Improved Stream Mapping Pilot Project

Final Report

By

Information Technology Services Office
Washington Hydrography Dataset Program

Washington State Department of Ecology

Olympia, Washington

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[1] https://ecology.wa.gov/research-data/data-resources/geographic-information-systems-gis/hydrography-dataset-washd

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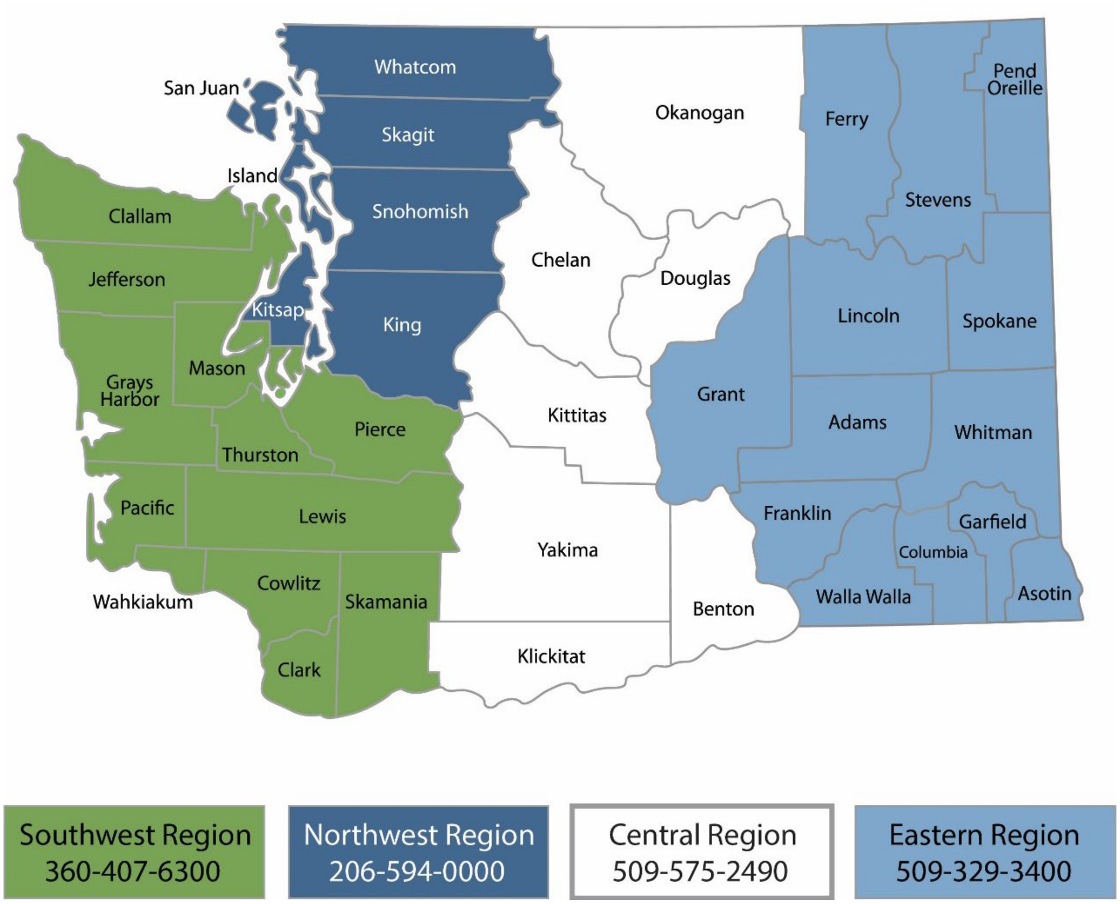
Department of Ecology’s Regional Offices

Map of Counties Served



Region	Counties served	Mailing Address	Phone
Southwest	Clallam, Clark, Cowlitz, Grays Harbor, Jefferson, Mason, Lewis, Pacific, Pierce, Skamania, Thurston, Wahkiakum	PO Box 47775 Olympia, WA 98504	360-407-6300
Northwest	Island, King, Kitsap, San Juan, Skagit, Snohomish, Whatcom	PO Box 330316 Shoreline, WA 98133	206-594-0000
Central	Benton, Chelan, Douglas, Kittitas, Klickitat, Okanogan, Yakima	1250 W Alder St Union Gap, WA 98903	509-575-2490
Eastern	Adams, Asotin, Columbia, Ferry, Franklin, Garfield, Grant, Lincoln, Pend Oreille, Spokane, Stevens, Walla Walla, Whitman	4601 N Monroe Spokane, WA 99205	509-329-3400
Headquarters	Across Washington	PO Box 46700 Olympia, WA 98504	360-407-6000

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DEPARTMENT OF
ECOLOGY
State of Washington

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Puget Sound Partnership
Washington State Department of Natural Resources
Washington Department of Fish and Wildlife
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Executive Summary

Washington State has a long history of mapping hydrography. Ongoing improvements in technology and analysis have advanced the accuracy of mapped data. Surface waters and their connected riparian zones are critical in supporting water quality and the health and diversity of aquatic and terrestrial species throughout Washington. Understanding the location of the state's surface water is needed to assess, monitor, and protect these ecosystems, while improving climate resiliency at statewide, watershed, and local scales. In 2022, the Department of Ecology received funding to conduct a pilot project to identify the technology, methods, datasets, and resources needed to refine and maintain the accuracy of the National Hydrography Dataset for Washington. This report covers the results of that assessment, including an evaluation of changes in national hydrography mapping standards that USGS implemented.

The Stillaguamish watershed was selected as the pilot study area based on available data, the diversity of the landscape, and the willingness of local agencies to collaborate. Work during Year 1 of the pilot project (Fiscal Year 2023) involved collecting local data, working with contractors to supply elevation-derived hydrography products, and evaluating the output for accuracy and useability. During the project, outreach included quarterly statewide stakeholder meetings with broad organization participation (Figure 3), and monthly steering and technical committee meetings.

Results of the assessment show that stream segment miles almost doubled, and mapped features within the pilot area have a high level of accuracy. Stream segment length increased from 3,683 miles in the National Hydrography Dataset (NHD) to 7,025 miles in the Elevation-derived Hydrography (EDH) dataset. Ninety-six percent of the stream segments did not require field checks or further review. The assessment suggests that the EDH methodology significantly improves the accuracy of where surface water flow is mapped, creating a more accurate hydrography dataset that can be used at a local scale. The updated national methods and resulting datasets are an improvement in hydrography mapping. However, several related datasets that are also important to Washington stakeholders were identified as missing.

Introduction

Background

Water is a fundamental element of life on Earth, and mapping the location of surface water has a long history. The oldest known landscape map was discovered in a cave in Spain and dates back more than thirteen thousand years (Utrilla, et al. 2009). While this map only shows a couple of landscape features, it does depict a river showing the best places to cross to get to a hunting area. Even the earliest maps relied on showing the location of surface waters.

Surface water mapping is part of the science of hydrography, the study and measurement of water bodies such as rivers, lakes, and oceans. Hydrography data includes the mapped locations of these water features. Today, our methods of interacting with hydrography data may be more technologically advanced—instead of stone tablets, we can create and view maps using digital databases and Geographic Information Systems (GIS) software—but our need to map water is as essential as ever. In Washington State, mapping streams and rivers is critical to several activities:

- **Environmental Management and Conservation**. Accurate mapping allows for a better understanding of the distribution, flow patterns, and connectivity of streams and rivers within an ecosystem. This information is crucial for managing and conserving these water bodies and the habitats they support. It helps identify sensitive areas, assess the impact of human activities, and develop strategies for protecting aquatic biodiversity.
- **Ecological Restoration**. Many streams and rivers have been altered or degraded due to human activities. Accurate mapping helps identify areas that require ecological restoration, such as reconnecting fragmented habitats, restoring natural channel patterns, and enhancing riparian vegetation (trees next to rivers). Restoration efforts can improve water quality, enhance wildlife habitats, and promote overall ecosystem health.
- **Floodplain Management**. Detailed stream and river mapping helps outline floodplains, which are the areas adjacent to water bodies that are prone to flooding. This information is crucial for land-use planning and development regulations. Accurate floodplain maps help reduce the risk of property damage and loss of life during floods by guiding construction and zoning decisions.
- **Water Resource Management**. Streams and rivers are sources of freshwater that support various human activities, such as agriculture, industry, and domestic use. Accurate mapping helps in estimating water availability, assessing water quality, and planning for sustainable water use. It also aids in the management of water allocations and rights among different stakeholders.
- **Infrastructure Development**. Mapping streams and rivers is essential for planning and constructing infrastructure projects such as bridges, culverts, dams, and wastewater

treatment facilities. Engineers and planners need correct information about water flow, channel characteristics, and flood risks to design these structures effectively.

- **Emergency Response**. During emergencies such as floods or hazardous spills, accurate stream and river mapping is crucial for emergency responders to plan evacuation routes, assess the extent of flooding, and allocate resources effectively.
- **Research and Scientific Understanding**. Stream and river mapping is fundamental for scientific research related to hydrology, geomorphology, ecology, and climate change. Researchers use these maps to study water flow dynamics, sediment transport, aquatic habitat suitability, and the impacts of various factors on river systems.
- **Education and Outreach**. Stream and river maps function as valuable educational tools for informing the public about hydrological processes, watershed dynamics, and the importance of water resources in ecosystems.

Overall, mapping streams and rivers provides a foundation for informed decision-making, sustainable resource management, and the protection of both human and environmental well-being.

Mapping hydrography is important, but the accuracy of the mapping is becoming increasingly more critical. The accuracy of surface water mapping can be broken into:

- **Location accuracy.** The location of the data on the map is important for analysis particularly when compared with other data. For example, if an analysis is measuring changes in forest cover next to streams, that measure will be inaccurate if the stream is two hundred feet off from the real location. Similarly critical area protections during a planning process will rely on knowing where a stream is located so they can avoid impacting the stream with development.
- **Omission and Commission** Not having any information at all for surface water not only impacts the analysis of the hydrography, but it also makes it impossible to connect ancillary data to the hydrography. For example, if water samples are connected to hydrography, the lack of a mapped stream reach means there is no water to connect to that sample point.
- **Attributes of data**. The information associated with each stream or waterbody segment is considered the attribute information. This is usually descriptive information about the data such as whether the waterbody is a pond or reservoir. If the attribute information is missing or incorrect it can have consequences to the analysis. Many of the activities listed above rely on attributes on the data for successful application. When the attribute data is incorrect it can make the data less reliable and make analysis incorrect or even impossible to complete.

Stream Definition

Most people recognize blue lines and shapes on a map as representing water bodies. Historically, these landscape features were mapped by either directly observing water in a channel or locating depressions that appear to have recently had water. Traditional paper maps have limited the complexity of information we associate with a blue line showing stream locations. As mapping has advanced and the use of GIS software has become widespread, there is a trend to extend mapping of surface waters to include all surface water flow. However, water is dynamic and changes in location daily, seasonally, and annually, and the exact meaning of blue lines on a map has become a challenge to define.

Currently, Washington State law does not include a definition for streams, so many users of water data have developed their own categories and definitions. As we move towards methods of digital stream mapping using GIS that model and predict water based on topography, there is an opportunity to classify water flow into more sophisticated categories for each stream segment or reach. When digital mapping is performed using a GIS, a layer includes many surface water flow types, and attributes such as width and flow permanence. This data can be attached to each line that allow different definitions to be applied to determine whether to display it as a stream or temporary water flow. For example, a definition for one user group could be, ‘if a channel is at least 3 feet wide and contains water more than 10% of the year, it is delineated as a stream.’ A generalized approach is supported by the U.S. Geological Survey (USGS), that broadly defines a stream as “a body of flowing water” whose upstream extent is “where the feature first becomes evident as a channel” (USGS 3DHP Acquisition specifications p.9). This approach is a good solution when working to create a single hydrography dataset accepted by a broad stakeholder group.

National Hydrography Dataset

The U.S. Geological Survey (USGS) National Hydrography Dataset (NHD) is the federal standard GIS dataset for hydrography, representing surface waters of the United States such as rivers, streams, canals, lakes, ponds, and coastlines. In 2009 both Washington and Oregon signed a Memorandum of Understanding with USGS to be the NHD stewards of data within their respective state. NHD stewards in each State coordinated with the USGS to make updates to the Federal dataset. In 2011 the Washington Office of the Chief Information Officer (OCIO) directed that the NHD be the standard for all surface water geospatial datasets in Washington State, and that the Department of Ecology (Ecology) serve as the state steward (OCIO Policy 161.03). This means all state agencies must use the NHD as their primary hydrography dataset as well as the base for any water-associated data, such as fish distribution, culvert locations, and environmental monitoring stations.

The NHD in Washington has approximately 250,000 miles of mapped watercourses and is a powerful, well-established framework used to analyze and associate critical information about the state’s hydrography. However, it is largely populated with data that was originally mapped at a coarse nationwide scale as shown in Figure 1(C). This data met the needs of hydrography users at the time it was created (between 1947 and 1992) and was the best available information, but it is not suitable for modern environmental analysis at the local level.

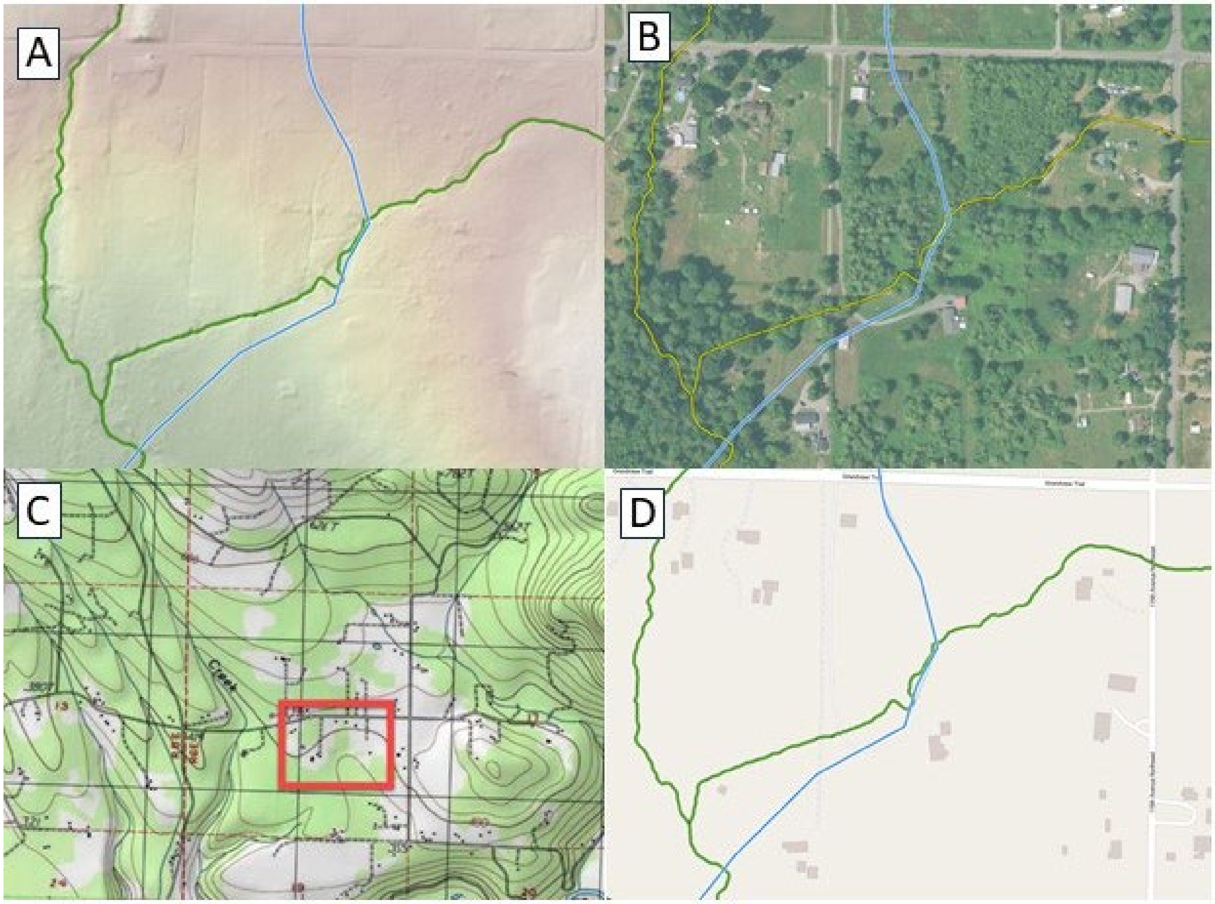

Figure 1. Comparison of old NHD (blue) to new Elevation-Derived Hydrography EDH (Green/Yellow): A. Hillshade, B. Aerial image, C. Original USGS 7.5-minute topo map, and D. Updated USGS National map.

Some small-scale improvements have been made since the adoption of the NHD state standard in 2011, but due to limited staff and funding, as well as the complexity of the NHD update process, large area updates have only occurred sporadically. Based on the rate of NHD updates over the last 10 years and current staffing levels, Ecology estimated it could take more than 20 years to update the NHD to a higher level of accuracy across the state.

To meet their need for more accurate hydrography data, many local governments have created and are maintaining their own hydrography datasets that are separate from the NHD. While this approach may work for some jurisdictions, not all jurisdictions have the ability or the financial resources to manage their own datasets, creating equity issues among communities. This approach has also resulted in data gaps within the NHD because changes in local hydrography data may not be incorporated into the state's dataset. These gaps can create challenges for state agencies and other resource managers that need to perform regional or statewide analyses, such as riparian and water quality assessments.

3D Hydrography Program

Nationwide, the NHD faces issues that mirror those in Washington State, with inconsistent accuracy levels and slow update timelines. In response, USGS is developing the new 3D Hydrography Program (3DHP), which will replace all forms of the NHD. 3DHP builds on the work of the USGS 3D Elevation Program (3DEP), a recent effort to acquire nationwide high-quality elevation data using Light Detection and Ranging (Lidar) technology. 3DHP will standardize and improve the level of detail, currency, and content of hydrography data by requiring that water bodies and watershed boundaries be derived from recent, high-quality 3DEP Lidar data. USGS has released specifications for creating these elevation-derived hydrography (EDH) products.

While the full specifications are specific and contain much needed detail, the basic definitions are as follows:

Stream/River is determined by the position of the visible edge of the banks as depicted on the digital elevation model.

- The upper limit of stream/river is where the feature first becomes evident as a channel.
- Shown as line: Less than or equal to 50' width.
- Shown as Polygon: Greater than 50' width.

Lake/Pond is a standing body of water with a predominantly natural shoreline surrounded by land.

- Waterbodies that are greater than 0.25 acres

The implementation of 3DHP marks the beginning of a new era of water data, and the first systematic remapping of the nation’s hydrography since the original USGS 1:24,000-scale topographic mapping program was active between 1947 and 1992.

Plans for 3DHP have been underway for several years. In late 2022, USGS announced that they would stop accepting updates to NHD by early 2023 to focus on creating 3DHP. A first-draft 3DHP data model, provisionally populated with NHD data, was released in October 2023. As of late 2023, USGS intends to begin “ingesting” new EDH data into the model starting in 2024 or 2025.

Decision Package

Given the issues with NHD in Washington State as well as the plans to move on from NHD at the federal level, the State has been aware for several years that a new hydrography solution is necessary. In 2021, Governor Inslee’s State-Tribal Riparian Protection & Restoration Workgroup determined improving hydrography data accuracy a top priority for developing a statewide riparian assessment and monitoring program. In response to these recommendations, the Department of Ecology submitted a decision package to the state legislature, requesting funding for a two-year pilot project to research best methods of updating the state’s hydrography. This funding was granted, and the pilot project began in July 2022.

Pilot Project Description

The primary objective of the pilot project was to assess various stream mapping methods in the Stillaguamish River watershed in northwest Washington. Specific performance outcomes outlined in the decision package were as follows:

1. Identify what elevation derived mapping method most accurately represents Washington water.
2. Determine if high-resolution land cover significantly improves mapped hydrography accuracy.
3. Document level of effort and process to integrate elevation derived datasets into WANHD.
4. Document level of effort, process, and training needed to incorporate local data into WA-NHD.
5. Document impacts to WA-NHD users and identify change management tools necessary to mitigate those impacts.
6. Determine resources needed to improve the accuracy of WA-NHD on a statewide, ongoing basis.

Considering recent developments with NHD and 3DHP, some of these performance outcomes evolved to move from supporting the NHD model and transition to the newer 3DHP. These changes are described in more detail at the end of this section.

In support of these goals, the decision package included funding for the addition of three new staff members to the NHD stewardship team, which previously consisted of just one full-time employee, as well as the hiring of a project manager to oversee the pilot project. Funds were granted to purchase several key datasets for the project area, including high-resolution land cover data and two Lidar-derived hydrography datasets. Finally, the decision package included financial support for local jurisdictions to allow them to assist in the creation of the new hydrography data.

The Stillaguamish portion of the pilot project was completed in Year 1 of the funding cycle. This report documents the process of the Stillaguamish update and discusses the findings of that process.

Study Area

The Stillaguamish watershed (Figure 2) was selected for the pilot project area because it is covered by high resolution Lidar data, has widespread project support from a variety of stakeholders at all organizational levels (Federal, Tribal, County, City, and State Lands), and has a good representation of several important land cover and use types including forested, agricultural, urban, and coastal environments. Terrain in the watershed ranges from mountains to plains and includes many unique landscapes on which to evaluate the accuracy of EDH techniques.

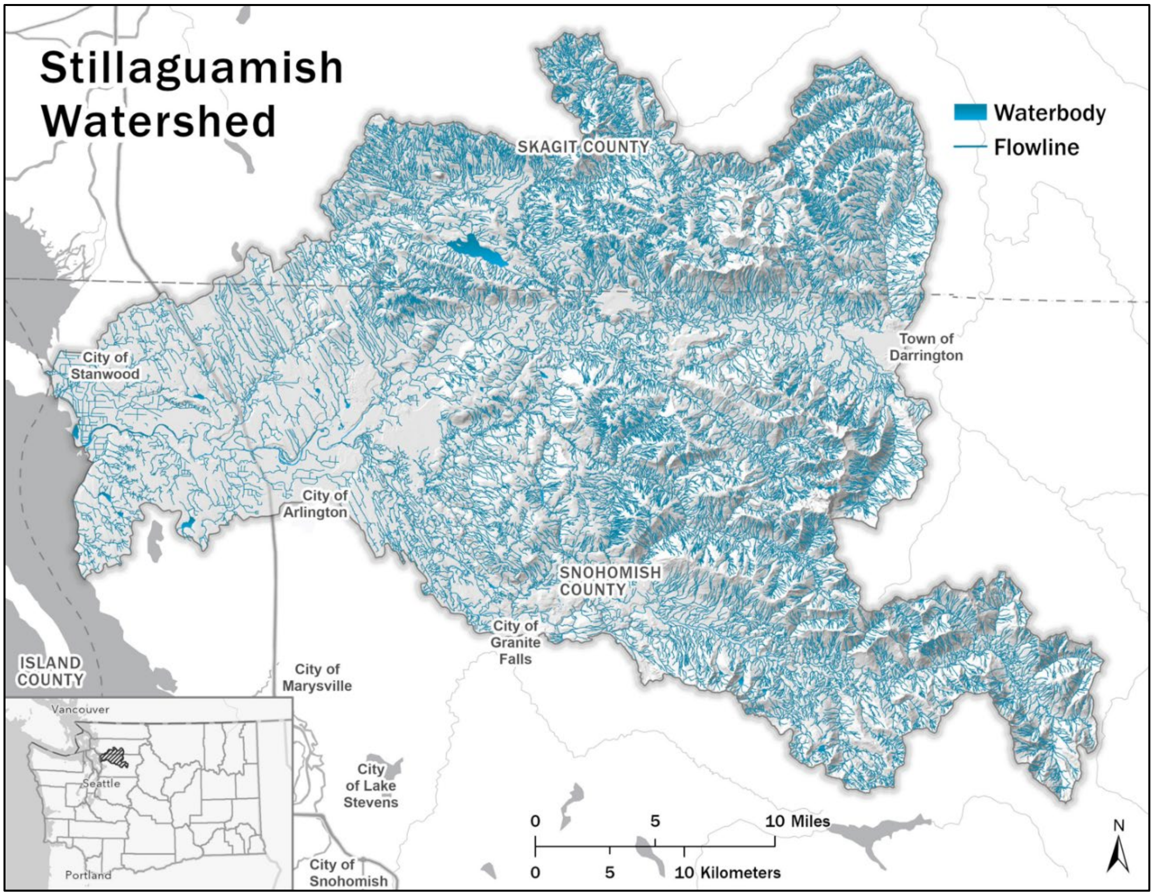

Figure 2. Overview of the Stillaguamish Watershed, including the final EDH polygons (waterbody) and line segments (flowline).

