Mapping the Nisqually River Delta Using Topobathymetric LiDAR, Aerial Imagery, and Mobile GIS

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- Washington State NHD data:
  http://www.ecy.wa.gov/services/gis/data/inlandWaters/nhd/NHDdownload.htm
- Billy Frank Jr. Nisqually National Wildlife Refuge:
  http://www.fws.gov/refuge/Billy_Frank_Jr_Nisqually/
- USGS NHD: http://nhd.usgs.gov/
- NOAA Digital Coast: https://coast.noaa.gov/digitalcoast/

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Cover photo: Nisqually Delta looking north, May 2010.

Abstract

The marine shoreline surrounding the Nisqually River Delta has changed dramatically since the removal of the Brown Farm dike in 2009. After over 100 years of closing off tidal flow to the interior delta, the dike was removed, inundating 762 acres of the Nisqually Wildlife Refuge with estuarine waters.

The Department of Ecology updated the National Hydrography Dataset (NHD) to reflect current conditions using a combination of topobathymetric LiDAR, aerial imagery, and mobile GIS using Esri's Collector for ArcGIS. This paper describes the methodology used in updating the NHD hydrography for the Nisqually Delta, based on the Mean Higher High Water tidal datum.

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Introduction and Study Area

Washington State adopted the National Hydrography Dataset (NHD) as its standard hydrography dataset in 2011 and appointed the State's Department of Ecology (Ecology) as the lead agency for NHD stewardship and maintenance. At that time there was an agreement between the Washington State Department of Natural Resources (DNR) and Ecology that the NHD marine shoreline would match DNR's shoreline that was mapped based on the perceived vegetation line.

One area of the Washington marine shoreline that has seen significant change since Ecology took over active maintenance of the NHD is the mouth of the Nisqually River near the southernmost portion of the Puget Sound. The shoreline surrounding the Nisqually River Delta has changed dramatically since the original shoreline was generated. After over 100 years of closing off tidal flow into the interior delta, the Brown Farm dike was removed in 2009, inundating 762 acres of the Nisqually Wildlife Refuge with estuarine waters. The Nisqually Indian Tribe also restored an additional 140 acres on the eastern side of the river. Because of both efforts, the Nisqually Delta is the largest tidal marsh restoration project in the Pacific Northwest [1].

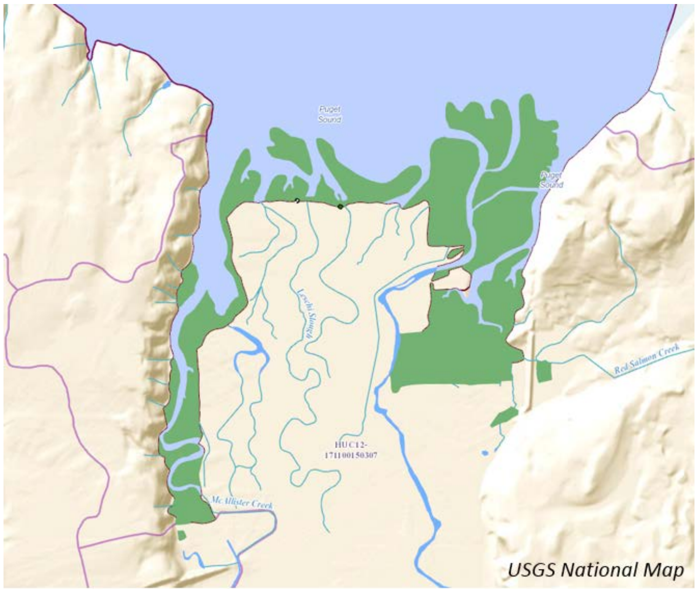

Figure 1: Old NHD hydrography shows Nisqually Delta before Brown Farm dike was removed in 2009. Out-of-date hydrography and marine shoreline facilitated the need to update the hydrography for this area.

Because this area is part of the National Wildlife Refuge System, and is Washington's largest relatively undisturbed estuary, Ecology updated the NHD hydrography to reflect current conditions using source data gathered via topobathymetric LiDAR, current aerial imagery, and field verification. The study area was constrained to the extent of the LiDAR acquisition which included the Nisqually Delta from valley wall to valley wall, and extended briefly on either side of the Nisqually Reach of Puget Sound.

