm\, 0.05t, & t \leq 20.0 \\ \multicolumn{2}{c}{\text{or}} \\ c_t = \pm\, 0.016t, & t \leq 20.0 \end{array} \qquad (1)$$

where c_t is the temporal confidence in feet (or meters) for time-period t. The temporal confidence at any particular site may exceed the value the confidence model predicts, particularly if a there is a large temporal discontinuity between the data used and the event being estimated. For this reason, estimates derived from data that were collected 20 years or more before or after the event being estimated are identified with an asterisk (*) to denote minimal temporal confidence. This metric is not meant to be interpreted as systemic error; it is intended to demonstrate the assessed reliability of an estimate based on the temporal relevance of the data used, functioning as a proxy for potential ground and infrastructure height changes that may have occurred in the intervening time between the date of an event and the collection of the data used to estimate that event. This time-based confidence metric is distinct from the previously discussed methodological and systemic errors, and is applied after all other sources of known potential error have been combined. In this way, the temporal confidence is provided as a contextual assessment of potential unquantifiable environmental errors that may be introduced over time. For this reason, all flood height estimates will include both an estimate confidence based on the combined known errors and a separate, temporal confidence.

Example Flood Estimation Scenario

DGGS travels to a community for a field investigation in 2023. A flood event that occurred in 2010 is identified during interviews with community members. A photograph of the flooding is provided that depicts the height of water in relation to a paint mark on the outer wall of the community store. A community member reports there was "a foot of water" in a shed near their home. A second community member reports water "reached the first step at my back door." Finally, an NWS storm report is reviewed that states "using a tape measure, water measured 9 inches deep inside the FAA garage." No water level sensor or physical HWM data are available in relation to this event. The gathered pieces of evidence all fall within a confidence rank of 2 and represent the available data with the highest confidence.

During the field investigation, DGGS performs a GNSS survey in a NAD83(2011) Universal Transverse Mercator (UTM) horizontal coordinate system and the NAD83(2011) vertical datum reported to the thousandth of a meter. GNSS observations are collected at each of the locations identified. For the evidence at the community store, a GNSS observation of the ground height is collected along with a measurement of 0.83 m from the ground to the height of the water depicted in the photograph using a tape measure. For the evidence at the shed and Federal Aviation Administration (FAA) garage, GNSS observations of the first-floor heights of these structures are collected. For the evidence at the community member's home, a GNSS observation of the height of the step is collected. The GNSS survey is post-processed using an Online Positioning User Service (OPUS) solution with a NAD83(2011) ellipsoid height vertical accuracy of ± 0.017 m (error used in equation 5). Table 1 lists the GNSS observation post-processing results.

Measurement heights and their accuracies are then converted to meters to the thousandth of a meter and added to the post-processed ellipsoid heights (table 2). The data point related to the community store is found to have an unreasonably low value in comparison with the other data, and further investigation reveals the store building was releveled in 2015; this data point is therefore not used during estimation. The remaining three values are averaged (equation 2), and the uncertainty of the result is calculated as the maximum difference between the average value and the upper and lower bounds of the total range of values (equation 3). The relative accuracy of the dataset is calculated as the average of the accuracies of the three data points (equation 4):

$$\bar{z} = \frac{14.256 + 14.252 + 14.263}{3} = 14.257 \tag{2}$$

$$\begin{gathered} u_{\bar{z}} = \pm \max\left(|\bar{z} - z|\right), \qquad 14.252 \le z \le 14.263 \\ u_{\bar{z}} = \pm\, 0.006 \text{ (error used in equation 5)} \end{gathered} \tag{3}$$

$$a_{\bar{z}} = \pm \frac{0.163 + 0.010 + 0.022}{3} = 0.065 \quad \text{(error used in equation 5)} \tag{4}$$

where $\bar{z}$ is the average value, z is any value within the total range of possible values between the upper and lower bounds of the data, $u_{\bar{z}}$ is the calculated uncertainty, and $a_{\bar{z}}$ is the relative accuracy of the dataset.

The flood height estimate is then converted from the NAD83(2011) to the NAVD88

Table 1. Example flood evidence GNSS observation post-processed results. Horizontal and vertical accuracies are calculated by post-processing software that can perform GNSS baseline corrections such as least-squares or network adjustments.