Key Data Sources

The original plan for the creation of new hydrography data in the Stillaguamish watershed was to test and compare various data sources and methods, including two elevation-based hydrography datasets developed using different methodologies, high-resolution land cover, and local data. These sources, and the reasons for their selection, are described below. More detailed information about each source, including a list of deliverables, can be found in the Methods section. A complete list of ancillary data used in the project is listed in Appendix C. Ancillary Data Sources.

NV5 Hydrography

NV5 Geospatial (NV5) was hired to delineate hydrography features according to the USGS specifications for Elevation-Derived Hydrography (EDH) in the READ Rules (USGS READ Rules online[3]). These specifications must be met for hydrography to be accepted into the future 3DHP data model. NV5 is one of several contractors that have worked closely with USGS in the

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[3] https://www.usgs.gov/ngp-standards-and-specifications/elevation-derived-hydrography-read-rules-table-contents

development and piloting of EDH methods and specifications. They also have experience incorporating new EDH data into NHD.

UMBC Hydrography

Dr. Matthew Baker and his team at University of Maryland, Baltimore County (UMBC) were hired to delineate stream networks from Lidar and land cover maps using recently developed computer vision algorithms. The UMBC method involves classifying the landscape into geomorphic features including peaks, ridges, slopes, and channels. After classification, stream channels can be extracted, and in some cases, it may be possible to estimate attributes such as bank height and channel width throughout the stream network. These algorithms are a departure from more standard GIS methods for creating stream flowlines from elevation data. In some cases, they have been shown to improve on these methods, providing benefits such as increased location accuracy and automatic detection of culverts. In spring of 2022, UMBC completed a pre-pilot study in a small area of the Stillaguamish watershed. Results from this pre-pilot were promising, and UMBC was included in the pilot project to assess whether their methods might meet the needs of the State better than USGS methods.

Land Cover

Land cover data for Western Washington has been created periodically over the last thirty years by the National Oceanic and Atmospheric Administration (NOAA) as part of their Coastal Change Analysis Program (CCAP)[4]. Historically, these land cover products have been created from satellite imagery, with each 30-meter pixel classified into categories including forested, developed, open space, wetlands, among others. More recently, aerial imagery has been used to create high-resolution land cover data in some areas of the country through partnerships between NOAA[5] and private companies. These newer datasets delineate features in vector format and capture surface water in greater detail than previous CCAP products. One objective of the pilot project was to determine whether this data could be used to create a more accurate hydrography.

Local Knowledge

One of the most effective ways of obtaining accurate hydrography data is by observing streams in the real world. This approach is not practical for updating large areas; it would simply be too time-consuming to complete on-the-ground surveys for every stream. Furthermore, many remote areas would be challenging or impossible to access. However, many local jurisdictions possess knowledge about stream locations that they have amassed over the years, and a goal of the pilot project was to determine the best methods for incorporating this knowledge into the new hydrography solution.

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[4] https://coast.noaa.gov/data/digitalcoast/pdf/ccap-faq-regional.pdf

[5] https://coast.noaa.gov/digitalcoast/data/ccaphighres.html

Committees

To help guide and assist project staff, a Steering Committee and a Technical Committee were established. The roles of each committee are described below, while the members of each committee are listed in the Credits. Committee meetings were held monthly.

Members of the Steering Committee were selected to represent individuals with broad awareness in organizations involved with hydrography. The role of the Steering Committee was as follows:

- Share information from meetings with the appropriate people within their organization.
- Champion the project within their organization.
- Contribute to the project priorities and scope.
- Proactively contribute to key project and policy decisions that cross organization lines.
- Respond to questions the project team may have and vote when project decisions are needed.

Members of the Technical Committee served as a technical resource to meet project objectives. The meetings included reviewing technical details and providing advice. Some topic meetings were also set up to allow a deeper dive into current knowledge of hydrography mapping elements such as initiation points of streams and methods to estimate flow permanence.

In addition to these committees, a Stakeholder group was established prior to the pilot project to assist with communications to stakeholders interested in hydrography in Washington State. During the pilot project, this group grew to over 150 participants from a variety of organizations, as shown in Figure 3. Stakeholder meetings have been held every 3-6 months and have been a useful way of sharing progress as well as get feedback on stakeholder needs.

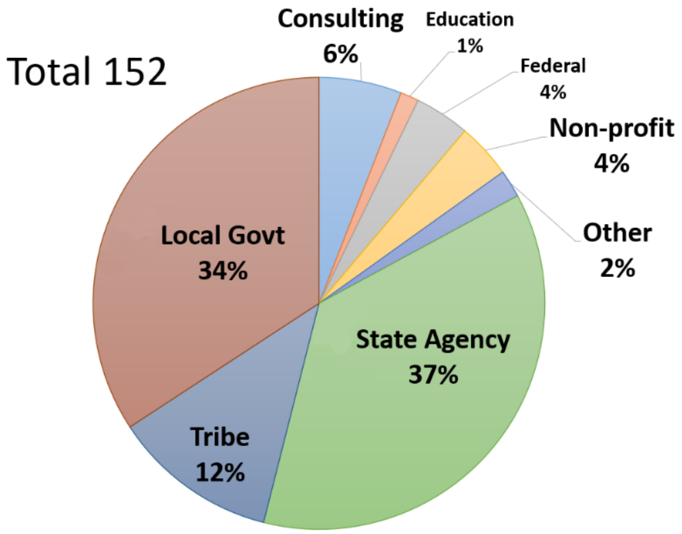


Figure 3. Organizations represented in Stakeholder group.

Project Changes

Several aspects of the pilot project underwent some changes over the course of the project. The most important changes are described below.

- **Compression of project schedule.** Originally the Stillaguamish portion of the pilot had been slated to occur over the whole first year of the project (July 2022 to June 2023). However, due to delays in finalizing contracts, this work ultimately occurred from January to June 2023.
- **Closing of NHD.** As mentioned in the Background section, USGS announced in late 2022 that they would stop accepting NHD updates in early 2023. The original plan had been for NV5 to incorporate the updated Stillaguamish hydrography into NHD, but due to USGS's accelerated timeline, this was not possible.
- **Prioritization of 3DHP-compliant hydrography.** As project staff contemplated the closing of NHD and weighed possible future actions, it was decided that acquiring hydrography products that would be accepted into 3DHP needed to be a priority; otherwise, the State would need to create its own database model for storing, maintaining, and distributing the data, which would likely be time-consuming and costly.
- **Prioritization of NV5 data.** An original intent of the pilot was to compare the NV5 and UMBC data and determine which one best met the needs of the State. However, most staff time and energy were ultimately focused on reviewing the NV5 data products. This prioritization was due to several factors. One factor was that only NV5 met the USGS specifications. Another factor was that several UMBC data deliveries were delayed and often incomplete. Finally, USGS updated their EDH review process to encourage the use of geomorphic features, which had previously been a unique benefit of the UMBC data.
- **Less consideration given to alternate data sources.** As stated, project staff determined early on that incorporating the new hydrography into 3DHP was a priority. USGS specifications are clear that hydrography data must be based on and consistent with Lidar elevation data. Over the course of the project, it became clear that other data sources, including land cover and local data, would not be able to be used as primary sources. Instead, they were used to check the data and flag possible errors, or to provide justification for decisions about which stream flowlines to include.

Methods

This section details the methods that were used in the creation and review of new hydrography data for the Stillaguamish watershed. This includes information about the data exchange processes and a description of the hydrography review procedures and communications among project staff, contractors, and USGS.

Data Exchange

NV5 Hydrography

NV5 delivered data over the course of several months for several watershed areas (Figure 4): first, a small headwater area in the South Fork (#1 in Figure 4) and then the entire South Fork (2), North Fork (4), Port Susan (3), and finally the entire Stillaguamish watershed. For each delivery, project staff spent several weeks reviewing the data and then gave feedback and change requests to NV5, who made changes and finalized the data.

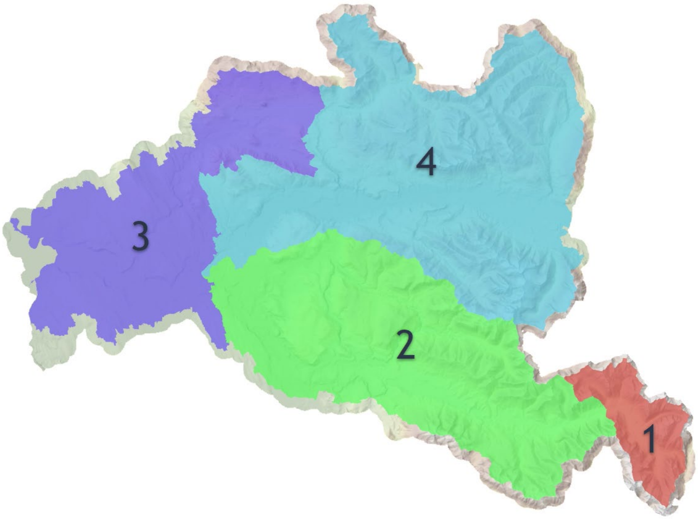


Figure 4. Contractor delivery regions.

Components of each for NV5 delivery includes the following:

- Elevation-derived hydrography data (points, lines, and polygons).
- Hydro-Enforced and Hydro-Conditioned Digital Elevation Models (DEMs).
- Conflated USGS event points and Geographic Names Information System (GNIS) names from current NHD to new EDH.
- Geomorphic index (GMI) raster datasets created to support delineation of elevation-derived hydrography.
- Fine-scale catchment delineations.

UMBC Hydrography

UMBC's process for creating and delivering the hydrography data was iterative, relying on little manual editing. Their workflow involved running the computer vision model on the entire watershed, then revising the model based on a review of the resulting data products. Their data was delivered to Ecology in two stages: first, an initial product in the South Fork of the Stillaguamish, and later, the entire watershed.

Deliverables from UMBC included:

- Line work for Stillaguamish watershed as GIS data with attributes.
- Valley network raster GIS data.
- Channel-like feature vector GIS data (with class probabilities).
- Channel width raster GIS data.
- Bank height raster GIS data.
- Presentation synthesizing findings and outcomes.
- Report synthesizing findings and outcomes.

Ancillary Data

Project staff acquired several other datasets to use as ancillary sources in the review process. Themes of these datasets included hydrography features, roads and trails, stormwater infrastructure, land cover, and imagery. These datasets originated from local, state, and federal organizations and varied in type and quality. A full list of these ancillary sources, and the predicted likelihood of using similar datasets in the future, can be found in Appendix C. Ancillary Data Sources.

Review Process

After receiving hydrography data from NV5, project staff performed basic data integrity checks such as topological tests of network connectivity and review of overall feature and attribute completeness. Data accuracy was then assessed by comparing the derived point, line, and polygon features to the source NV5 geomorphic index rasters (GMI described in Appendix A), Lidar surfaces, and ancillary data. Accuracy review focused on location, origination, omission, and commission errors and potential data gaps. For each feature, assessment results were captured in attributes with defined values (e.g., error present, error type, comparison data source). When necessary, more detailed feedback was provided in a "Notes" attribute. Staff also flagged questionable features for field check or more discussion.

Ecology staff met regularly to discuss questions, error patterns, and review techniques. Meetings with NV5 were then scheduled to address potential resolutions or modifications. Staff also took part in a field trip in March 2023 to explore areas in the watershed with suspected commission errors and provide feedback about those situations to NV5. Technical and steering committee meetings were used to update members on the status of the project and discuss broader project concerns. Committee meeting decisions were used to inform mapping priorities and related data acquisition efforts.

Contractor Feedback

Feedback was provided to NV5 in three primary ways. Evaluation spreadsheets, emails, and meetings were used to discuss overall questions, patterns, and results. A more detailed assessment of the data including feedback categorized by feature was recorded in Ecology's QA dataset attributes and returned to NV5 to update their deliverables. Where possible, NV5 modified their model and review processes in response to requests from Ecology. One common theme of Ecology feedback was a request for more information about NV5's method. In response, NV5 stated that they would review the model and quality assurance details provided in their deliverable reports and add content about their internal decision-making processes. It is expected that contractor products and services will continue to evolve as USGS finalizes its specifications.

Given the significant database structure changes from NHD to the new 3DHP, there were questions about impacts to current business workflow which rely on NHD. These impacts were discussed with USGS, NV5, and the pilot project committees.

USGS Review and Feedback

USGS is developing a procedure for ingesting new EDH data into 3DHP, which will involve a series of automated reviews. Although their methods are not yet defined, at the end of the pilot project, USGS staff performed a limited, initial review of the Stillaguamish data. This review used sources including a GMI raster which was created using slightly different procedures than those employed by NV5 (Appendix A), as well as several ancillary comparison datasets like what Ecology staff used in their assessment (Appendix C. Ancillary Data Sources). This review revealed several issues. The pilot project data was created from a surface projected to Washington State's standard spatial reference system instead of the Albers projection required by USGS, therefore the number of floating vertices was above USGS's accepted threshold. Floating vertices are stream nodes that have an elevation point above the elevation surface used. The steep terrain present in the Stillaguamish watershed may also cause these types of errors. In addition, projection offsets may cause profile errors in low areas next to streams. These errors will need to be corrected before the data can be accepted.

The tools used by USGS to perform the evaluation are being converted to Esri's ArcGIS Pro software but will not be available for widespread use. However, it is hoped that the tool output will be available to Ecology and its partners. The comparison datasets used for review by USGS and Ecology staff are being recommended for inclusion by contractors as part of their internal quality assurance process. Regarding GMI raster differences, USGS staff acknowledged that no single GMI raster can accurately represent all water feature possibilities in every landscape.

Stormwater Integration to Hydrography

Often water flow is under-mapped in urban areas since much of the flow is sub-surface. While jurisdictions often have good records of stormwater infrastructure, combining them with surface flows can be challenging. A representative hydrography dataset needs to incorporate both the surface flows that can be modeled with Lidar, as well as the sub-surface flows commonly found in urbanized areas. The purpose of the stormwater pilot project was to provide Ecology staff with sample data from which to evaluate the feasibility and value of integrating mapped stormwater networks in urban areas with other surface hydrography as part of the development of the new hydrography dataset.

For this pilot project, a small area of Snohomish County was selected to represent varying densities and types of urbanization, as well as areas of mapped and unmapped stormwater networks.

This project involved three phases. Each phase included a review session with Ecology staff. The first phase was to evaluate the current available stormwater data in terms of accuracy, completeness, and topological correctness. Subsurface networks cannot be accurately mapped with remote sensing, so the success of any integration of surface and subsurface flow is dependent on the quality of the subsurface network data. The second phase was to map the surface flow and route it to the inlets and from the outlets of the subsurface network to create an integrated hydrography line network. The last phase of the project was to develop catchments from the integrated network based on contributing area to unique terminal outlets or combinations of outlets depending on the structure of subsurface network. Deliverables from each phase were as follows:

- Phase 1:
    - Report section on subsurface network quality.
    - Revised version of network with any changes made to the direction, topology, or location of network features.
- Phase 2:
    - Report section on subsurface network and surface flow integration.
    - Integrated hydrographic line network.
- Phase 3:
    - Report section on catchment delineation,
    - Catchment boundaries.

A final report was provided to assist in determining necessary data to perform a stormwater integration in the future.

Results

Review of EDH

In the review of EDH data from NV5, project staff assessed 74,931-line segments and 1,135 polygons. The finalized dataset created by NV5 in response to this review contained 73,794-line segments and 1,137 polygons. An estimated 2,300 hours of review time of the pilot watershed data occurred over a 6-month period.

When discussing these results, it is important to distinguish between the "assessed" and "final" version of the dataset. Unless noted, it can be assumed that the final version is being referred to. The slight decrease in segment total between the assessed and final version can be attributed to the fact that NV5 had removed some flowlines that were found as having no stream presence and excluded draft segments that had been added to demonstrate alternative routes or possible additional streams. The minor increase in polygons was due to NV5 adding more snow-covered polygons in the final version. They also removed small lake/ponds that did not have water present per the error comments, but the addition of the snow polygons outweighed this change.

Flowline Statistics

There were several different types of flowline segments in the assessed EDH dataset, which included headwater streams in the mountains, canals running through farms, and culverts connecting streams crossing underneath roads. Figure 5 shows the diversity of segment types within the Stillaguamish watershed.

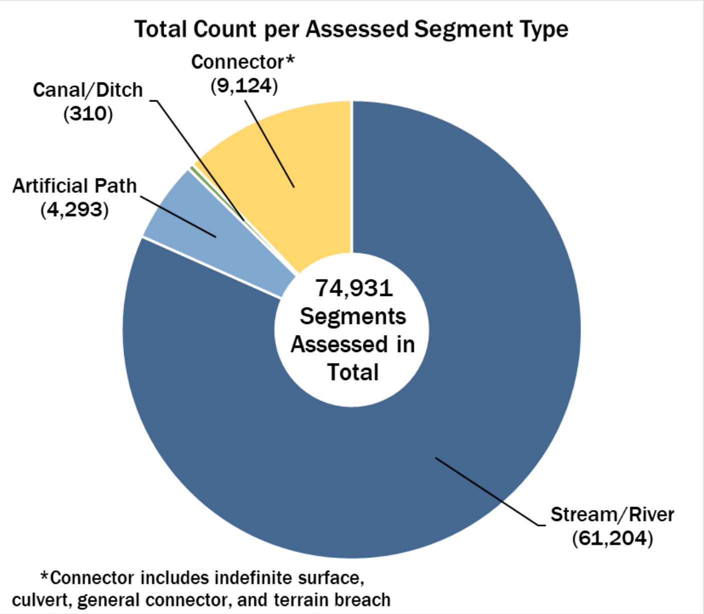


Figure 5. Total assessed segments categorized by segment type. Note connector is a general grouping of types of stream connectors due to their smaller individual counts. Pipelines (3 in total) were excluded from statistics and analysis.

Segments where the project team found a potential issue were marked as errors or field checks. When the team had confidence that an error was present and that there was a more accurate option for a line, it was marked as an error. NV5 would take a closer look at the segment in question and decide if it should be removed (Figure 6). If the team was unsure or the error was unclear, it was marked as a field check for future reference.

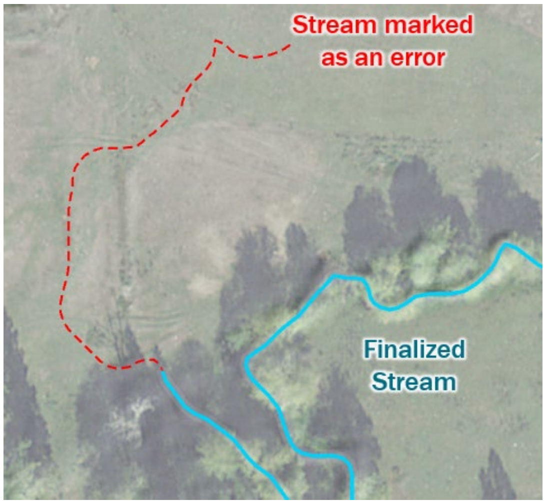


Figure 6. An example of a stream that NV5 removed after Ecology staff marked it as an error due to multiple reference variables indicating no stream presence.

Out of the 74,931 assessed segments, there were 1,137 segments marked as containing errors, of which 105 were also marked as potential field check locations. There were also 1,758 segments that were just marked as field checks. In total, 72,036 segments (98.5% of the total) contained neither errors nor field checks. Figure 7 shows these error and field check counts as a proportion of the total number of segments. In the final version, NV5 made changes to 84.8% of the segments that were marked as errors.

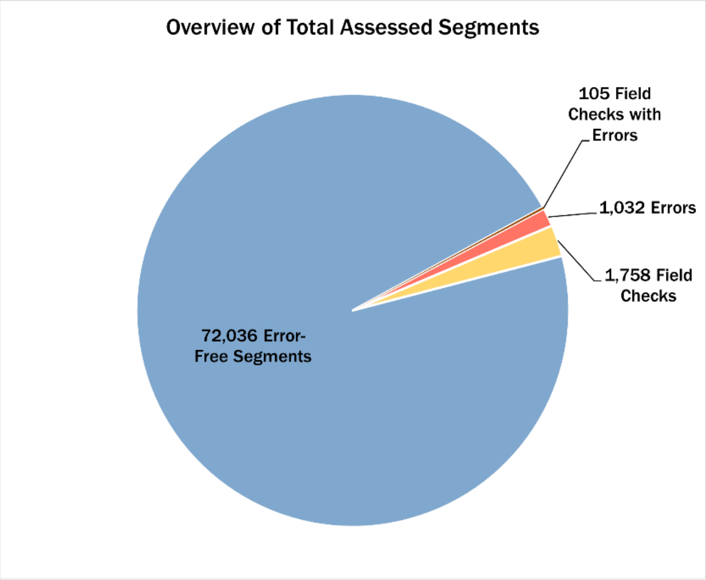


Figure 7. Overview of total assessed segments with errors marked as field checks, errors, and field checks with errors highlighted. The 72,036 total was free from errors and field checks.

Most of the errors (78%) were found on segments classified as streams or rivers, as these were most of the data (Figure 8). Common errors within this category were inaccurate streams suggested to be removed (commission), incorrect stream paths suggested to be rerouted, high stream density at the confluence of two streams coming together, and uncaptured streams suggested to be added (omission). The second largest portion of errors were stream connectors. Many of these errors were culvert-related, including inaccurate culvert placement and erroneously classified streams. Culverts contributed about 13% of the total errors, more than the other connector subcategories. Errors found in artificial paths included missing GNIS names and inaccurate path direction. Segments classified as canals or ditches, which were found mainly within agricultural areas, had the fewest errors. Within this small category, errors included segments improperly categorized as canals/ditches and missing culverts or terrain breaches, based on visible farming and property crossings in the imagery and Lidar.

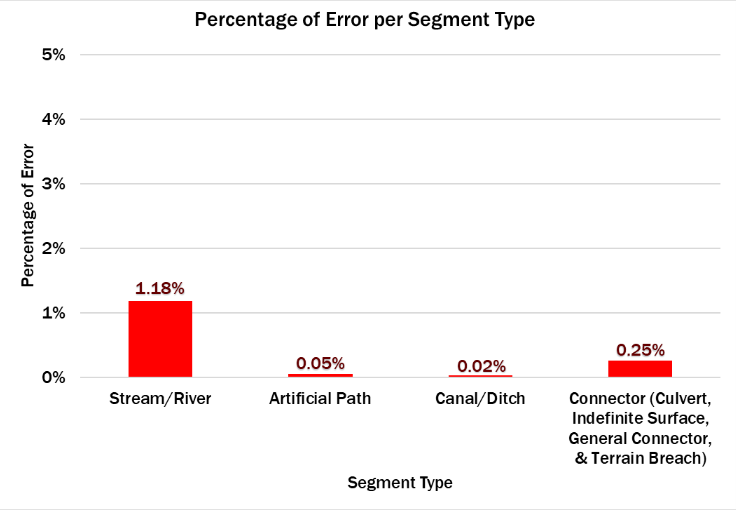


Figure 8. Percentage of error per segment type.