Methods

LiDAR Derived Shoreline Based on Mean Higher High Water

In 2014, the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) collected topobathymetric LiDAR of several key areas around the Puget Sound in conjunction with the U.S. Army Corps of Engineers (USACE), U.S. Geological Survey (USGS), and National Oceanic and Atmospheric Administration (NOAA). The Coastal Zone Mapping and Imaging LiDAR (CZMIL) system was used to collect valid topographic and bathymetric data simultaneously. The Nisqually Delta was one of the areas flown by JALBTCX, and the data are available for download on NOAA's Digital Coast data viewer in several different formats.

Due to the file size of the raw LiDAR data, the datasets were subdivided into quarter-quads, or 5km boxes, resulting in a total of four data pieces to cover the Nisqually Delta. The point data had been classified as 1 (valid non-ground topographic data), 2 (valid ground topographic data), and 29 (valid bathymetric data). The original classified point data in LAZ format was downloaded in order to generate a new shoreline based on a specific tidal datum. LASTools software was used to extract the LAZ files to LAS format which allowed viewing of the data within ESRI's ArcMap. The horizontal positions of the original LiDAR point data were provided in decimal degrees of latitude and longitude, and referenced the NAD83 NA2011 datum. The vertical positions were referenced to the NAD83 NA11 ellipsoid and provided in meters [2].

A preliminary review of the LiDAR data and aerial imagery resulted in the decision that the shoreline in the Puget Sound region is best represented by the Mean Higher High Water (MHHW) mark, as it provides a better representation of the vegetation line, and includes all areas inundated during high tide. Water quality monitoring data and aerial photo verification were used to validate the decision to select the MHHW line as the official shoreline and thus our division between freshwater and marine environments. Washington's water quality standards state "in brackish waters of estuaries, where different criteria for the same use occurs for fresh and marine waters, the decision to use the fresh water or the marine water criteria must be selected and applied on the basis of vertically averaged daily maximum salinity" [3]. A polygon layer showing areas of estuarine influence developed from salinity monitoring data by

Ecology's Water Quality Program was used to support the use of the MHHW line as the official shoreline. Figure 2 shows the areas of estuarine influence for the Nisqually Delta (blue) and that it best matches the delineated MHHW shoreline.

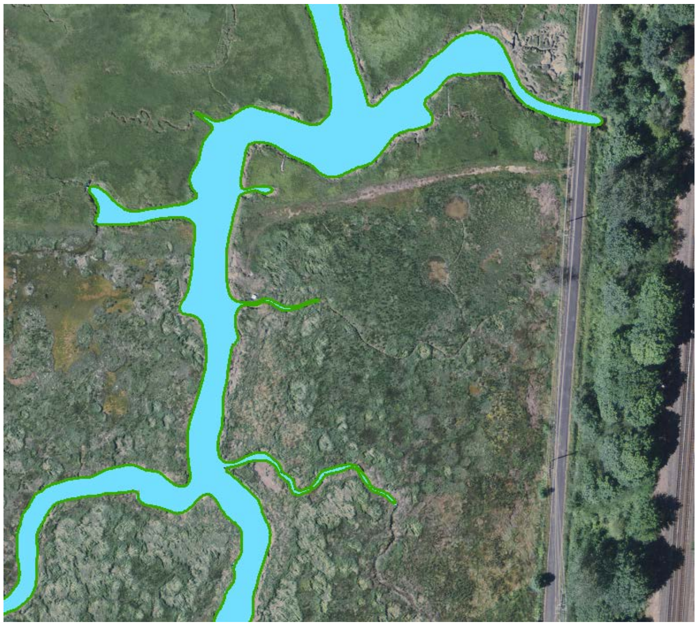

Figure 2: Estuarine influence polygon (blue) matches the delineated MHHW shoreline (green)

In order to generate a shoreline that was based on the MHHW tidal datum, the vertical datum of the LiDAR point data needed to be transformed to reference MHHW. NOAA developed a program, VDatum, which transforms LiDAR data to reference a user-defined horizontal and vertical datum. Tidal datums, such as MHHW, are calculated by extracting and averaging the high and low water values from a specific time series. These tidal data are observed and averaged over a period of 19 years and are called the National Tidal Datum Epoch (NTDE). VDatum utilizes a gridded representation of Puget Sound that contains the tidal datums that reference the most recently recorded Tidal Epoch, 1983-2001 [4] [5]. Because tidal elevations fluctuate depending on location in Puget Sound, the VDatum software contains the measured tidal datums for the entirety of Puget Sound and will reference the LiDAR data according to the datum at a specific location.