Point ID	Northing	Easting	Ellipsoid Height (m)	Horizontal Accuracy (m)	Vertical Accuracy (m)	Location/Source
3001	6691951.917	628850.605	13.258	0.008	0.012	Store; Photograph
3004	6691954.367	628853.320	13.951	0.008	0.011	Shed; Interview
3012	6691717.119	627662.170	14.252	0.008	0.010	Home; Interview
3040	6691716.617	627664.845	14.034	0.007	0.009	FAA Garage; NWS

Table 2. Example combined GNSS observation and measurement heights. Measurement precision uncertainty is determined according to the methodology for individual data point accuracies described in the Estimate Confidence section.

Point ID	Ellipsoid Height (m)	Post-processed Vertical Accuracy (m)	Additional Measurement Height (m)	Measurement Precision Uncertainty (m)	Combined Height (m)	Combined Individual Accuracy (m)
3001	13.258	0.012	0.830	0.005	14.088	0.017
3004	13.951	0.011	0.305	0.152	14.256	0.163
3012	14.252	0.010	0.000	0.000	14.252	0.010
3040	14.034	0.009	0.229	0.013	14.263	0.022

(GEOID12B) datum using the most recent version of VDatum, which provides an orthometric height of 3.510 m and a conversion uncertainty of ± 0.060 m (error used in equation 5), before it is converted to the MHHW datum using the offset listed for the local CO-OPS tide station, -2.083 m. Thus, the flood height estimate is 1.474 m in the MHHW datum.

Next, all sources of potential error are combined using the RSS method (equation 5):

$$u = \pm\sqrt{a_s{}^2 + u_{\bar{z}}{}^2 + a_{\bar{z}}{}^2 + u_c{}^2} = \pm\sqrt{0.017^2 + 0.006^2 + 0.065^2 + 0.060^2} = \pm 0.090 \quad (5)$$

where u is the total combined uncertainty, a_s is the survey accuracy, $u_{\bar{z}}$ is the calculated uncertainty of the estimate, $a_{\bar{z}}$ is the relative accuracy of the dataset, and u_c is the conversion uncertainty.

Next, the temporal confidence, c_t, is calculated using equation 1:

$$c_t = \pm 0.016\ (2023\text{–}2010) = \pm 0.016\ (13) = \pm 0.208$$

Finally, the estimate, combined uncertainty, and temporal confidence are converted from meters to feet for reporting, making the final result:

	ft MHHW	m MHHW
Flood Height	4.8	1.47
Estimated Confidence	± 0.3	± 0.09
Temporal Confidence	± 0.7	± 0.21

FLOOD IMPACT CATEGORIES

The NWS (2023a) classifies flooding into major, moderate, and minor categories to describe the impacts caused by an event. Definitions in the NWS guidance specific to Alaska are provided in the form of statements regarding flood impacts, some of which are more qualitative than quantitative (NWS, 2023a), prompting us to develop our own quantifiable criteria. For these purposes, "flooding" is defined as any amount of water above the given feature height (e.g., top of berm, first-floor height, etc.).

To categorize past flood events, we use the most temporally relevant data available, while the most recent data available are used to evaluate risk assessments, since these compare potential flood impacts to current conditions within a given community. For example, if two DEM datasets, collected in 2015 and 2023, are available for a location, a flood event that occurred in 2016 would be estimated using the 2015 DEM, while the 2023 DEM would be used to delineate the mapped flood impact categories and display the current risk to that community.

The following questions and methodological responses are meant to replace the questions posed in table 1 and the appendix of RI 2021-1 (Buzard and others, 2021). These questions are based on the statements found in the NWS guidance (NWS, 2023a). Not all questions in each category will be relevant to all locations or events, nor will all locations experience flooding or projected risk in all categories. When categorizing a historical flood, we compare the flood height estimate to the height required to answer each question. The most severe category with at least one question receiving an affirmative answer determines the final categorization of a flood event. Similarly, when categorizing flood impact risks, the lowest flood height at which any question within a category can be answered affirmatively is the defining criteria for classification within that category.