Error percentage per segment type out of total assessed streams. Percentage capped at 5% due to low percentages.

Field Checks

On the ground accuracy confirmations were performed during two field trips. Areas that were commonly accessible and sought out were culverts crossing under roads and streams that passed through fields or more developed areas. While all flowlines marked as field checks should be checked, this was not possible due to time and location limitations (Figure 9). Points of interest were chosen beforehand to decide areas to prioritize. Flowlines that were chosen were often representative of a broader question about the data and were beneficial to locate and assess. These lines represent the most questionable portion of the data, so categorization was done with extra caution. The field check process was conducted using Esri's ArcGIS Online applications. This involved creating a web map that could be accessed when offline (to account for areas with no cell service) and editing data through Field Maps when in the field. GPS was sometimes used for location accuracy.

The results of the field checks were mixed. Some sites were inaccessible, often due to poor road conditions, private property restrictions, or remote, heavily forested locations. The general location of EDH culverts was typically accurate, but this did not always equate to having stream flow (Figure 10). Culvert markings on the roads (typically a painted white dash line on the side of the road) often matched the EDH data. The checks also confirmed team instincts on questionable stream presence, especially in agricultural fields that appeared to lack flow. Overall, the checked flowlines were split evenly between matching and not matching real-world conditions.

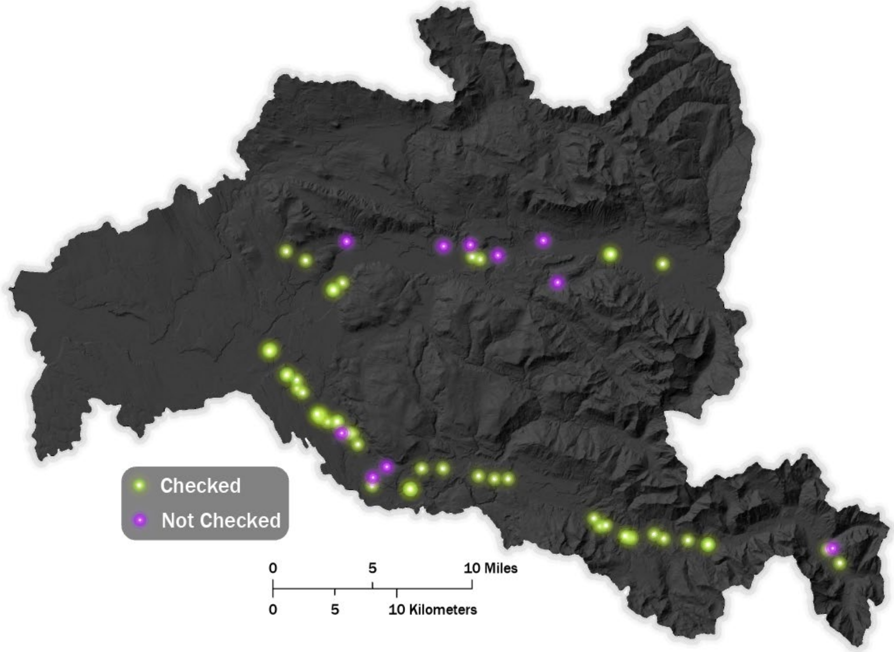


Figure 9. Checked and unchecked points of interest within the Stillaguamish Watershed.

Field with no stream presence.

Culvert confirmed, with road wash out.

In addition to confirmed culvert and stream flow, additional culvert found.

No sign of stream. EDH indicated a stream and indefinite surface.

Figure 10. Examples of field checked points (green).

Examples of field checked points (green) and accompanying photographs of the areas. Light blue lines are streams, darker blue lines are artificial lines, red lines are culverts, and dotted blue lines are indefinite surfaces.

Four examples of field checks. Each example includes an aerial photo showing the location and a close-up photo taken at the site. 1. Field with no stream presence. 2. Culvert confirmed, with road wash out. 3. In addition to confirmed culvert and stream flow, additional culvert found. 4. No sign of stream. EDH indicated a stream and indefinite surface.

Land Cover Statistics

The purchased 2021 land cover data from Ecopia was created using aerial imagery captured in the fall of 2021. The land cover data helped quantify that the watershed was mainly made up of forested land (Figure 11), and the majority of the final EDH streams fell into that category. Pie charts shown in Figure 12 are the non-normalized coverage of land cover types that the streams (length in miles) and waterbodies (area in acres) fell within. If a segment or polygon was located within multiple land cover types, it was split up accordingly to account for all categories. Based on the results it appears that the EDH flowlines were more likely to be in forested areas.

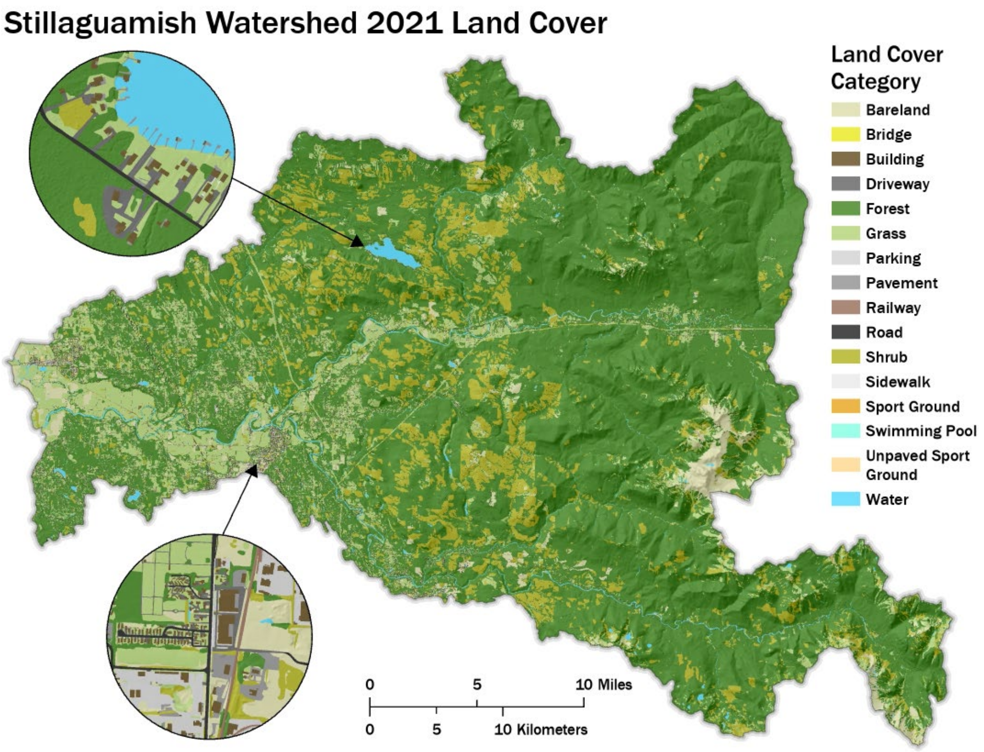
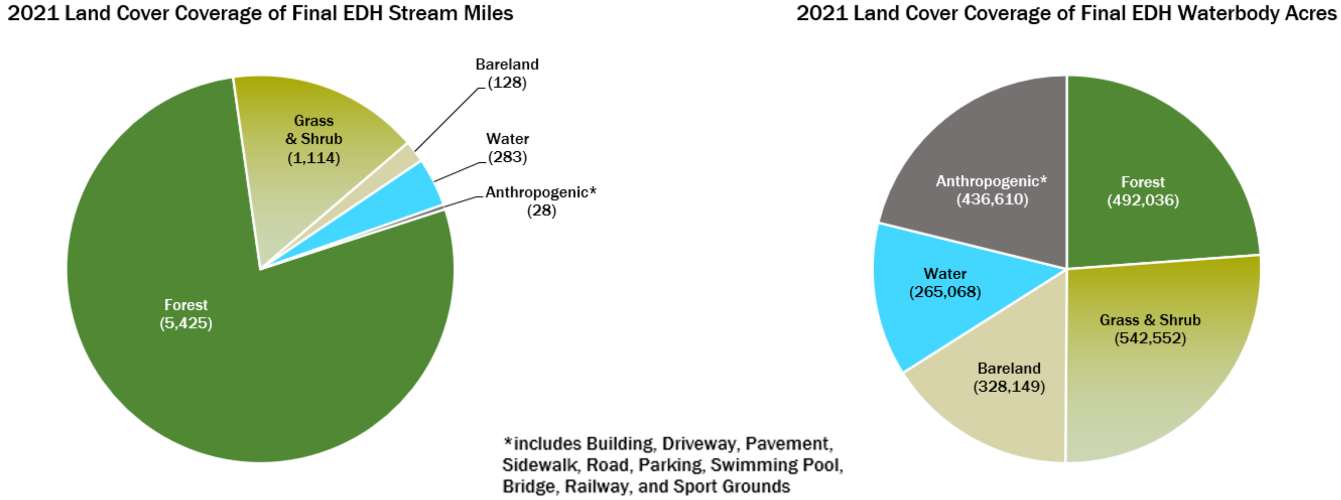

Stillaguamish Watershed 2021 Land Cover

Figure 11. Overview of 2021 land cover data in the Stillaguamish watershed.

However, the watershed does not have an equal distribution of land cover types, so the analysis will be biased. For example, much of the landscape is forested, therefore a random distribution of streams would mostly fall in forested land.


2021 Land Cover Coverage of Final EDH Stream Miles

2021 Land Cover Coverage of Final EDH Waterbody Acres

*includes Building, Driveway, Pavement, Sidewalk, Road, Parking, Swimming Pool, Bridge, Railway, and Sport Grounds

Figure 12. Aggregated, non-normalized land cover coverage for the final EDH streams (miles) and waterbodies (acres). Both mileage and acreage are rounded to the nearest whole number.

To account for the unequal distribution of land cover type, the data was normalized to assess EDH location as if all land cover types were equally present. Using this method, the EDH location is reported as either being present on a land cover compared to a random distribution

(Figure 13). Results are reported as number of miles expected for that land cover. For example, total stream length in "bareland" has a negative value of –92 miles; this means the length of streams within bareland areas were ninety-two miles less than expected when looking at the Stillaguamish as a whole. Forested areas had more streams than expected. The same comparison with waterbodies had less than expected forest cover (Figure 14).

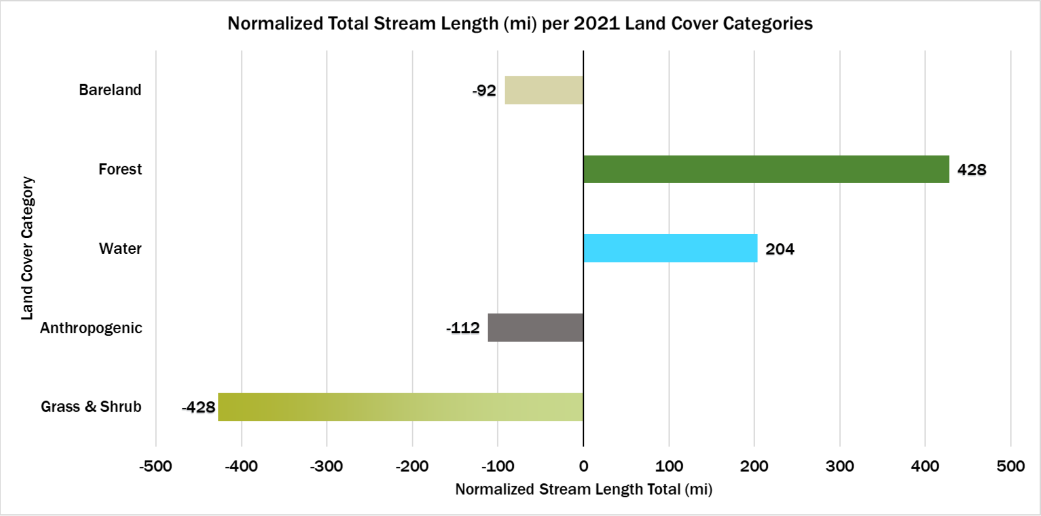


Figure 13. Normalized approximate stream length total (miles) per 2021 land cover categories, which are compiled. Anthropogenic includes buildings, driveways, pavement, sidewalks, roads, parking, swimming pools, bridges, railways, and sport grounds.

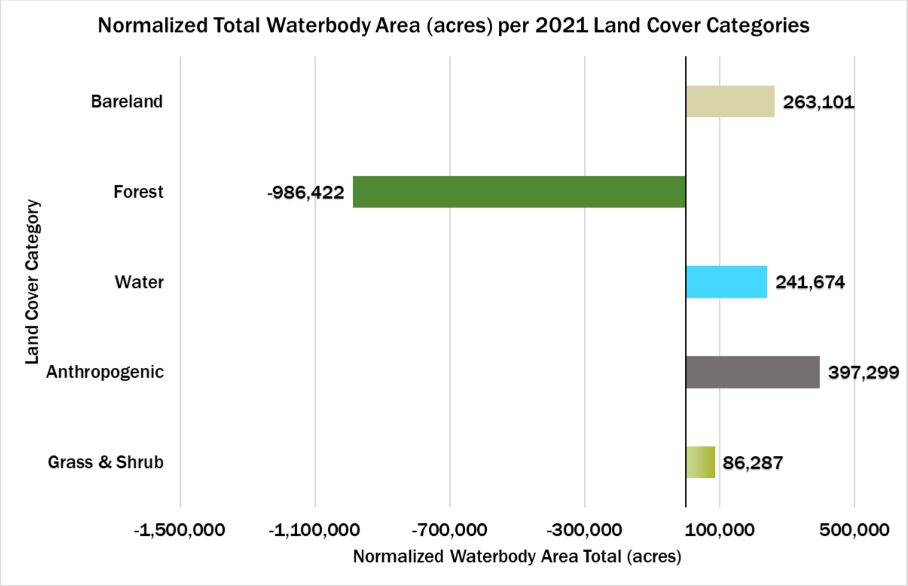


Figure 14. Normalized approximate waterbody area total (acres) per 2021 land cover categories, which are compiled. Anthropogenic includes buildings, driveways, pavement, sidewalks, roads, parking, swimming pools, bridges, railways, and sport grounds.

The results of this assessment suggest that smaller surface water flow do not affect the land cover, such as streams flowing underneath tree canopy. Larger bodies of water do affect the land cover for example they are open water.

The land cover information can be helpful when doing future assessments of accuracy. When assessing large amounts of data during a Statewide update, every EDH feature cannot be evaluated. Therefore, methods to help find areas expected to be wrong will be helpful and the land cover is based off aerial imagery instead of Lidar so serves as an independent data source. For example, areas where land cover is showing open water would be expected to also have either an EDH flowline or waterbody feature in that location. Similarly, EDH waterbody features that are located on a land cover type of Forest could be evaluated for accuracy.

Comparison of NHD and EDH

EDH and NHD lines and polygons were compared using both qualitative observations and quantitative statistics. To fairly compare EDH to NHD, only the shared categories of lines and polygons were included. NHD categories such as swamp/marsh polygons and coastline segments were excluded as they could not be compared with the EDH categories. Pipelines were also excluded, as there was a negligible number of pipelines in each dataset. Throughout this section, blue tones are EDH and yellow tones represent NHD.

Conflated Streams

In comparing NHD and EDH features, it was sometimes useful to compare individual streams that were conflated (matched) between the two datasets. To this end, features that were part of the Geographic Names Information System (GNIS), which is a centralized federal database of place names, were often used. Typically, inclusion in GNIS indicates that a feature is large or important. GNIS names were the only attributes that were conflated between the NHD and EDH data; other identifying attributes such as reach codes were not carried over. In the final EDH dataset, GNIS streams make up just under ten percent of the total stream mileage. Figure 15 shows where GNIS streams are in the watershed.

Figure 15. GNIS streams (thick lines) and non-GNIS streams (thin lines) from final EDH dataset in the Stillaguamish watershed.

In addition to the GNIS streams, streams were manually conflated in three small catchment areas: one heavily forested, one agricultural, and one highly urbanized. The agricultural and urban catchments were contiguous, so for the sake of the conflation they were treated as one area. Figure 16 shows these selected catchment areas. Figure 17 shows the locations of streams in these catchments. To supply a more complete stream network for analysis and avoid cutting streams off awkwardly, some segments that extended upstream and downstream of the catchment boundaries were included.

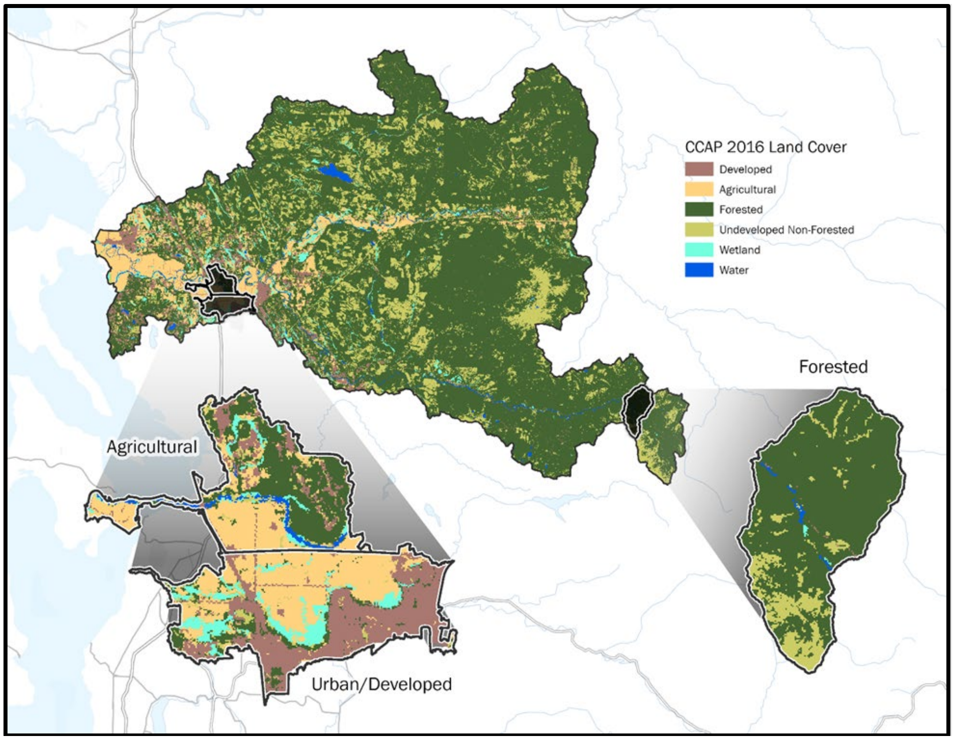


Figure 16. Catchments with varying land cover selected for conflation.

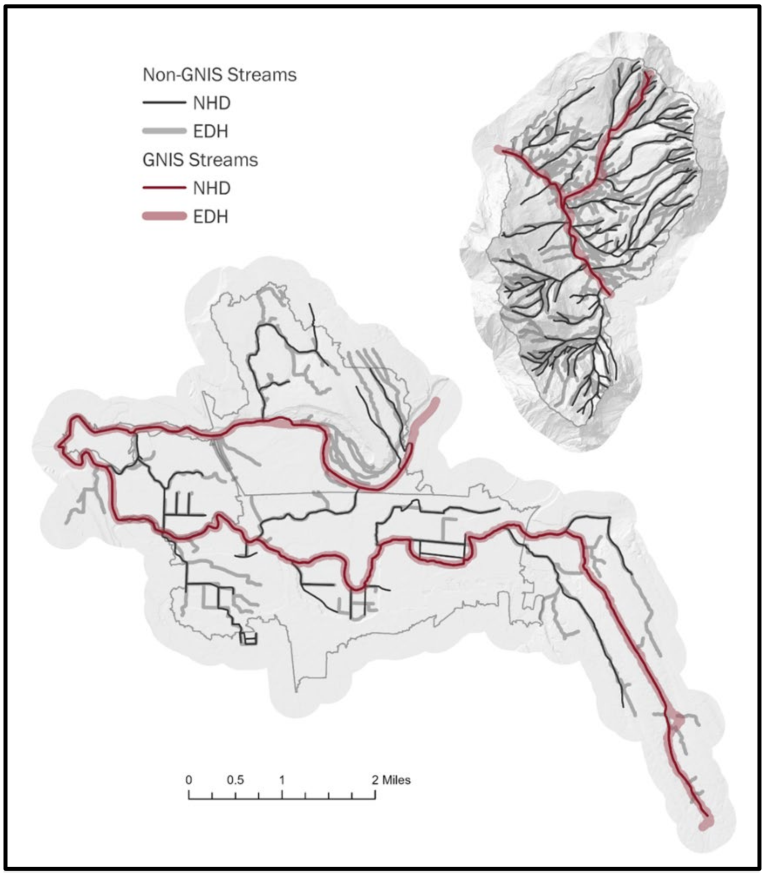


Figure 17. GNIS and non-GNIS streams within selected catchments.

During the conflation process, some matches were obvious; in other cases, it was a matter of choosing the best of several possible matches or figuring out that a match was not possible. Most of the NHD streams—about sixty-five miles of streams out of a total of approximately seventy-five miles—were assigned a match in EDH. The converse is not true: out of approximately 120 miles of streams in the EDH dataset, only about seventy-five miles were assigned a match. This suggests that the EDH data includes most of the streams that were already mapped in NHD, plus many new, previously unmatched streams.

Comparing Number and Total Size

EDH had more lines and polygons than NHD, both in terms of total number of features and total line length and polygon area (Figure 18). This increase occurred throughout the watershed: in each of the twenty HU12 hydrologic units that make up the Stillaguamish watershed, the total stream mileage increased by more than fifty miles between NHD and EDH.

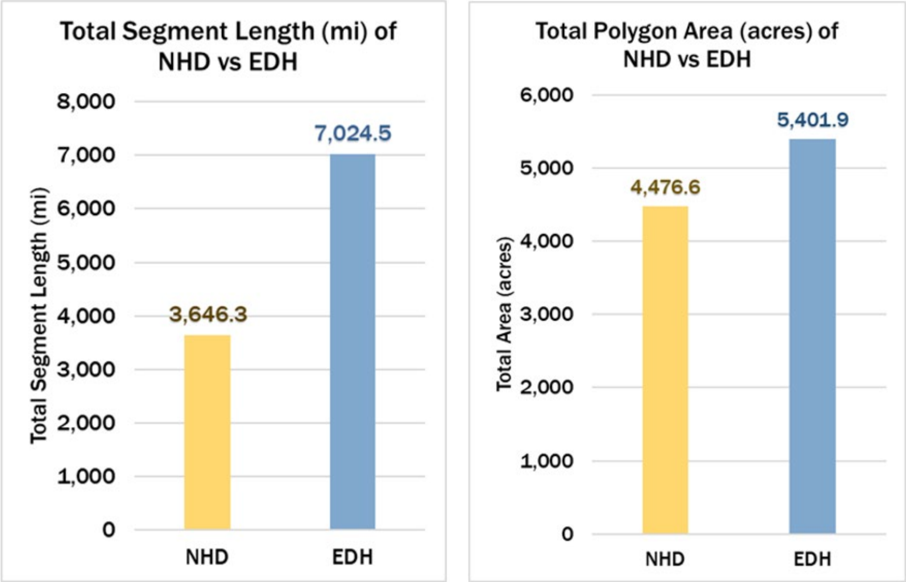


Figure 18. Comparison of NHD and EDH total segment length (miles) and total polygon area (acres).