Because the tidal data that VDatum utilizes for the Nisqually Delta references the 1983-2001 Tidal Epoch, and the dike was not removed until 2009, there were no tidal data for the southernmost portion of the study area that was previously diked off and is now inundated by tidal flow. Because of this, the southernmost portion of the four source LiDAR data pieces was not properly transformed to reference the MHHW mark. To work around this, only three of the four sections were transformed, and the ArcGIS raster calculator was used to extract the values from the original LiDAR-generated digital elevation model (DEM) (referenced to NAD83 NA11 and including all four sections) that correspond to the MHHW mark of the new DEM. Once the values from the original DEM that correspond to the MHHW mark were obtained, the DEM was reclassified so that the 0 ft elevation value was equivalent to MHHW. This gave a continuous line referenced to MHHW for the entire study area that was then used to generate the new shoreline. The line was visually inspected for any irregularities, and then generalized and smoothed to remove any inconsistencies from the LiDAR data, as well as to create a single continuous shoreline (see Figure 3).

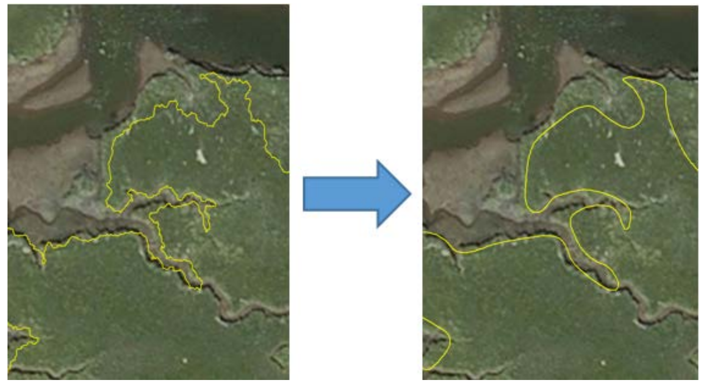

Figure 3: (Left) Original MHHW contour from LiDAR).
(Right) MHHW shoreline after being generalized and smoothed using ArcMap's generalization toolset. (Images at 1:600 scale)

There are several raised salt marsh features at the northern end of the delta and at the westernmost areas near McAllister Creek that were included in the NHD as swamp/marsh features. These features were distinctive, but true to their classification, the full vegetated extents of the features were mostly inundated at higher tides and not delineated well cartographically by the MHHW elevation selected to define the tidal shoreline. The Mean High Water (MHW) line (approximately 0.91 feet below MHHW) was chosen as the best representation of the salt-tolerant vegetated extent (see Figure 4).

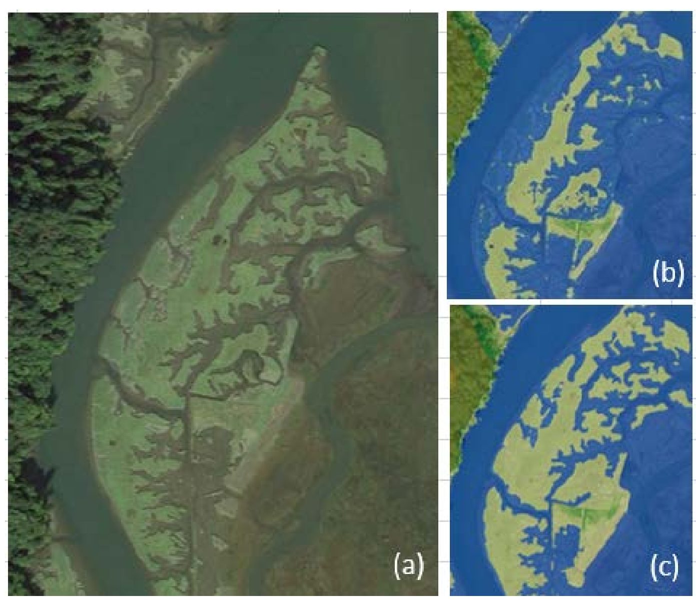

Figure 4: (a) Aerial imagery of western area of Nisqually Delta near McAllister Creek shows exposed salt marsh "islands" during high tide.
(b) Salt marsh features extracted using MHHW line.
(c) Same features extracted using MHW line. The salt marsh features extracted from the MHW line were incorporated into the NHD.

Foreshore features were added to show the areas that lie between the MHHW shoreline and the Mean Lower Low Water (MLLW) that are affected by the tides. These foreshore features (or mud flats) are used primarily for cartographic purposes and were captured as NHDArea features in the NHD. To determine the extent of the foreshore features, the DEM was classified to reference the MLLW line (approximately 13.51 feet below MHHW). The same methodology as described above was used in extracting the line that corresponds to MLLW. The line was generalized and smoothed to remove inconsistencies, converted to polygons, and clipped to the study area extent.

