DEPARTMENT OF
ECOLOGY
State of Washington

Quality Assurance Project Plan for:

Channel Migration Assessments of Puget Sound SMA Streams

Funded by the U.S. EPA, Region 10
Grant PC-00J281-01 and
National Estuary Program

Prepared by:
Patricia Olson, PhD, LHG
Washington Department of Ecology

Prepared for:
U.S. EPA Region 10

June 2012

Publication No. 12-06-006

Publication Information

This project is being funded by the US EPA, Region 10. The first phase of work was conducted under a Scientific and Technical Investigation Grant (PC-00J281-01). The second phase, completion of the work begun, is supported by EPA's National Estuary Program (NEP) funds.

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

The plan for this study is available on Ecology's website at

https://fortress.wa.gov/ecy/publications/SummaryPages/1206006.html

Author and Contact Information

Patricia L Olson, Senior Hydrogeologist, PhD, LHG
P.O. Box 47600
Shorelands and Environmental Assistance Program
Washington State Department of Ecology
Olympia, WA 98504-7600

This plan was prepared by a licensed hydrogeologist. A signed and stamped copy of the report is available upon request.

For more information contact: Communications Consultant, phone 360-407-6834.

Washington State Department of Ecology - www.ecy.wa.gov/

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

Quality Assurance Project Plan for

Channel Migration Assessments
Puget Sound Region SMA Streams

June 2012

Approved by:

Signature: Date:
Jonathan Pavy, EPA, Project Officer, EPA Region 10

Signature: Date:
Gina Grepo-Grove EPA, Regional QA Manager, EPA Region 10

Signature: Date:
Patricia L Olson, Author / Project Manager & Principal Investigator, SEA

Signature: Date:
Brian Lynn, Unit Supervisor, SEA

Signature: Date:
Gordon White, Program Manager, SEA

Signature: Date:
Bill Kammin, Ecology Quality Assurance Officer

Signature: Date:

Signatures are not available on the Internet version.

SEA: Shoreline and Environmental Assessment Program

Table of Contents

List of Figures and Tables

Page

Figures

Tables

Abstract

River floodplains and channel migration zones (CMZs) are ecologically productive areas heavily impacted by development. Their importance is detailed in the NMFS Biological Opinion declaring the FEMA program results in “take” of Puget Sound Chinook salmon and steelhead. Flood hazards consist of both inundation and erosion (channel migration). Understanding the extent of a CMZ is critical to assessing risks to development as well as habitat. The Washington State Shoreline Master Program (SMP) requires identifying CMZs but this has not been done for much of Puget Sound shoreline streams. Moreover, already completed CMZs methods and delineations are not consistent and often do not address future erosion risks and the loss of historic CMZ areas due to development. Current methodologies do not include evaluating future channel response to altered hydrologic and sediment regimes from climate change and development. Tasks include updating the CMZ mapping methodology, map areas for baseline trend analysis, and develop technical assistance for integrating with SMP and floodplain management and restoration/ protection strategies including climate change scenarios. This QAPP addresses Phase 1 funded by the EPA funded grant PC-00J281-01: WDOE Channel Migration Assessments project and Phase 2 funded by National Estuary Program.

Project Description and Objectives

Background

The Washington State Department of Ecology (Ecology) is the agency responsible for regulating shoreline and floodplain development through its Shoreline and Floodplain Management Acts. Both Acts direct Ecology to develop appropriate administrative codes and to provide assistance to local communities for developing shoreline and management plans and ordinances for both freshwater and coastal areas.

The Washington State Shoreline Management Act's policies include both protecting shoreline resources of the state while allowing appropriate and reasonable land use of shorelines. "*Permitted uses in the shorelines of the state shall be designed and conducted in a manner to minimize, in so far as practical, any resultant damage to the ecology and environment of the shoreline area and the public's use of the water (RCW 90.58.020)*".

The Washington State Shoreline master programs (SMP) carry out the policies of the Shoreline Management Act at the local level, regulating use and development of shorelines. Local shoreline programs include policies and regulations based on state laws and rules but tailored to the unique geographic, economic, and environmental needs of each community.

One required element of the SMP under its inventory and watershed characterization phase is: "Identify the general location of the channel migration area and floodplain" WAC 173-26-201(3)(c)(vii). Under the SMP channel migration zones are considered critical habitat and flood hazards. The SMP guidelines provide the policy and regulatory framework addressing protection and appropriate land use within channel migration zones and to accomplish flood hazard reduction.

Ecology is directed to provide the scientific basis and technical assistance on delineating regulatory channel migration zones for the Shorelines Master Program. However the SMP guidelines provide little technical guidance on how to identify the general location of the CMZ. Moreover many local communities do not have the resources (qualified staff or funds) to identify (map) channel migration zones, Ecology through its technical assistance mapped some channel migration areas. But Ecology had very limited resources (1 staff person for the state) and money to do the mapping for the communities.

While the Federal Emergency Management Agency has already mapped much of the 1% probability (100-year) floodplains in Washington, channel migration zones have only been sporadically mapped. Some counties have completed channel migration assessments for a few rivers as part of their Growth Management Critical Areas program and for Comprehensive Flood Hazard Management Plans. Most of these channel migration delineation studies required intensive evaluation of archival materials, mostly air photos and maps for mapping channel locations over time and geomorphic field data collection. Yet the techniques and quality of mapping to date has been inconsistent and not done for most of the Puget Sound.

Ecology applied for US Environmental Protection Agency grant to map channel migration areas in the Puget Sound for the local communities updating their Shoreline Master Programs. Ecology received the grant and has already mapped the general location of the CMZ for approximately 512 stream miles in the Puget Sound under Phase 1. These are only a subset of all migrating streams in this region. They were chosen based on the local communities SMP update schedules.

The U.S. Environmental Protection Agency (EPA), Region 10 Puget Sound Scientific Studies and Technical Investigations Assistance Program in Support of Implementing the Puget Sound Action Agenda provided funding for identifying channel migration zones for Washington State Shorelines Master Program updates for Phase 1. Phase 2 is being funded under the EPA National Estuary Program. The Puget Sound Partnership (PSP) has identified loss of floodplain functions and processes as a threat to ecosystem benefits in six of their eight project areas. The PSP action strategies include reconnecting floodplains, side channels and increasing channel complexity and implementing the state Shoreline Master Program (SMP) and Floodplain Management Programs. Priority Action A.2 identifies permanently protecting the intact areas of the Puget Sound ecosystem that still function well as a keystone piece of Puget Sound protection. The Action Agenda Priority A also addresses identifying areas at immediate risk to conversion or development and updating Washington State Shoreline Master Programs as near-term actions.

In the Puget Sound ecoregion, channel migration is the primary floodplain geomorphic process that creates a shifting mosaic of habitat patches of different ages within the river corridor (Fetherston et al 1995). This mosaic provides highly productive ecological areas for aquatic organisms as well as terrestrial species. The channel migration processes occur on a variety of spatial and temporal scales from local bank erosion to avulsions that create many kilometers of new channel to entire reworking of floodplains. Rivers erode some .patches each year while other patches accrete sediment and gradually rise in elevation above the river bed (Nanson and Beach, 1977; Brummer, Abbe and others 2006). The high density of complex boundaries between ecotones (Ward et al 1999) creates more environmental complexity, maintained by interactions between river channels and floodplain forests.

The regulatory and legal environment also recognizes the importance of channel migration processes and areas in creating critical habitat in the Puget Sound. In accordance with the judicial order in NWF v. FEMA, 345 F. Supp. 2d 1151 (W.D. Wash. 2004), the National Marine Fisheries Service (NMFS) Biological Opinion declared the Federal Emergency Management Agency (FEMA) floodplain management program results in a "take" of Puget Sound Chinook salmon, steelhead and Orca whales (NMFS 2008). The NMFS opinion allows for reasonable and prudent alternatives to be implemented that would avoid the likelihood of jeopardizing the continued existence of listed species or result in destruction or adverse modification of critical habitat. The NMFS discussed with the FEMA the availability of a reasonable and prudent alternative that the FEMA can take to avoid violation of the Endangered Species Act section 7(a)(2) responsibilities (50 CFR 402.14(g)(5)). The FEMA lists the Washington State Shoreline Master Program updates as a reasonable and prudent alternative to implementing the channel migration requirements of the biological opinion.

In contrast, channel migration is also a flood hazard to people, property, critical infrastructure, and potential pollutant sources such as waste water treatment sites and old landfills that are located within floodplains. Where rapid migration occurs, risk to people and infrastructure often is much greater than flooding alone. This contrast creates an inherent conflict between land uses and the beneficial services provided by floodplain ecosystems. Control of channel migration processes including channelization, dredging, gravel mining, levees, dikes, bank hardening and wood removal has contributed to listing of salmon under the Endangered Species Act (NMFS 2008).

These stressors have consequences not only for the sustainability of fluvial ecosystems but also society. The extent of flood inundation is becoming a greater societal issue as floodplain natural functions such as storage and aquatic habitats are lost due to increased floodplain development. The sustainability of these ecosystems is important for traditional cultures and present and future regional economics.

Description

In August 2009, Ecology identified approximately 550 miles of shoreline stream in the Puget Sound Basin having channel migration potential using geology and soil erosion potential, valley to channel characteristics, orthophoto time series, and LiDAR (Figure 1). The purpose was to provide information to communities updating their Shoreline Master Programs. However, this information only identified potential and not the spatial channel migration area, processes, habitat, floodplain condition or hazards. The EPA funded grant PC-00J281-01: WDOE Channel Migration Assessments provides funds to map the channel migration zones for the streams identified, where they do migrate. The mapping will be incorporated into the Washington State Shoreline Master Programs as well as provide scientific basis for protecting channel migration zones to reduce flood hazards and aid in salmon recovery in Washington.

Existing channel migration assessments will be compiled and evaluated in terms of usefulness for identifying hazards and protection and restoration opportunities. This information will be discussed under an update of best available science literature and information on processes and delineation methodologies. Methods described in Rapp and Abbe (2003) and in the Ecology's channel migration web guidance (Olson 2008) will be used and results will be compared. Using information synthesized from literature review and the method comparisons, we will identify and map channel migration areas and habitats, areas for protection and restoration, high hazard areas, and evaluate relationships between valley setting, migration, channel planform, habitat and climate change.

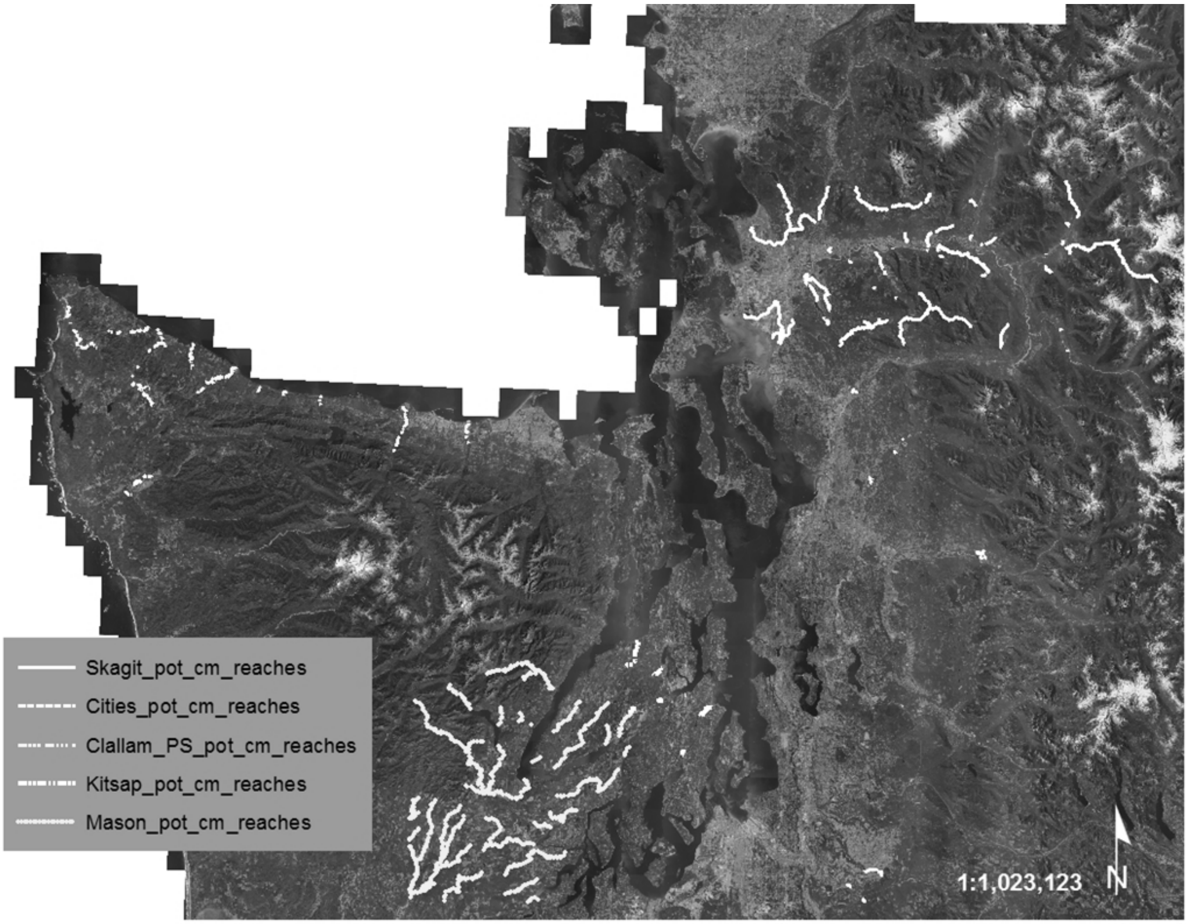


Figure 1: Approximately 550 stream miles in Clallam, Mason, Kitsap and Skagit Counties having potential to migrate.

In this group, channel migration zones will be mapped on those stream reaches with evidence of channel migration.

Archival mapping methods have been the mainstay of channel migration analyses and mapping for over 2 decades (e.g., Collins et al 2003, Rapp and Abbe 2003). Mapping the historic and current channel migration area is ***not*** by itself adequate to address hazards and restoration questions. For example, air photos and archival maps have limitations for evaluating channel migration on smaller streams that are heavily vegetated. Other methods such as LiDAR, stream power analyses (e.g., Church 2002), geology and soils, valley configuration, and field observations will be used and evaluated for streams where traditional archival mapping does not work. Key elements for delineating a CMZ, as discussed in Rapp and Abbe (2003), but which have not been applied in much of the CMZ mapping to date involve the erosion potential of earth materials, the influence of vegetation (e.g. Michelli et al. 2004), and geotechnical setbacks along high banks susceptible to erosion. These elements will be included in our assessment.

Project Purpose

Develop a planning level channel migration zone (CMZ) delineation methodology to identify the "general location of channel migration zones..." (WAC 173-26-201(3)(c)(vii)) for shoreline master program updates (SMP) and use for mapping CMZs for SMP updates; provide channel migration maps to the Puget Sound local communities for their Washington State Shoreline Master Program (SMP) updates and floodplain management; evaluate existing channel migration methods and assessments as to their usability for predicting future channel response under different development and climate change scenarios; refine the existing Ecology decision framework for conducting channel migration assessments using appropriate methodologies; and update existing scientific literature review documents.

Project Objectives

There are 2 phases of the project covered by this QAPP. Phase 1 project objectives are:

- Develop a planning level channel migration delineation methodology that relies on existing GIS data (Table 3), use this methodology to identify "the general location of channel migration zones..." (Washington State Shoreline Master Program (SMP) Guidelines language, WAC 173-26-201(3)(c)(vii):) and delineate the channel migration zones (CMZ), as required by the SMP guidelines along migrating shoreline management act streams in Kitsap, Clallam, Mason and Skagit Counties (Figure 1) in the Puget Sound region. The CMZ maps will be included in local community SMP updates (WAC 176-26-201(3)(vii)) and floodplain management. This objective is a first priority objective in order to meet the timeline requirements for Puget Sound communities to update their Shoreline Master Programs.
    - Much of this objective has been completed under Phase 1. A planning level channel migration delineation methodology has been developed (Figure 3 and Appendix D) and applied to 528 stream miles in the Puget Sound. CMZ maps, GIS data and reports have been sent to Kitsap, Clallam, Mason, and Skagit Counties. Maps and GIS data have also been sent to some small municipalities—Buckley, Wilkeson, Arlington and Granite Falls.

Phase 2 objectives are:

- Evaluate existing detailed channel migration assessments and delineations in the Puget Sound region in terms of study methods, objectives and sufficiency to address: 1) future channel migration response under increased sediment and peak flow likely caused by development and climate change; 2) reduce hazards to people, infrastructure; and 3) protect and restore critical habitat that is created by channel migration processes for salmon and riparian species. Detailed channel migration assessments include intensive historical analysis and field data collection.
- Use detailed assessments to assess channel migration processes by valley geologic setting, valley-channel configuration, channel planform, riparian vegetation condition, and development to develop a channel migration classification system.
- Compare CMZ maps created using the planning level CMZ delineation methodology developed under objective 1 to a sample of maps evaluated under objective 2 to

assess credibility and usefulness of a planning level CMZ delineation methodology in comparison to more detailed channel migration assessments for:
    - NMFS-FEMA Biological Opinion requirements for CMZ mapping
    - Identifying floodplain functions and beneficial services
    - Identify identifying opportunities for restoration and protection
- Sample of stream reaches used in the comparison in objective 3 for a rapid fluvial geomorphic field assessment to identify and locate channel migration historic and current features and extent of channel migration zone and compare to map results.
- Update the existing Ecology channel migration scientific literature review document (Rapp and Abbe 2003) and Ecology web technical guidance (Olson 2008) regarding channel migration and response.
- Identify channel migration potential for other Puget Sound shoreline streams.

Organization and Schedule

Project personnel organization/responsibilities

The Washington Department of Ecology, Shorelands and Environmental Assistance Program are the project lead. Dr. Patricia Olson is the Project Manager and Principal Investigator. Ecology has hired consultants and University of Washington staff to assist on the project. Project organization, titles, relationships among participants and QA responsibilities are outlined in Figure 2, Table 1.

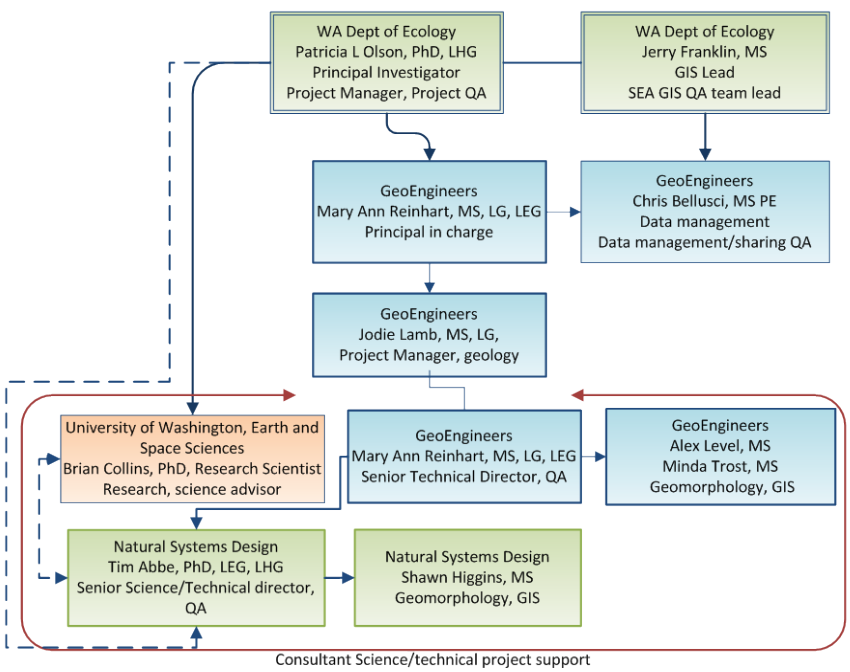


Figure 2: Organizational chart.

The chart shows project personnel, major responsibility including QA, and relationship to other project participants. The acronyms LG, LEG, LHG refer to Washington State licenses for geology and specialty licenses for engineering geologist and hydrogeologist, respectively. These licenses are required under Washington State law to practice geology in the state.

Table 1: Qualifications and responsibilities for key staff.

Name	Title, expertise	Responsibility
Patricia Olson, PhD, LHG 360-407-7540 pols461@ecy.wa.gov	Ecology, senior scientist (hydrogeology series) for SEA program with focus on hydrology and fluvial geomorphology, Washington State Licensed geologist and hydrogeologist	Principal Investigator and overall Project Manager. Science and technical lead for project, review methods and products, CMZ mapping and revised methods, science literature review, Writes the QAPP, conducts QA review of data, analyzes and interprets data. Writes the draft report and final report
Jerry Franklin, MS 360-407-7470 jfra461@ecy.wa.gov	Ecology, SEA program senior GIS staff, floodplain and risk mapping	Project lead GIS staff, develop GIS methods, evaluate GIS data, coordinates with GeoEngineers data management and GIS staff, conducts QA review on GIS data, assists Project manager on writing QAPP
Tom Gries: (360) 407-6327	Ecology NEP Quality Coordinator	Review draft QAPP and report(s) and recommend for approval.
William R. Kammin 360-407-6964	Ecology Quality Assurance Officer	Review draft QAPP and report and approve the final QAPP and report.
Brian Collins, PhD 206-616-6584 bcollins@u.washington.edu	Univ. of Wash., Earth and Space Sciences, Research Scientist, Fluvial geomorphology and GIS	Provide CMZ delineation review, review science documents, develop channel migration typology
Mary Ann Reinhart, MS, LG, LEG 425-861-6065 mreinhart@geoengineers.com	GeoEngineers Associate Fluvial Geomorphologist, WA State licensed geologist, engineering geologist	Project scope and design, technical lead for GeoEngineers, senior analyst and reviewer, review methods and products, CMZ mapping and revised methods, science literature review, conducts QA review of data, analyzes and interprets data
Tim Abbe, PhD, LEG, LHG 206-834-0175 tim.abbe@gmail.com	Principal, Tim Abbe Natural Systems Design, Principal geomorphologist, WA State licensed geologist, engineering geologist and hydrogeologist,	Project scoping and design, senior science and technical review, review methods and products, CMZ mapping and revised methods, science literature review, Conducts QA review of data, analyzes and interprets data
Jodie Lamb, LG, LEG 509-363-3125 jlamb@geoengineers.com	GeoEngineers Sr. Project Geologist, WA State licensed geologist	Consultant project manager responsible for managing communications and budgets, geomorphologist, technical analyst for geomorphology and CMZ delineation.
Shawn Higgins, MS	Natural Systems Design ,Sr. Staff Geomorphologist	Project geomorphologist, technical analyst for geomorphology and CMZ delineation
Chris Bellusci, PE cbellusci@geoengineers.com	GeoEngineers Technical Program Manager	GIS lead and database management.