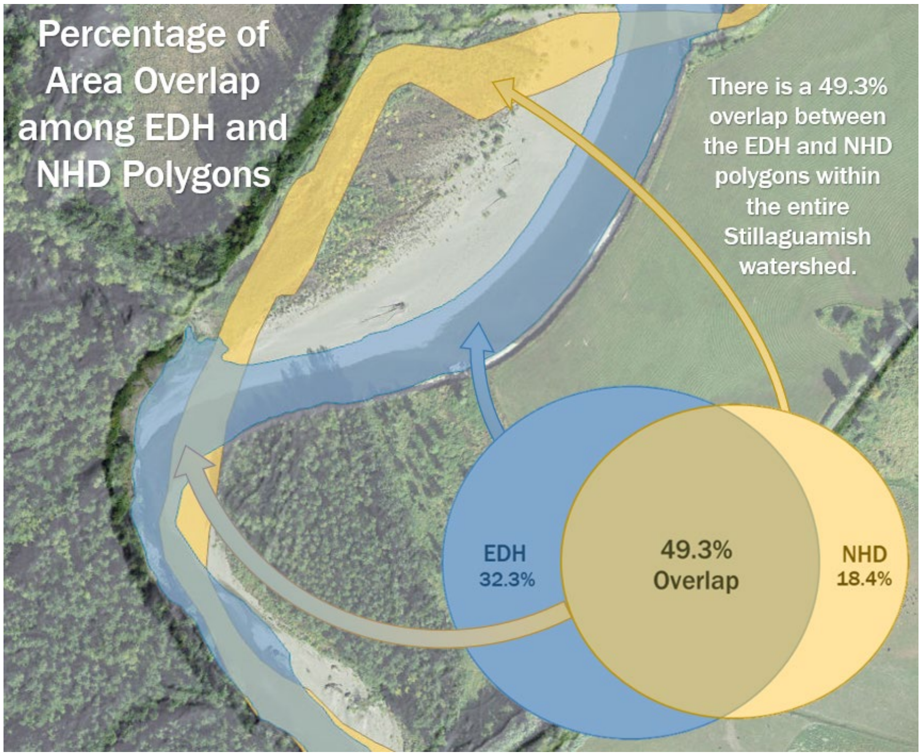


Figure 19. Percentage of area overlap between EDH and NHD polygons. Area measured in square kilometers.

These increases can be attributed to a few causes. For the flowlines, EDH mapped streams with more sinuosity and detail than NHD and captured more small headwater stream segments. For the polygons, EDH generally captured more polygons in the landscape (Figure 19), and the stream polygons extended further upstream. Figure 20 shows some of the differences between NHD and EDH and illustrates how the latter is overall a better match to the imagery and Lidar data.

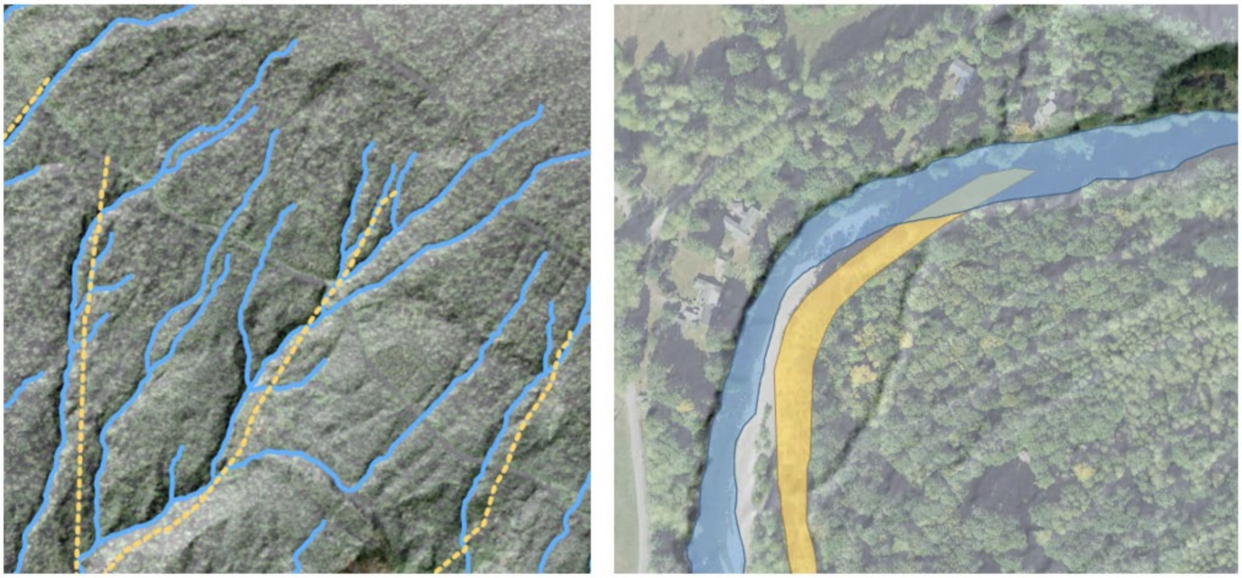


Figure 20. Examples of EDH data, including more detailed headwaters (left) and farther extension of stream/river polygon length in comparison to NHD (right). Yellow is NHD and blue is EDH.

Some changes between datasets can be accounted by movement in the river location over time. It is important to track when hydrography was mapped, since movement of the water is expected. While this still can be considered an error in current location, the data was correct in the past. Updating hydrography over time is an important factor to consider when assessing location accuracy.

To assess the extent to which the increase in stream mileage was due to increased sinuosity or bending in a stream, the length of ten randomly selected GNIS streams were compared. After clipping off any beginning or end portions that do not match to ensure that the streams begin and end in roughly the same place, it was found that the EDH streams were consistently longer than the NHD streams. The length increases varied from about 1% to 20% (Figure 21). The clipped-off portions between the two datasets were also compared but no discernable trends concerning upstream or downstream extent were found.

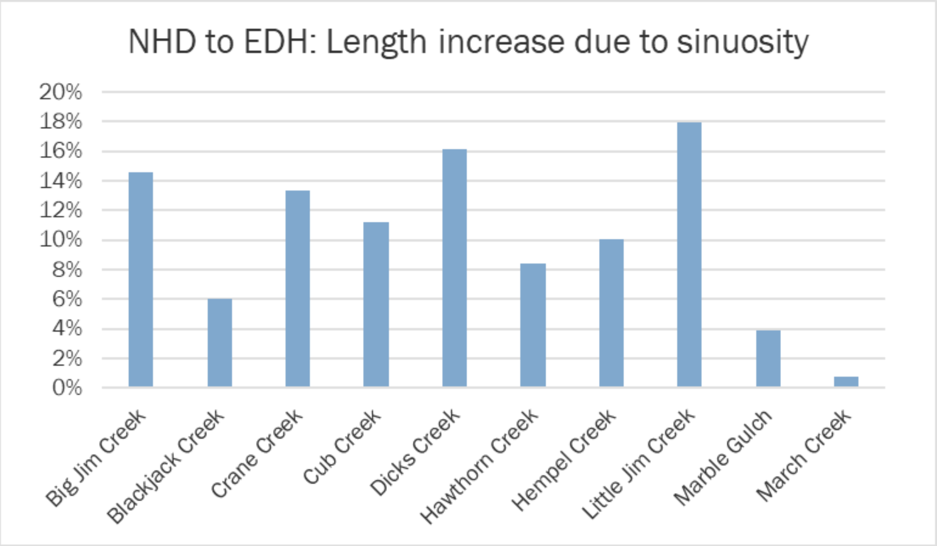


Figure 21. NHD to EDH: Length increase due to sinuosity.

Comparing Location

To account for possible change in the upper versus lower watershed, a comparison of EDH and NHD streams at different elevations was made. To allow for this, the Stillaguamish watershed was divided into upper and lower portions. The division of the watershed was figured out by road and building presence shown in local data, with 650 feet elevation as an approximate cut off for the main lowland urbanized areas. As mentioned previously, the Stillaguamish watershed has a range of elevation values and land cover types, so separating the “lower” and “upper” portions of the watershed into more urbanized/agricultural (lower) areas and more forested/mountainous (upper) areas helped with comparisons. The upper watershed was more than double the area of the lower watershed. Figure 22 shows the divided watershed as well as the results of comparing NHD and EDH in the two areas, which revealed that there were increases in stream length for both watershed portions, but more so in the upper watershed. This increase in length in the upper watershed supports the idea that EDH captured more small headwater streams.

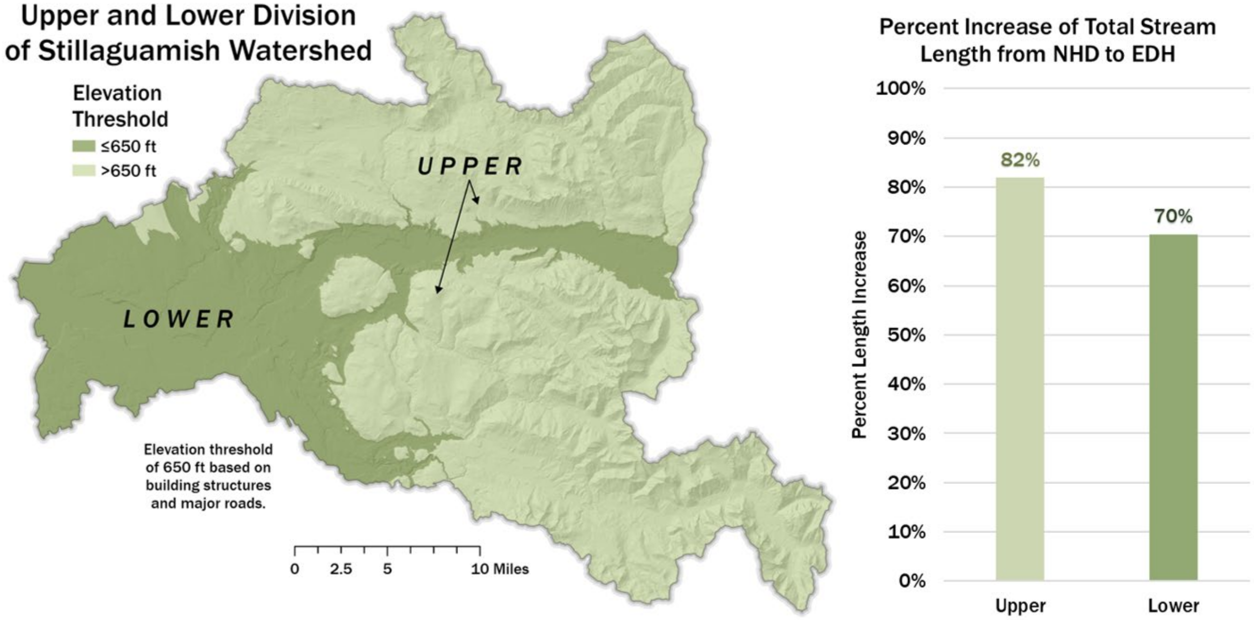


Figure 22. Approximate percent increase of total stream length (miles) from NHD to EDH in the upper and lower watersheds.

To compare locations of flowlines, a 50-foot buffer was created around NHD flowlines, and the percentage of EDH flowlines that extended outside of this buffer were decided (Figure 23). The results were then examined in the upper and lower watersheds. About 75% of the stream mileage found outside of the NHD buffer was in the upper watershed, while only about 25% was in the lower watershed.

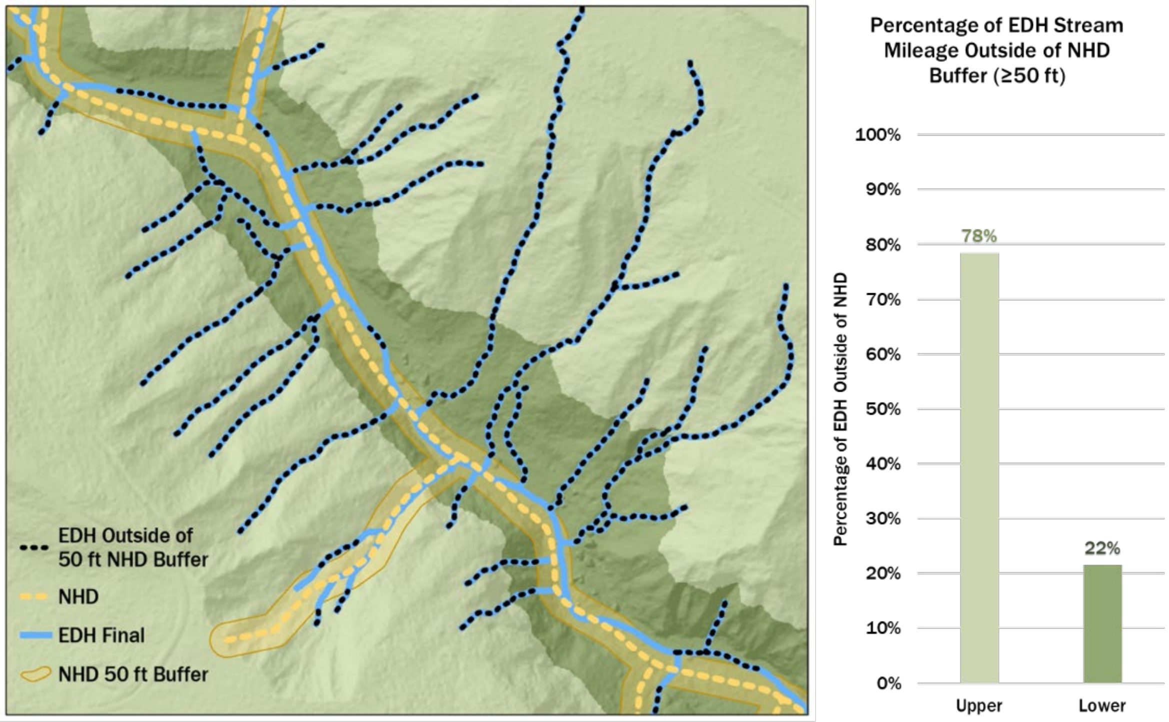


Figure 23. Example of EDH extension 50 feet or more past NHD within the upper and lower divisions of the Stillaguamish watershed (left). Approximate percentages of final EDH stream length (miles) that fall outside of the NHD buffer (right).

Comparing Stream Order

Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on numbers of tributaries. Some characteristics of streams can be inferred by simply knowing their order (Esri Online Help 2024). Calculating stream order is relatively simple and only requires that the data is set up to have a flow network. Washington State has added stream order data to the NHD high resolution data using the Strahler (1957) technique and made that available as part of the state's hydrography download. The Strahler method was also used to calculate stream order for the EDH data in the pilot project area and is less likely to change with increased first order segments as compared to the Shreve method. There was an expectation that the increased stream length and the detection of smaller streams would have an impact on the distribution of stream order data.

The calculated length of stream order segments increased but mostly uniformly across all orders (Figure 24). Differences between the EDH and NHD lengths were noted when compared as the percent change from NHD (Figure 25). So, if the total length of segments of a given stream order did not change between NHD to EDH, it would be zero percent, and if it doubled in length, the value would be 100%.

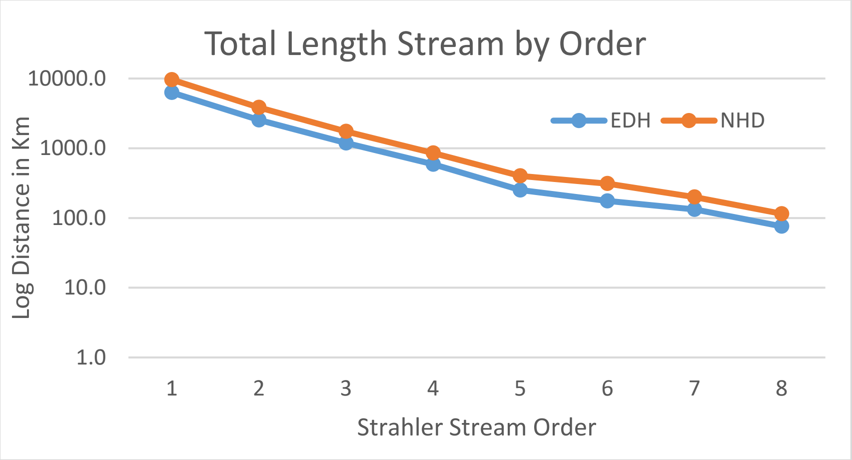


Figure 24. Comparison of EDH and NHD total line length by stream order.

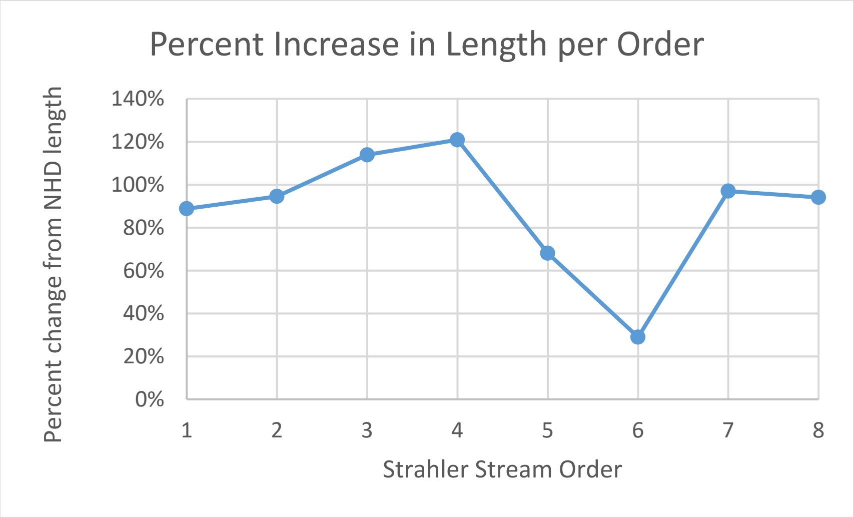


Figure 25. Change in length from NHD to EDH of total stream order segments as a percent increase.

The results from this comparison likely will change with different landscapes. The lower amount of increase in stream order 5 and 6 segments (Figure 26) seems to be specific to this watershed. The increased number of stream segments is increasing the stream order of all streams, and there were some longer order 6 streams in the NHD that became order 7 streams in the EDH. Overall, individual streams show an increase in stream order between NHD and EDH mapping.

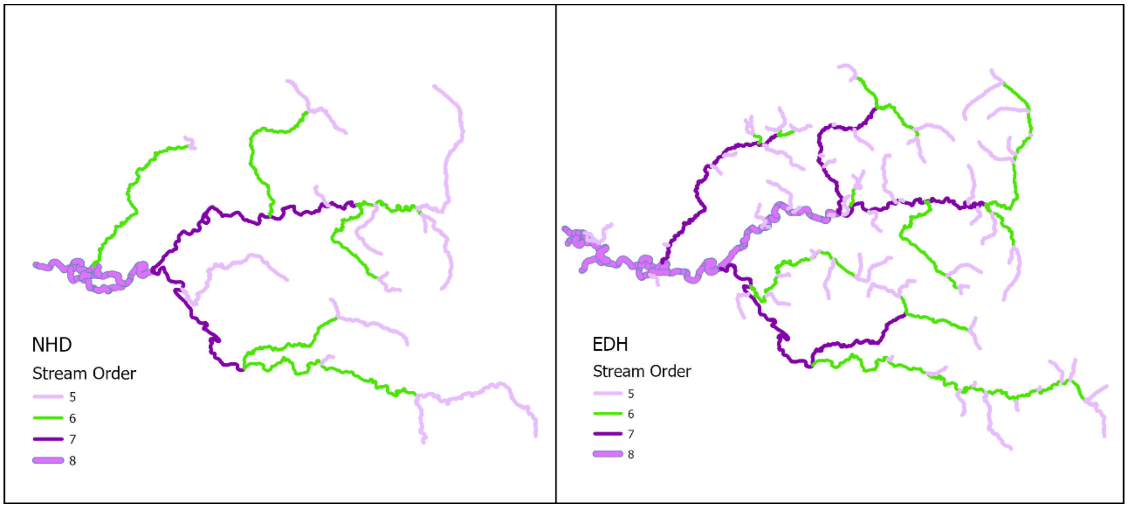


Figure 26. Comparison of stream order (Strahler method) 5 to 8 with NHD and EDH.

The most important point is that there will be changes to stream order as many streams are expected to increase their order number because of this mapping update.

Comparing Conflated Stream Locations

To further assess the difference in location of the EDH and NHD flowlines, the project team compared them using multi-ring buffers on pairs of conflated streams. This assessment gave an indication of how far the new EDH line was from the original NHD. This could be interpreted as how inaccurate was the original NHD data, but also shows areas of spatial separation that can be reviewed for underlying reasons the EDH was different. The method, which is shown in Figure 27, was as follows:

1. Identify a conflated pair of EDH and NHD streams as well as any polygons associated with the EDH stream.
2. Create multi-ring buffers around the EDH lines and polygons.
3. Determine what portion of the NHD lines falls within each buffer.

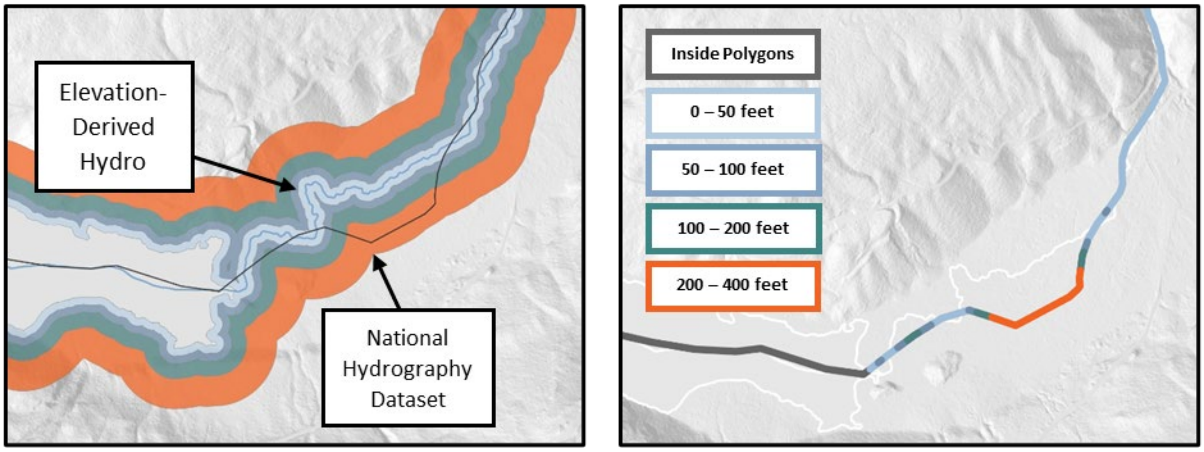


Figure 27. Buffer analysis process.

Figure 28 shows the results of the buffer analysis on the GNIS streams. For the most part, the NHD streams fell within 50 feet of the EDH streams and/or inside of the EDH polygons. Only about 15-20% of the total stream mileage was located outside of this range.