Of note during this process was that the LiDAR data of the northern edges of the foreshore features produced a lot of "noise" due to the very gradual change in elevation at the northernmost extent of the features. The features required a greater tolerance when generalizing to remove sharp edges and inconsistencies in the data. Despite there being a significant amount of LiDAR noise from the gradual drop in elevation, a single continuous line with a great amount of detail was still able to be extracted.

Updating the Freshwater Hydrography of the Nisqually Wildlife Refuge

In addition to generating a new LiDAR-derived shoreline, the hydrography within the freshwater portion of the delta was updated as well. A combination of recent aerial imagery, LiDAR elevation data, and field verification was used to generate updated stream and pond features. Many of the streams that exist within the study area were not visible from aerial imagery, requiring the use of the LiDAR DEM and hillshade to delineate stream channels. When LiDAR elevation data were not sufficient to visualize stream channels due to minimal relief, flow direction and accumulation grids were created from the DEM in order to delineate the stream network using the ArcHydro toolset. Delineated streams that drained a total of 6 acres were included in the NHD; streams that drained less than 6 acres were excluded unless they were observable in aerial imagery or field verified.

C. Using Esri's Collector App to Verify New Hydrography

Ecology received federal funding from the USGS to improve hydrography in several key locations including the Nisqually Delta. A significant portion of the grant involved feasibility testing of Esri's Collector for ArcGIS in mobile data collection to improve and verify the accuracy of the NHD hydrography. Field verification of the newly developed LiDAR-based hydrography was done to not only satisfy the requirements of the grant funding but also to ensure the new hydrography matched current ground conditions.

A feature service was published to ArcGIS Online (AGOL) that included the working LiDAR-based hydrography data, as well as some additional feature layers that would enable notes to be taken directly on the map and indicate points of interest or areas in need of verification. Each of these feature layers were added to an AGOL Web Map that was then uploaded to the Collector app on an Apple iPad Air. Because offline functionality had been enabled within the Web Map, the iPad was able to be brought into the field to collect data that could then be brought back to the office and synced with the original dataset. While out in the field, the new hydrography was verified against current ground conditions. The Collector app gave the ability to add additional NHD features that weren't currently in the dataset, indicate points of interest, flag features that needed correcting, and attach photographs for visual analysis for use later (see Figure 5). The newly collected, field-verified data were then brought back to the office and synchronized with the original dataset. New NHD features were added to the official NHD, and incorrect features were either corrected or deleted.

**Figure 5: (a) Screenshot from Esri's Collector app shows added points of interest and swamp/marsh feature collected while in field.
(b) Channels at MHHW line, correspond to LiDAR-derived shoreline.
(c) Same location but at king tide (2.03 ft higher than MHHW on 1-14-16).**

Summary

Upon visual examination of the new LiDAR-derived shoreline in conjunction with recent aerial imagery, it is clear that the MHHW line best represents the vegetation line and the full area inundated by tidal flow in the Nisqually Delta and the surrounding area. Deriving a shoreline based on high-resolution elevation data such as LiDAR has distinct advantages over traditional methods such as visually interpreting a shoreline based on aerial imagery. NOAA's VDatum software provides users with an efficient and accurate way of generating LiDAR-derived DEMs that reference specific tidal datums. These tidally referenced DEMs can then be used to generate accurate and consistent shorelines that correspond to a specific tidal datum at a given location. Because the shoreline is derived from the elevation data that are tied to a specific tidal datum, VDatum allows for consistent shoreline delineation regardless of the topographic features of the natural coastline. Variations in the natural shoreline (e.g. dunes, rocks, vegetation) may introduce errors when the shoreline is solely being mapped based on visual interpretation of the aerial imagery. Because VDatum uses the National Tidal Datum Epoch that consists of a computed average value of tidal elevations over the course of 19 years, no interpretation of aerial imagery is required, thus minimizing the amount of human error introduced when generating the shoreline [5].