Ecology contracted with Brian Collins, University of Washington through an interagency agreement. Ecology issued an RFP for consultant scientific and technical support. The RFP meet the state requirements for large personal services contracts as well as Federal requirements. Ecology contracted with Cardno ENTRIX as the prime consultant. GeoEngineers is the sub-consultant to Cardno ENTRIX for this project. Cardno ENTRIX and GeoEngineers have committed to working together and with Ecology by signing a teaming agreement that describes how the companies will interact with each other and with Ecology as equal partners. This teaming agreement includes elements that go beyond typical subcontracting agreements. Key elements relevant to this QAPP are:

- As teaming partners, both parties are expected to contribute roughly 50 percent of the work effort for both the proposal and the project work scope.
- As teaming partners, both parties will be included in, and/or informed of, all communications with Ecology.
- Both parties will be fully represented in all work products, including maps, memos, reports, and digital files.
- No work products will be submitted to Ecology unless they are reviewed and approved by both Cardno ENTRIX and GeoEngineers.
- GeoEngineers will provide data management services for the project team. The data management will be designed to provide full on-demand access to the data base for designated Cardno ENTRIX and Ecology staff. Protocols specific to data base compilation, utilization, and version control will be developed in concert with Ecology and Cardno ENTRIX GIS technical staff.
- Upon completion of the project, all digital files, including intermediate and final work products, will be distributed to all parties

Project schedule

Table 2: Proposed schedule for completing tasks and reports, with lead staff identified

Phase I	Due date	Lead staff
Project Management		
Issue RFP for personal services & hire, hold scoping, data sharing meeting	12/2010	Patricia Olson/Jerry Franklin
Map CMZs for Clallam, Kitsap, Mason and Skagit Counties for their SMP updates		
Develop planning level CMZ delineation methodology	06/30/2011	Patricia Olson, Tim Abbe, Mary Ann Reinhart, Brian Collins
Map channel migration zones	10/30/2011	Tim Abbe, Mary Ann Reinhart
Semi-annual reports to EPA	Semi-annual: April, Oct	Patricia Olson
QA/QC review and edits	12/15/2011	Patricia Olson, Tim Abbe, Mary Ann Reinhart, Jerry Franklin
Disseminate draft maps, reports and GIS data to communities	12/30/2011	Patricia Olson, Jerry Franklin

Phase II	Due date	Lead staff
Write QAPP	5/22/2012	Patricia Olson [1]
Meet with communities to discuss maps	06/30/2012	Patricia Olson
Assess detailed CMZ delineations		
Review, evaluate channel migration assessments and application in Puget Sound	12/2012	Patricia Olson, Tim Abbe, Mary Ann Reinhart, Brian Collins
Evaluate and verify planning level CMZ delineation methodology		
Compare CMZ's mapped using the planning level methodology to detailed assessment maps	04/2012 06/2012	Patricia Olson, Brian Collins, Tim Abbe, Mary Ann Reinhart
Identify sample stream reaches for rapid fluvial geomorphic field assessment and conduct field evaluation	06/2012-11/2012	Patricia Olson, Brian Collins
Incorporate comparison and field results into maps and planning level methodology	06/2012-01/2013	Patricia Olson, Brian Collins, Mary Ann Reinhart
Update CMZ guidance documents		
Update channel migration literature/report	06/2013	Patricia Olson, Brian Collins
Update CMZ web based guidance and publish hard copies of guidance	03/2013	Patricia Olson, Cedar Bouta
Create group of external experts for external scientific review and QA/QC	01/2013	Patricia Olson
Draft due to external experts	07/2013	Patricia Olson
Final (all reviews done) due to Plain Talk & publications coordinator	11/2013	Patricia Olson
Final guidance due on web	01/2014	Patricia Olson/Cedar Bouta
Final report		
Draft due external experts	10/2013	Patricia Olson
External expert comments incorporated	12/2013	Patricia Olson
Maps uploaded to Ecology's Coastal Atlas	12/2013	Patricia Olson, Dan Saul
Final report due on web	02/2014	Patricia Olson/Cedar Bouta
Final report due to EPA	03/2014	Patricia Olson

[1] QAPP submitted for review 06/2011 and revised QAPP based on comments received. Substantially completed but not formally approved by EPA

Secondary Data

Secondary data sources/specification

In this project Ecology will not be analyzing discrete environmental data. Ecology (and its consultants) will be interpreting and measuring from existing secondary data for identifying the extent of channel migration and erosion, evaluating channel response, and developing methodologies. Field observations will consist of identifying and locating channel migration features and evaluating a sample of mapped channel migration boundaries. No discrete sampling is proposed for the EPA funded portion.

The project relies primarily on secondary data including:

- GIS (Table 3, layers, sources, scale/resolution and purpose).
- Historic maps and aerial photography not currently in a GIS environment.
- Geologic reports from the USGS and Washington Department of Natural Resources.
- Existing channel migration assessments and delineations.
- Photographs, restoration projects and other information that shows channel conditions.
- Data generated from other EPA funded projects such as the Puget Sound Watershed Characterization Project and the NetMap project. The latter will provide information on sediment sources, delivery and routing to streams.

Table 3: Summary of data, source, and use of GIS data for this project.

State Acronyms: University of Washington (UW); Washington Department of Natural Resources (WDNR); Washington Department of Fish and Wildlife (WDFW); Washington Department of Ecology (Ecology); Washington Department of Transportation (WDOT). <u>All have metadata that meets the Washington State Geographic Information Council Geospatial Data Guidelines or FGDC Content Standards for Digital Geospatial Metadata</u>.

Data	Source/custodian	Scale/ resolution	Purpose
WA State National Hydrography Data	WA State	1:24k	Used in all CMZ analyses and general mapping references. Preferred over the NHD due to the geomorphic stream segmentation versus the NHD hydrologic segmentation.
SSURGO soil data	NRCS	1:24k	Soil erosion potential for floodplains and stream banks (see attachment A for method)
Washington State Geology	WDNR	1:100k	Geology erosion potential and sediment source information. The larger map scale on Geology layers does not alter the final products for channel migration maps because the geology detail is sufficient to identify erosion potential and sediment sources
Liquefaction Susceptibility	WDNR	100k	
Landslides (DGER)	WDNR-DGER	1:24k	
LiDAR	Puget Sound LiDAR consortium	2 meter horizontal accuracy; vertical accuracy	Mapping channels and producing relative water surface elevation maps, developing channel and valley characteristics such as gradient, channel width, sinuosity, confinement, stream power
DEM 10 m	UW/USGS	24k	The 10 meter DEM is used to evaluate general valley and stream characteristics, for example, valley and stream gradient, valley configuration where LiDAR is not available.
DEM 10 meter hillshade	UW/USGS	24k	
NAIP orthophotos	National Agricultural Imagery Program	Various resolutions	Mapping channel location over time and measuring migration rates over time. The historic channel migration zone boundaries are determined from current and historic stream locations. ESRI imagery data used to evaluate stream conditions and proposed channel migration maps on a 3-D platform (Arc Explorer). **Note:** Because of certain license restrictions, Ecology cannot use Google Earth. However, consultants can use it and will use it. The imagery is the same.
DOQQ	USGS	36 inch horizontal accuracy	
Washington State 24K DRG Image Library	USGS	1:24k	
ESRI World satellite imagery	ESRI	NA	
Historic air photos, maps	Puget Sound River History Project, UW	various	
LandSat Images 1972-2010	USGS/Ecology	30-meter	Provides information on large changes in land use, wetlands, and stream planform pattern (meander, straight, braided, multi-channel.

Land Cover: 1991-2006	NOAA	NA	Provides information for evaluating channel response related to changes in land cover that influence sediment and hydrologic regimes and delivery
Impervious surface: 1986-2006	Sanborn/NOAA	NA	Provides information for evaluating channel response related to changes in land cover that influence sediment and hydrologic regimes and delivery
Forest Canopy 1991-2006	Sanborn	NA	Provides information for evaluating channel response related to changes in land cover that influence sediment and hydrologic regimes and delivery
FEMA Flood Hazard Zones	FEMA	1:24k	Location of FEMA floodplains in relation to channel migration areas and developing channel migration erosion hazard maps
Shoreline Management Act (SMA) Suggested Arcs	Ecology	1:24k	Provides location of the upstream point for state shorelines
Priority and critical species and habitat	WDFW	NA	For identifying reaches with priority and critical habitat
Salmon and Steelhead Habitat Inventory and Assessment Program (SSHIAP)	WDFW	1:24k	For evaluation fish related conditions for identifying important fish habitat reaches
ESA Salmon Listing	NOAA-NMFS	1:100k	For identifying reaches with ESA salmon species
Salmon Recovery Regions	WDFW	1:500k	Identifying reaches salmon recovery needs ,existing Endangered Species Act listings, proposed listings, and where there is a strong likelihood for future listings
Water Resource Inventory Areas (WRIA)	Ecology	1:24k	Organizational units for watershed condition assessments
Watershed Administrative Units (WAU)	WDNR	1:24k	Organizational units for watershed condition assessments
Railroads	WDOT	1:24k	Provide information on potential channel migration barriers as defined under the Shoreline Management Act and Shoreline Master Program guidelines. Provide registration points for georeferencing maps and aerial photographs not already in GIS environment
Washington State Routes	WDOT	1:24k	Provide information on potential channel migration barriers as defined under the Shoreline Management Act and Shoreline Master Program guidelines. Provide registration points for georeferencing maps and aerial photographs not already in GIS environment
Washington State Local Roads	WDOT	1:24k	Provide information on potential channel migration barriers as defined under the Shoreline Management Act and Shoreline Master Program guidelines. Provide registration points for georeferencing maps and aerial photographs not already in GIS environment
Public Land Survey Township, Range, section	WDNR	1:24k	Registration points for georeferencing scanned aerial photographs and maps
Puget Sound River Basin Team GIS datasets	Ecology	Various	Additional information on watershed characteristics and conditions
Channel migration assessments and maps	Counties/ consultants	Various generally < 24k	Evaluate objectives, maps, capability to identify future channel response, and to compare with maps generated by the planning level CMZ methodology

Quality Control Procedures

Secondary data requirements

Quality metrics or standard operating procedures are generally available through Washington State Department of Ecology's (Ecology) GIS/IT program. These, in addition to project specific requirements, are used to develop quality requirements and quality control. Ecology has no agency QAPP for using secondary data nor does it have quality metrics for assessing channel migration or channel response processes.

- All GIS data will meet the Washington State Geographic Information Council Geospatial Data Guidelines or FGDC Content Standards for Digital Geospatial Metadata and National Map Accuracy Standards.
- Digital geospatial data compiled from sources outside the project will be accompanied with metadata produced by the original sources.
- Ecology uses the following data storage and import standards. The original source properties including coordinate system, projection, and cell size for all DEM's used for analysis were maintained throughout the process. Only vector data was projected if necessary. All GIS data produced for this project will meet these standards.

Horizontal Datum	NAD 83 HARN*
Vertical Datum	NAVD-88**
Projection System	Lambert Conic Conformal
Coordinate System	Washington State Plane Coordinates
Coordinate Zone	South
Coordinate Units	U.S. Survey Feet
Accuracy Standard	+/-40 feet or better
Vector Import Format	ArcExport E00 file, Shapefile, File Geodatabase, Personal Geodatabase
Raster Import Format	TIFF, BIL/BIP, RLC,GRID, ERDAS
Metadata	Federal Geographic Data Committee (FGDC), Metadata Content Standards*

* More information is available on the Washington Geographic Information Council (WAGIC) website at http://wagic.wa.gov/Techstds2/standards_index.htm.

** North American Vertical Datum 1988 (NAVD88) as defined by the National Geodetic Survey (NGS) is the official civilian datum for surveying and mapping in the United States.1 The Washington Department of Ecology is adopting NAVD88 as the agency standard vertical datum. All elevation data created by or submitted to Ecology should be collected in or converted to NAVD88. The collection method used to determine elevation should be specified. Elevations may be recorded in either feet or meters as long as the unit of measure is explicitly stated in the metadata

- All maps and aerial photographs not in a GIS environment will meet National Map Accuracy Standards.
- Standards for Spatial Point Attributes Stored in Non-Spatial Databases (web site): Ecology databases should support the following spatial features and address

methods throughout agency level database systems. This structure will ensure: consistency; understanding; and ease of integration between both tabular and geospatial data systems. A spatial address refers to the geographic point location of an object, and is used to define the point of that object or "Ecology thing" that information is being collected about (e.g. well, spill, facility). The standard of point data collection method is in latitude-longitude degrees, minutes, seconds. This allows one standard way to collect and report information within the agency. This suggested format will provide the agency with greater pay back in uniformity, ease of data comparison and compilation, and lessen the storage of redundant data.

- Published data will have been scientifically peer-reviewed or externally reviewed by experts.
- Existing channel migration assessments and mapping should meet Ecology standards for GIS data and spatial attributes.

Procedures for quality control of the secondary data and derived products

Much of the project GIS data is developed and maintained by county, state and federal agencies (Table 3) and comply with the Washington State Geographic Information Council Geospatial Data Guidelines or FGDC Content Standards for Digital Geospatial Metadata and National Map Accuracy Standards (Geospatial data and map: http://nationalmap.gov/gio/standards/). The accuracy of this information is the responsibility of the agencies and organizations that disseminate the data. Use of such digital databases, in the absence of independent validation of their accuracy, is commonplace in academia, government (including in the EPA), and the private sector.

Ecology has access to these databases and their metadata. These data are shared with Ecology's consultants for this project. The following outlines our steps for maintaining consistency in GIS analysis, interpretation and management.

- Best Available Digital Elevation Models: all GIS analysis used to develop or assist in the development of CMZ's operated on the latest and best available LiDAR aerial surveys from a single source and time frame.
- Digital Elevation Models: all DEMS's used in analysis were derived from single source datasets with consistent raster properties.
- All DEM source properties such as cell size, projection, and attribute values were maintained as is from the original sources. All GIS data produced for this project will meet Ecology standards (http://www.ecy.wa.gov/services/gis/data/standards/standards.htm and http://wagic.wa.gov/Techstds2/standards_index.htm).
- Digital data produced through the project will be accompanied by metadata that meets the content standards for geospatial metadata set forth by the FGDC. The metadata will include descriptions of data fields, data types, and coding schemes used in theme attribute tables. The metadata will document processes involved in

the production, manipulation, and modification of all data files included in the GIS project and will provide an accuracy assessment of each file.

- All created data not in GIS will meet Ecology Standards for Spatial Point Attributes Stored in Non-Spatial Databases.
- The scale of most of the primary GIS data used in the project scale is 1:24000. This scale is adequate to identify development, erosion potential, base streamline, channel planform pattern (meander, straight, multi-channel, and braided), valley characteristics and form, riparian vegetation change, and other factors that influence channel migration processes. Products produced from this data will adhere as closely as possible to National Map Accuracy Standards for 1:24000 scale maps. Some existing geospatial data that is to be incorporated into the GIS is originally produced at scales smaller than 1:24000. The positional accuracy of the data will be refined by editing point and vertices positions to match the features as they appear on an aerial image that meets the required accuracy.
- Some GIS data are at scales smaller than 1:24000, for example, the WDNR Geology layer scale is 1:100000. Some GIS data, such as the FEMA floodplain boundaries, have lower certainty than others such as streamlines derived from recent orthophotos. The uncertainty resulting from analyzing these data sets is documented so that users of the resulting analysis (geographic overlay of recent streamlines and flood zones) understand uncertainty.
- All GIS products developed in this project will be reviewed by the GIS Lead (Jerry Franklin) and Chris Bellusci (GIS Lead, GeoEngineers) for accuracy and meeting GIS standards and to ensure that data processing uses consistent GIS methods and that data interpretation follows a consistent sequence. Review will include evaluating consistency, map accuracy, and data limitation assumptions and appropriateness. Data will be managed by Chris Bellusci as per draft memo, May 18, 2011 (Appendix A).
- All products developed in this project will go through a quality review by the Project Manager (Patricia Olson) and consultant technical and scientific leads (Tim Abbe, Mary Ann Reinhart). Each reviewer evaluates products independently and then meets to discuss review and give back to analysts for revision. The final product is given another review to ensure that edits were made correctly. The review includes checks for computational accuracy, technical soundness of analysis, reasonableness of results and conclusions, clarity of presentation, and appropriateness of the limitations of the data. All reviewers are licensed geology professionals in Washington and must adhere to highest standards as per licensure requirements.
- Historic maps and aerial photographs created by the federal agencies usually meet the National Map Accuracy Standards. Published maps meeting these accuracy requirements shall note this fact in their legends, as follows: "This map complies with National Map Accuracy Standards." Published maps whose errors exceed those standards must omit from their legends all mention of standard accuracy. In those cases, the accuracy of any map may be tested by comparing the positions of points

whose locations or elevations are shown upon it with corresponding positions as determined by surveys of a higher accuracy.

- Existing channel migration assessments and maps will be reviewed based on Ecology GIS and spatial attribute standards and products will be tested for accuracy by comparing positions of known features from GIS data with higher standards or accuracy.
- GPS surveys will be used on sample of stream reaches (Objective 5) to evaluate how closely well defined features and CMZ boundaries derived from GIS data and imagery represent surface features on the ground. Differences should adhere as closely as possible to National Map Accuracy Standards for 1:24000 scale maps. The standard specifies that 90 percent of well-defined features are to be within 0.02 inches, which is 40 feet, of the true mapped ground position. Deviations beyond this standard will be noted in enough detail so subsequent data users will be able to determine the data's usability under scenarios different from those included in project. If features are identified from imagery older than the most recent channel changing high flows, alternative GPS sites will be identified. Deviations from National Map Standards may require alternate GPS sites because fluvial and other feature locations associated with channel response and migration vary temporally.
- At the end of each process, a series of final checks will be implemented to make sure the data will be usable by the intended audience. Checks (and their descriptions) include verifying that:
    - Each output data set falls into the correct geographic location and has the specified coordinate system and precision.
    - Files to be delivered are in the format as specified in secondary data requirements.
    - Each data set can be unpackaged, uncompressed, or otherwise configured for use by end-users.
    - All database features and tables are present and complete unless otherwise noted.
    - Final non-digital map products are consistent, for example, all the specified layers exist in the map; title is correct; legend reflects the data layers in the map and the template symbology; the map covers the correct geographic extent.

EPA evaluation of quality of data

EPA will not be evaluating the quality of the secondary data. A disclaimer will be added to any project deliverable to indicate that the quality of the secondary data has not been evaluated by EPA for this specific application.

Example Disclaimer Language: The Environmental Protection Agency is not responsible for ensuring that the secondary data and subsequent products meet specified data quality and accuracy standards. Washington Department of Ecology is the responsible agency for insuring data quality and accuracy for this project.

Data analysis, interpretation, and management

Data analysis methods

Archival mapping methods have been the mainstay of channel migration analyses and mapping for over 2 decades (e.g., Collins et al 2003, Rapp and Abbe 2003). Channel migration change over time is generally identified from historic maps, aerial photographs and orthophotos and field verification and measurements. In this project mapping of channel migration stream lines, active channel, channel bars and other fluvial landforms, channel width and gradient, valley width and gradient over time is done at a display scale of 1:5000 or less. Most GIS LiDAR DEMs, aerial photographs and orthophotos (Table 3) resolutions are sufficient for mapping at this display scale.

While channel migration assessment methods based on secondary data are well developed and reported in peer-reviewed science literature these methods may not apply for some conditions:

- Erosion potential or erosion hazard area: Lahar, glacial or fluvial terraces can be easily eroded or become instable by channel migration processes. Vegetation (e.g. Michelli et al. 2004) also influences bank and floodplain susceptibility to erosion. Most channel migration assessments do not include geotechnical setbacks along high banks susceptible to erosion or the influence of vegetation. These erosion processes and controls are not always obvious from the aerial photograph and map record. Geology and soils data are used to identify areas that can be easily eroded or destabilized. Methods to identify and quantify these processes without rigorous field assessment will be evaluated. Methods include using regime theory models (e.g. Millar 2000, 2005) and bank stability models (e.g. Simon, A., Langendoen 2006).
- Small streams with vegetation canopy: air photos and archival maps have limitations for evaluating channel migration on smaller streams that are heavily vegetated. Other methods such as LiDAR, stream power analyses (e.g., Church 2002), geology and soils, valley configuration, and field observation will be used.
- Recent channel response to development and climate change: The relationships are not well documented in historic maps, aerial photographs or other secondary data sources. The USGS and North Cascades and Mt. Rainer National Park studies are studying the effects of retreating headwaters glaciers on stream response. These studies provide channel dimension and sediment data and other relevant information documenting recent changes. The channel and sediment data from

these studies can be used to identify the magnitude of change and possible trajectories for future channel response. Increase in peak flows can also alter channel response. Peak flow hydrograph analysis using Bulletin 17B procedures incorporated into the USGS model PEAKFQ (Flynn et al 2006a, 2006b). The peak flow analysis is done on the entire annual peak flow record, and then the time series are divided into pre-change and post-change series. Records before Water Year (WY) 1950 are often used for the pre-climate change series. On gages without long-term records, the time series comparison is 1) earliest record to most recent annual peak flow; 2) 1970 to present.