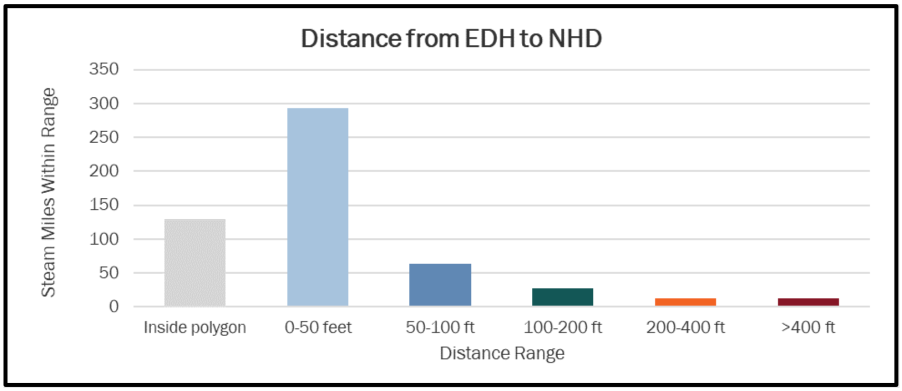


Figure 28. Distance from EDH to NHD for GNIS streams.

The map in Figure 29 shows specific examples of places where the two datasets diverged significantly and offers some explanation as to why this difference occurred.

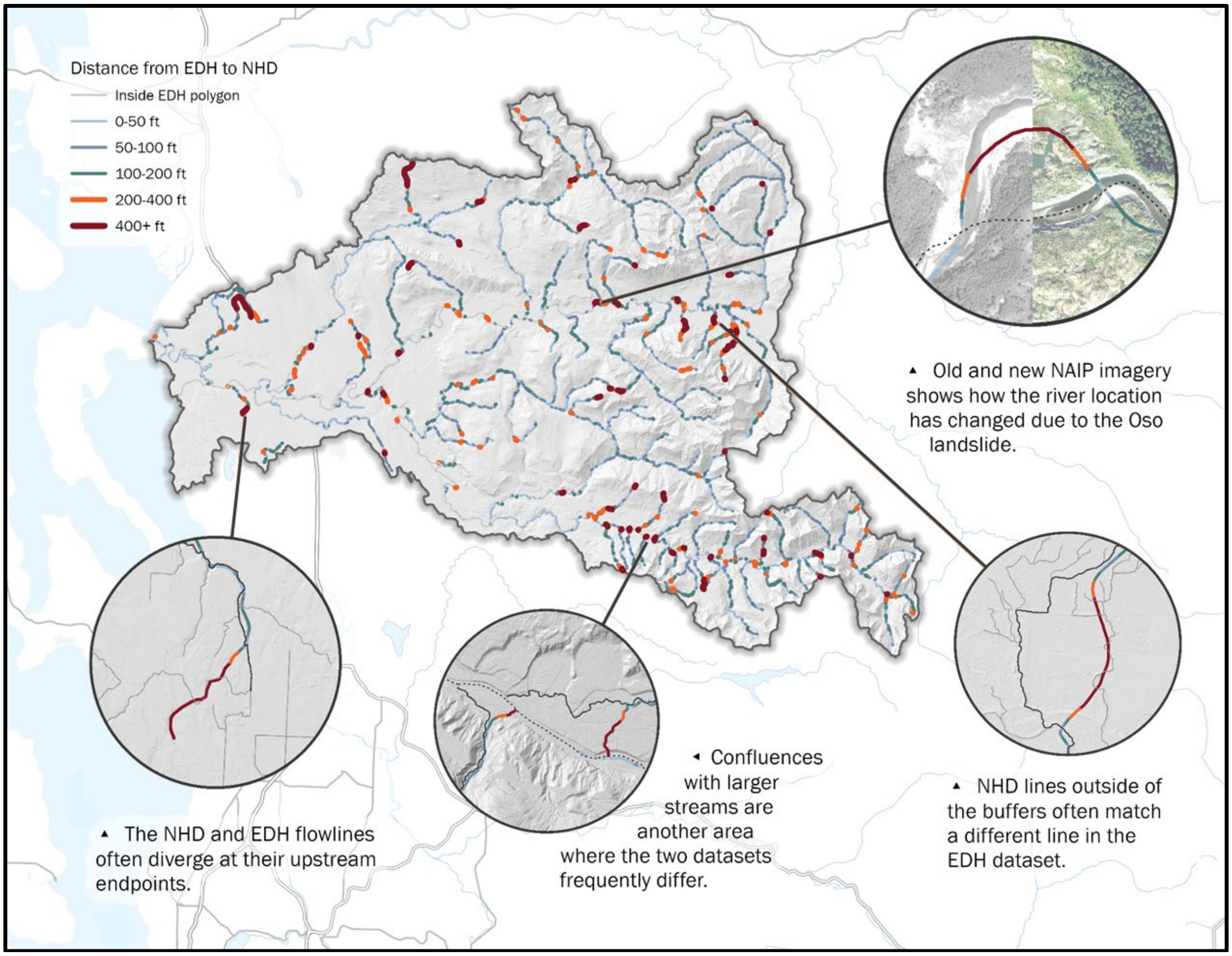


Figure 29. Close-up view of areas where EDH and NHD stream locations significantly differ.

The team was concerned that sampling bias may have been introduced by only performing this analysis on the GNIS streams, so the process was repeated in the manually conflated catchments. Figure 30 shows the results of this assessment. The two datasets were well-matched in the agricultural and urban catchments but less so in the forested catchment.

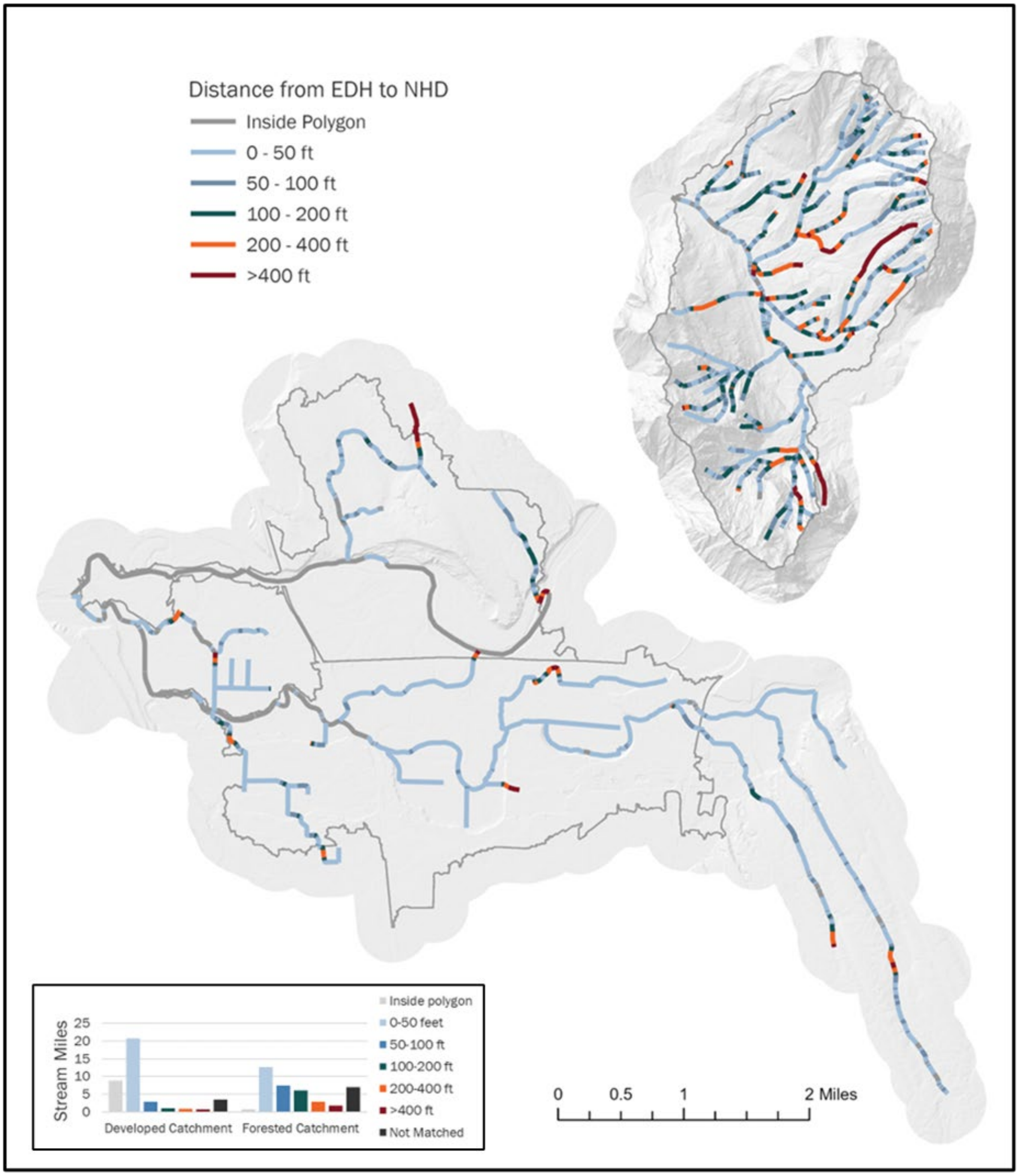


Figure 30. Distance from EDH to NHD for conflated streams.

Figure 31 shows how GNIS and non-GNIS streams differed in the conflated catchments. The results for the GNIS streams are like what was found in the earlier assessment—about 90% of the stream miles fell within fifty feet of their matched EDH stream or polygon—but for the non-GNIS streams, it was only about 50%.

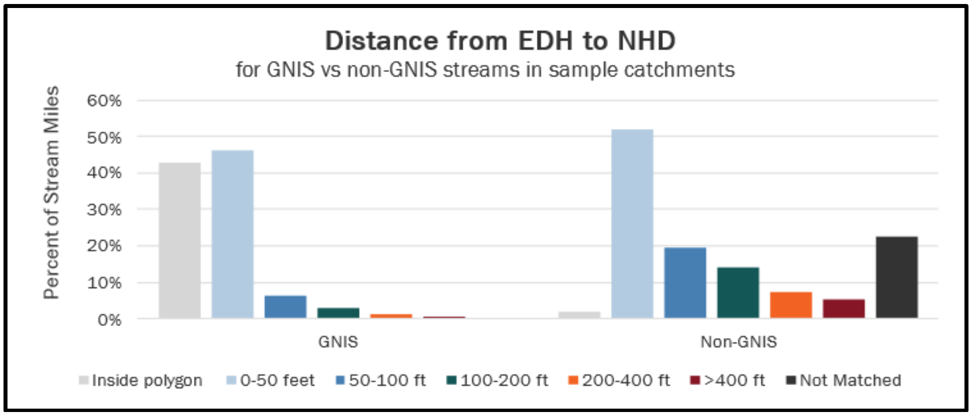


Figure 31. Distance from EDH to NHD for GNIS vs non-GNIS streams in conflated catchments. GNIS streams make up 27% of the stream miles within these catchments.

UMBC Results

The review of the UMBC flowlines consisted of visual checks throughout the study area as well as a more detailed inspection in the same three sample catchments that were used for manual stream conflation. This review turned up several unexpected and potentially problematic phenomena. These phenomena are discussed below, and some examples are included in Figure 32.

- The flowlines are highly segmented. While the total stream mileage for UMBC is slightly less than the final EDH dataset (see Figure 33 for comparison), the UMBC dataset has more than ten times the number of segments in the EDH. The average segment length for the UMBC streams is only about thirty feet long, compared to the EDH average of about 490 feet. This seems to be because the UMBC streams are split every time they fall outside of a pixel that is characterized as a channel, while in contrast, the EDH streams are only divided when there is a longer stretch with no channelization. For both datasets, but especially for UMBC, it would likely be helpful to dissolve stream segments into longer reaches before conducting analysis.
- There are several inexplicable small gaps between stream segments, leading to a disconnected stream network that caused some difficulties with analysis and comparison methods. In the three sample catchments alone, approximately 150 of these gaps were found.
- There are several places where the flowlines followed an unusually jagged pattern after a confluence. About four or five instances of this phenomenon were found in the sample catchments.
- In a few places, typically agricultural landscapes dominated by canals, the UMBC flowlines do not fall into clear channels in the Lidar and are instead slightly offset.
- There was some confusion around the attributes classifying the different types of connector segments. In general, connectors were marked as either “water and wetland” or “road and ridge”. However, some connector features were classified as both, and some as neither of the two. More information may be needed to clarify the meanings of these attributes.

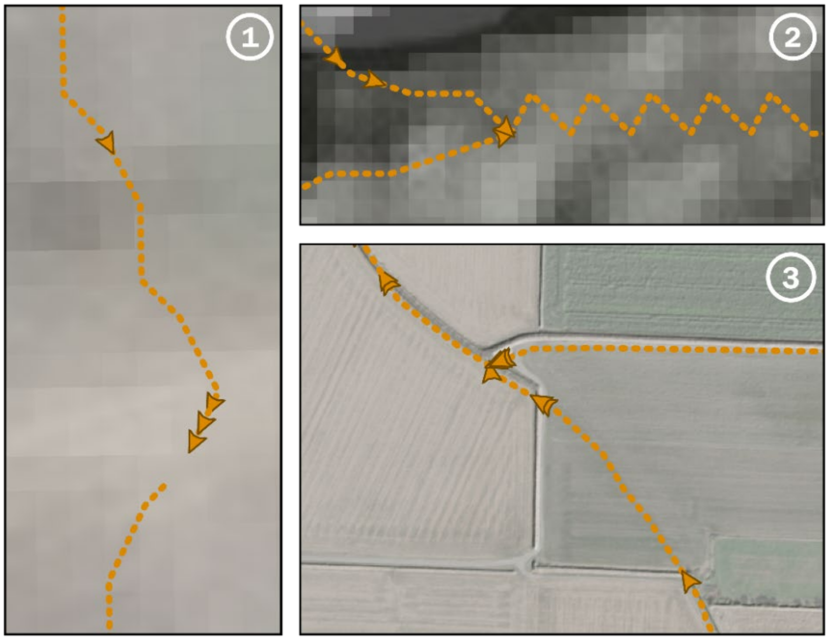


Figure 32. Examples of UMBC issues including short stream segments and disconnected network (1), jagged lines after confluences (2), and linework offset from well-defined channels (3).

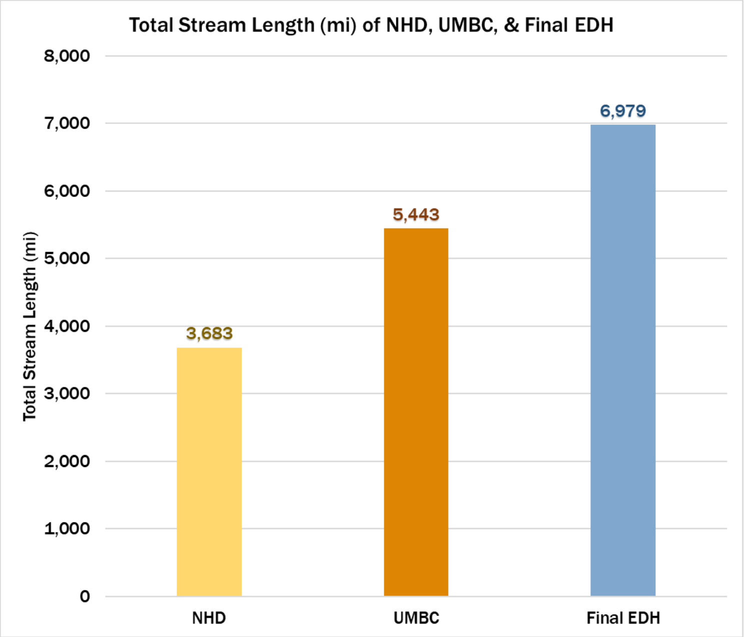


Figure 33. Comparison of total approximate stream miles of NHD, UMBC, and Final EDH. Conversions are approximately 5,928 km (NHD), 8,760 km (UMBC), and 11,231 km (Final EDH).

These issues aside, the UMBC flowlines generally follow similar paths to the EDH lines. There are some differences in which smaller streams are included or excluded from each dataset, but in places where the two datasets mapped the same stream, the flowlines are typically within five feet of each other. While the team did not do a statistical analysis of UMBC versus EDH, the main noticeable trends were that UMBC did not include as many smaller streams as EDH and had more difficulty around road crossings. Figure 34 shows some examples of these differences.

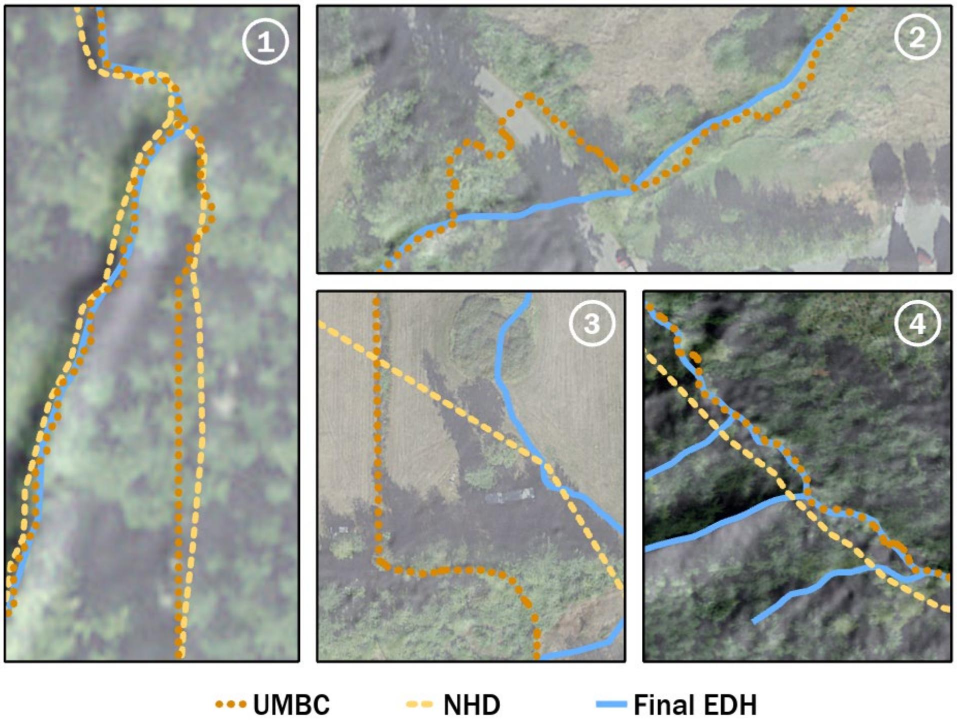


Figure 34. Comparison of NHD, UMBC, and Final EDH where UMBC deviates from a defined channel (1), deviates from a road crossing (2), captures an alternative flowline in a ditch (3), and follows the larger streams in EDH but does not include smaller streams (4).

In addition to the flowlines, the UMBC stream polygons were examined throughout the watershed, and two main quality issues were found. Firstly, in several places there were multiple identical overlapping polygons – in some cases there were around 15 or 20 of them stacked on top of each other. The polygon attributes and accompanying documents did not seem to supply any explanation for this. Secondly, the polygon boundaries were often jagged and often did not line up with the streambank, even in places where there was a clear hydroflattened edge. These edges would need to be cleaner and more accurate for the polygons to be useable.

Overall, the flowlines that UMBC captured were more accurate near the EDH main stems and less accurate in more complex areas. Inconsistent linework and lack of topology make it less useful. It was an improvement from the NHD flowlines and at times captured other possible lines that the EDH did not. However, NV5 modeled both line and polygon features throughout the watershed more accurately and consistently while also meeting USGS specifications.

Stormwater Results

The stormwater pilot project demonstrated the increased detail and complexity of mapped features in an urban environment (Figure 35).

The Snohomish stormwater pilot went through all three phases of the project. The primary conclusion is that the success of the analysis is highly dependent on the quality of the stormwater network. It is essential to have line direction and true connection points accurately represented in the vector geometry. Analysis of the network itself will always need to be performed first. While the stated end goals of the analysis are to understand drainage patterns in each urban landscape and to correlate inlet and outlet locations of the storm water system, the process has the potential to aid in finding network issues that can then be resolved. Multiple iterations of the network grouping and catchment delineation can be performed on networks known to have line direction and snapping issues and local knowledge looked to resolve them. If necessary, field investigation can be targeted to critical areas. In other words, the process can also help improve the quality and integrity of the subsurface information for other analysis.

Secondly, it is important to be able to accurately classify features as either surface or subsurface and to have correct catch basin locations to find the exact areas where water can enter and exit the subsurface system. Surface features must be accurately mapped and aligned with the source elevation data for successful catchment generation. The results of the analysis are not meant to be perfect. Artifacts left in the DEM in urban areas as the result of building removal and other built-up features can obstruct and slightly skew catchment boundaries. Nevertheless, the process is an efficient way to model how the stormwater system changes drainage patterns and catchment areas on the landscape. The resulting information can then be used to reduce and focus field efforts related to maintenance of the overall stormwater system.

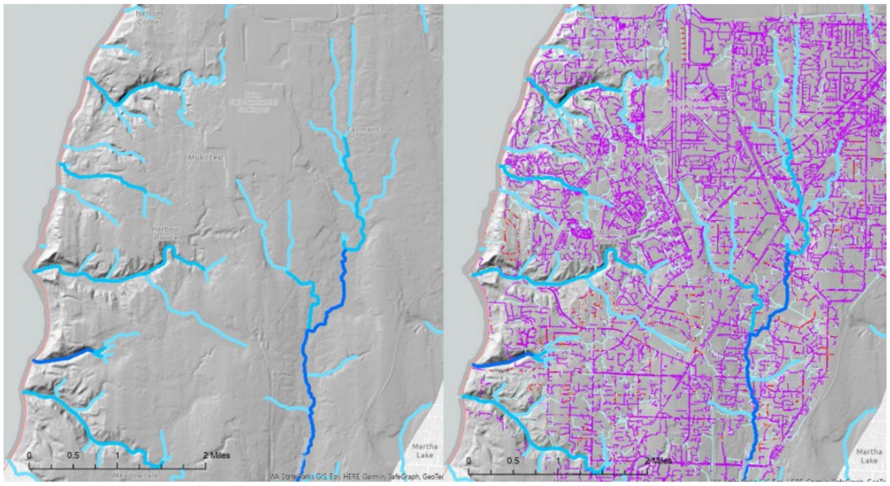


Figure 35. Increased density of water features. NHD (left), NHD and stormwater (right). Data provided by Snohomish County.

Discussion

This project started before the USGS had announced the transition to a new hydrography data program (3DHP), and this change changed the project's designed approach. Originally the project was going to figure out the best method of creating an elevation-derived hydrography dataset but pivoted to evaluating the new USGS approach. This allowed a thorough comparison of the EDH results created to meet the 3DHP specifications as well as a determination of how effectively 3DHP meets the needs of Washington hydrography stakeholders.

Known Issues

During this project, staff discovered several consistent error types and data gaps which were discussed and documented. Some of these issues have been resolved as 3DHP specifications and contractor mapping methods are standardized. Other issues fall outside of this project's scope and require feedback, decisions, or data from external groups.