The upper limit of each category is the lower limit of the next, more severe category, though the major category technically has no upper limit. For the purposes of impact risk assessment, we use the highest estimated historical flood height as an upper limit of expected flooding, which functionally acts as an upper limit to whichever category it falls within. For quantifying the lower limit of each of the three NWS categories, we subtract the confidence of the estimated height at which that category's defining criteria is reached from the estimated height of that defining criteria. For the lower limit of the extreme category (i.e., the upper limit of expected flooding), we use the highest estimated historical flood height and add the confidence of its estimate. The confidence of the defining criteria for each category is dependent on the data used to calculate its related flood height. A categorization based on a critical building might derive confidence from a first-floor height or GNSS survey, while a categorization based on critical road access might derive confidence from a DEM.

Minor Flooding

Defined as "minimal or no property damage, but possibly some public threat" (NWS, 2023a).

Q: Is there any amount of flood water (interpreted from "a little water") in at least one but no more than two homes?

A: From the first-floor height data, determine the two lowest residential buildings. Water heights between these values are considered minor flooding.

Q: Have flood waters reached the airstrip?

A: Use a bathtub model to determine the minimum height at which flood waters would reach any section of the airstrip.

Q: Has water overtopped important roads to a depth of less than 1.0 ft (0.30 m) (interpreted from "not very deep")?

A: Use a bathtub model to determine the minimum height at which any important road, such as an evacuation route or airstrip access road, would be inundated across its full width and add 1.0 ft (0.30 m). This is assumed to be the maximum depth for reasonably safe travel on flooded roads (NWS, 2023b).

Q: Has water come into low-lying areas or under buildings, or has it reached personal property?

A: When available, extract the average ground heights beneath structures from a bare-earth DTM. Use these ground heights to determine the minimum height at which flooding would reach personal property such as dog houses, *maqi* (traditional steam bath houses), sheds, or heating fuel tanks, as well as the water height at which flooding would be observed under occupied buildings. Occupied buildings are residential, public, or commercial structures in which people live or work. This may also be accomplished by identifying occupied buildings and personal property, then applying a bathtub model to a DSM to determine the minimum height at which flood waters would reach these structures.

Moderate Flooding

Defined as "some inundation of structures and roads… Some evacuations of people and/or transfer of property to higher elevations may be necessary" (NWS, 2023a).

Q: Do the lowest homes need to be evacuated?

A: From the first-floor height data, determine the second lowest residential building and add 1.0 ft (0.30 m). Water heights at or above this value are considered moderate flooding.

Q: Are more than one but less than six occupied buildings (interpreted from "several buildings") flooded to a depth of less than 1.0 ft (0.30 m) (interpreted from "minor to moderate damage")?

A: From the first-floor height data, determine the five lowest occupied buildings and add 1.0 ft (0.30 m) to the second and fifth lowest. Water heights between these values are considered moderate flooding.

Q: Have critical subsistence materials, equipment, or structures been washed away or damaged (interpreted from "normal life is disrupted and some hardship is endured")?

A: When available, extract the average ground heights beneath structures from a bare-earth DTM. Use these ground heights to determine the water height at which flooding would reach personal property such as fish and game processing stations and drying racks; vehicles and boats; or food storage structures. This may also be accomplished by identifying subsistence materials, equipment, or structures, then applying a bathtub model to a DSM to determine the minimum height at which flood waters would reach them.

Q: Has access to the airstrip been cut off?

A: Use a bathtub model to determine the minimum height at which all access roads to the airstrip are inundated across their full width and add 1.0 ft (0.30 m).

Q: Has water overtopped important roads to a depth of 1.0 ft (0.30 m) or more (interpreted from "deep enough to make driving unsafe")?

A: Use a bathtub model to determine the minimum height at which any important road is inundated across its full width and add 1.0 ft (0.30 m).

Major Flooding

Defined as "extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary" (NWS, 2023a).

Q: Are more than five occupied buildings (interpreted from "many buildings") flooded to a depth of 1.0 ft (0.30 m) or more (interpreted from "substantial damage")?