A primary objective of this project is to provide channel migration maps for communities to update their Shoreline Master Plans (SMP). We did not find any established methods to identify "the general location of channel migration zones..." (Washington State Shoreline Master Program (SMP) Guidelines language, WAC 173-26-201(3)(c)(vii)). We developed a planning level channel migration delineation methodology that relies on existing GIS data under this project (Figure 3 and Appendix D) and applied to 528 stream miles in the Puget Sound. CMZ maps, GIS data and reports have been sent to Kitsap, Clallam, Mason, and Skagit Counties.

Part of this project is to develop new methods where standard methods do not apply. Analysis methods are being developed to meet the 3 conditions listed above. Remote sensing will continue to play a critical role in our analysis. Remote sensing is the most practical and cost-effective way to evaluate and understand time-sensitive processes important to creating fluvial responses and landforms especially in terms of different temporal and spatial scales. In particular, LiDAR (**L**ight **D**istance **A**nd **R**anging, also known as Airborne Laser Swath Mapping or ALSM), in combination with digital high resolution orthophotos and aerial photographs, will be used to develop higher resolution DEMS to identify and measure landforms and to some extent human created features in the floodplain, determine vegetation canopy coverage; habitat type, channel migration history, quantify changes in the geomorphic floodplain; and assess flood and erosion hazards such as avulsions.

Relative water surface elevation models (RWSE), also called height above water surface (e.g. Jones 2006) derived from the LiDAR bare earth DEMS provide information on channel location and features, fluvial and hillslope processes over time and potential avulsion paths. Methods to derive RWSE DEMs are included in Appendix B. Other uses for LiDAR in this project include evaluating results of channel migration assessment methods that used standard archival methods without using LiDAR. LiDAR will be used to evaluate more practical and cost-effective tools for local communities to identify channel migration areas for floodplain and shoreline management, areas for ecological protection and/or restoration and identify relevant processes and templates for restoration. LiDAR bare earth data are also used to measure channel width and gradient for stream power analyses as well as develop relative water surface elevation models and identify historic and current fluvial landforms in the valley bottoms.

Channel gradient data is used for a stream power analysis. Unit stream power indicator (fluid density (ρ), acceleration of gravity (g)*channel gradient (S)* effective discharge (Q)

/active or bankfull channel width (w)) provides information on stream sediment transport capacity that is the ability of the stream to transport sediment:

$$P = \frac{\rho g S Q}{w}$$

Stream power from this equation is watts per unit channel width or unit power (Newton · m s^{-1}). High transport capacity can result in channel incision and bank erosion. Low transport capacity may cause channel aggradation. Bankfull discharge can be calculated from instantaneous annual peak flow data available from USGS or Ecology stream gages. On streams that have no discharge gage stations or none in close proximity to reaches of interest, the USGS Streamstats program will be used to estimate the bankfull flood discharge (http://water.usgs.gov/osw/streamstats/Washington.html). Our definition for bankfull discharge is the discharge where sediment transport, channel movement and other geomorphic work is done.

Although the average bankfull discharge in Washington approximates the 1.4-1.5-year flood frequency (Castro and Jackson 2002), the bankfull discharge varies depending on channel geometry and other factors. Since there are no predictive equations for these flood recurrence intervals, we assume that the 2-year flood is bankfull.

GIS analysis, interpretation and mapping of vegetation, floodplain landforms, channel migration and floodplain inundation boundaries will be done in ArcGIS 10. Office delineation will be followed up with field inspections to sample stream reaches to refine delineation and assess the accuracy of remote sensing and GIS methods.

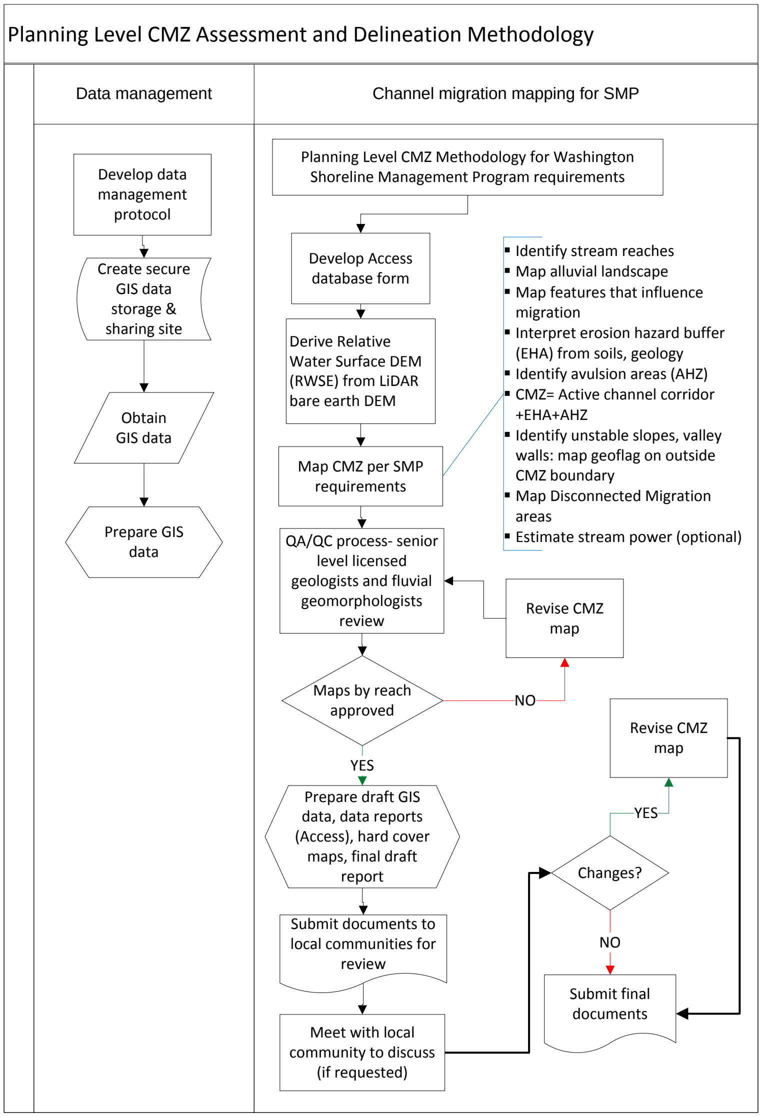


Figure 3: Methodology for planning level CMZ assessment and delineation.
Refer to Appendix D for more detailed description and example.

Assessment Method: Existing channel migration studies

Key questions include:

- What are the assessment assumptions, objectives and limitations and method protocol?
- Was LiDAR used in the assessment?
- Was assessment conducted on closed canopy stream reaches? What methods were used?
- Does the assessment consider stream valley-scale domains and channel planform (e.g., single thread meandering, anabranching, wandering)?

- Were migration rates measured? What methods were used?
- Did assessment include other elements such as alluvial fans, erosion hazard areas and geotechnical setbacks? Could the assessment be used to determine these elements?
- What methods were used to identify erosion hazards and geotechnical setbacks?
- Were geologic characteristics such as bedrock control, tectonics, and geotechnical conditions on slope stability and surface geology erodibility considered or estimated?
- Were soil types and geology considered for erosion hazard analysis? What criteria were used?
- Were avulsions considered? If so, what were the criteria and methods?
- What data were used? Were field data collected? Was there QA/QC protocol?
- Were hazard ratings used in assessment? What methods or criteria were used?
- Did assessment identify areas for aquatic and terrestrial habitat protection or restoration? Could you identify those areas from this assessment?
- Does the assessment consider and incorporate:
- Changes in hydrology or climate?
- Changes in sediment production, supply and / or transport capacity?
- The influence of riparian vegetation?
- Changes in land management?
- Was infrastructure mapped as constraints to CMZs? If so, what criteria were used to determine the infrastructure capability to withstand water erosion forces? Were the disconnected CMZ's mapped?
- Do CMZ boundaries still encompass current channel locations? If not why, e.g. channel response to high flow events, episodic sediment delivery, vegetation removal?

LiDAR will be used to evaluate results of channel migration assessment methods that used standard archival methods without using LiDAR. Once the evaluation criteria have been established and significant events in each basin identified, an assessment matrix will be populated by applying the evaluation criteria to the existing CMZ delineations.

The individual CMZ delineations will be evaluated to see how it responded to recent storm events by comparing delineations and stream banks with recent aerial photos or LiDAR maps. Areas with poor coverage or obscured by riparian cover will be identified. Past CMZ delineations will be classified as having passed, where the current channel configuration is within that predicted by the report, or failed, where the streams exceeded mapped CMZ delineations or moved at a rate faster than predicted. Passing streams will be further subdivided into the following categories: a) no significant events occurred within the basin, b) a significant event occurred and the method and margin of safety was appropriate, and c) a significant event occurred, but the method or the margins of safety were inappropriate. A report will be prepared focusing on the streams that failed, the streams that passed for the wrong reasons, and an analysis of the probable causes. Project staff will not evaluate reports authored by their own company.

Field observations

Field identification of fluvial features and channel migration processes and boundaries will be done on some stream reaches. For the Shoreline Master Program CMZ maps, field site visits will be done on an as needed basis. Need is defined as the reaches, mostly smaller streams with heavy canopy cover, where channel migration processes could not be determined remotely. For evaluating previously existing channel migration assessments and new methodologies, sample reaches will be chosen using a stratified approach where valley geologic setting is the top-level stratification, the next level is landscape units (e.g., alluvial fan, fluvial valley, hillslope-stream valley), and then channel planform.

The locations of fluvial features related to channel migration and identifiable channel migration indicators and boundaries and other significant features will be recorded using an automated GPS/GIS field mapping system. GIS base map data will be transferred to the mobile GPS/GIS mapping system (Trimble Geo XT, sub meter, with GPS Pathfinder Office and TerraSync Professional field software). The location of known targets for mapping will be entered or marked in the system. The GPS/GIS mapping system will be used to navigate to GIS mapped boundaries and fluvial features. Ecology has standard operating procedures (SOP) for using hand-held GPS receivers (Janisch, 2006, ECY_EAP_SOP_013 Assigning GPS Coordinates, approved 09/6/2006 by Ecology QA Officer). This SOP will be used to maintain QA/QC on GPS measurements. Photographs will be taken with a digital camera and the photo id numbers will be recorded in the GPS/GIS system. All information will be transferred back to the GIS data and attributes added.

If errors appear the for location accuracy of positional data points, further testing and calibration against established survey benchmarks will be requested. If inconsistency or errors are discovered in the attribute data, instructions will be given on how to enter the data and any automated processes will be adjusted or reprogrammed as necessary. If CMZ boundaries and fluvial features are incomplete or inconsistent in content and quality, instructions will be provided on how to maintain consistency.

Riparian vegetation plays an important role in mediating channel response and channel migration, degree of site disturbance and habitat quality. Riparian vegetation structure will be visually characterized using Ecology SOP for Visual Characterization of Riparian Vegetation Structure for the Extensive Riparian Status and Trends Monitoring Program (Werner, 2009, SOP067VisualCharacterizationofRiparianVegetion_v1_0, approved by Ecology QA Officer, 11/27/2009). This SOP will be used to maintain QA/QC on visual riparian characterization.

Data organization

Data organization includes:

- Organize GIS data and results for general channel migration mapping under Shoreline Master Program guidelines.
- Matrix table to organize answers to questions during evaluation of detailed assessments.

- Field data form for rapid fluvial geomorphic field assessment of channel migration features and boundaries

Each person developing specific data related to this project will use the appropriate forms[2]. Their data will be independently validated for data emissions or errors by other project staff. Data that is missing is identified and data sources (e.g., GIS, maps, aerial photos etc) are checked to identify data absence reasons. If omission rather than data not available, the data will be added.

Accuracy refers to the closeness of a measured or computed value to its *true* value, where the *true* value is obtained with perfect information. Due to the natural heterogeneity and random variability of many environmental systems, this *true* value exists as a distribution rather than a discrete value. In geomorphic process studies, the underlying distributions for channel response and channel migration are often not known.

Data accuracy or errors instead will be based on the assumption that data generated for a specific parameter falls within an acceptable range of values for that parameter. Data that fall outside of acceptable limits, for example physical constraints on parameters such as channel gradient, channel width, channel location, stream power, and LiDAR generated DEMS and relative water surface elevation models, are identified by staff. These data errors or accuracy will be reviewed and validated by lead or senior project staff: Patricia Olson, Jerry Franklin, Brian Collins, Tim Abbe, and Mary Ann Reinhart.

Statistical analysis

This project does not include statistical analysis because there is little or no published (or other sources) studies or methods to determine error and bias in cases such as:

- Conducting channel migration assessments on small streams that are not readily visible on aerial photographs and only coarsely mapped on historic maps.
- Channel migration approaches or methodologies addressing migration processes and channel responses by valley configuration, channel planform pattern, land development/management, or changes in sediment or hydrologic reaches.
- Quantifying channel migration related erosion hazard areas for lahars, fluvial or glacio-fluvial terraces.

An addendum to this QAPP will be submitted if statistical analyses become relevant to the project.

[2] The data forms may be changed during the project if the current ones do not meet the project data requirements.

Reporting

Deliverables

All project participants work as a team. The deliverables are developed by the team.

- Planning level channel migration delineation methodology and channel migration zone maps generated using the methodology, reports, GIS data and other supporting materials for Kitsap, Clallam, Mason and Skagit Counties Washington State Shoreline Management streams (512 stream miles have already been mapped using the planning level channel migration delineation methodology, Figure 3 and Appendix D).
- A report that discusses methods used in existing channel migration assessments and delineations. The report will include information matrix developed during the evaluation of existing channel migration studies, recommendations for improved set of methods or more unified approach to determining the appropriate assumptions based on geomorphic setting/conditions to be incorporated into existing Ecology CMZ guidance.
- Document describing use of LiDAR derived elevation products for improving methods and providing cost-effective tools.
- A series of reports that incorporate relevant external quality assurance through expert opinions : a) description of appropriate methodologies based on the extrinsic and intrinsic controls; b) migration maps, data and methods, rationale for delineations, limitations and errors associated with delineations and comparisons with previously mapped areas; c) actions identified including hazard reduction, habitat protection, and habitat restoration based on identified risks (including threats and drivers) and potential climate change driven modifications to hydrologic, sediment and wood regimes.
- Documentation of meeting minutes, including meeting objectives and conclusions and appropriate suggestions for amending maps from local community meetings.
- Scientifically credible guidance applicable to regulatory programs.
- Final documents for channel migration technical guidance, methods manual, GIS maps for local communities to use in planning and implementing regulations, and scientific documents, externally reviewed by experts, on channel migration processes in western Washington, methods, project results and discussion, and recommendations.

GIS Derived Products

All products will include metadata and secondary data sources used to develop them. GIS products produced from the interpreted existing GIS data include:

- Relative water surface elevation map from LiDAR bare earth data
- Shapefiles of channel characterizations, current and historical which may include: streamlines, active channel, fluvial features, channel gradient, channel width, stream power, riparian conditions / changes
- Maps showing the general location of channel migration zones as per SMP guidelines

- Areas for protection/restoration
- Areas amenable to future development
- Channel migration classification based on geomorphic and geologic setting
- Channel migration areas uploaded to the Coastal Atlas (http://www.ecy.wa.gov/programs/sea/sma/atlas_home.html)

Final Reports

Final reports include:

- Channel migration maps generated for Skagit, Mason, Clallam and Kitsap Counties Shoreline Master Program updates, GIS data, and reports covering assessment protocol, analysis, interpretation and recommendations for SMP and floodplain management including restoration or protection actions
- Existing channel migration studies assessment results
- Revised Ecology Channel Migration Web Guidance
- Updated scientific literature review
- Results of comparing existing channel migration assessments
- Journal articles on method assessment, channel migration typology / classification, improved or new delineation methods

References

Brummer, C. J., T. B. Abbe, et al. (2006). Influence of vertical channel change associated with wood accumulations on delineating channel migration zones, Washington, USA. Geomorphology, 80(3-4): 295-309.

Collins, B.L., Montgomery, D.R., and Sheikh, A.J., 2003, Reconstructing the Historical Riverine Landscape of the Puget Lowland, Pages 79-128, in D.R. Montgomery et al, eds. Restoration of Puget Sound Rivers, Center for Water and Watershed Studies, University of Washington Press, Seattle, WA.

Collins, B. D. and D. R. Montgomery, 2011. "The legacy of Pleistocene glaciation and the organization of lowland alluvial process domains in the Puget Sound region." Geomorphology 126(1-2): 174-185.

Church, M. 2002. Geomorphic thresholds in riverine landscapes. Freshwater Biology 47: 541-557.

Environmental Protection Agency, 2011. NRMRL QAPP Requirements for Secondary Data Projects, revision (0).

Fetherston, K.L., Naiman, R.J., Bilby, R.E., 1995. Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest. Geomorphology 13, 133-144

Flynn, K.M., Kirby, W.H., and Hummel, P.R., 2006a, User's manual for program PeakFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines: U.S. Geological Survey Techniques and Methods Book 4, Chapter B4, 42 pgs

Flynn, K.M., Kirby, W.H., Mason, R.R., Cohn, T.A., 2006b, Estimating magnitude and frequency of floods using the PeakFQ program: U,S. Geological Survey Fact Sheet 2006-3143, 2 pgs.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood-flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston,Va., 183 p., http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html

Janisch, J., 2006. Standard Operating Procedure for Determining Global Position System Coordinates ,Version 1.0. Washington State Department of Ecology, Olympia, WA., SOP Number EAP013. www.ecy.wa.gov/programs/eap/quality.html

Jones, J.L., 2006, Side channel mapping and fish habitat suitability analysis using LIDAR topography and orthophotography: Photogrammetric Engineering & Remote Sensing, November 2006, vol. 71, no. 11, p. 1202-1206

Lombard, S. and C. Kirchmer, 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. www.ecy.wa.gov/biblio/0403030.html.

Micheli, E.R., J.W. Kirchner, and E.W. Larsen, 2004. Quantifying the effect of riparian forest versus agricultural vegetation on river meander migration rates, Central Sacramento River, California, U.S.A., *River Research and Applications*, **20**, 537-548,

Millar, R. G. (2000). Influence of bank vegetation on alluvial channel patterns. Water Resour Res **36**(4): 1109-1118.

Millar, R. G. (2005). Theoretical regime equations for mobile gravel-bed rivers with stable banks. Geomorphology **64**: 207–220.

Nanson, G.C., Beach, H.F., 1977. Forest Succession and sedimentation on a meandering-river floodplain, northeast British Columbia, Canada. Journal of Biogeography 4, 229-251

National Marine Fisheries Service (NMFS), 2008. Biological Opinion from the Endangered Species Act Section 7 Formal Consultation and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation for the on-going National Flood Insurance Program carried out in the Puget Sound area in Washington State. HUC 17110020 Puget Sound., 238 pp, September 22, 2008, NOAA, Seattle, WA

Olson, P.L, (2008), Web Guidance for Channel Migration Assessment under SMA, Washington Department of Ecology Publication 08-06-013, Olympia WA http://www.ecy.wa.gov/biblio/0806013.html http://www.ecy.wa.gov/programs/sea/sma/cma/index.html

Rapp, C. and Abbe, T., 2003. A Framework for Delineating Channel Migration Zones, Washington Department of Ecology Publication 03-06-027, Olympia WA, http://www.ecy.wa.gov/biblio/0306027.html

Simon, A., Langendoen, E.J. 2006. A deterministic bank-stability and toe-erosion model for stream restoration. In: Proceedings of the Environmental and Water Resources Congress (R. Graham, Ed.), May 21-25, 2006, Omaha, Nebraska.

Washington Department of Ecology, 1993. Field Sampling and Measurement Protocols for the Watershed Assessments Section. Washington State Department of Ecology, Olympia, WA. Publication No. 93-e04. www.ecy.wa.gov/biblio/93e04.html

Werner, Liz, 2009. Standard Operating Procedure for Visual Characterization of Riparian Vegetation Structure for the Extensive Riparian Status and Trends Monitoring Program, Washington State Department of Ecology, Olympia, WA., SOP Number EAP067 (http://www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_067VisualCharacterizationofRiparianVegetation_v1_0.pdf)

Appendix A. Draft Data Management Memo

GeoEngineers: 8410 154th Avenue NE, Redmond, Washington 98052, Telephone: 425.861.6000, Fax: 425.861.6050 www.geoengineers.com
Cardno Entrix: 200 First Avenue West, Suite 500, Seattle, Washington 98119, Telephone 206-269-0104, Fax 206-269-0098 www.cardnoentrix.com

DRAFT - Technical Memorandum

To: Washington State Department of Ecology

Authored by: Chris P. Bellusci, Mary Ann Reinhart, LEG and Jodie D. Lamb, LEG, GeoEngineers, Inc.

Reviewed by: D. Eric Harlow, Cardno Entrix, Inc.

Date: May 18, 2011

Subject: Ecology CMZ Project Data Management Outline and Spatial Data Standards

Ecology CMZ Project Data Management Outline:

Objective

This document outlines the systems, processes and naming conventions related to the exchange of GIS data for the Washington State Ecology (Ecology) Channel Migration Zone (CMZ) project.

Systems Overview

Two systems are in place for project data exchange, which are outlined below along with their uses.

Project SharePoint Site:

- Storage and exchange of GIS Shape files and other project documentation (maximum file size limit 25M).
- GIS Folders will have alerts. As data is "dropped off", GIS contacts will be notified via e-mail.

Project FTP Site:

- Used only for exchange of GIS Data (maximum file size limit 100M).
- Data will be purged after an agreed upon time frame to reduce potential errors, e.g., every 2 weeks (GIS users will be notified prior to purge).
- GIS contacts will notify users of GIS data via e-mail when a file has been uploaded to the FTP site.

Note: Large base data sets such as LiDAR and/or Imagery will not be exchanged between systems (SharePoint/FTP).

GIS Points of Contact

To streamline communication on data related tasks and coordination, two GIS data stewards have been identified for each work group as indicated below.