- **Glaciers and Snow Fields.** Glacier and snow field features were mapped inconsistently, and stream features connected to them did not follow expected paths based on surrounding landscape features. USGS has since updated requirements for how features in these areas should be captured and represented.
- **Data Collection and Processing Timelines.** Lidar data and derived surfaces spanned several years. Features derived from older surfaces were not always representative of current conditions, especially in dynamic environments.
- **Spatial Reference Systems.** Reprojection of Lidar surfaces to match Washington State's spatial reference system caused location and elevation errors in the derived data which need to be corrected before the data can be accepted into the 3DHP. USGS has recommended that Lidar surfaces are kept in a spatial reference system developed for the conterminous United States.
- **Wetlands.** Open water features may be part of larger, unmapped wetland areas. Unmapped wetland areas can produce stream location uncertainties because multiple likely flow paths may exist. Wetlands are discussed in more detail in the following sections of this report.
- **Reservoirs.** USGS has stated that the reservoir waterbody classification will not be included in the 3DHP; these features will be captured as lake/pond.
- **Culverts.** Culvert terrain breaches may not match actual culvert locations because of both omission and commission errors and may require field verification. Local comparison datasets, while potentially helpful, may be undocumented or incorrect.
- **Stormwater Systems.** Features in modified landscapes require more investigation of their location, flow permanence, and connection to stormwater infrastructure. Mapping and incorporating stormwater-related features in the 3DHP is currently being explored and is discussed in more detail in the following sections of this report.
- **Groundwater Connections.** Subsurface flow representation as indefinite surfaces is inconsistent. USGS is refining identification of these connections.

- **Canals/ditches.** Incomplete canal/ditch classification rules for features in agricultural and developed areas. Some of these features may be excluded from the 3DHP. In Washington State, definition and oversight of these features is typically the responsibility of local districts.
- **Feature Names.** GNIS name disagreement or omission. Oversight of this attribute is the responsibility of USGS.
- **Stream Initiation and Flow Permanence.** Unclear stream initiation rules and headwater channel attribution when mapping segments. Classifying headwater segments as drainageways is a possibility but parameters are still being refined. Stream initiation is discussed in more detail in the following sections of this report.
- **Stream Bank Width Options.** Differences in stream bank width definition based on regulation. Bankfull width is discussed in more detail in the following sections of this report.
- **Conflation.** Conflation of core NHD to 3DHP attributes to recreate events integral to existing business workflows throughout Washington State.
- **Resolution of data.** Data scale and its effect on catchment and hydrologic unit boundary interpretation in relatively flat or densely developed landscapes. With higher resolution data, catchment boundaries can change and more detail may be needed to figure out exact locations of flow paths.
- **Feature Derivation Models.** Variations in contractor geomorphic indices that model hydrographic features in different landscapes. According to USGS, no single model can accurately represent all water feature possibilities in every landscape, and contractor adjustments to these indices based on regional conditions are likely.
- **Confidence Assessment and Tracking.** No way to track confidence of stream segment location and whether a feature was identified for field check within the current 3DHP schema.

Recommendations

Other organizations' datasets were extremely useful during the review process, particularly in areas where current, high-quality imagery was not available or where smaller features were not visible. Available and complete metadata will be essential when screening comparison datasets for quality and compatibility during future phases. In developed areas, engineering and survey datasets associated with water and stormwater utility infrastructure supplied clues about water flow when mapped features were not apparent in Lidar or imagery, or when mapped features appeared to be incorrect in location or type. Road and trail datasets were helpful in remote areas, especially when trying to confirm culvert locations. Access to local expert knowledge and feedback earlier in the review process may help show potential problem areas and ways to document or resolve issues sooner for future phases.

Requirements for EDH

USGS 3DHP is a national program and requires a consistent and measurable set of specifications for new hydrography data. While the requirements for NHD were less stringent, the 3DHP have a tight set of rules based on the relationship between the hydrography and the Lidar data.

These specifications are listed as two documents on the USGS web site and include the acquisition specifications and the READ rules (Representation, Extraction, Attribution, Delineation): https://www.usgs.gov/ngp-standards-and-specifications/elevation-derived-hydrography-specifications.

Both documents are updated by USGS, and it is important to reference the online versions to avoid out of date specifications. While methods for creating elevation-derived hydrography have existed for many years, older and less stringent results are not likely to meet these specifications unless the model was specifically designed for this purpose. Being close is not enough to pass the verification process the USGS uses to ensure the data meets their requirements.

Changes to Ecology’s Quality Assurance Process

Procedural

This project was a pilot. Quality assurance methods evolved as Ecology staff learned about USGS requirements and NV5 derivation processes. While NV5’s feedback about potential errors and suitable corrections helped refine review techniques, staff felt that a more timely, interactive approach including detailed explanations for all correction decisions would be necessary for future deliverables. Landscape obstacles and limited site access within the project area required staff to be selective when flagging features for field check. Because future phases will encompass much larger project areas, the incorporation of automated feature comparisons to highlight areas requiring more staff attention will be necessary. Features in areas that are managed by tribal organizations or federal agencies such as Bureau of Land Management and Forest Service will be evaluated by their staff separately. Ideally, local government staff and other experts will also supply feedback on features within their jurisdictions, especially in rapidly developing areas where changes to the landscape are impacting natural water flow patterns, and features may no longer match corresponding Lidar or imagery features.

Technical

To prepare for data review, project staff determined several attributes to complete when evaluating contractor deliverables. These attributes will be revised for future phases. Attribute dependencies will be established to limit inconsistent choices and unexpected null values. Software version differences will be noted, and file format incompatibilities will be resolved before data is delivered. Staff suggested that supporting separate reviewer feature classes may be more useful for error tracking and contractor feedback instead of jointly editing a versioned copy of the deliverable. Another possibility in future phases is the ability to review the data and provide feedback to the contractor through a web-based application managed by the contractor.

Complete Hydrography Data System (OneHydro)

Through this pilot project and discussions with stakeholders, a basic needs assessment was made. While accuracy of hydrography data was most important, some overall data gaps were also found. Some of these gaps are already present and known, and some have been created by the transition from NHD to 3DHP.

NHD to 3DHP Changes

Changes from the original NHD include the loss of the following data features; unique reach codes, perennial and intermittent flow categories, swamp/marsh polygons, and geometric networks. Geometric networks are considered a change only because they are not supported in the Esri ArcGIS Pro software. Washington State has historically added stream order to each reach and reprojected the State dataset to State Plane South. After processing, the dataset was made available to stakeholders and referred to as the WASHD version of NHD.

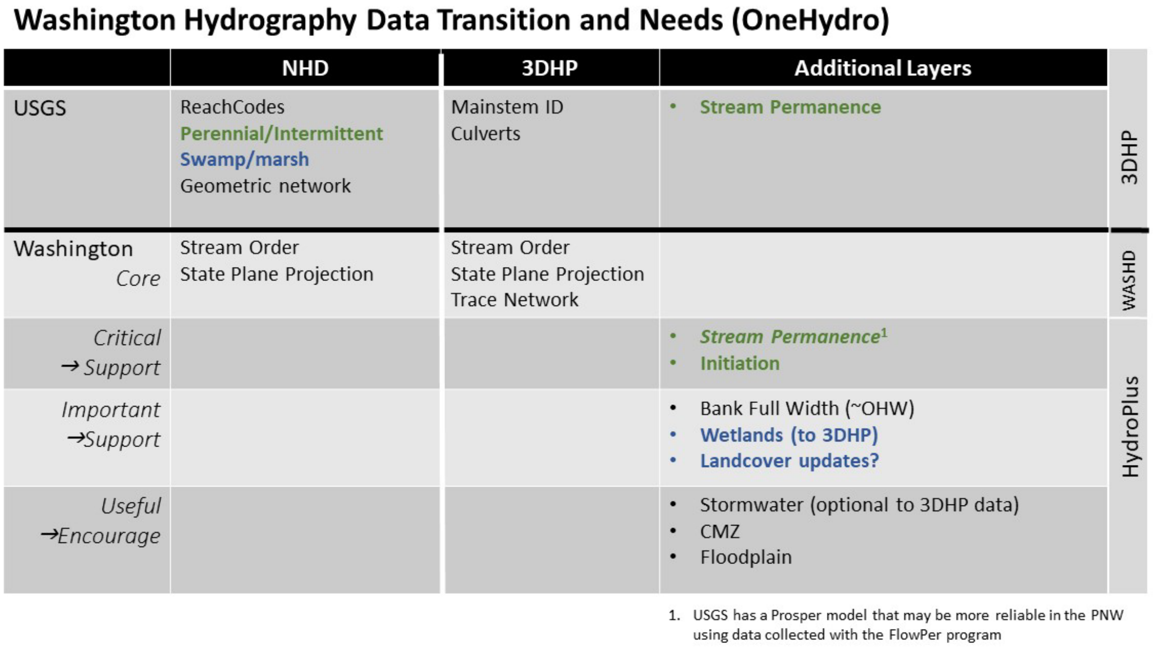
For the purposes of this project, distinct datasets for which the WASHD program is responsible have been defined. Throughout this document, they will be referenced by name as detailed here. The 3DHP data schema will be replacing reach codes with a Mainstem ID, which will be a unique identifier for the entire stream length. A new feature code to identify terrain breaches over roads can be used to locate culverts and is a new addition to the dataset. Washington State will be able to calculate stream order for reaches and reproject the dataset to State Plane South as was done for NHD. In place of a geometric network, a trace network can be created to provide similar functionality of locating upstream and downstream reaches.

A concept of an integrated set of data and information for hydrography is being introduced and further explained in this section. To help explain the concept of OneHydro, the terminology shown in Table 1 is used for this report:

Table 1 Definitions used to explain the OneHydro concept.

Name	Description
NHD	The legacy hydrography federal dataset that will be replaced.
3DHP	The federal hydrography dataset that must be maintained and shared with USGS.
WASHD	The hydrography dataset with minor changes (made by Ecology) to meet needs that are unique to Washington stakeholders (example – stream order). This dataset is still considered authoritative and should physically match the federal dataset.
HydroPlus	Additions to the federal dataset (from Ecology and other agencies or jurisdictions) to meet Washington stakeholder needs. These additions may result in critical or other data layers or attributes associated with WASHD.

Together, these datasets create what this document will refer to as OneHydro: the data ecosystem for hydrography analysis and mapping. The following sections provide details and examples of the data gaps identified in Figure 36.



Washington Hydrography Data Transition and Needs (OneHydro)

	NHD	3DHP	Additional Layers	
USGS	ReachCodes **Perennial/Intermittent** **Swamp/marsh** Geometric network	Mainstem ID Culverts	• **Stream Permanence**	3DHP
Washington *Core*	Stream Order State Plane Projection	Stream Order State Plane Projection Trace Network		WASHD
Critical *→ Support*			• ***Stream Permanence***[1] • **Initiation**	HydroPlus
Important *→Support*			• Bank Full Width (~OHW) • **Wetlands (to 3DHP)** • **Landcover updates?**	
Useful *→Encourage*			• Stormwater (optional to 3DHP data) • CMZ • Floodplain	

1. USGS has a Prosper model that may be more reliable in the PNW using data collected with the FlowPer program

Figure 36 OneHydro concept as it relates to changes and needs created by the transition from NHD to 3DHP as well as data gaps identified by stakeholder needs.

HydroPlus Data Layers

Stakeholders identified several important data attributes and layers. The layers shown in Figure 36 are categorized into important and useful but are difficult enough to create that they are outside the scope of the WASHD program. While the WASHD program recognizes these layers as a significant part of a complete hydrography data ecosystem, the program can only support or encourage their creation. The long-term goal is the creation and integration of these data layers into 3DHP and WASHD for a more complete dataset with improved analysis capabilities. The WASHD program intends to support the integration of the HydroPlus data layers to maximize the usefulness of the data for stakeholders.

Stream Initiation

It is important to be consistent in determining stream locations and attributes including the upper extent of a mapped stream. The starting point of a mapped stream is often called the initiation point. While USGS defines the initiation point as the point where the landscape has evidence of a channel, finding this location can be challenging using only remote data. The analysis of the pilot project data showed that more streams were mapped outside of the NHD stream in the high elevation areas of the watershed. This, combined with the overall doubling of stream miles mapped, suggests that the initiation points of the EDH data were farther upslope than the original NHD data. In addition, both USGS and the contractor have suggested it is better to map beyond a typical initiation point so that the initiation point can be decided later using consistent attribute data. This generally makes sense, but it requires that second step of following up with a consistent initiation point. There isn’t agreement across organizations that map hydrography on what criteria best determine initiation points on EDH data. This lack of consistency on an important part of the hydrography mapping solution is what led the team to categorize this topic as a critical future need.

Stream Permanence

An important attribute of stream mapping is stream permanence, or how often is there flowing water in the stream channel. The NHD had three defined categories and a possibility for unknown flow shown in Table 2.

Table 2 NHD flowline categories for stream permanence (USGS Data Dictionary).

Feature Code	Stream River Hydrographic Category	Feature Definition
46000	no attributes	A body of flowing water. Portion of the year the feature contains water unknown.
46003	Intermittent	A body of flowing water that contains water for only part of the year, but more than just after rainstorms and at snowmelt.
46006	Perennial	A body of flowing water that contains water throughout the year, except for infrequent periods of severe drought.
46007	Ephemeral	A body of flowing water that contains water only during or after a local rainstorm or heavy snowmelt.

The specifications for 3DHP do not include any values of stream permanence, although it is likely that attributes will be calculated in future years. The permanence of water in a channel has ecological implications and can be part of a determination of stream initiation. In Washington State, some agency stream categories are dependent on flow permanence information (i.e., DNR stream typing) that decide policies such as setbacks and vegetation protection zone sizes. Like stream initiation, flow permanence was determined to be an important attribute needed by many stakeholders and therefore defined as a critical future need.

Bankfull Width (Active Channel)

While 3DHP defines the edge of water as the location of water at time of the Lidar flight, many Washington State regulations reference Ordinary High Water (OHW) defined in the Revised Code of Washington: RCW 90.58.030[6]

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[6] https://apps.leg.wa.gov/rcw/default.aspx?cite=90.58.030

> "Ordinary high water mark" on all lakes, streams, and tidal water is that mark that will be found by examining the bed and banks and ascertaining where the presence and action of waters are so common and usual, and so long continued in all ordinary years, as to mark upon the soil a character distinct from that of the abutting upland, in respect to vegetation as that condition exists on June 1, 1971, as it may naturally change thereafter, or as it may change thereafter in accordance with permits issued by a local government or the department: PROVIDED, That in any area where the ordinary high water mark cannot be found, the ordinary high water mark adjoining salt water shall be the line of mean higher high tide and the ordinary high water mark adjoining fresh water shall be the line of mean high water;

While the delineation of this line legally requires authoritative determination, it is possible to make an approximation of this line referred to in riverine systems as Bankfull Width (BFW) or Active Channel (Figure 37).

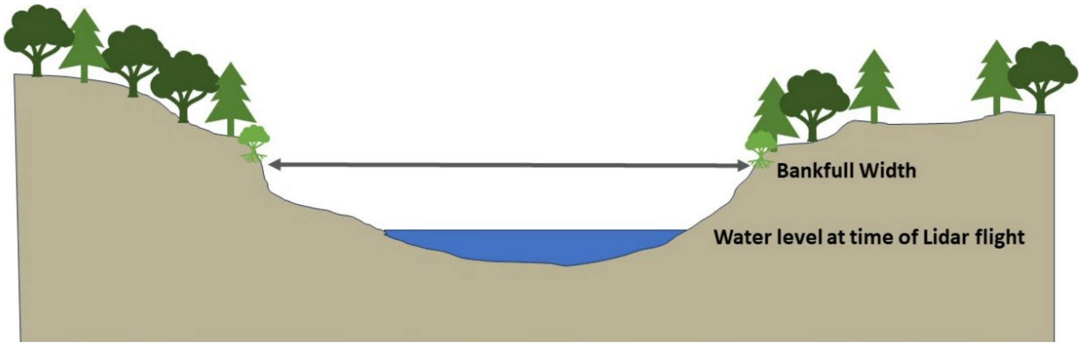

Figure 37. Relationship of water level at lower flow to the Bankfull Width.

For this pilot project, a collaboration was set up between Puget Sound Partnership, Western Washington University (WWU), and Skagit System Cooperative to research methods of mapping active channels remotely. Accurate evaluation of riparian forests depends on precise delineation of both bankfull width (active channel) and single-thread hydrography. Local land use and salmon recovery planners use hydrography as a reliable tool for understanding and managing watershed impacts across the state. Active channel mapping allows practitioners to delineate riparian zones, examine the shading effects of riparian vegetation, map the location, extent, and distribution of anadromous and resident fish as well as find fish blocking culverts, map protective stream buffers, and accurately inventory existing hydrography (Hyatt et al, 2022). These active channel polygons represent the approximate location of wetted channels of rivers and streams as well as adjacent unvegetated cobble and gravel bars that are inundated during high flows. The active channel polygons are digitized from high resolution elevation data (Lidar) and high-resolution imagery. In this method, the active channel is analogous to the "bankfull channel" (Leopold and Maddock 1953, Leopold et al 1964, Williams 1978) or the ordinary high-water mark line (OHWM), where the presence and action of waters are "so common and usual, and so long continued in ordinary years as to mark upon the soil or vegetation a character distinct from the abutting upland," (WAC 220-660-030(111)). In places where this line cannot be delineated, the ordinary high-water line is delineated along the elevation of the three year mean annual flood.

In many areas, the BFW extends quite a bit beyond the 3DHP waterbody delineation. As shown in Figure 38, the BFW is 180 feet over bare gravel from the time of the image. The method uses a combination of Lidar relative river elevation and bare ground visible in imagery to estimate the high-water elevation for every segment of the river. When modeling or monitoring riparian buffers, this delineation can be helpful in determining the beginning of the riparian forest area.

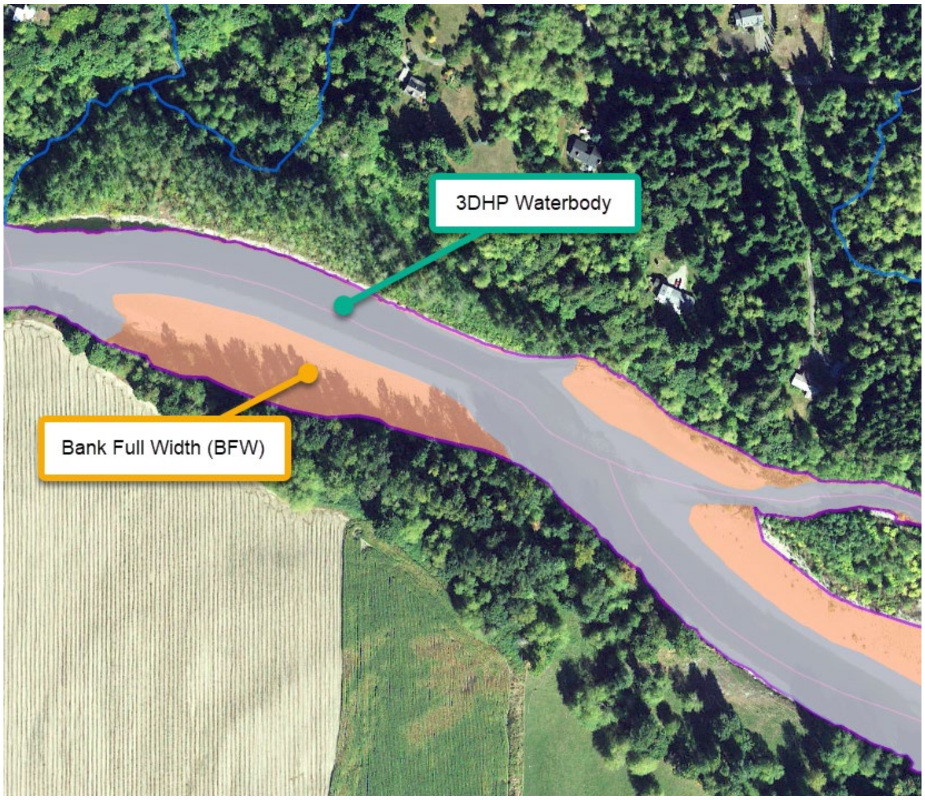

Figure 38. Example of difference between 3DHP water polygon and Bankfull Width. Mapping provided by WWU.

The results of the WWU work are a helpful compliment to the 3DHP data and could be a part of the statewide implementation.

Wetlands

The 3DHP waterbody polygons do not include the “Swamp/Marsh” category that was previously mapped in the NHD (Table 3).

Table 3 Categories of Swamp Marsh from NHD (USGS Data Dictionary).

Feature Code	Swamp Marsh Hydrographic Category	**Feature Definition**
46600	null	A noncultivated, vegetated area that is inundated or saturated for a significant part of the year. The vegetation is adapted for life in saturated soil conditions.
46601	Intermittent	A noncultivated, vegetated area that is inundated or saturated for a significant part of the year. The vegetation is adapted for life in saturated soil conditions. Contains water for only part of the year, but more than just after rainstorms and at snowmelt.
46602	Perennial	A noncultivated, vegetated area that is inundated or saturated for a significant part of the year. The vegetation is adapted for life in saturated soil conditions. Contains water throughout the year, except for infrequent periods of severe drought.

USGS plans to have the US Fish and Wildlife Service (USFWS) integrate the National Wetlands Inventory (NWI) with 3DHP to provide the mapped delineation of wetlands for their location. In Washington State, much of the NWI data has not been updated in recent decades and does not align well with the EDH data being collected. Figure 39 illustrates the inaccuracy of NWI and its general misalignment with 3DHP.

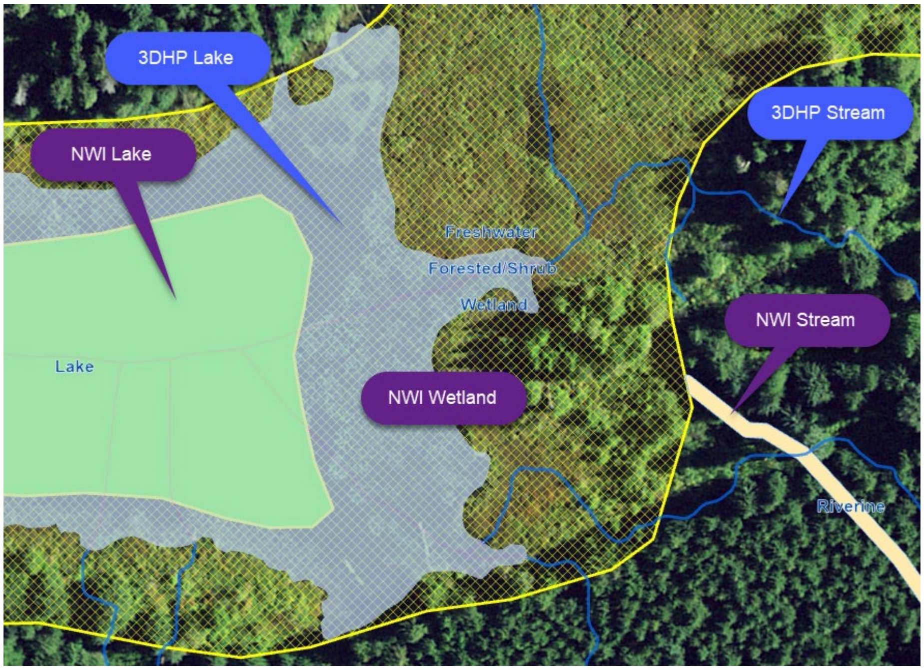

Figure 39. Comparison of EDH (3DHP) and NWI.

A successful wetland replacement for the Swamp/Marsh category should be accurate while also topologically connected to the EDH. For example, if NWI does not have open water mapped in the same location as 3DHP, it can be challenging to reconcile those differences. Ideally, the waterbodies would be delineated by 3DHP and the wetlands by NWI with common boundaries and comparable accuracy levels.

A visual comparison was made in the pilot area between data layers that represent wetlands associated with hydrography (examples of the layers in Appendix B. Wetland Examples). Other data layers did not reveal a perfect solution. A promising interim solution would be to use wetlands from the NOAA CCAP high resolution land cover data from 2015. A sample of this data is shown in Appendix B (Figure 48). While this data is based on imagery instead of Lidar, it could be reconciled with the updated 3DHP to create wetland extents.