Traditional topographic LiDAR typically uses infrared lasers that cannot penetrate water. If the analyst wishes to extract a shoreline that references a specific tidal datum, it's important to note the time of day the LiDAR was collected (i.e. at low or high tide). Any topographic features below the tide line at the time of collection will not be able to be processed by VDatum. However recent advancements in LiDAR technology have allowed for simultaneous collection of both topographic and bathymetric elevation data, allowing for data to be collected for the full intertidal zone on a single dataset. The Coastal Zone Mapping and Imaging LiDAR (CZMIL) used in this study provides the ability for a seamless bathymetric and topographic DEM to be generated [6]. This allowed for the entirety of the intertidal zone to be analyzed, and a line representing each tidal datum to be generated. This was valuable in determining the extent of the foreshore features that extend to the MLLW water line, as there was valid bathymetric data that extended a great deal beyond the lowest measured tidal datum (see Figure 6).

Figure 6: (Left) Both MHHW and MLLW tidal datum line could be generated from single CZMIL LiDAR dataset.
(Right) Foreshore features consist of the area between MHHW and MLLW. Topobathymetric LiDAR and VDatum provide an easy and consistent method of extracting tidal datum lines.

The use of the Collector for ArcGIS app on the Apple iPad Air provided an efficient method for collecting data while out in the field. Its usability and ease of use allowed for a consistent method for acquiring new data, as well as verifying and modifying existing NHD data. Features could easily be added, edited, or deleted based on observations in the field, and then brought back to the office to be synced with the original dataset.

An update to the NHD was prepared to include the newly generated shoreline based on MHHW, as well as the LiDAR-derived and field-verified stream network (Figure 7). The package was uploaded to the USGS NHD national repository database and incorporated into the official NHD. The new data will be available in Ecology's spring 2016 release of Washington NHD hydrography.

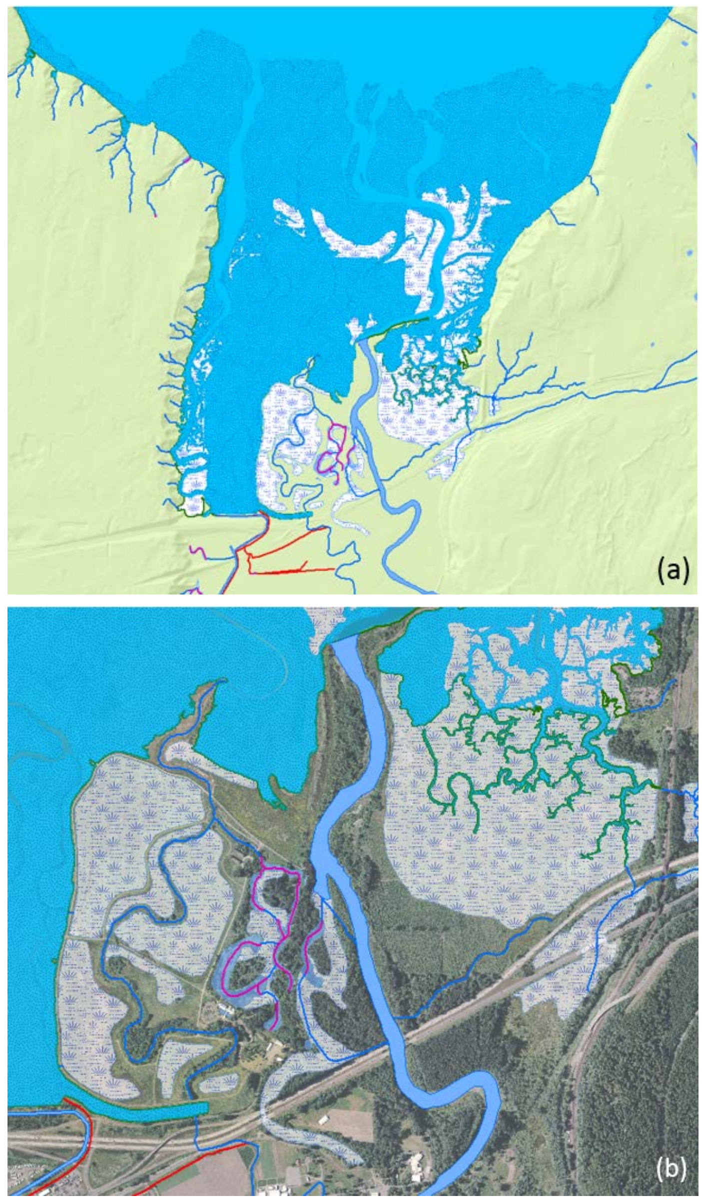

Figure 7: (a) Updated LiDAR-based hydrography for entirety of Nisqually Delta study area.
(b) Close-up of freshwater portion of Nisqually Wildlife Refuge.

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