Ecology:

1. Jerry Franklin - Primary
2. Patricia Olson – Secondary

GeoEngineers:

3. Jodie Lamb - Primary
4. Mary Ann Reinhart - Secondary

Natural Systems Design:

5. Shawn Higgins - Primary
6. Tim Abbe - Secondary

SharePoint GIS File Structure

The GIS Shape file library will be organized by county with sub-folders organized by streams or watershed with outlined example below:

County Folders:

- Clallam
- Kitsap
- Mason
- Skagit
- Mason Non Puget Sound

County subfolders will be organized by major drainages as shown in the example below:

- Clallam
  - Clallam
  - Deep Creek
  - East Twin
  - Hoko
  - Lyre Creek
  - Etc.

Drainage subfolders will be organized into two sub-folders, "Draft" and "Final" as shown in the example below:

- Clallam
  - Draft - This folder will store working revisions of the associated shapefiles.
  - Final – This folder will store the final QA/QC'd data for the respective section of the stream/watershed.

An example of a full SharePoint document library path for shape files is shown below:

- Clallam PS CMA

- Clallam
    - Draft
    - Final

GIS File Naming Convention

A standardized naming convention will be used for the exchange of GIS shape files between the teams. The proposed file naming is based on the following: County (abbreviation); Stream Number; Segment Number; and Revision Number.

To keep naming consistency, a coding system will be used for Steam Number and Segment Number:

Example:

County_StreamNumber_SegementNumber_File_ndentifer_Revision Number would equal CLM_16_01_Lidar_Rev.03

The numbering convention will be developed by the project GIS team and a conversion table will be published to the team for reference. Segments will be numbered starting at the stream mouth.

Revisions

Revisions for this project is defined if a GIS Shape File is downloaded and modified in any way then uploaded back to the project web site; the analyst will update the revision number before uploading the file. The revision number will begin with Rev1 for the first shape file loaded to the project site and progress in ascending order for subsequent file revisions.

When a GIS shape file is complete and final, the revision number will be replaced with the word "Final." Example:

CLM_16_01_Lidar_Rev.03 > CLM_16_01_Lidar_Final

The final file will be saved with the QA/QC form in the final folder under each stream folder on SharePoint.

Loading GIS Shape Files

When loading GIS shape files to the project website there will be a meta data form to fill out. The site will automatically prompt the user to fill out basic information about the GIS shape file being loaded. Meta data fields will cover the following:

Field Name	Definition
Modified By	Who modified the file
Edit Comments	Brief description of edits made
QA/QC Status	Check box indicating – Waiting, Final

Spatial Data Standards (Ecology requirements)

The Department of Ecology uses GIS software from Environmental Systems Research Institute (ESRI):

- ArcGIS Version 10.0
- ArcGIS Server 10.0

- ArcIMS 10.0
- ArcSDE 10.0

Data submitted to Ecology should be in ESRI ArcExport (E00), shapefile, ESRI Personal Database or File Geodatabase format. (**Note**: Final GIS results and products can be published in file or personal geodatabases as necessary. All datasets, structures, and formats are maintained or established to the highest quality assurances. There are no limitations to the analysis team as to the designation/denomination of databases. All spatial databases will be in Arc 10.0 to maintain compatibility.)

The agency utilizes the following data storage and import standards:

Horizontal Datum	NAD 83 HARN*
Vertical Datum	NAVD-88**
Projection System	Lambert Conic Conformal
Coordinate System	Washington State Plane Coordinates
Coordinate Zone	South (or zone-appropriate if not statewide)
Coordinate Units	U.S. SurveyFeet
Accuracy Standard	+/-40 feet or better
Vector Import Format	ArcExport E00 file, Shapefile, File Geodatabase, Personal Geodatabase
Raster Import Format	TIFF, BIL/BIP, RLC,GRID, ERDAS
Metadata	Federal Geographic Data Committee (FGDC), Metadata Content Standards*

Reference

http://www.ecy.wa.gov/services/gis/data/standards/standards.htm

Appendix B. Relative water surface elevation methods

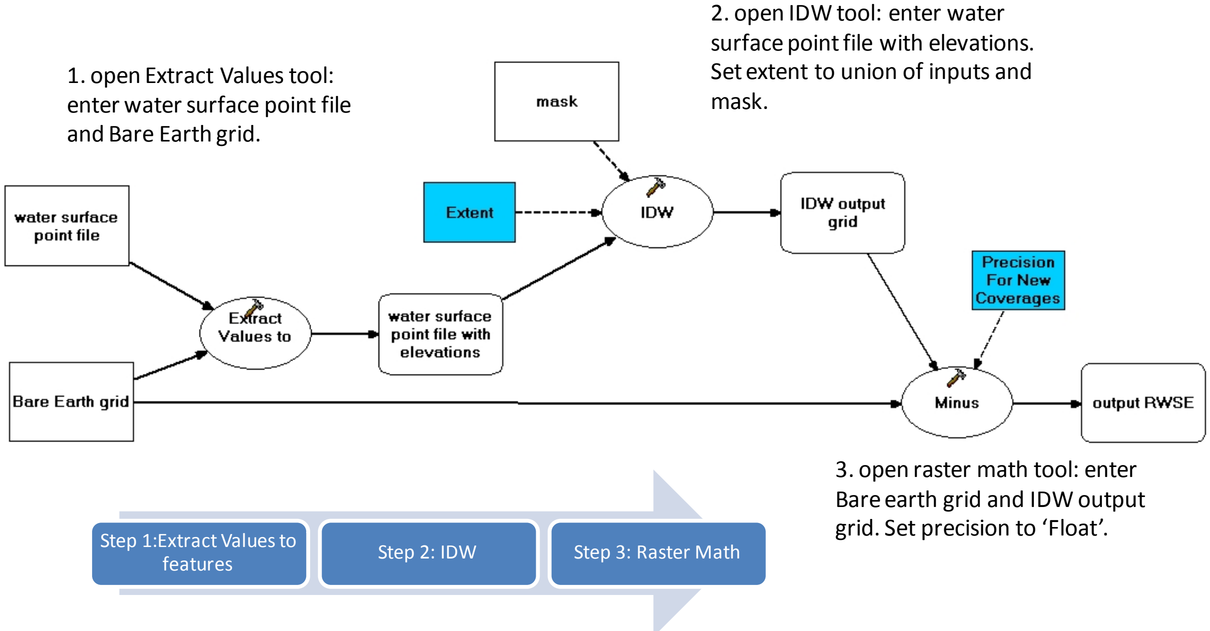
Relative Water Surface Elevation Model (RWSE)

Diagram showing the RWSE model for use in ArcGIS model builder

Relative Water Surface Elevation Model Diagram

Three layers are required:

1. **point file of water surface locations**
2. **Bare Earth grid**
3. **mask to limit interpolation**



Method 1: Relative Surface Model: Tin Interpolation (GeoEngineers)

This is a step-by-step explanation GIS practitioners can use to derive a relative water surface elevation model from LiDAR bare earth DEM. This explanation is geared toward river systems and generating water surface models.

Definition: A relative surface model is a way by which a user-defined surface can be shown graphically across varying terrain. For example, an inundation map can be created showing which areas on a floodplain (variable surface) are below the flood stage elevation (user-defined surface).

Theory

The basic theory behind relative surface models is simple. First, a base-surface must be available for the project area. The base surface is most commonly derived from LiDAR. Secondly, a user-defined surface is created. This user-defined surface is commonly a water surface depicting a flood stage, or base flow in a perched river system. The two surfaces are subtracted from one another creating a new "relative" surface with the value "zero" equal to the user-defined surface elevation. As a result, it is easy for the user to graphically display those areas above the user-defined surface (positive numbers) in one color gradation and those areas below (negative numbers) in a different color gradation. This can be used to show flood inundation areas, perched floodplains, cut and fill areas in a grade plan, or any other comparison between two surfaces.

Where the theory becomes more complex is during the user-defined surface creation. It is not practical to manually populate an entire grid with specified elevations. Also, in the case of water surfaces, the user-defined surface should be relatively flat. A series of 3-D cross sections is the best approximation method from which the user-defined surface can be created in a river system. In the simplest scenario, the river would run perfectly straight, parallel to the valley it occupies. As a result, all cross sections would be perpendicular to both the river and the valley, and the user-defined surface would be relatively flat across the entire floodplain. Because rivers have meanders and often do not flow either straight or parallel to the valley, a compromise must be made. The compromise is that cross sections should be drawn both perpendicular to the valley and perpendicular to the channel. To do this, the cross sections often end up with kinks or bends in them. The fewer the kinks the better, but drawing a cross section that is perpendicular to the channel and perpendicular to the valley is key. Depending on the water surface being modeled, the cross sections should be drawn roughly perpendicular to the dominant flow vector. Sometimes the high flow vectors are much more uniform in their direction than are the low flow vectors. As a result, fewer kinks should be required to model a high flow given this scenario.

The goal is to create a user-defined surface that accurately portrays the predicted water surface across the entire floodplain from a series of cross sections. To achieve this, once the cross sections are drawn, each cross section line must be populated with an elevation equal to the elevation of the water surface at that location. Then all of the cross sections are combined into a surface (Tin then converted to a Grid). When the created surface is subtracted from the base surface, the difference represents the value above or below the calculated surface.

Warning This method does <u>not</u> produce a true inundation area; it simply illustrates the areas above or below the specified surface throughout the modeled extent. It is up to the user to determine if the results of the surface model accurately reflect inundation potential.

Methods

- Create cross sections spanning the entire valley as would be done in HEC-RAS, or use the HEC-GeoRAS cross sections.
- Add a field to the cross sections called "Elev"
    - Use the field "Double" to ensure enough decimal places.
- Close the cross sections and remove them from the MXD.
- Navigate to where the cross sections shapefile is saved using file explorer (not Arc Catalog), and open the cross section *.dbf file with Excel.
- Populate the "Elev" column with the desired elevations. The "Elev" field can be populated with water surface elevations copied-and-pasted from HEC-RAS (since the

cross sections correspond with those in HEC-RAS) or otherwise defined as required by the user. If not using HEC-RAS, the user-defined elevation will typically equal the water surface elevation at the point where the cross section intersects the river in the LiDAR.

  - Format the cells in this column as "Number" with up to 10 decimal places.

- Add the cross section shapefile to the MXD again.
- Using 3D Analyst, convert features to 3D
  - Select the cross section shapefile
  - Select "Elev" as the input feature attribute
- Using 3D Analyst, Create a Tin from features
  - Click in the box for the 3D cross sections
    - Set the height source = "Elev"
  - Click in the box for a Bounding Polygon (if you have created one)
    - Set the height source = "none"
    - Select "Hard Clip"
- Using 3D Analyst, convert Tin to Raster
  - Set the cell size equal to the cell size of the base raster (LiDAR).
- Using Spatial Analyst – Raster Calculator
  - Expand the calculator to view all options by clicking the right-facing double arrow button.
  - Click "Float" under Arithmetic to calculate using floating values.
  - Within the parentheses of the "Float" command, subtract the new surface grid from the base (LiDAR) grid. The algorithm should look like this:
    - Float([LiDAR]-[newGrid])
  - If the calculation isn't working properly try:
    - Close everything.
    - Reboot the computer,
    - Save the LiDAR and new Grid in their own file on the C:/ drive
    - Make sure there are no spaces or long names in the path to the chosen directory on the C:/ drive
    - Open a new MXD with only the LiDAR and new Grid
    - Turn off all other programs
    - Try the calculation again.

- Change the symbology as necessary to display the new Relative Surface Model as desired.
- Double check the results to see if there are any abnormal surface features (holes or peaks).
- Right click on the calculation in the Table of Contents and select "Make Permanent"
- Save the Relative Surface Model in the project folder.
- Create a README text file in the same folder explaining the values used to create the Relative Surface Model and anything else that should be documented with regard to the creation and use of the Relative Surface Model. Be sure to include the full path of the Relative Surface Model in the README text so the two can be reunited if separated.

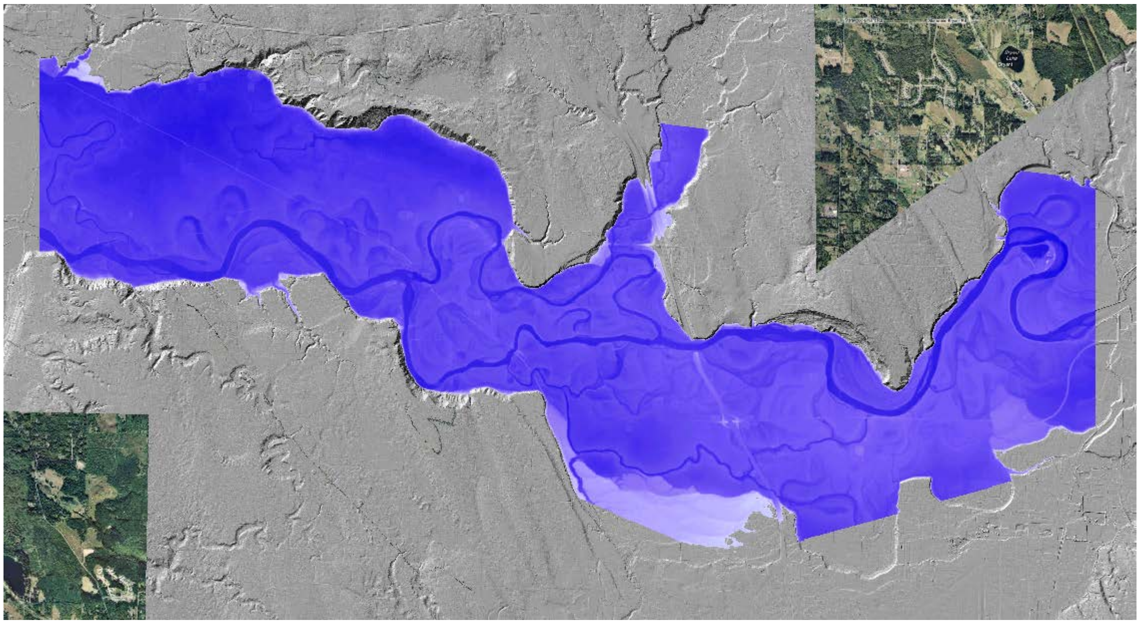
Method 2: Relative Water Surface Elevation (RWSE)

TIN Interpolation Methodology

Jerry Franklin, Ecology

This method uses user-defined cross sections containing bare earth LiDAR elevations at the water surface. Cross sections are used to create a water surface TIN. The TIN is then converted to a water surface raster and subtracted from the bare earth LiDAR DEM to produce a relative water surface with values ranging from the maximum water depths, to zero at the water surface, and up to the maximum topographic heights of the input data sets.
Data processing is organized in the following steps:

Prepare Elevation datasets
Create Cross Sections
Add elevation data
Create Water Surface TIN & Rasters
Calculate final Relative Water Surface Elevation Grid (RWSE)



Elevation dataset preparation

- Mosaic 'Bare Earth' LiDAR tiles if necessary to create one continuous surface for analysis

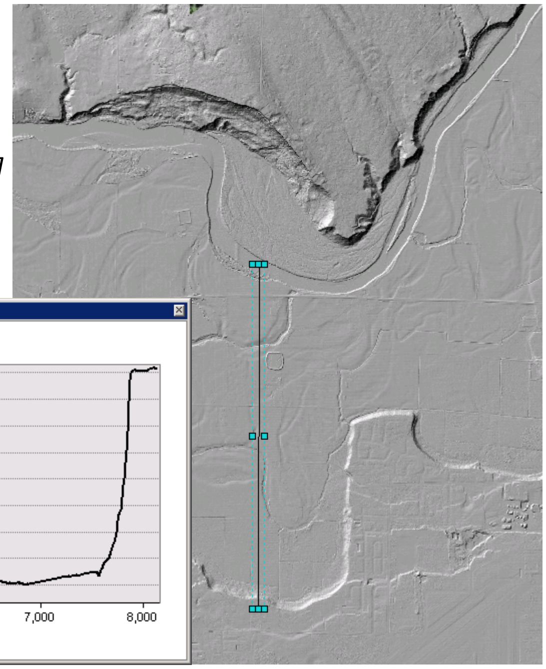
  ArcToolbox *[data management tool|raster|mosaic to new raster]*

  [set cell size to 6' (equal to LiDAR)]
- Create shaded relief

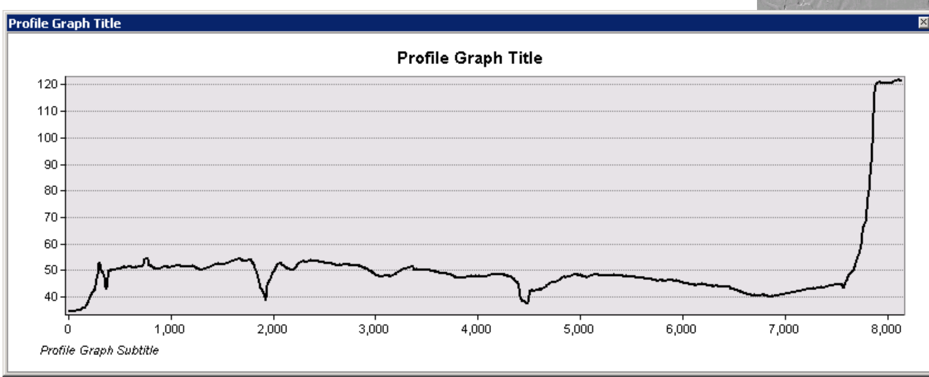
  Spatial Analyst [surface analysis|hillshade]

  [set cell size to 6' (equal to LiDAR)]

  [name file and specify output location]



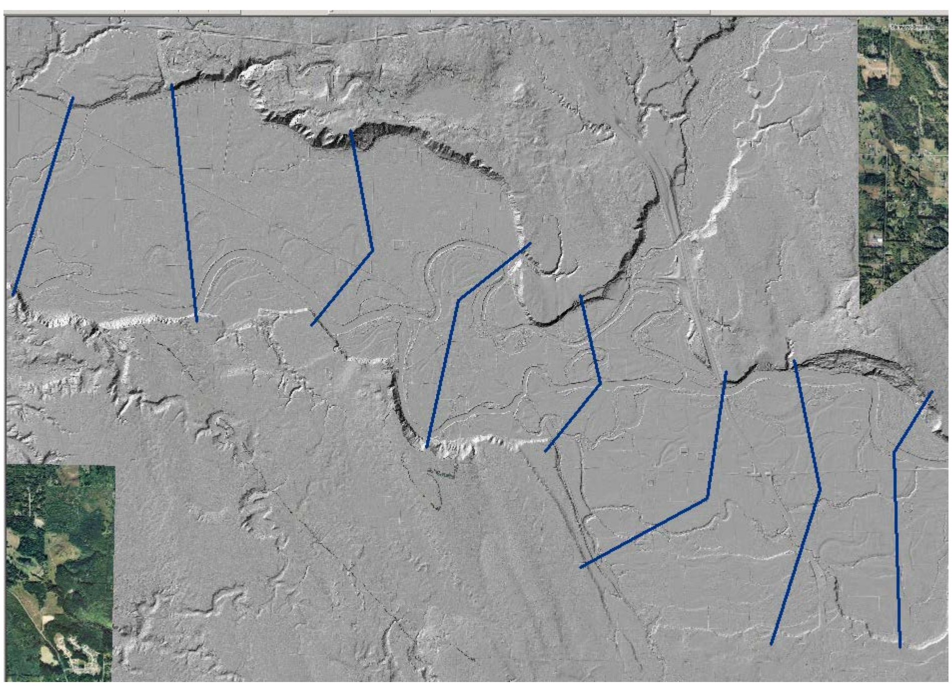
Use 3D Analyst to determine cross section extent



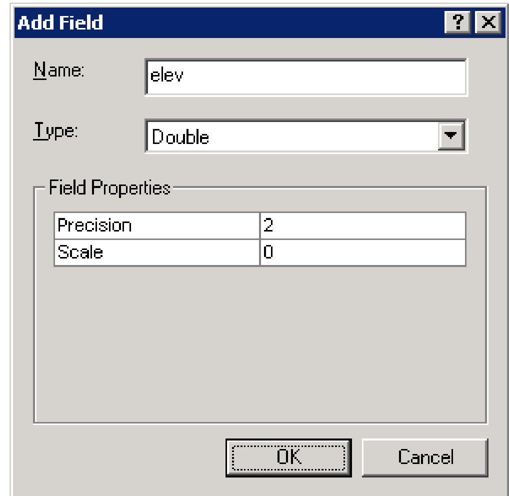
Cross Sections

- Create cross sections of the valley floor perpendicular to the mainstem

  Use [*New line graphic tool]*



- Use Xtools Pro to Convert Graphics to Shapes
  Select all graphic lines
  [xtools pro|feature conversions|convert graphics to shapes]
  Name shapefile "xsections"

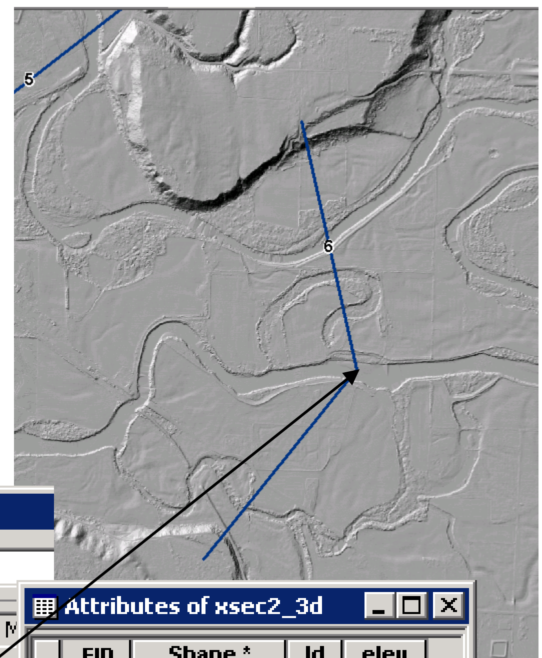


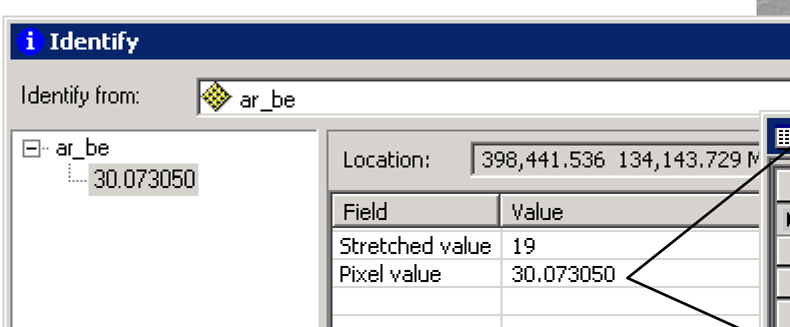
Calculate elevation values

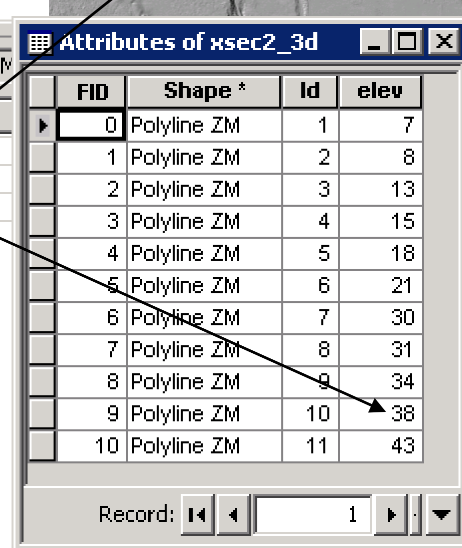
- Add elevation to attribute table
  Open cross section attribute table
  [OPTIONS| addfield| Name: 'elev'|Type:Double]