Land Cover

Land cover is the classified description of the physical earth surface. It is usually created from aerial imagery and is current to the time of the image. Most land cover classifications have a category for “open water”. The advantage of an image-based classification versus a Lidar-derived delineation is that imagery is cheaper and acquired more frequently. While the classification of imagery is an additional cost, Washington State recently purchased a high-resolution statewide land cover classification based on 2021 imagery. Lidar in Washington State is generally refreshed every 5-8 years for a region, and it is possible that land cover can serve as a short-term indicator of change. The refresh schedule for 3DHP requires Lidar to be acquired, processed, and analyzed before submitting an update. This could potentially create delays in updates to the hydrography data. In areas where hydrography changes often, land cover could serve as an additional reliable data layer to accompany 3DHP. The example shown in Figure 40 illustrates how the North Fork of the Stillaguamish has moved between the 2017 Lidar acquisition and 2021 image acquisition. This change could be important for local analysis where the edge of the water delineation has moved 250 feet. Over time these areas could be indicators of hydrographic change that need to be updated with new Lidar and EDH.

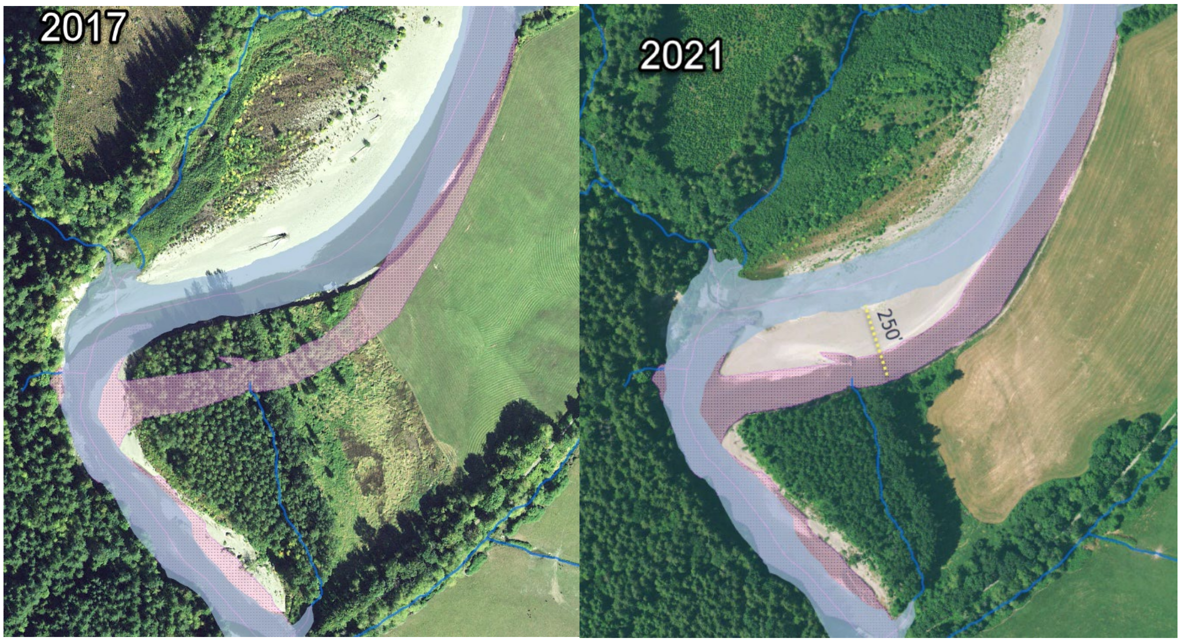

Figure 40. Example of North Fork of the Stillaguamish River moving 250 feet south-east from 2017 to 2021. EDH data (2017 Lidar) shown in blue and Land Cover-Water data (2021) shown in red.

Stormwater Data

Mapping stormwater in urban environments is challenging when using topography data such as Lidar. Most urban and suburban regions have significant water diversion methods, and many of them are sub-surface or not detectable using Lidar data. The pilot project showed that with the proper data these stormwater systems can be integrated into the EDH data used for 3DHP. Not all elements of a stormwater system need to be integrated with 3DHP to appreciate the benefits. As shown in Figure 41, the new stormwater data derived from the pilot project are denser than the original NHD. This shows a more accurate understanding of water movement in a region. This improved understanding of water movement can help in tracing nutrients, pollutants, or possible impacts of a toxic spill.

While there are strong benefits of including stormwater data with 3DHP, it relies heavily on local jurisdictions. If the data doesn’t exist with the proper level of detail and mapping, it doesn’t help to be included. It is beyond the scope of the WASHD program to try to collect or improve stormwater data. However, the program can encourage and educate local jurisdictions on both the benefits and best practices for integrating stormwater into 3DHP.

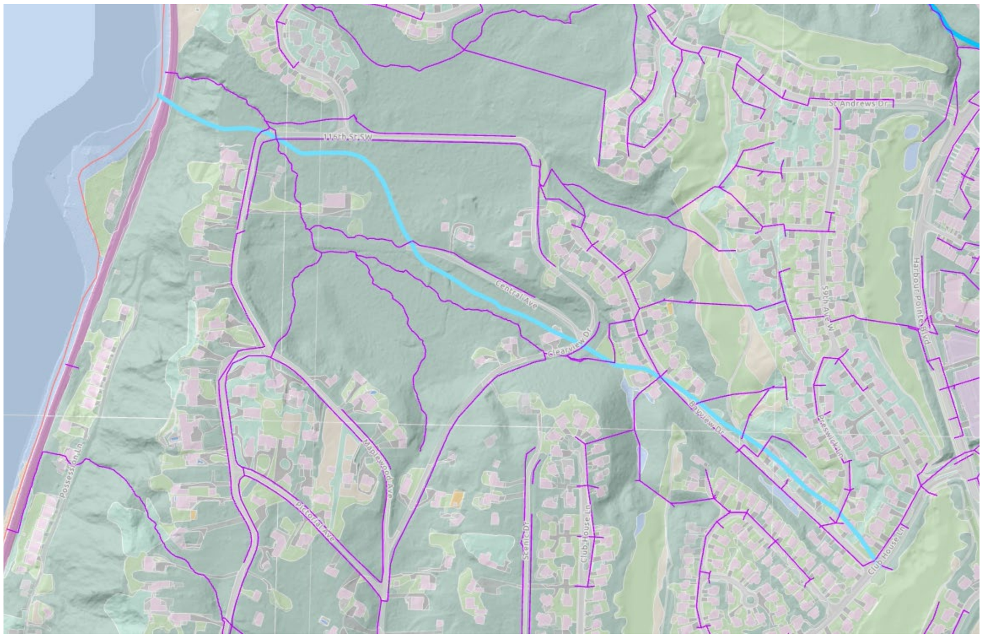

Figure 41. Original NHD in blue and stormwater data added in purple.

Conclusion

The use of new technologies, particularly those based on elevation data, has proven instrumental in enhancing the accuracy and precision of hydrography mapping. The advantages of incorporating elevation-derived hydrography are many. The increased accuracy in mapping water features leads to improved critical areas assessment, watershed management, and enhanced environmental monitoring. When the data is inaccurate, it either is not used or it can cause errors that interfere with assessments. This inaccuracy is likely why very few local government agencies in Washington State have used the NHD. The cascading effect of local agencies not using and improving the same hydrography dataset is that their more accurate updates are not incorporated into the State's hydrography dataset, making it even less useful.

The USGS 3DHP has set up a standardization for EDH to help meet a consistent nationwide hydrography product. Consistency is important since watershed boundaries rarely follow jurisdictions. While many methods exist for Elevation-Derived Hydrography, we found that unless the process is specifically designed to meet the USGS 3DHP specifications, the data will vary enough to fail the USGS verification process.

One of the key advantages of adopting a standardized hydrography dataset is the potential for significant cost and time savings. A single, universally accepted dataset would streamline mapping processes, reduce redundancies, and ensure consistency across various agencies. This efficiency not only benefits governmental agencies and research institutions but also extends to industries reliant on accurate hydrography data, such as timber companies, natural resource consultants, and urban planners.

Despite the benefits of 3DHP, it is crucial to recognize that additional data layers are still needed to further enrich the mapping process. Integrating diverse datasets, such as wetlands, stream permanence values, and active channel edges, can provide a more holistic understanding of aquatic ecosystems and contribute to a more comprehensive hydrography dataset.

We continue to witness rapid advancements in technology. The future of hydrography mapping holds the promise of even greater accuracy, efficiency, and accessibility. Collaborative efforts in mapping hydrography datasets will be pivotal in harnessing the full potential of elevation-derived hydrography, ushering in an era where precise and up-to-date water feature information is readily available for a myriad of applications, ultimately contributing to more informed decision-making and sustainable resource management.

Citations

Hyatt, Tim. 2022. "A lidar-based assessment of riparian shade and large wood potential in the Skagit River watershed, WA." *Journal of the American Water Resources Association* 00(0): 1–19. https://doi.org/10.1111/1752-1688.13099.

P. Utrilla, C. Mazo, M.C. Sopena, M. Martínez-Bea, R. Domingo, A Paleolithic map from 13,660 cal BP: engraved stone blocks from the Late Magdalenian in Abauntz Cave (Navarra, Spain), Journal of Human Evolution, Volume 57, Issue 2, 2009, Pages 99-111. https://doi.org/10.1016/j.jhevol.2009.05.005.

Esri Online Help 2024, How Stream Order Works. https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/how-stream-order-works.htm

USGS 3DHP READ rules. https://www.usgs.gov/ngp-standards-and-specifications/elevation-derived-hydrography-read-rules-table-contents

USGS 3DHP Acquisition Specifications. https://www.usgs.gov/ngp-standards-and-specifications/elevation-derived-hydrography-data-acquisition-specifications

USGS National Hydrography Dataset (NHD). https://www.usgs.gov/national-hydrography/national-hydrography-dataset

USGS Data Dictionary: National Hydrography Dataset (NHD) Data Dictionary Feature Classes. https://www.usgs.gov/ngp-standards-and-specifications/national-hydrography-dataset-nhd-data-dictionary-feature-classes

NOAA CCAP Program. https://coast.noaa.gov/data/digitalcoast/pdf/ccap-faq-regional.pdf

Washington Senate Bill 5727 - 2022 Regular Session. https://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/Senate%20Bills/5727.pdf?q=20220128090218

Riparian Task Force Final Report. https://one.ofm.wa.gov/sites/default/files/public/publications/RiparianTaskForceFinalReport2022.pdf

Effectiveness of State Programs on Riparian Habitat Protection and Restoration Analysis and Recommendations Final Report | Dec. 1, 2022. https://ofm.wa.gov/sites/default/files/public/publications/RiparianFinalReport.pdf

Ecopia Land cover. https://www.ecopiatech.com/

Appendix A. NV5 Delivery Report

This report was prepared by NV5 as part of the contract agreement and provided to Ecology at the completion of the data creation (July 2023). This version was modified slightly to be more concise and fit the formatting of the report. The full report is available by request at *joshua.greenberg@ecy.wa.gov.*

In November 2022, NV5 Geospatial (NV5) was contracted by Washington State Department of Natural Resources (WADNR) to collect elevation-derived hydrography (EDH) for the Stillaguamish 8-digit hydrologic unit (17110008) totaling approximately 449,719 acres in northwestern Washington State. Previously collected lidar data served as the elevation source data for the project. Fine-scale catchment delineation based on the new hydrography and the transfer of GNIS names to the new line and polygon vectors were also contracted. Data were collected to meet standards laid out in the Elevation-Derived Hydrography Acquisition Specification and the Elevation-Derived Hydrography READ Rules. This report accompanies the elevation-derived hydrography and documents processing methods and approaches for the Stillaguamish AOI (17110008).

Source Data

The Stillaguamish 8-digit hydrologic unit EDH data was derived using a combination of 6 different previously collected lidar projects. When available, breaklines delineating stream/rivers and lake/ponds used in the hydroflattening of these datasets were also used. In addition to the elevation data, the US census Bureau’s TIGER (Topologically Integrated Geographic Encoding and Referencing) road lines were used to help improve hydrographic delineation and accuracy. Figure 42 illustrates the geographic breakdown of the source elevation data.

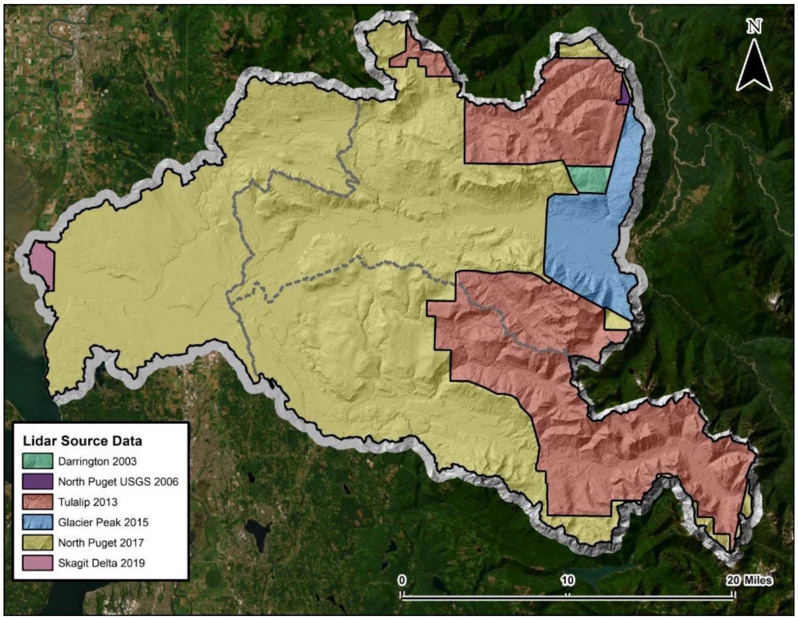

Figure 42. Geographic breakdown of the Stillaguamish 8-digit hydrologic unit (17110008) data sources.

2D Delineation

The first step in the EDH delineation process is to create and finalize all 2-dimensional (2D) polygon features within the study area. These are the first features analyzed, updated, and finalized when deriving hydrography from elevation data due to the subsequent necessary integration with the 1-dimensional (1D) polyline features.

Three of the six source datasets had previously collected lidar breaklines covering all lake/ponds >2 acres and all stream/rivers >30m nominal width in accordance with the USGS lidar base specification (LBS). These breaklines were utilized for the project by applying a small negative buffer to ensure all vertices were placed directly on the hydroflattened surface. Vertices were then removed as necessary to ensure the EDH required minimum vertex spacing of 1.5 meters (4.92 feet).

While the lidar breaklines served to capture all major water features in the study area, EDH specifications call for higher resolution capture thresholds than the LBS. Per EDH specifications, lake/ponds > ~.1 hectares and stream/rivers or canal/ditches >~15m require 2D delineation. Additionally, there is a requirement to collect all previous legacy NHD polygon features regardless of size, assuming there is still evidence of the feature in the elevation data. Additional capture to EDH specifications was done manually. The legacy NHDWaterbody and NHDArea polygons were used as reference during this process.

Once all 2D polygons were delineated, Z values were assigned from the lidar DEM. Lakes, ponds, and reservoirs meeting the LBS thresholds were assigned a consistent elevation for the entire polygon from the hydroflattened DEM. Rivers meeting the LBS threshold were assigned consistent elevations on opposing banks with downstream flow through the entire river channel from the hydroflattened DEM. The newly delineated polygons also had elevation values extracted from the DEM, but no hydroflattening was performed resulting in variable Z values for these features.

1D Delineation

Hydro-enforcement

Hydro-enforcement is a prerequisite for hydrography development and is the process of removing false obstructions such as culverts and other spurious barriers to flow from the DEM. Hydro-enforcement is performed through a combination of automated and manual techniques. Automation of hydro-enforcement is primarily performed through sink/depression identification (indicative of a barrier to flow) and least cost path analysis to find the barrier outlet based on DEM elevation. While this method can and does successfully breach many barriers, it is often not comprehensive enough and the accuracy of the breach outlet can vary in undesirable ways, specifically in built-up terrain. The critical nature of hydro-enforcement to successful stream extraction necessitates manual review and often additional enforcement. Ancillary raster layers and supplemental data are used by trained analyst to draw focus to areas where flow is not being correctly modeled.

Once the hydro-enforcement lines have been finalized, elevations from the DEM are extracted to the line, monotonicity is enforced, and the elevations of the lines replace those of the original DEM to breach the false obstruction.

Flow Direction & Flow Accumulation

After hydro-enforcement, the remaining small micro sinks and depressions are filled to allow for continuous flow across the landscape. The flow direction for each individual cell is then calculated using the D8 method. This process assigns a standard numeric integer to each cell indicating which of the surrounding 8 neighbors contains the lowest elevation value and thus the direction of flow. The flow direction raster is then run through a flow accumulation routine which sums the number of upstream cells for all cells in the raster. The value of the flow accumulation raster represents the upstream drainage area for every cell in the analysis area.

Flowline Delineation

The next step in the process requires determining a flow accumulation threshold at which to initiate stream delineation. Cells with high flow accumulation are highly likely to represent stream flow paths, however there are many smaller streams on the landscape that only drain small areas but are nevertheless true streams that should be mapped. If too high of a stream threshold is selected many smaller ephemeral streams will be missed and many headwaters will be downstream of their true location. The net result of selecting too high of a flow accumulation/stream initiation threshold is an abundance of omission errors. If too low of a stream threshold is selected there will be many false-positive streams mapped (commission errors) where there is no evidence of channelization in the ground model. A balance therefore must be struck between selecting a low enough flow accumulation to map all visible stream channels while avoiding the generation of an abundance of false-positive streams that will need to be filtered out. An initial flow accumulation threshold of 0.5 acres was used to generate the initial flowlines.

XY Smoothing

After automated stream generation, the network must be smoothed to remove the rasterization of the flow lines. The automated flowlines are run through a custom XY smoothing routine that removes the rasterization while maintaining alignment with the stream channels of the DEM.

Network Integration

Once the stream lines have been cartographically smoothed, they must be incorporated with the updated 2D polygons. The previously discussed flow direction and flow accumulation routines do not run well on the completely flat surface that hydroflattening produces. In these areas flowlines are often incorrectly delineated as parallel lines running toward the outer edges of these features rather than representing the centerline of the 2D polygon. In order to avoid excess artificial paths within polygons and create true centerlines, the data is run through a custom network integration routine that removes all automatically generated streamlines within the polygons and replaces them with true centerlines. The integration process then creates artificial path lines to join all inflowing streams to the main centerline of the feature.

Commission and Omission

Omission and specifically commission identification are particularly important in creating high accuracy hydrography. In order to aid in omission and commission identification, several derivative rasters were generated and used for both automated and manual omission and commission. These include calculations of geomorphons, planform curvature, multiscale elevation percentiles, and Bothat filtering. Geomorphons is a method for delineating the landscape into discrete geomorphic classes such as pit, valley, peak, etc. from which the landform types associated with streams (footslope, valley, and depression) are extracted. Curvature can help quantify the degree of channelization, while Bothat filtering helps identify low relief channels. Lastly, multiscale elevation percentile calculations help identify low areas in the DEM where water is likely to flow but where channelization may not be present. These layers are then combined to create a single raster indicating stream probability referred to as the Geomorphic Index (GMI). (Figure 9) Automated commission filtering is performed by comparing the auto generated stream lines to this layer. All streams that are found to have good correlation with the geomorphic indicators are retained. These flowlines are then used with network tracing routines to identify additional stream lines that do not necessarily display channelization in the ground model, but are necessary to retain for network connectivity. Channel signature locations without associated streamlines can be identified during manual review and investigated for inclusion in the network.

Manual Review

Once the automated filtering has been run, the data is passed to a trained analyst for review. Analyst are also provided the GMI layer to aid in their manual review and ensure flowlines remain in the stream channel throughout the length of the line. If omission errors are identified, additional finer scale stream lines for the localized area are generated using a lower flow accumulation threshold and are added to the stream network.

Quality assurance layers are provided to the editors to draw attention to things such as lines flowing across ridges, lines or line segments not corresponding to the GMI, and long unnaturally straight segments. Editors then use the GMI and DEM layers to better adjust line placement.

Z values

Post manual review, once all XY feature positions are finalized, Z values are added to the line work and downstream monotonicity enforced using custom scripting routines based on line direction. All vertices were compared to the DEM to ensure vertical alignment.

Connector Attribution

Connector: Culvert

The elevation derived hydrography specification calls for the segmentation and distinction of culvert features from the rest of the flowline network. Culvert features were automatically identified by comparing the monotonically enforced elevation values to the elevation ground model. Vertices that are misaligned with the DEM surface after monotonic Z smoothing and in close proximity to ancillary road and culvert data were extracted and used to classify culverts within the network. This segmentation process was manually reviewed. Additional culverts were manually extracted as necessary.

Connector: Terrain Breach

All line vertices >1m (3.28 ft) below the surface are investigated to ensure the validity of the stream placement. If validity of the location was verified, the stream segment > 1m below the elevation surface is attributed as a Connector: Terrain breach. These features begin at the first vertex with the same elevation of the vertex sitting >1m below the surface and end at the next vertex with a lower elevation. (Figure 10) If this results in a terrain breach >100m (328 ft) in length, the feature was converted to a Connector: Indefinite surface feature and downstream monotonicity was not enforced as indicated in the comment field.

Connector: Indefinite Surface

Connector: Indefinite Surface features are classified in two ways. First, as previously mentioned, flowlines >100m long where DEM alignment was not maintained after monotonic smoothing were attributed as Connector: Indefinite surface. Downstream monotonicity was not enforced in the Z value of these features and this is indicated in the comment field. Secondly, any contiguous flowline feature >656 ft (200m) in length not aligning with the GMI were also classified as Connector: Indefinite Surface. These features do still have monotonicity enforced.

XY Alignment

Feature alignment was assessed using the previous mentioned GMI layer. When alignment was measured, 75.11% of all stream lines corresponded to the combined stream probability layer. Indefinite surface connectors, culvert, terrain breach, and artificial paths were excluded from the analysis as alignment with the GMI is not expected for these features.

Z Alignment

Z alignment was assessed by comparing the final 1D feature vertex Z values to the elevation ground model. All 2D polygon vertices are placed on the hydroflattened surface or have their elevation extracted directly from the DEM. The below table summarize the results for 1D polyline vertices compared to the DEM, broken out by Fcode.

Density The legacy NHD for the Stillaguamish area of interest contained ~ 3,678 miles of hydrography flowlines. The elevation derived hydrography contains ~6,979 miles, representing a 1.9 density increase of mapped flowlines.

Legacy NHD Comparison

Polygons

Of the previously existing 624 NHD waterbody lake/pond and reservoir polygons, 475 of these are represented in the updated breaklines. The omitted 147 lakes were not detected as waterbody features in the lidar DEM and intensity images. None of the omitted legacy NHD lake features was an officially named feature within the GNIS database.

Polylines

The NHD was used as an aid in flowline delineation to ensure previously delineated features were captured if supported by the elevation data. All named streams within the AOI were specifically reviewed to ensure capture and connectivity. When comparing the legacy NHD to the updated elevation-derived hydrography, 75.73% of legacy lines representing 87.61% of the total length of the legacy NHD intersected the updated hydrography. When the search radius is expanded to 9 ft or 3 pixels 80.09% of legacy lines representing 89.7% of the total length of the legacy NHD were represented. If the search radius is further expanded to 50 ft 90.24% of legacy lines representing 94.6% of the total length of the legacy NHD were represented. Finally, when the search radius was expanded to 100 ft 94.03% of legacy lines representing 96.36% of the total length of the legacy NHD flowline network were represented. The remaining lines were reviewed and generally appeared to represent headwater streams where channelization was not visible in the ground model.