A: From the first-floor height data, determine the fifth lowest occupied building and add 1.0 ft (0.30 m). Water heights above this value are considered major flooding.

Q: Have flood waters reached drinking water facilities and/or sources?

A: Identify the first-floor heights of drinking water facilities and the ground heights of drinking water sources; if there are multiple values (e.g., more than one water tank), use the lowest value, unless the facility or water source is protected by a containment structure, berm, or levee, in which case use the lowest height atop the protective structure.

Q: Have flood waters reached wastewater facilities or lagoons?

A: Identify the first-floor heights of wastewater facilities and the ground heights of wastewater lagoons; if there are multiple values (e.g., more than one wastewater lagoon), use the lowest value, unless the facility or lagoon is protected by a containment structure, berm, or levee, in which case use the lowest height atop the protective structure.

Q: Have flood waters reached fuel storage or power production facilities?

A: Identify the first-floor heights of fuel and power facilities; if there are multiple values (e.g., more than one storage tank), use the lowest value, unless the facility is protected by a containment structure or berm, in which case use the lowest height atop the protective structure.

Extreme Flooding

Reports or forecast communications may include descriptions of potential or observed events as extreme, catastrophic, or record flooding (NWS, 2018). We have chosen to use the term extreme to avoid any confusion that might arise from the use of the term catastrophic, which conveys a destructive connotation, or record, which poses an internal terminology conflict within our reporting. In the context of flood impact risk assessment, the categorization extreme is location-specific and is meant to denote flooding that would reach a height above the anticipated maximum based on the specifics of the local historical flood record. A future event in any of the three NWS defined categories may also be considered extreme for a given location if the peak flood height reached during the event is greater than the highest flood height found in the local historical record.

FLOOD IMPACT CATEGORY MAPPING

Flood impact categories are displayed using a still water inundation model (SWIM; Horen, 2024). This method addresses hydrological connectivity and eliminates disconnected areas that would otherwise be included in a simple bathtub model. Additionally, the SWIM method maintains surface and subsurface connectivity that might otherwise be overlooked using other enhanced bathtub models (Perini and others, 2015; Sekovski and others, 2015). We use Esri's ArcGIS Pro software to perform geospatial calculations and analysis, as well as to create maps and figures for community-specific reports. To model inundation extents, a raster layer is generated for each flood impact category based on the upper bound of that category. The flood impact category mapping process deviates from the method described by Horen (2024) in that it stops short of generating inundation depth rasters and instead uses Esri's "Merge Rasters" tool to combine the category layers into a single raster output. This is done by providing all category layers as inputs and selecting "Min" from the "Resolve Overlap Method" dropdown menu. The output raster layer symbology is then classified using the values of the upper bounds of the flood impact categories to delineate the inundation extents for each.

FLOOD ESTIMATE LIMITATIONS

Flooding is a highly dynamic process involving the interaction of multiple hydrological, geomorphological, and infrastructural components that determine water height and inundation extent. Tides, storm surge, wave setup, and wave runup can contribute to variable flooding in coastal areas, yet much of Alaska's coastline lacks the high-resolution bathymetric, topographic, and wave data (Overbeck, 2018) necessary to run hydrodynamic models that take these wave-induced and terrestrial components into account (Overbeck, 2017). Similarly, riverine flooding is subject to localized variability due to precipitation, runoff, and streamflow rates, as well as drainage basin and channel geomorphology. Calibrated hydraulic models are needed to accurately map stream stage, depth, and extents during riverine flood events.

It is important to differentiate hydrodynamic, model-derived estimation from the observation-based estimate methodology described in this report. Flood estimates in DGGS reports represent still water inundation—"the total water [height] that occurs on normally dry ground" (Stone, 2023)—and are not derived from shore zone or river channel modeling. Unlike DGGS's SWIM method (Horen, 2024), hydrodynamic models take into account dynamic flooding processes, which, though transitory, may reach higher than the still water height and potentially overtop barriers or other protections, causing additional flooding to areas that might otherwise be unaffected. Previous flood impact assessments may have identified wave runup risks for specific infrastructure, and while this updated methodology does not invalidate those findings, future reports will not include such designations in the absence of hydrodynamic modeling.

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