- Edit attribute table to add elevations from LiDAR shade relief
  [Editor|start editing]
  Label the cross section shapefile to see ID's
  Open cross section attribute table and move aside to view the LiDAR shaded relief

- Extract Bare Earth DEM' elevation values
  Using the shaded relief as a guide, use the
  Identity Tool to Identify from the
  'Bare Earth DEM' elevation pixel values
  where the cross sections intersect with the mainstem.
  [It is important to extract water surface elevations from the Bare Earth DEM]
  Manually enter pixel values into attribute table
  by selecting the 'elev' cell of the corresponding
  polyline and typing in the pixel value



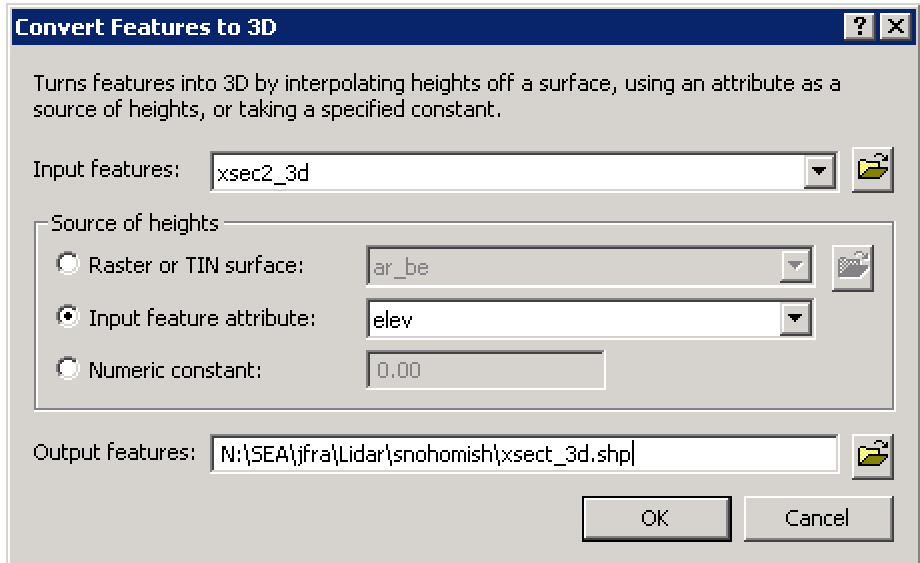




- When done entering all elevation values
  [Editor|stop editing|save edits]

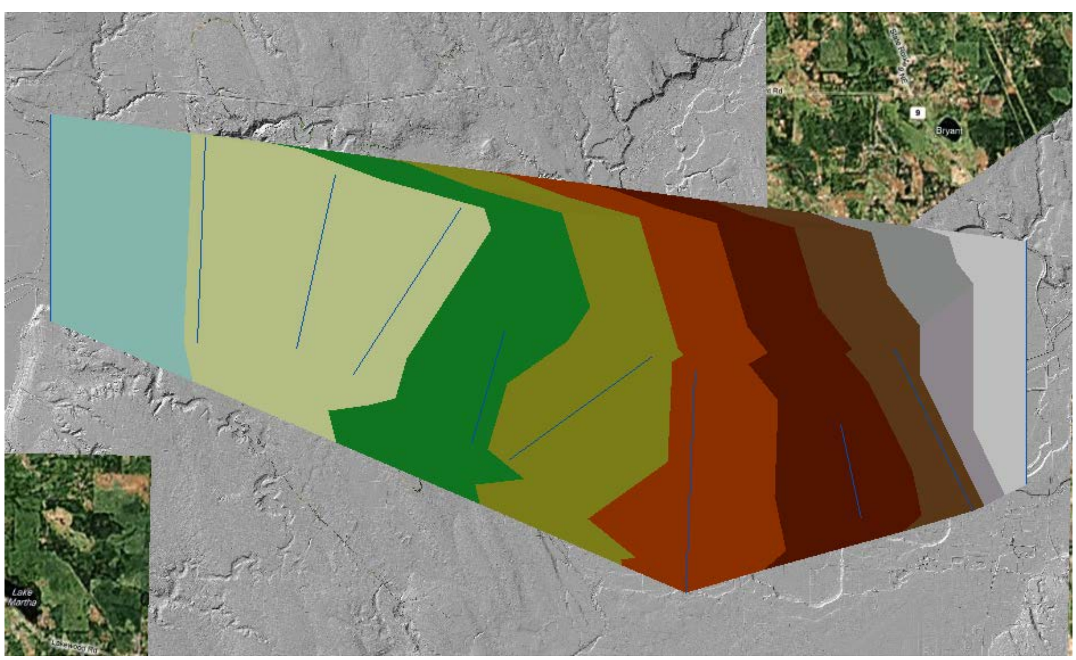
- Convert Features to 3D for use in creating Relative Water Surface Raster TIN

3D Analyst: [Convert Features to 3D]
Input features = xsect.shp
Source of heights
Input feature attribute: 'elev'
Output 3D xsection shapefile



Create Rasters

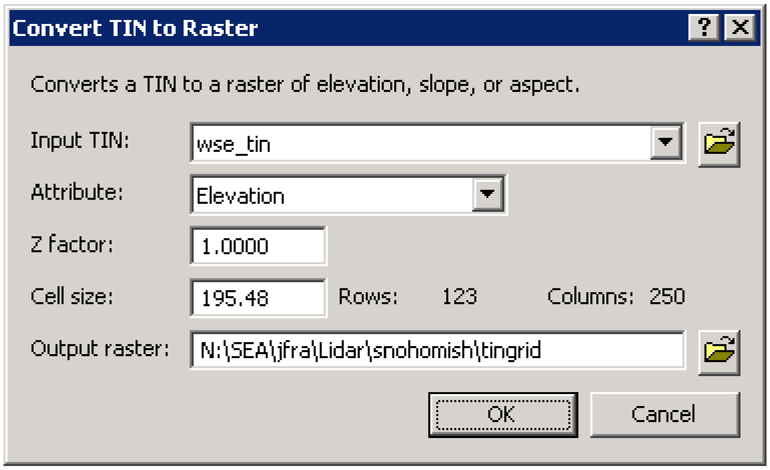
- Create a Raster Tin from 3D cross sections
  [3D Analyst: Create/Modify Tin| Create TIN from features]
  input layer= 3D xsection shapefile
    height source = 'Elev'
    triangulate as = 'hardline'
    output TIN

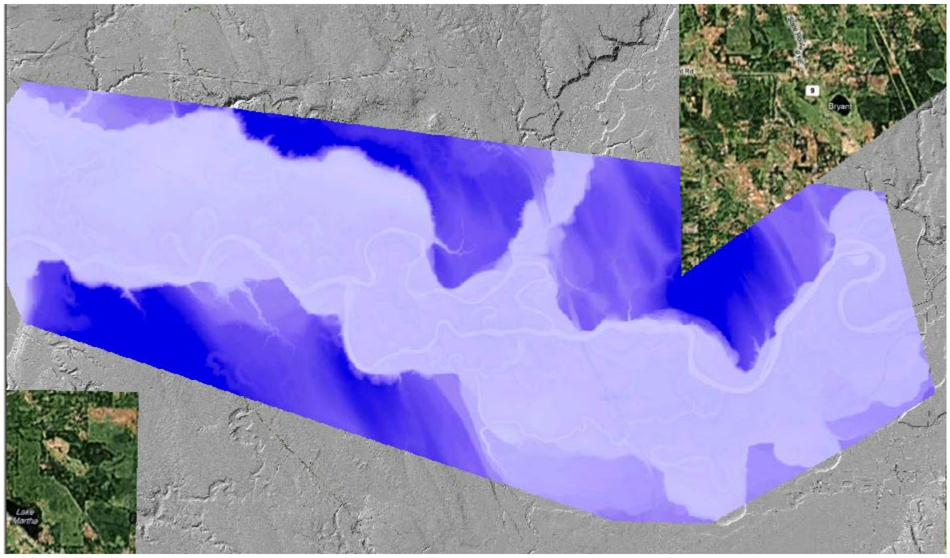


The resulting TIN should appear similar to the image above

- Create Raster Grid from the 3D TIN to subtract the RWSE grid from the Bare Earth elevation grid.

  [3D Analyst| convert Tin to Raster]
  Input TIN = wse_tin
  Attribute = Elevation
  Z factor = 1.000
  Cell size = 6 (Bare Earth grid cell size)
  Output RWSE Raster





Open the resulting grid properties and change the symbology to stretched and a color ramp of blue. The grid should appear similar to the image above.

Create final Relative Water Surface Elevation Grid (RWSE)

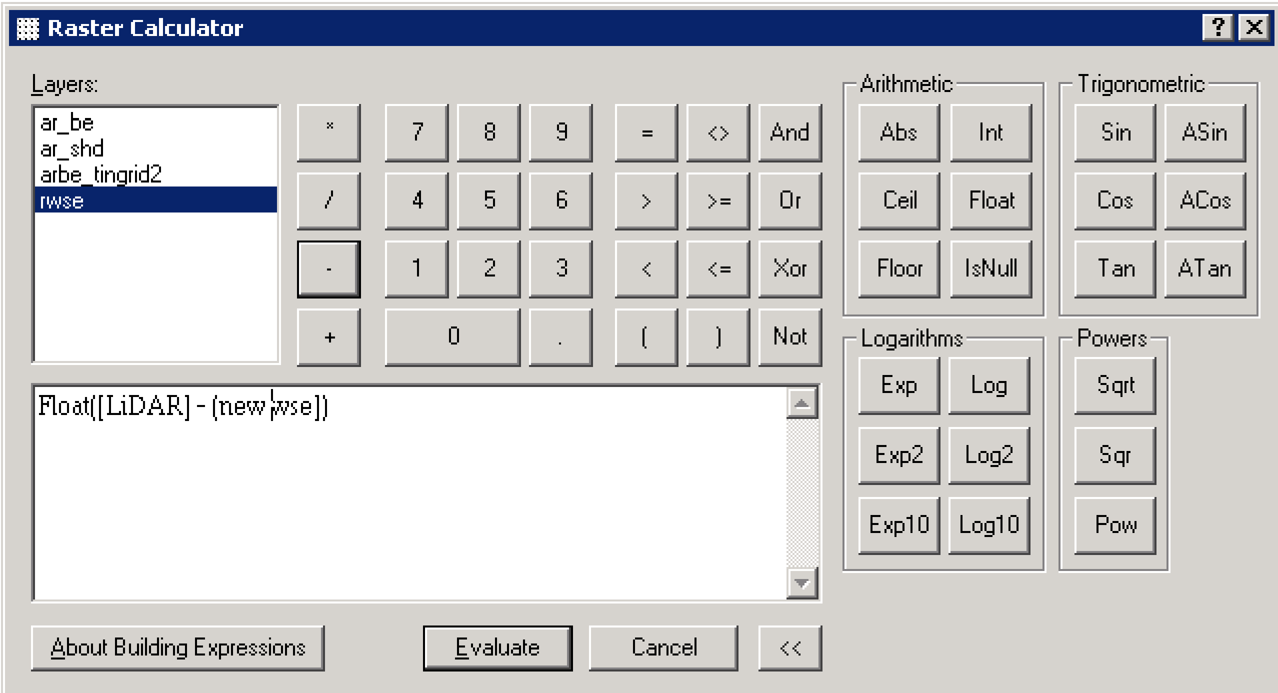
Each cell of the RWSE grid should contain values of zero at the water surface taken from the Bare Earth grid and range from the greatest elevation difference above and below the extracted water surface elevation
(e.g. zero at the water surface to six feet of bathymetry below the water and hundreds of feet of topography above the water.)

- Spatial Analyst – Raster Calculator (Subtract Raster_WSE from LiDAR)
  Expand the calculator
  [Choose the 'Float' Arithmetic function]
  [Choose the Bare Earth grid first, subtraction, then choose the new wse grid]

[Evaluate]

The calculation should look as follows: Float([LiDAR]-[new wse])

- **Save new Relative Water Surface Elevation grid**



Or, because there is always more than one way...

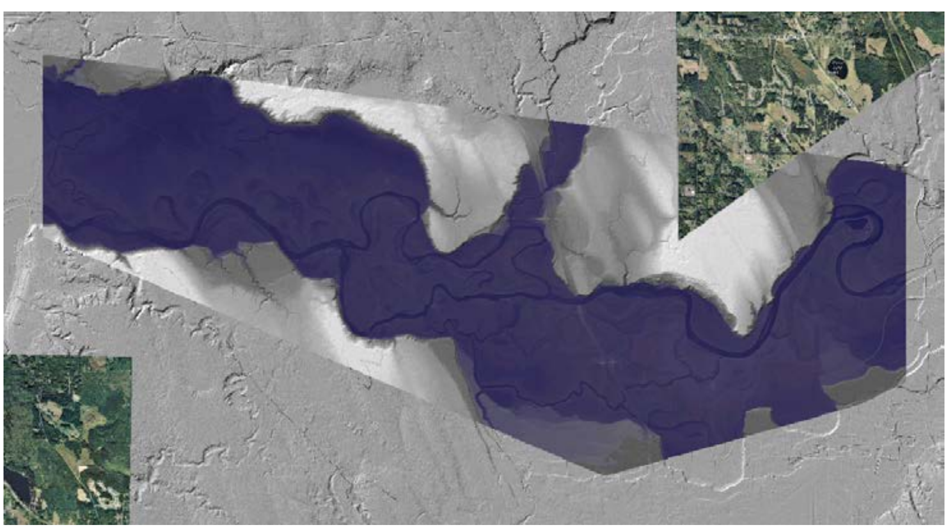
Arc Toolbox

3D Analyst Tools|Raster Math|MINUS

Choose Bare Earth and raster input 1|Choose new WSE grid as raster input 2

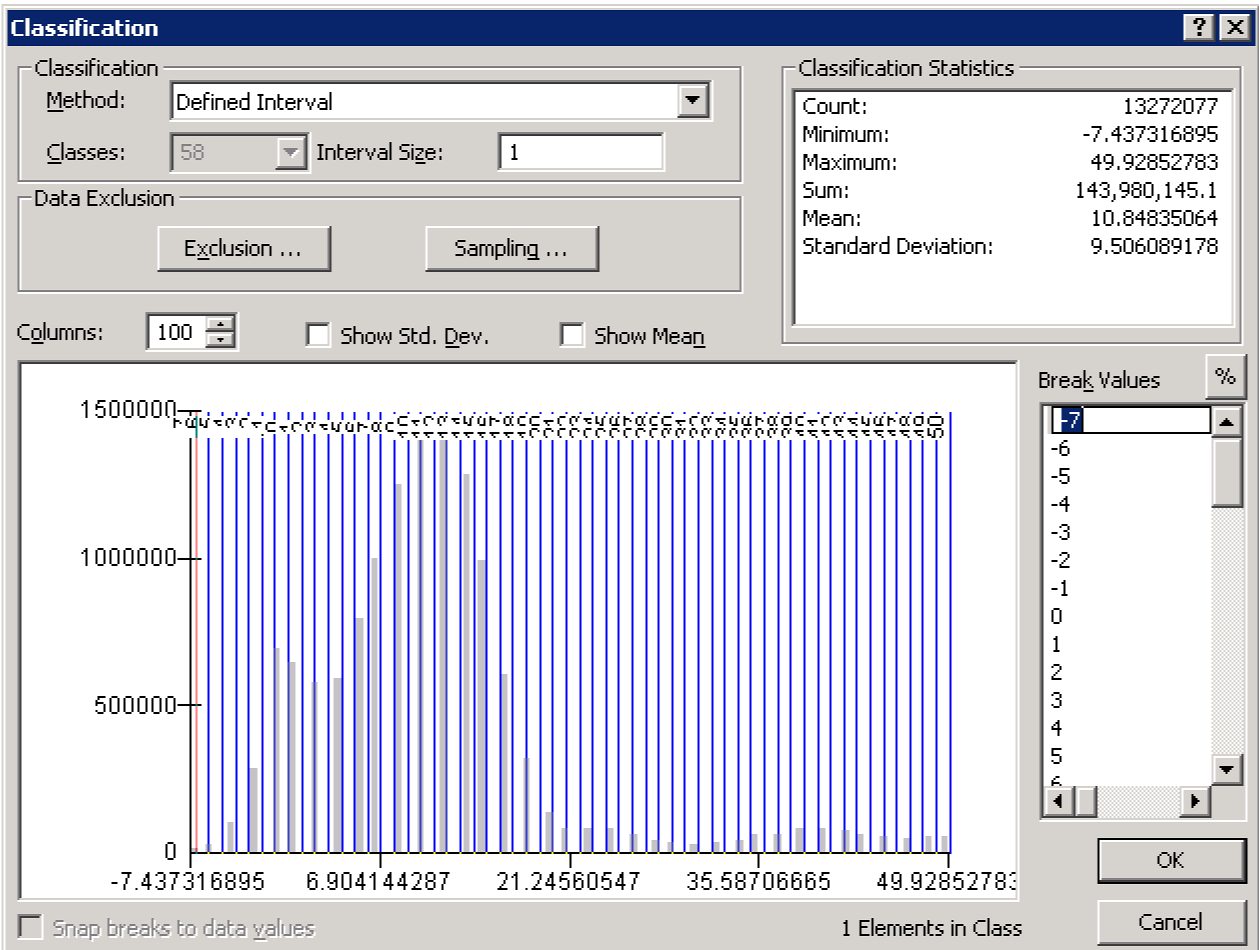
Out put new RWSE grid

The grid should appear similar to the image above.

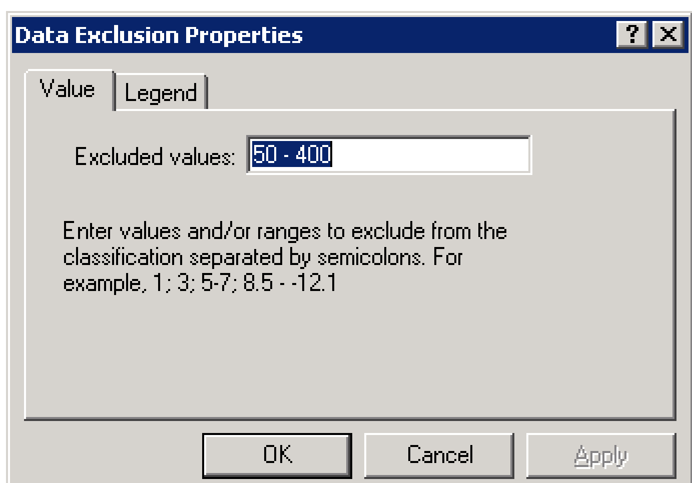


Classify and Ramp Symbology

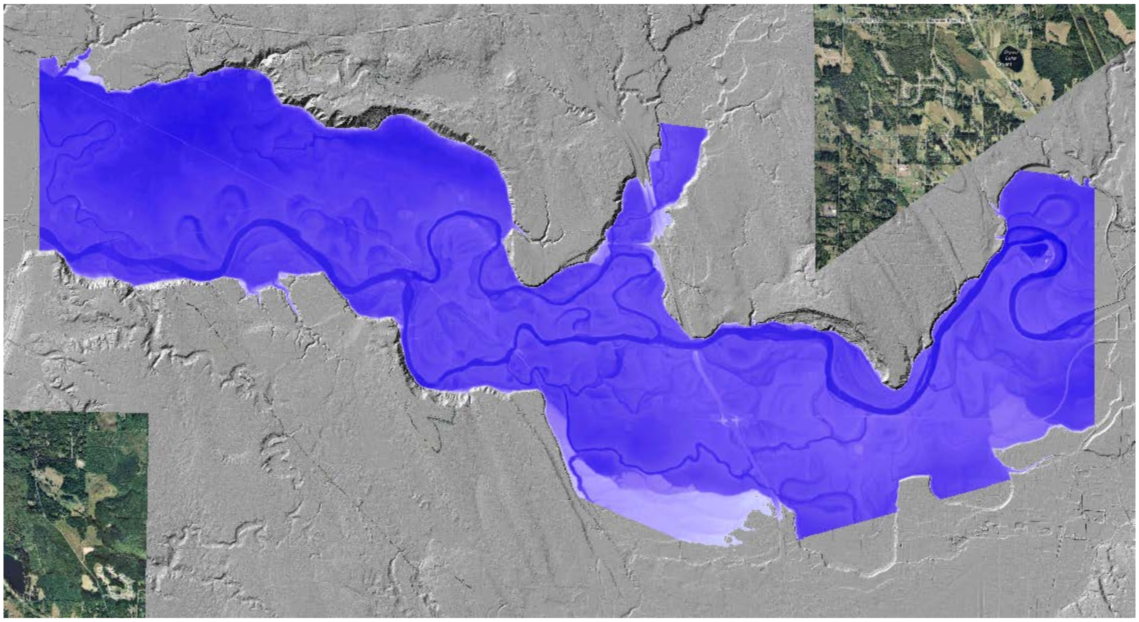
Open the RWSE grid properties|symbology|Show as Classified|Choose classification method as 'defined interval'



Choose 'exclusion' to minimize the relative elevations to the floodplain
Exclude values above the desired range of elevations relative to channel migration.