Appendix B. Wetland Examples

121.9461605°W 48.1731981°N
Twin Lakes

Examples of data within the study area that help explain the challenges of mapping wetlands with updated hydrography. Several GIS datasets are shown for a particular lake with adjoining wetlands to illustrate the lack of alignment.

Figure 43. Aerial imagery – 2017 1 foot.

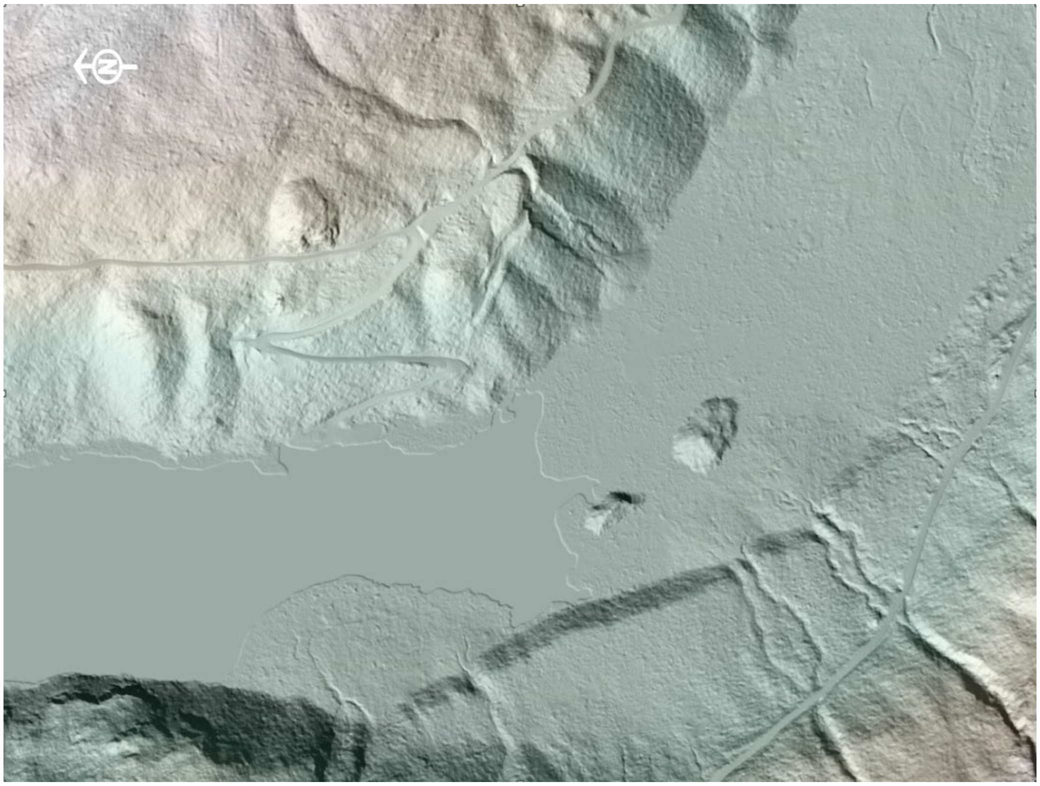
Figure 44. Lidar Hillshade.


Figure 45. NHD (National Hydrography Data).

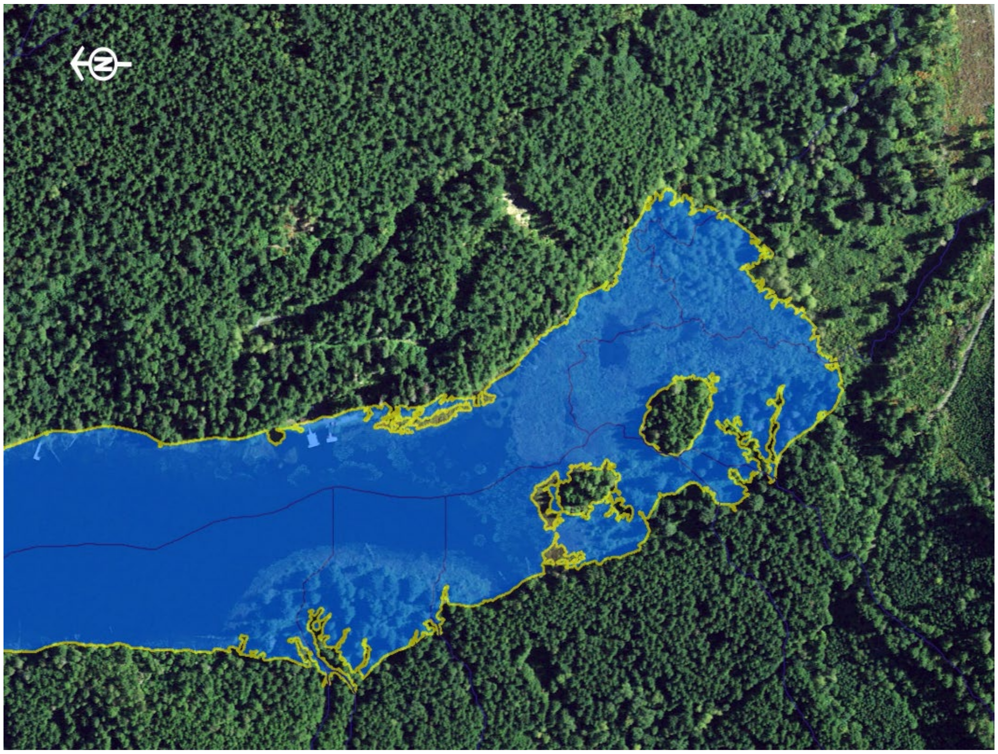

Figure 46. University of Maryland (UMBC) geomorphon mapping of water.

Figure 47. National Wetlands Inventory data (NWI).

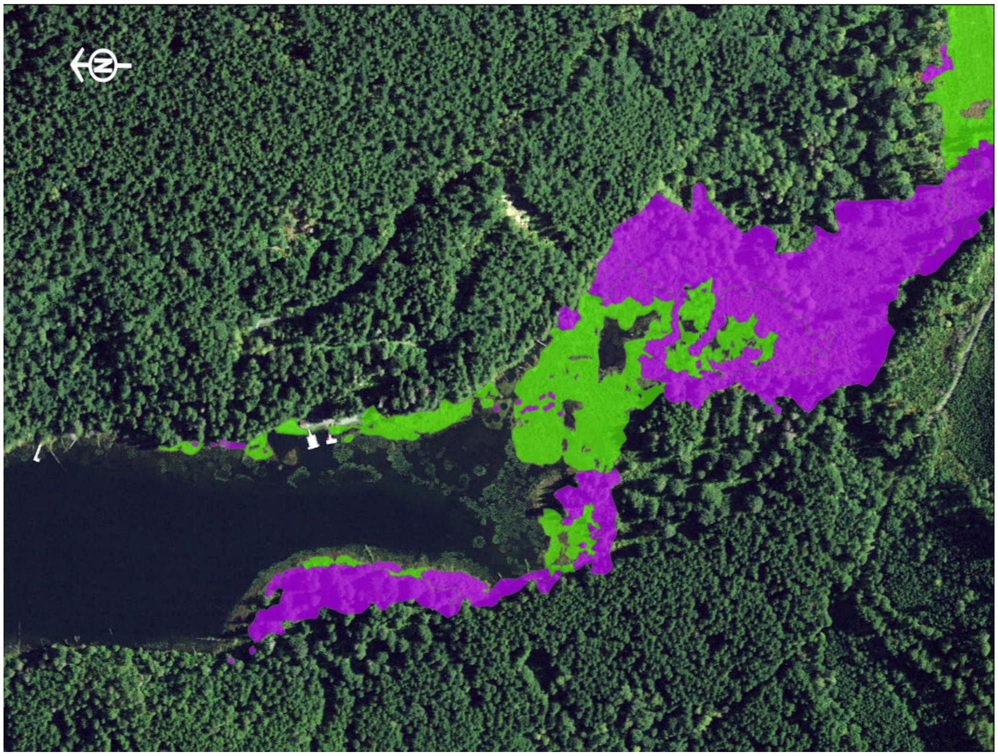

Figure 48. NOAA CCAP 2015 (wetlands only shown).

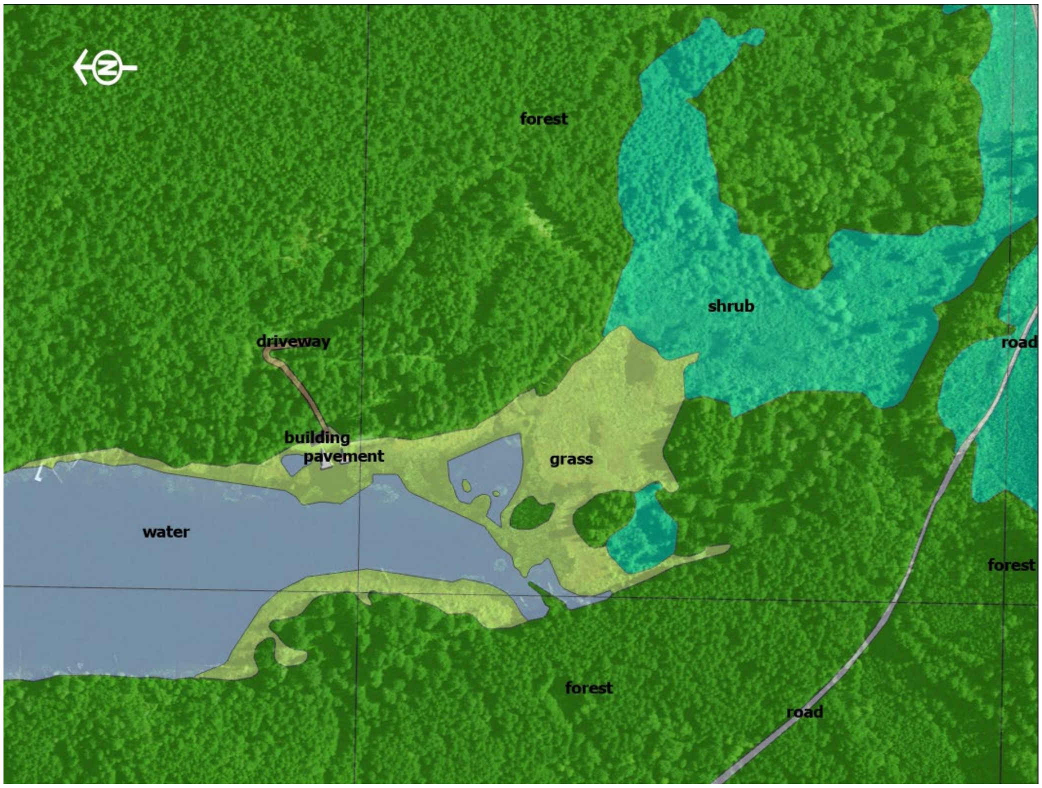

Figure 49. Ecopia 2021 Land Cover.

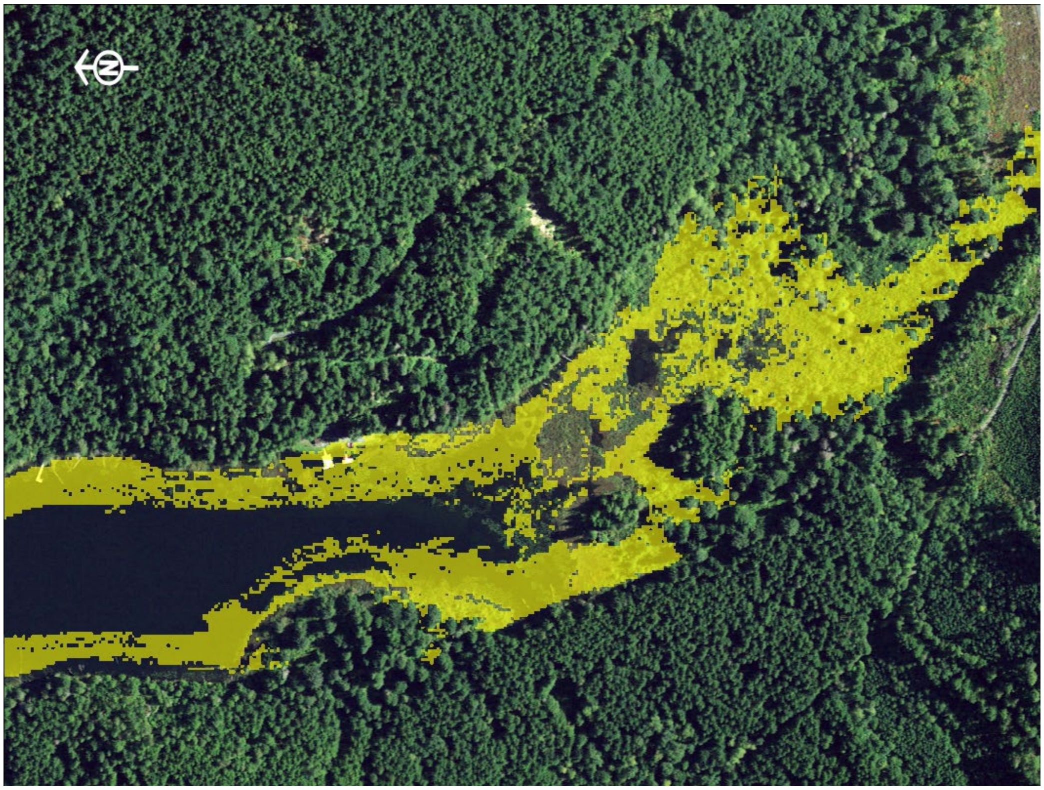

Figure 50. Wetland Intrinsic Potential (WIP) Model Analysis with >90% probability of wetland presence.

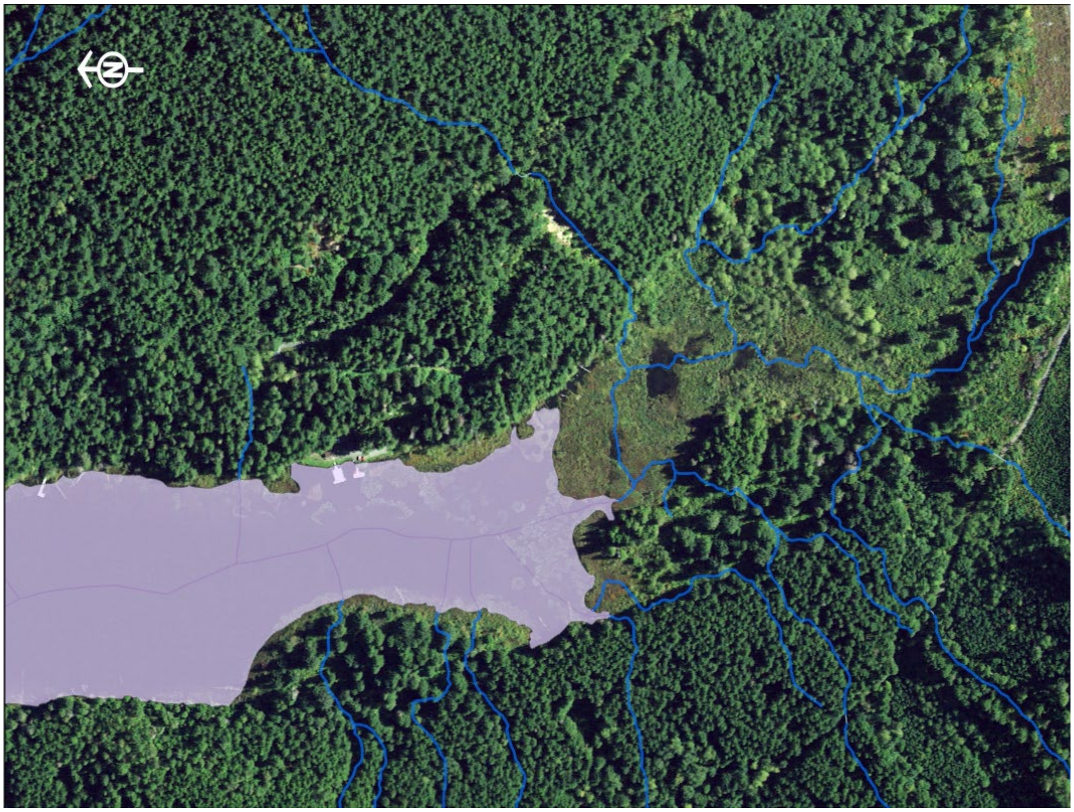

Figure 51. EDH for 3DHP (NV5).

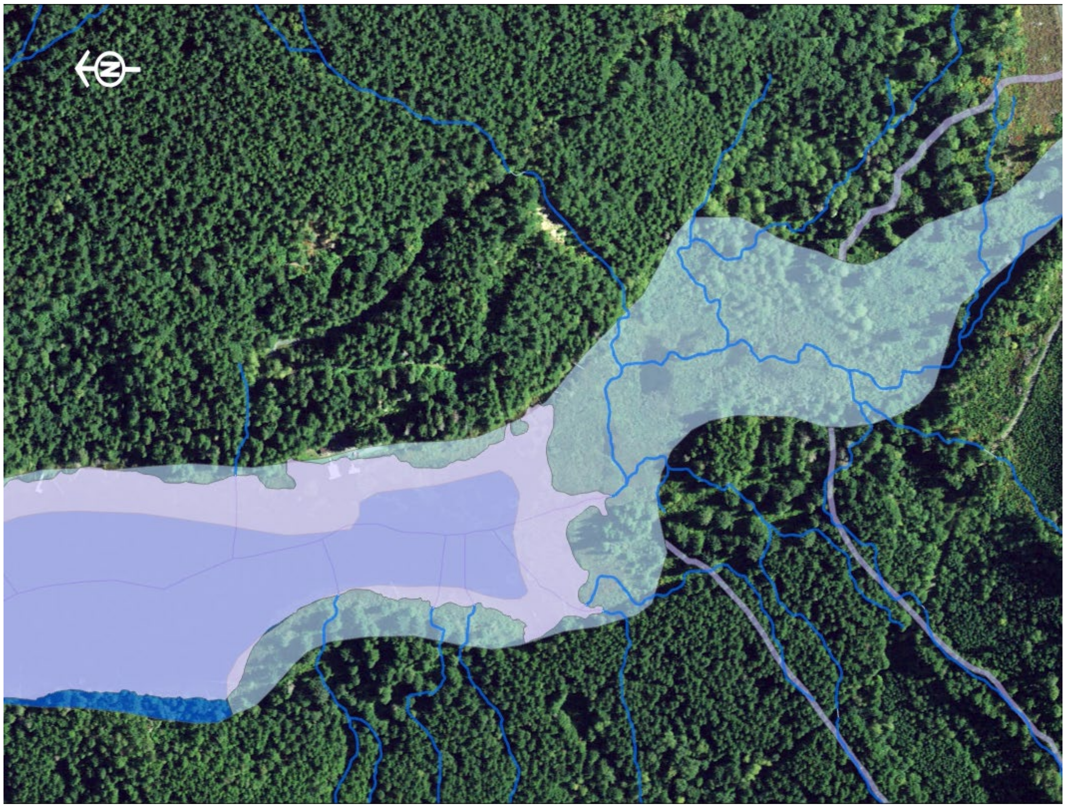
Figure 52. NWI and EDH (NV5).


Figure 53. Hyatt/Tyson Bankfull Width 2021.

Appendix C. Ancillary Data Sources

Table 4. Ancillary Data Sources for Hydrography Review.

Source	Dataset	Notes	Future Use?
UMBC	Streams, culverts		
	Valley network		
	Channel width		
	Bank height		
	Channel polygons		
WWU	Bank width	Draft; limited area	
NOAA/Ecopia	Land cover	2015 (wetlands); 2021 (open water)	
Snohomish County	Streams/lakes, roads, culverts, pipes, ditches, outfalls, engineering survey points and cross sections		
City of Arlington	Streams, roads, culverts, outfalls		
WA OFM	Structures	Historical population proxy	
WA DNR	RSHydro (streams), FPHydro (streams/lakes), culverts, roads		
WA DFW	Fish passage/blockage sites		
WA ECY	Legacy NHD features, EIM sites, wetlands, imagery		
US Department of Defense	Jim Creek – streams, wetlands		
US Forest Service	Roads, trails		

US Fish and Wildlife Service	Wetlands		
Miscellaneous	Flow accumulation, flow direction, topographic and basemaps, elevation contours, administrative and parcel boundaries, imagery		

Appendix D. Terms and Technology

3DHP (3D Hydrography Program) USGS program to map hydrography of the nation.

Active Channel (also Bankfull Width) The area that is covered by water during normal high flow.

Bankfull Width (also Active Channel) Defined in WAC 220-660-030 (12) The width of the surface of the water at the point where water just begins to overflow into the active flood plain. In streams where there is no flood plain it is often the width of a stream or river at the dominant channel forming flow that reoccurs every one to two years.

Catchment An area that flows to a single point

DEM (Digital Elevation Model) A digital representation of the elevation of the ground

EDH Elevation Derived Hydrography. The hydrography data that is created using models of the earth's surface.

Geomorphology The scientific study of the origin and evolution of the shape of the earth's topography.

Geomorphons A representation of landscape based on elevation differences within the surrounding area of a target cell.

GIS Geographic Information System. A computer system that analyzes and displays geographically referenced information.

GMI A combination of geomorphon and other terrain measures that help locate channelization that is expected with stream flow. (note: a new term and few published definitions. Described in Appendix A -Commission and Omission)

GNIS Name The Geographic Names Information System assigned proper name, specific term, or expression by which a particular geographic entity is known. (USGS Data Dictionary)

Lidar (Light Detecting and Ranging) A remote sensing method that uses light in the form of a pulsed laser to measure distances to the Earth. These light pulses—combined with other data recorded by the airborne system — generate precise, three-dimensional information about the shape of the Earth and its surface characteristics. (NOAA webpage[7])

OneHydro (defined for this project) A data ecosystem for hydrography analysis and mapping.

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[7] https://oceanservice.noaa.gov/facts/lidar.html

Projection Any of a broad set of transformations employed to represent the curved two-dimensional surface of a globe on to a plane.

Raster data GIS data that consists of a matrix of cells (or pixels) organized into rows and columns (or a grid) where each cell contains a value representing information, such as temperature. Rasters are digital aerial photographs, surface elevation data (see DEM), digital pictures, or even scanned maps.

Stream Reach A section of stream or river (may also be the length of a stream or river between two streamgages) in which similar hydrologic conditions exist, such as discharge, depth, area, and slope.

Reach Code Unique identifier used for each river reach of the NHD. (USGS Data Dictionary)

USGS definition of NHD Stream Permanence[8]

- **Stream River** (no attributes=46000) A body of flowing water. Portion of the year the feature contains water unknown.
- **Stream River Intermittent** (Hydrographic Category = 46003) A body of flowing water that contains water for only part of the year, but more than just after rainstorms and at snowmelt.
- **Stream River Perennial** (Hydrographic Category = 46006) A body of flowing water that contains water throughout the year, except for infrequent periods of severe drought.
- **Stream River Ephemeral** (Hydrographic Category = 46007) A body of flowing water that contains water only during or after a local rainstorm or heavy snowmelt.

USGS (U.S. Geological Survey) Federal organization that spans the disciplines of biology, geography, geology, and hydrology.

Vector GIS Data Spatial data representing map features as points, lines, and polygons.

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[8] https://www.usgs.gov/ngp-standards-and-specifications/national-hydrography-dataset-nhd-data-dictionary-feature-domains