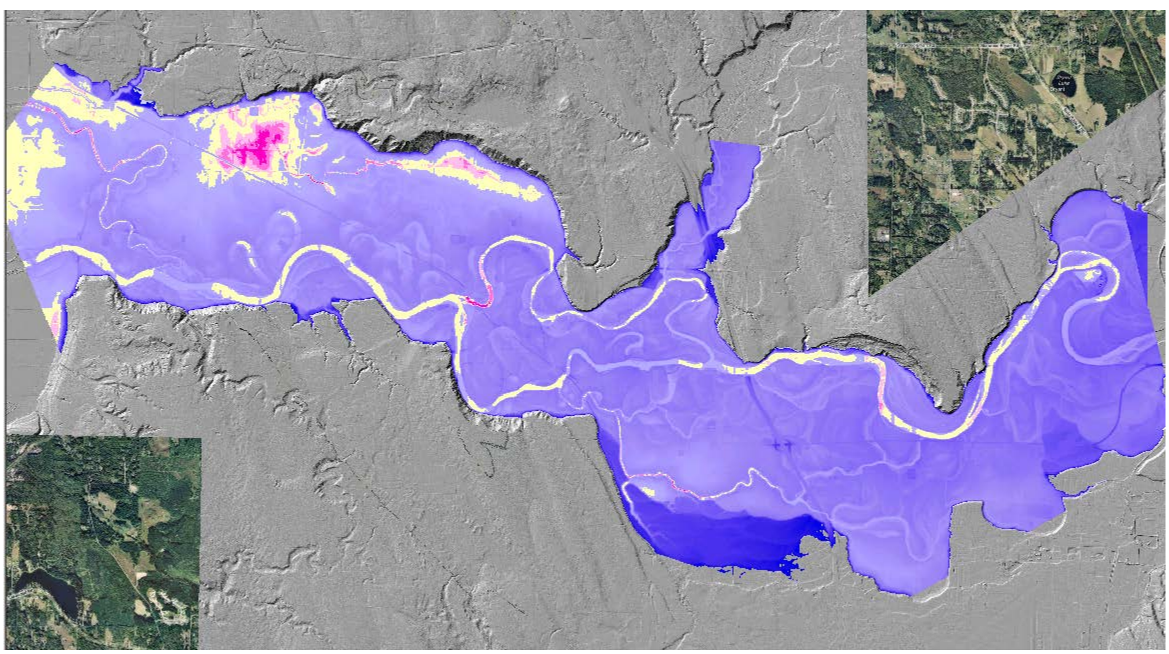


Color ramp light blue to dark blue
The grid should appear similar to the image on the next page.



Explore the grid for accuracy.

For example, change the color of zero (theoretically the water surface) to bright yellow to see if the Relative Water Surface Elevation grid values reflect the true water surface.



Method 3: Relative Water Surface Elevation (RWSE)

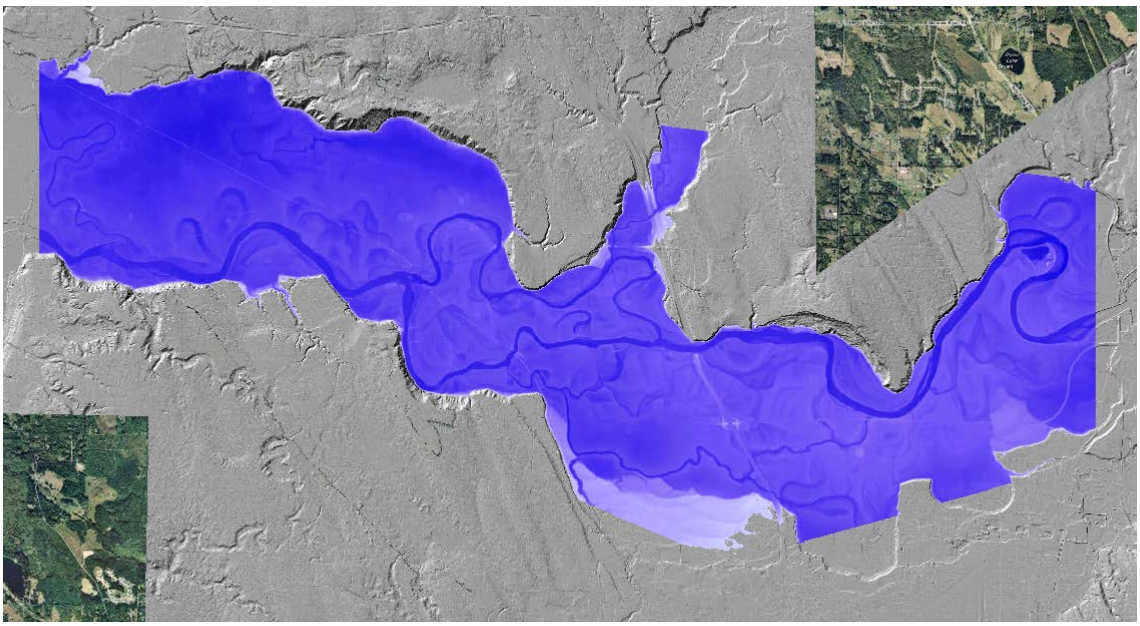
IDW Interpolation Methodology

Jerry Franklin, Ecology

This method uses user-defined points containing bare earth LiDAR elevations at the water surface. Points are used to create a water surface raster and subtracted from the bare earth LiDAR DEM to produce a relative water surface with values ranging from the maximum water depths, to zero at the water surface, and up to the maximum topographic heights of the input data sets.

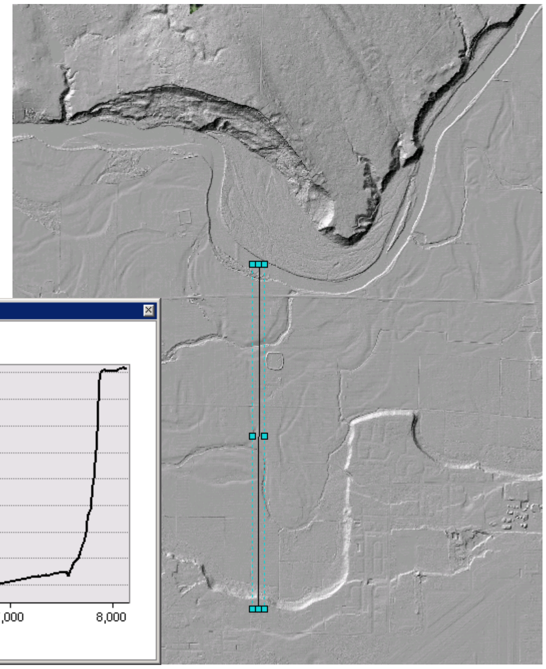
Data processing is organized in the following steps:

- Prepare Elevation datasets
- Create Points
- Add elevation data
- Create IDW Raster
- Calculate final Relative Water Surface Elevation Grid (RWSE)

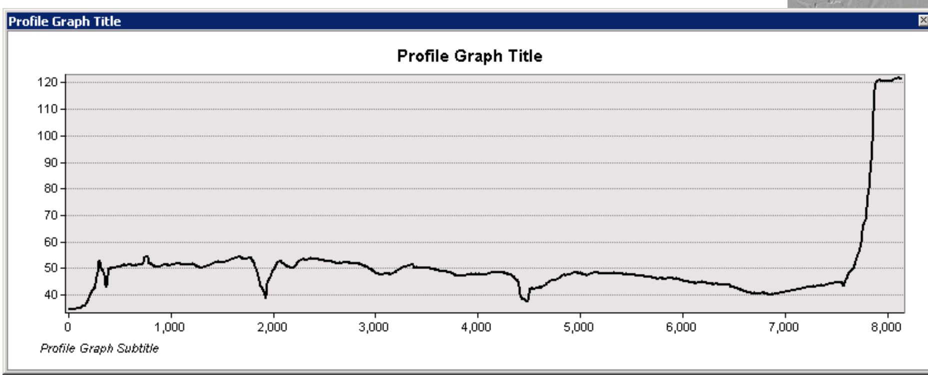


Elevation dataset preparation

- Mosaic 'Bare Earth' LiDAR tiles if necessary to create one continuous surface for analysis
  ArcToolbox *[data management tool|raster|mosaic to new raster]*
  [set cell size to 6' (equal to LiDAR)]
- Create shaded relief
  Spatial Analyst [surface analysis|hillshade]
  [set cell size to 6' (equal to LiDAR)]
  [name file and specify output location]

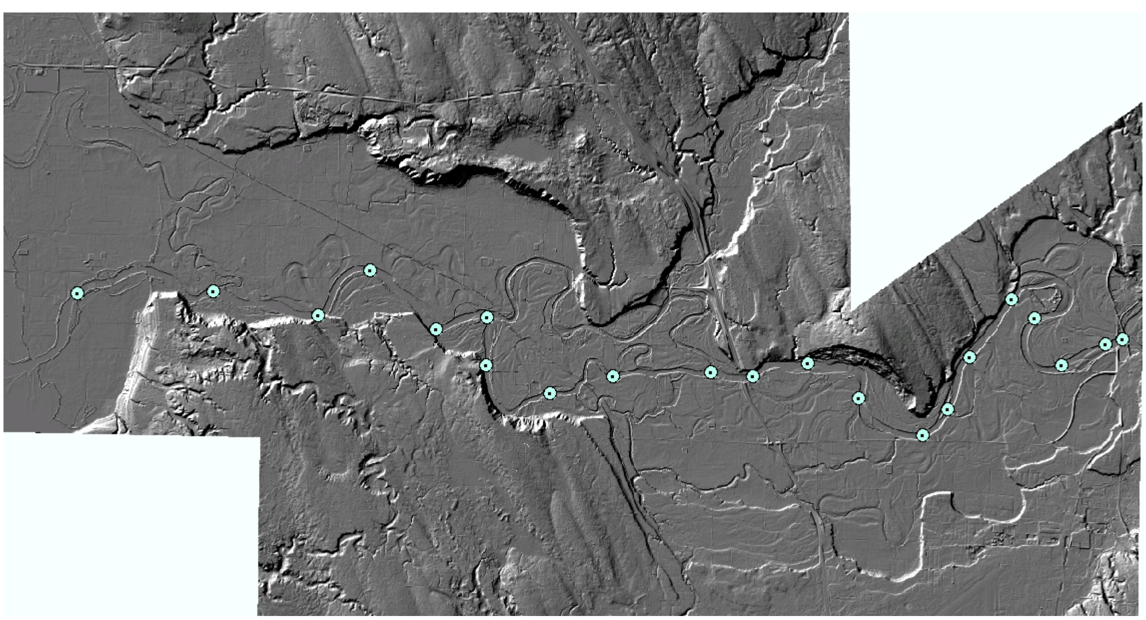


Use 3D Analyst to determine cross section extent



Elevation Points

- Create points along the mainstem watersurface
  Use [*New point graphic tool]*



Use Xtools Pro to Convert Graphics to Shapes

Select all points

[xtools pro|feature conversions|convert graphics to shapes]

Name shapefile "wse_pnts"

Calculate elevation values

- Add elevation to attribute table

  ArcToolbox [Spatial Analyst Tools|Extraction|Extract Values to points]

  Input Point Feature = wse_pnts

  Input Raster = Bare Earth LiDAR

  Output shapefile = wse_pnt_el

The resulting table should contain elevation values at the intersection of the point file and raster dataset.

This function will add an attribute to the output point file "rastervalu'

Add a new field called 'elev' and calc 'elev' = 'rastervalu'

- Add elevation attribute to table

  Open point attribute table

  [OPTIONS| addfield| Name: 'elev'|Type:Double]

  [right click on the title 'rastervalu'|Options :delete field]

Create Raster using IDW Interpolation function

ArcToolbox

[Spatial Analyst Tool|Interpolation|IDW]

input point featurer= 3D pointfile

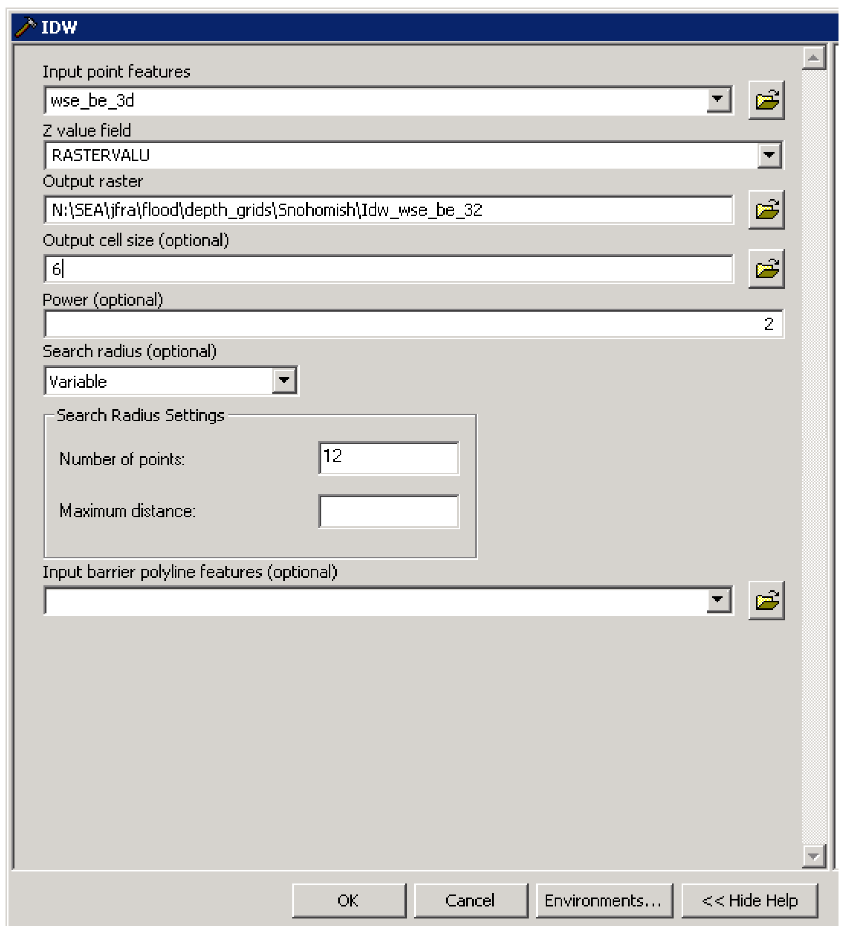
Z value = 'Elev'

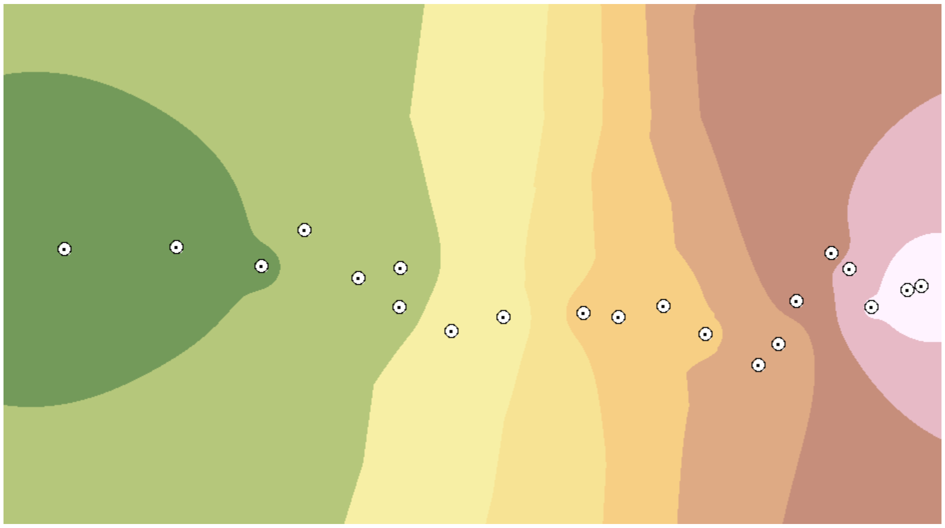
Output Cell size = 6

Choose Environments at the bottom of the box

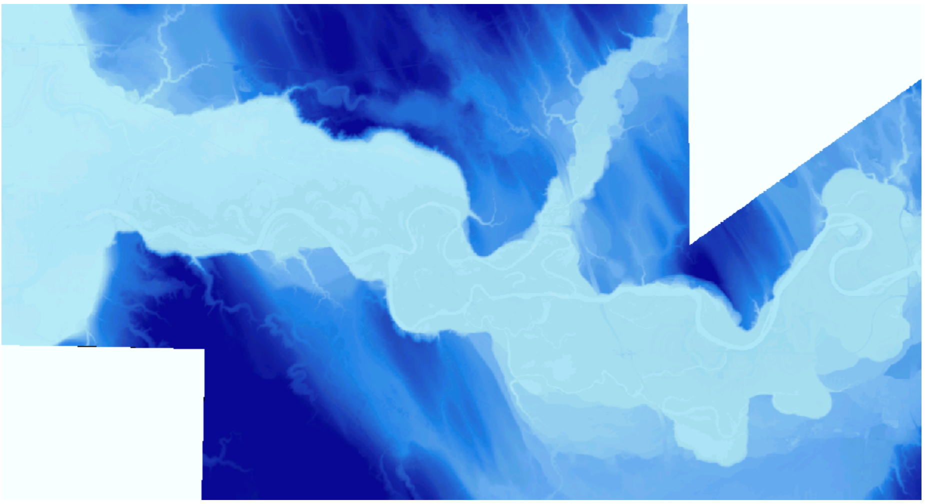
Choose General Settings

Extent = same as bare earth LiDAR extent





The grid should appear similar to the image above.
Export the resulting 'calculation' file as a grid; cell size = 6



Open the resulting grid properties and change the symbology to stretched and a color ramp of blue.
The grid should appear similar to the image above.

Create final Relative Water Surface Elevation Grid (RWSE)

Each cell of the RWSE grid should contain values of zero at the water surface taken from the Bare Earth grid and range from the greatest elevation difference above and below the extracted water surface elevation
(e.g. zero at the water surface to six feet of bathymetry below the water and hundreds of feet of topography above the water.)

- Spatial Analyst – Raster Calculator (Subtract Raster_WSE from LiDAR)
  Expand the calculator

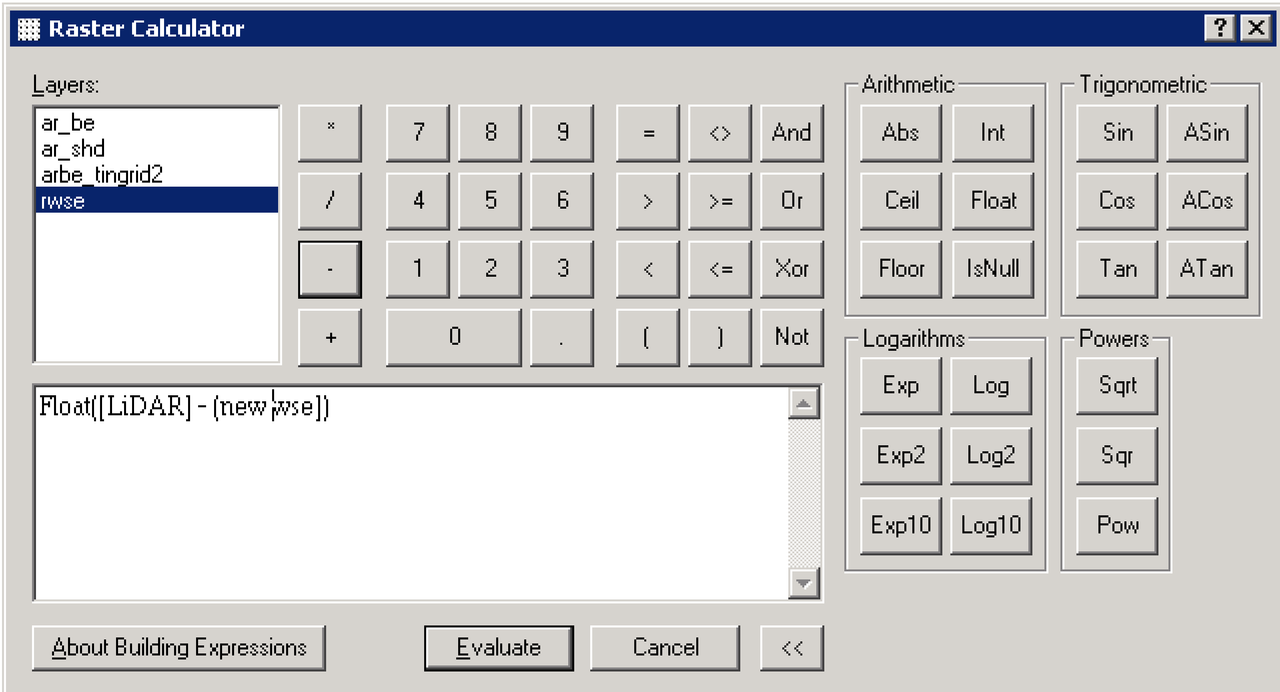
[Choose the 'Float' Arithmetic function]

[Choose the Bare Earth grid first, subtraction, then choose the new wse grid]

[Evaluate]

The calculation should look as follows: Float([LiDAR]-[new wse])

- **Save new Relative Water Surface Elevation grid**



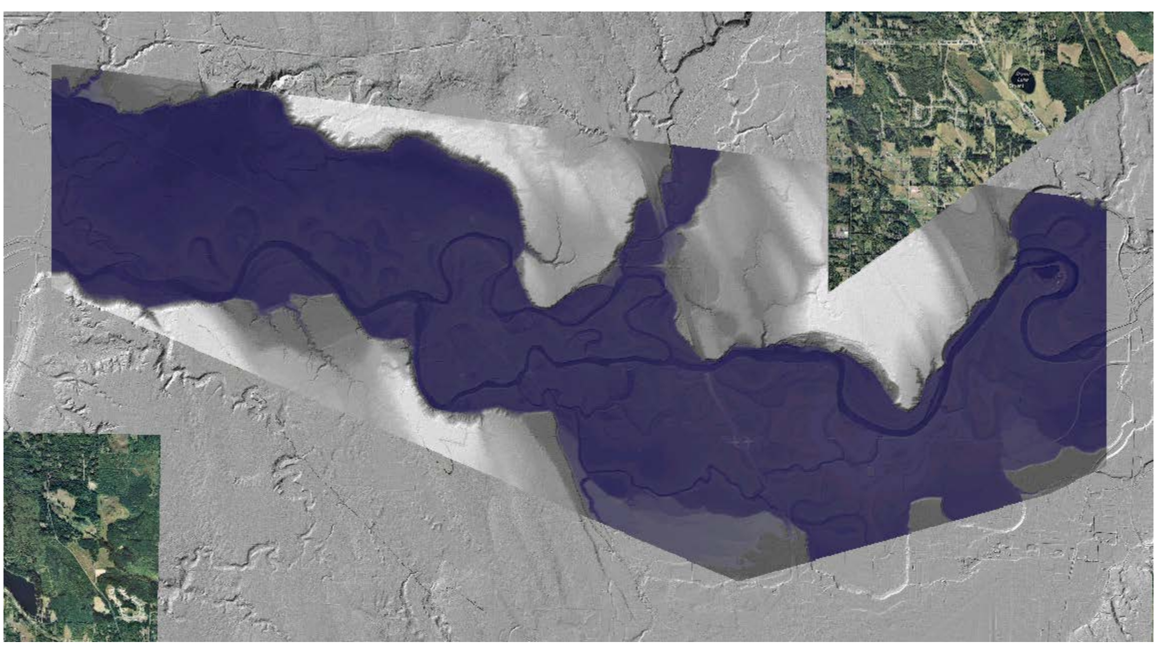
Or, because there is always more than one way...

Arc Toolbox

3D Analyst Tools|Raster Math|MINUS

Choose Bare Earth and raster input 1|Choose new WSE grid as raster input 2

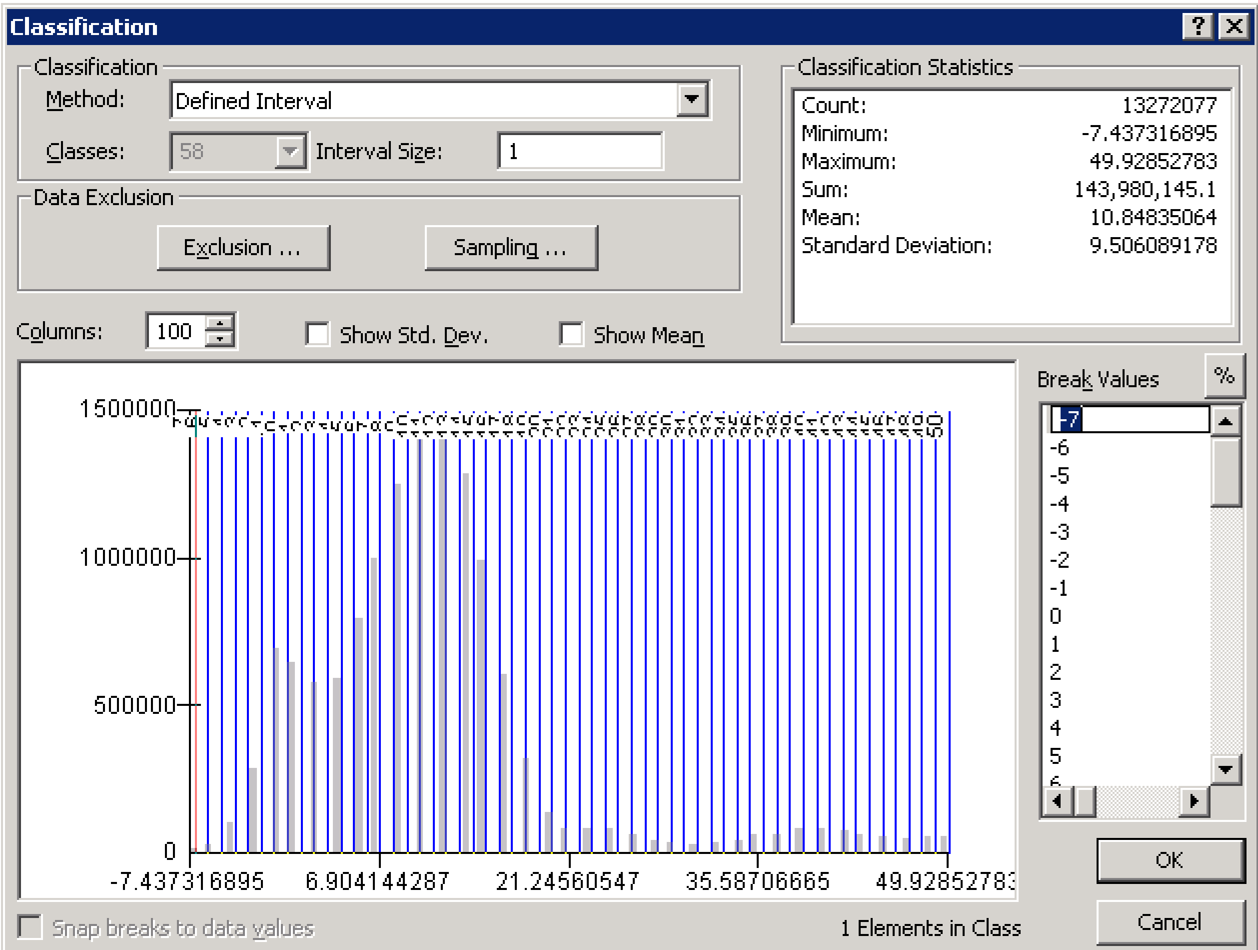
Out put new RWSE grid



The grid should appear similar to the image above.

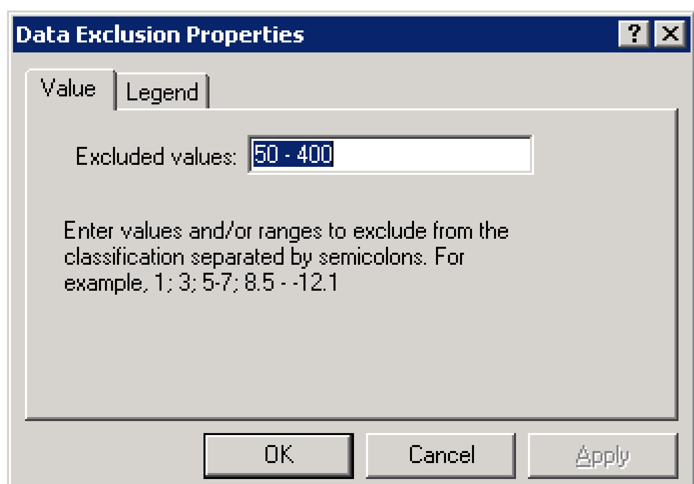
Classify and Ramp Symbology

Open the RWSE grid properties|symbology|Show as Classified|Choose classification method as ‘defined interval’



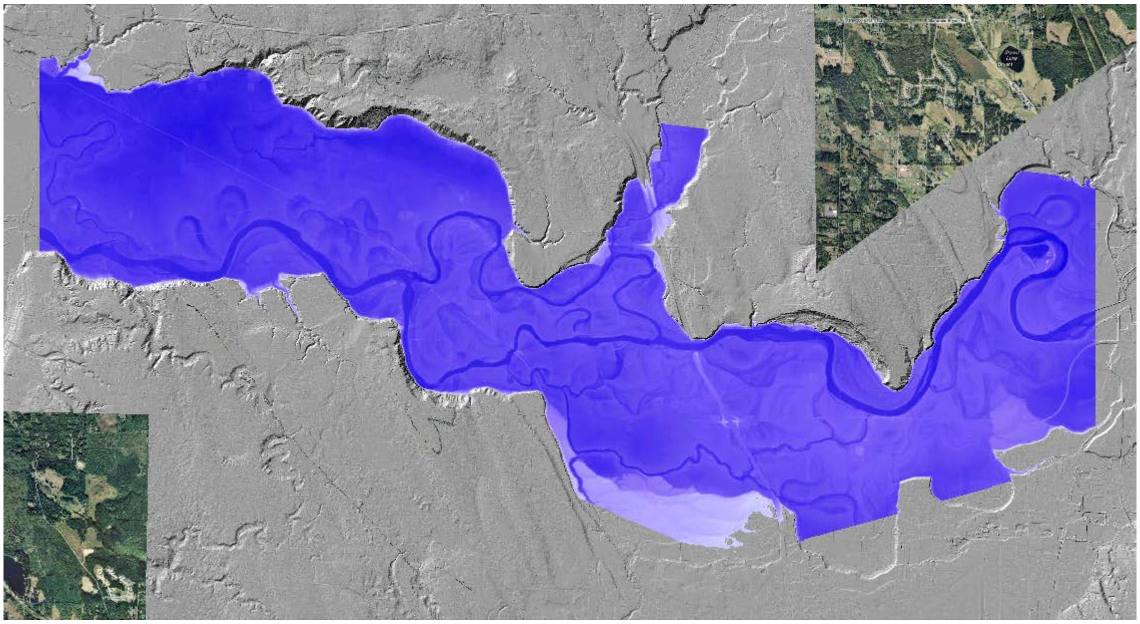
Choose ‘exclusion’ to minimize the relative elevations to the floodplain

Exclude values above the desired range of elevations relative to channel migration.



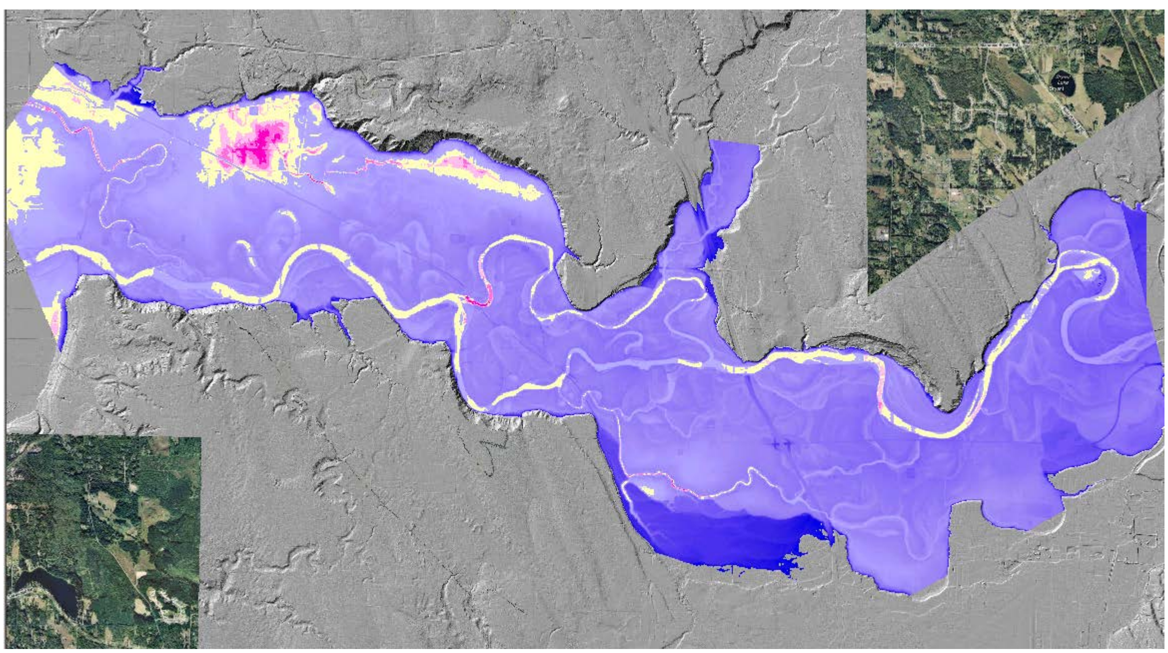
Color ramp light blue to dark blue

The grid should appear similar to the image below.



Explore the grid for accuracy.

For example, change the color of zero (theoretically the water surface) to bright yellow to see if the Relative Water Surface Elevation grid values reflect the true water surface.



Appendix C. Data Organization Forms

Form 1: Microsoft Access database form used to summarize data for channel migration mapping

CMZ Geomorphic Assessment

Reach ID		Date	
Stream Name		Assessed By	
Stream Number		Checked By	
County			

Data Inventory

Topography Data	
Orthophotographs	
Additional Data	

Alluvial Landform

Geology Units and Erodibility		Underfit Stream	☐
		Alluvial Fans	☐
		Eroding Valley Margin	☐
		Terraces	☐
Soil Units and Texture		Landslides	☐
		Sediment Input Changes	☐
		Discharge Changes	☐
		Channel Widening	☐
Other Basin Characterisitics		Channel Movement	☐
		Tidal Influence	☐

Hydrological Analysis Needed ☐ Note: If checked, fill out CMZ Basin Hydrology Form

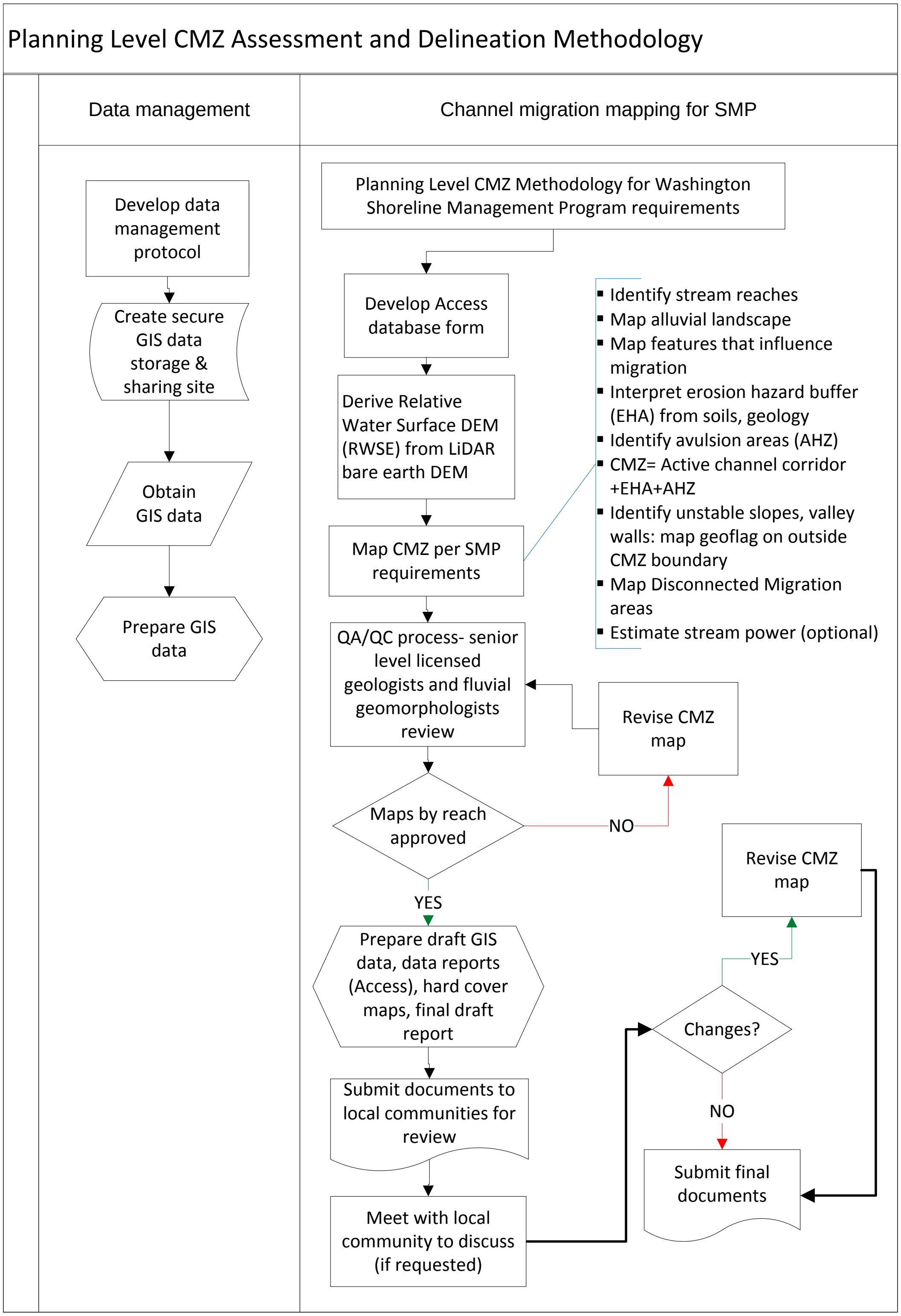
Reach ID | | Stream Name | | County |
|---|---|---|---|---|---|

Basin Hydrology

Basin Drainage Area (sq mi)	
Relief (ft)	
Average Slope	
Area with Slope Over 30 % (sq mi)	
Area of Forest Canopy (sq mi)	
Mean Annual Precipitation (in/yr)	
Peak Flow--2 yr (cfs)	
Peak Flow--10 yr (cfs)	
Peak Flow--25 yr (cfs)	
Peak Flow--50 yr (cfs)	
Peak Flow--100yr (cfs)	

Appendix D. Planning level channel migration delineation methodology

Flow Chart: SMP Planning Level CMZ Assessment Methodology



Definitions: Planning Level Methodology

Methodology example is from Clallam County CMZ Report, however, terminology and methodology description is consistent across all reports. Only descriptions and illustration specific to streams in each local government jurisdiction vary.

Table 4.1: Terms used in this report and similar terms used in Rapp and Abbe (2003).

Term used in this report	**Definition**	**Similar term used in Rapp and Abbe (2003)**
Active channel corridor	The active channel corridor, as defined for this method, generally corresponds to the meander bel of the active channel (unvegetated area) and has a width approximating the meander amplitude of the analysis reach (See Figure 4.4)	Historical Migration Zone (HMZ)
Avulsion Hazard Areas	The area in the floodplain at risk of avulsion	Avulsion Hazard Zone (AHZ)
Erosion Hazard Buffer	The area added to the active channel corridor as a basis for the CMZ. It is based on ½ to 1 width of the active channel corridor and adjusted based on loca conditions including geology, soils, geomorphology, vegetation, etc. See Figure 4.4 for an illustration.	Erosion Hazard Area (EHA)
Disconnected Channel Migration Zone (DCMZ)	The area located in CMZ where publicly maintaine man-made structures restrict channel migration. The specifics are outlined in WAC 173-26-221(3)(b).	Disconnected migration area (DMA)
General Channel Migration Zone (CMZ)	The result of the streamlined process described in Chapter 5- includes the erosion hazard buffer and the avulsion hazard buffer. Based on the SMP definition: Channel migration zone (CMZ)" means the area along a river within which the channel(s) can be reasonably predicted to migrate over time as a result of natural and normally occurring hydrological and related processes when considered with the characteristics of the river and its surroundings. (WAC 173-26-020(6)).	CMZ=HMZ+AHZ+ EHA-DMA

Geotechnical setback buffer	Channel and terrace banks at risk of mass wasting due to erosion of the toe were assigned a geotechnical setback buffer. For this study, geotechnical buffers were applied to the channel migration zone delineation where there was an elevation difference of 25 feet between the water surface as designated in the RWSE and the elevation of the delineation. Geotechnical buffers indicate where additional geotechnical review should be conducted in the field to determine the width of the geotechnical buffer.	Geotechnical Setback (GS)
Alluvial Fan	A low, outspread mass of loose materials (sand, cobbles, boulders), with variable slope, shaped like an open fan or a segment of a cone, deposited by a stream at the place where it issues from a narrow mountain or upland valley; or where a tributary stream is near or at its junction with the main stream. Alluvial fans were delineated from LiDAR and DEM maps for this project (See Section 4.4 (6) below).	Not part of Rapp and Abbe (2003)
Potential Inundation Zone (PIZ)	Areas of the valley bottom that are at or below the approximate water surface elevation as indicated on the RSWE map. These areas are likely subject to inundation when there is an over-bank flood.	Not part of Rapp and Abbe (2003)

Example: Clallam County

Planning Level Channel Migration Methodology

The planning level channel migration methodology developed for this study is based on analysis of existing GIS data. This methodology differs from more detailed methods such as Rapp and Abbe (2003), which estimates historic channel migration rates, avulsion hazards, erosion hazards, and disconnected CMZ. Rapp and Abbe (2003) or other more specific methods should be used for site-specific investigations to delineate detailed channel migration zones where needed for development or flood hazard reduction. The following outlines the procedure used to delineate the areas that have a high probability for channel migration.

GIS Database Management

GIS-mapping projects were created to develop the channel migration assessment for each stream in the analysis. Data sources included in the review and delineation are described in the section above. Due to the size of the project area and budget limitations, field data were not collected.

GIS shapefiles were created for the channel migration assessment, as well as for supporting features such the stream line with segment breaks and river miles, alluvial fans and features, geomorphic features, and areas that should have a geotechnical assessment where the channel migration assessment intersects a valley wall or terrace (Table 4.4). Each feature is described in more detail in the sections below. The three counties with the most stream miles to assess under the EPA grant were Mason, Skagit, and Clallam Counties.

Table 4.4 GIS files created for the channel migration assessment.

Filename	File Type	Purpose
[County code][1]_streams.shp	polyline	Streamline with segment breaks (this layer was adapted from the layer provided by Ecology with the study stream segments, which was based on the USGS hydrography layer)
[County code]_landforms.shp	polygon	Alluvial valley and alluvial fans
[County code]_features.shp	point	Geomorphic evidence for channel migration
[County code]_ XS.shp	line	Cross-sections from LiDAR
[County code]_CMZ.shp	polygon	Estimated channel migration zone delineation and disconnected channel migration zone protected by certified structure (described in section 5 below)
[County code]_geoflag.shp	line	Potential geotechnical hazard requiring further investigation

[1] The [County code] refers to the county where the assessment is being conducted

Reach Delineation

Streams were subdivided into geomorphic reaches for the channel migration assessment. Each reach was assigned a unique identifier using the format: [County code]_[stream number]_[segment number]. Numbering of geomorphic reaches started at the downstream end and increased in the upstream direction. Criteria considered when delineating reach breaks included:

- Changes in gradient (proportional to sediment transport capacity)
- Changes in valley width
- Tributary inputs (increasing discharge)
- Change in channel type
- Braided channels
- Meandering braided channels
- Anabranching channels
- Single thread straight channel
- Single thread meandering channel
- Changes in infrastructure or channelization
- Changes in geology/erodibility of substrate
- Changes in land use pattern
- Document Reach Characteristics

Physical characteristics of the stream were documented in a data sheet (see completed segment data sheets in Appendix E for each geomorphic reach). The data sheet provides information on the data used to complete the assessment, geomorphic features observed in each reach, stream characteristics, infrastructure, and notes from the analyst and QA/QC review (See Appendix C for Microsoft Access data forms for each segment as an example). The data form provides supporting details for each segment map, and factors considered in the delineation. Some data forms may contain more or less information, depending on the features present, data included on forms for adjacent segments, and professional judgment.

Delineate areas of potential channel migration

The area of potential channel migration was defined for this study as the area with a high probability of channel movement, according to the regulations (WAC 173-26-020(6)). The general channel migration zone includes the active channel corridor, the avulsion hazard areas, and the erosion hazard buffer, which will be explained in detail in this section. Once the general channel migration zone was established, additional features such as potential inundation zones, disconnected channel migration zone, alluvial fans, and the geotechnical buffer were added.

Active Channel Corridor

The active channel corridor, as defined for this method, generally corresponds to the historic extent of the active channel if known from existing data or has a width approximating the meander amplitude of the analysis reach (Figure 4.4). The active channel corridor varies in width depending on the characteristics of the stream channel in a given reach. In some cases, the active channel corridor was difficult to determine and meander amplitudes from other nearby sections of channel were used. For example, in areas where the channel had been modified or straightened, meander amplitudes from nearby reference sections that had not been modified were used instead if the geomorphic characteristics of the reaches were similar.

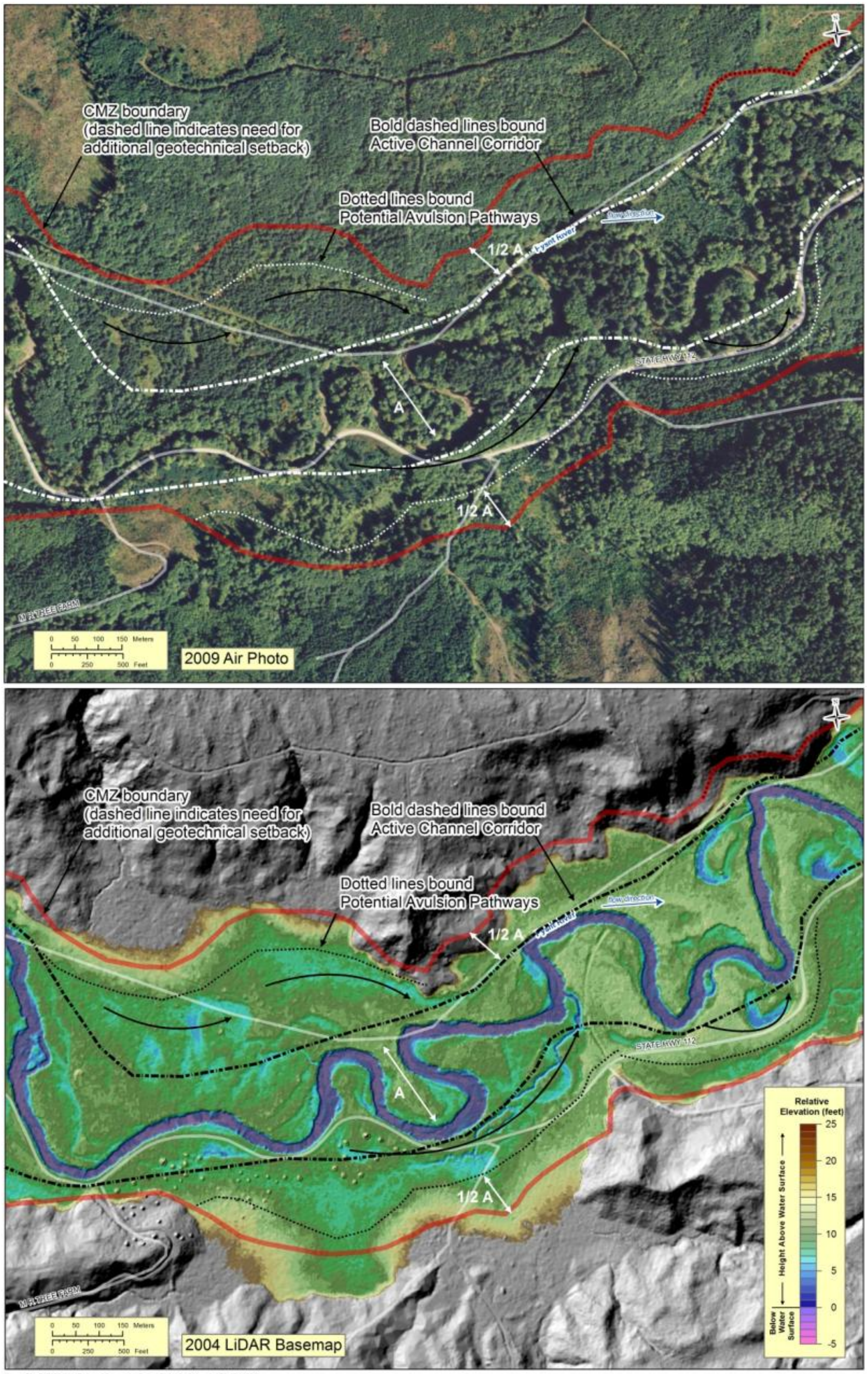


Figure 4.4: Aerial image (above) and RWSE map (below) for Pysht River showing the Active Channel Corridor, potential avulsion pathways, and channel migration buffer.

Avulsion Hazard Areas

Avulsion hazard areas typically occur in side channels or low-lying portions of the floodplain that could be activated if accumulations of wood or sediment were to obstruct and deflect flows laterally, or if flooding were sufficiently intense. Such avulsions are common in streams flowing through forested floodplains around Puget Sound. Accumulations of wood can produce stable structures which alter flow hydraulics and trigger sedimentation on the upstream side (Abbe and Montgomery 1996, 2003, Montgomery and Abbe 2006). Accumulation of sediment in the stream channel (aggradation) increases the potential for channel migration. An example of a recently formed logjam affecting channel migration is shown in Figure 4.5. Rapp and Abbe (2003) discuss the importance of considering vertical channel variability in assessing channel migration and Brummer et al. (2006) recommend that CMZ delineations in forested areas in Washington account for 2 m of vertical variability of the streambed and valley bottom areas within 2 meters (m) of the bankfull elevation are susceptible to channel migration. Potential avulsion pathways and low-lying portions of the floodplain were delineated from the RWSE maps in GIS and included in the channel migration boundary.

Non-meandering streams (defined by a narrow active channel corridor where no bank erosion is apparent) can be subject to avulsions if there is a low lying area adjacent to the stream and the active channel becomes obstructed by a logjam or landslide deposit, or if the stream is subject to an overbank flood event. If the avulsion channel is situated in a similar context as the main channel, such as forested banks, then a similar erosion hazard area was applied. If a non-meandering stream avulses into a more erosive setting such as agricultural fields lacking forested banks, then the avulsion hazard area would need to be substantially larger than the pre-existing active channel corridor. In this case, the avulsion hazard area was extended the width of the disturbed floodplain.

The avulsion hazard area was delineated if one or more of the following criteria were present: low lying ground that is equal to or below the water surface elevation of the current channel as indicated on the RWSE map, the avulsion path would shorten the length of the stream channel, or the stream was located in an erodible substrate. Additional avulsion factors considered included: presence of relict channels, potential for logjams or landslides to elevate water surface elevations upstream of low-lying areas, evidence of aggradation, and upstream or downstream tributaries that could contribute sediment or floodwaters. Potential avulsion pathways and low-lying portions of the floodplain were delineated from the RWSE maps in GIS and included in the channel migration boundary.

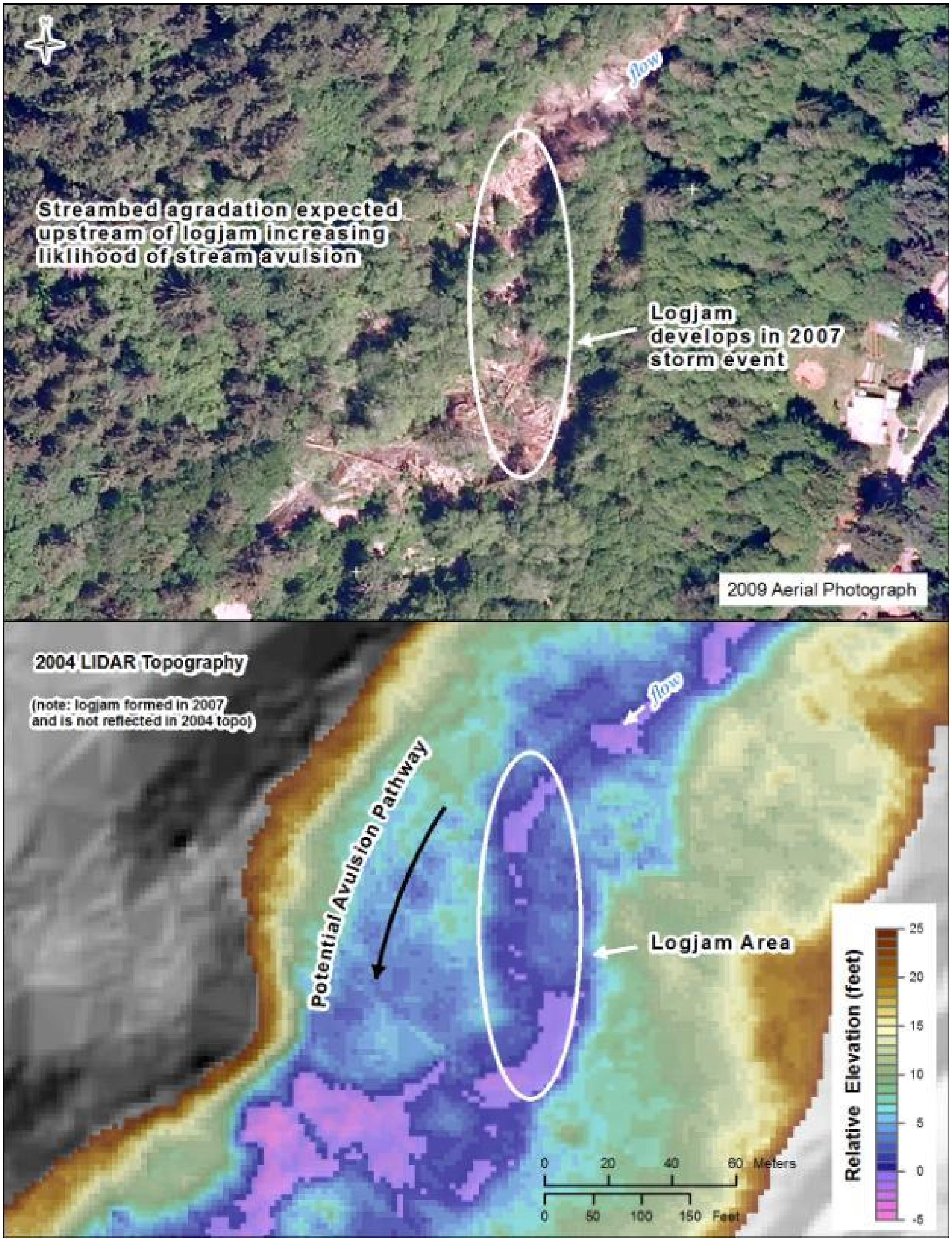


Figure 4.5. Mission Creek near Belfair, Washington provides an example of wood accumulations that trigger channel migration (channel widening and lateral migration). This section of Mission Creek is downstream of the location shown in Figure 1.1, and may contain some of the riparian woody material removed from the streambank at that location.

Erosion Hazard Buffer

An erosion hazard buffer was applied to account for future channel migration beyond the active channel corridor and potential avulsion pathways. The buffer width was based on the meander geometry of the study reach, topography near the stream, and erodibility of earth materials near the stream (the substrate). In low relief areas with highly erodible substrate the buffer was set at 50% to 100% of the meander amplitude. In areas of modest to high relief and in areas with less erodible substrates the erosion buffer was set at 1 channel width to 50% of the meander amplitude. This buffer width was based on historic activity, professional judgment of assessment team, and King County Critical Area Ordinances for channel migration zones (King County 1999, Figure 4.4). The width of the erosion hazard buffer was adjusted based on geomorphic conditions in each reach, including rate of recent channel migration, erodibility of the substrate, floodplain development, stream size and power, location in the valley bottom, and geomorphic setting such as an underfit or actively forming valley (described below).

Physical characteristics of the reach informed the decision where the erosion hazard boundary was located beyond the active channel corridor and avulsion hazard areas. Factors considered in this process included:

- Indicators of past channel migration from aerial imagery,
- Floodplain topography such as side channels and oxbows,
- Erosion potential of bank materials based on soils and geologic data,
- Characteristics of the valley margin such as indicators of previous stream erosion,
- Potential influence of wood accumulations or landslides that obstruct and deflect flows and raise water elevations.

Table 4.5 summarizes the general guidelines used for initial delineation of the erosion hazard buffer, which were then adjusted based on the factors described above. The next sections describe typical geomorphic valley types in Clallam County and how they were delineated.

Table 4.5 Decision guidelines used to identify the erosion hazard buffer and geomorphic features

Feature	Guideline
Erosion hazard buffer base width	In low relief areas with highly erodible substrate, set buffer to 50% to 100% of the meander amplitude (Figure 4.4).
	In areas of modest to high relief and in areas with less erodible substrates, set erosion buffer to one channel width to 50% of the meander amplitude.
Avulsion Hazard Areas	Delineate an avulsion hazard area when one or more of the following criteria are present: low lying ground that is equal to or below the water surface elevation of the current channel as indicated on the RWSE map, the avulsion path would shorten the length of the stream channel, and the stream is located in an erodible substrate. Additional avulsion factors to consider: presence of relict channels, potential for logjams or landslides to elevate water surface elevations upstream of low-lying areas, evidence of aggradation, and upstream or downstream tributaries that could contribute sediment or floodwaters.
Wetlands	With no defined channel- do not include in CMZ
	With defined channel, include in CMZ
Alluvial Fans	If the channel is on an alluvial fan, delineate the entire alluvial fan as a CMZ. If an alluvial fan falls within valley bottom, delineate as separate alluvial fan.
Small streams without poorly defined or visible channel	Confined- delineate valley bottom as CMZ
	Unconfined or underfit- active channel corridor or valley bottom
Valley edges or terraces	If unconsolidated or easily erodible, include valley edge in buffer and include geotechnical buffer
	If resistant to erosion, look for indicators of past erosion (scallops, etc), and place CMZ boundary at extent of past erosion in valley wall and include geotechnical buffer. Indicators of past valley wall erosion include: scallops in valley walls, slumps, landslides, undercutting.
Potential Inundation Zone (PIZ)	Label areas of the valley bottom that are at or below the approximate water surface elevation as indicated on the RSWE map.
Disconnected Channel Migration Area (DCMZ)	Identify infrastructure in the valley bottom that meet the criteria for barriers to channel migration. In Mason county, these include railroads and state highways. Delineate area within the erosion hazard buffer and behind the infrastructure as a DCMZ.
Geotechnical setback buffer	If the regulatory CMZ boundary intersects a terrace or valley wall greater than 25ft above the approximate water surface elevation, add geotechnical buffer flag

Actively Forming Valleys

Many streams evaluated by this study have formed the valley in which they flow by incision into an upland surface composed of unconsolidated sediments. These valleys formed during the Holocene period (following the recession of the Puget Ice lobe approximately 10,000 years ago) and continue to expand as the stream episodically erodes the valley margin. A key indicator that a stream valley is actively forming and expanding the valley is the presence of concentric arcs along the valley margin that have a radius of curvature similar to the meander geometry of the adjacent stream. Figure 4.6 illustrates an example of such erosion in an actively forming valley. The stream is presently flowing directly against the hillslope at a 90 degree bend and has eroded a concentric arc into the valley margin. Topography above the stream channel indicates mass wasting (slumps) are occurring and young vegetation visible in the air photo indicates recent instability. This example provides evidence that the stream has sufficient power to erode material at the valley margin in that section of the river. Note that the valley margin has similar sized arcs in areas up- and downstream where the channel is not flowing against the hillslope. These arcs in the valley margin are evidence that the river migrates across its valley over time and episodically removes sections of the hillslope at the valley margin. Given that such erosion is expected to continue into the future, the channel migration boundary must be set back from the valley margin (into the hillslope) in anticipation of additional valley wall erosion.

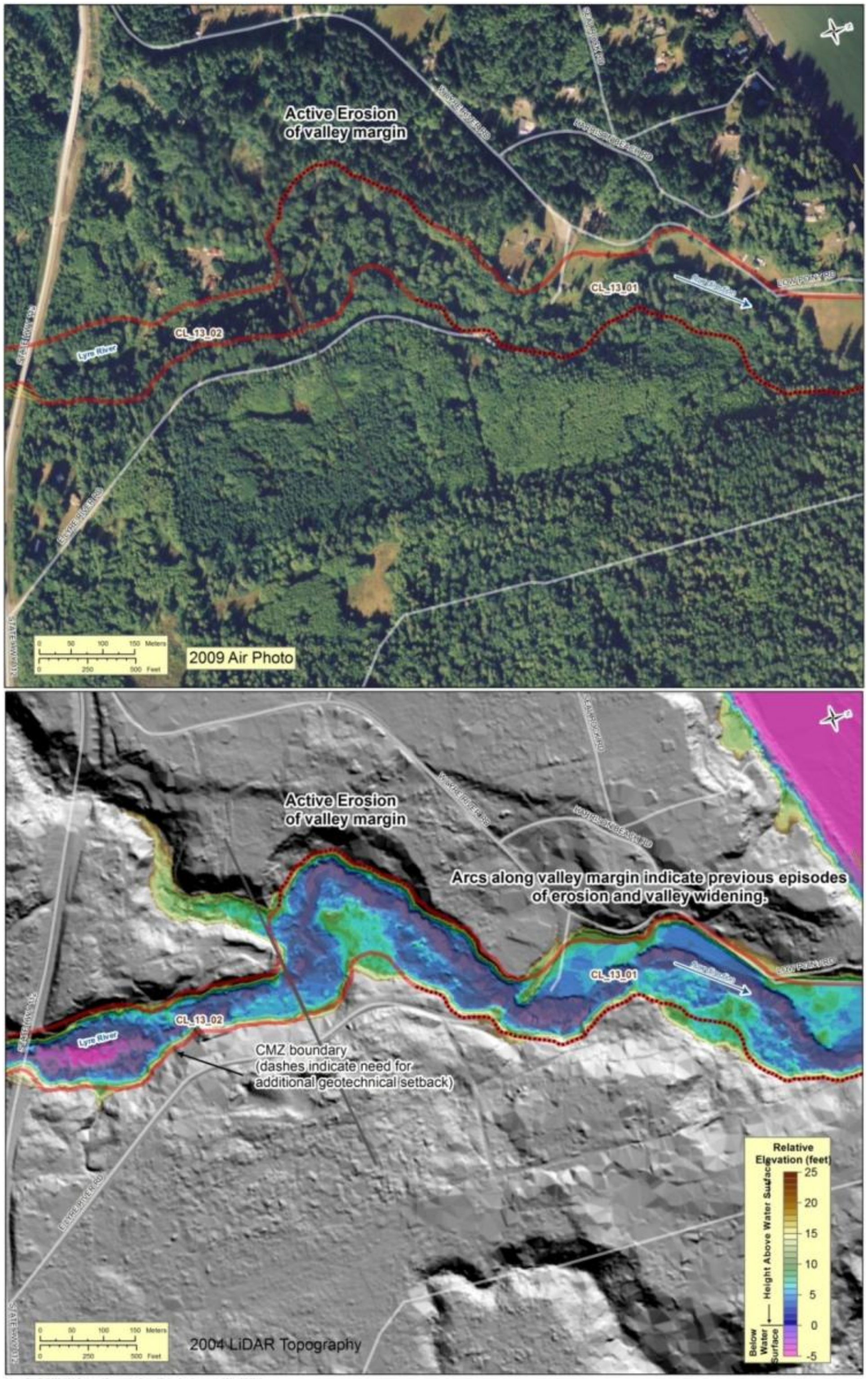


Figure 4.6. Aerial imagery (above) and RWSE map (below) showing a reach on the Lyre River where the stream is actively widening its valley.

Figure 4.7 presents an example of an underfit reach of Sooes River. The lower reaches of Sooes River flow within a valley that was created by a much larger channel that existed during the period of glacial recession. The valley margin has erosional features with a radius of curvature that is much greater than the radius of curvature associated with Sooes River. It is unlikely that the current Sooes River channel migrates across the entire valley in its current regime. As such, the channel migration delineation includes only that portion of the valley within a corridor that encompasses the active channel and an erosion hazard buffer equal to one half of the meander amplitude. The lower gradient of the underfit segment of the channel translates to a lower stream power available to erode the valley margin. Therefore, the channel migration area does not extend into the hillslope, or require an additional geotechnical setback, as indicated for the actively forming valley segment downstream. Clearing vegetation within the floodplain would elevate risk of increasing bank erosion and avulsions, so the assumption is that vegetation will remain intact in low lying areas. In cases such as this highly sinuous reach of Sooes River (Figure 4.7), where the creek has a distinct meander envelope (area defined by outer apexes of meander bends that contains the stream), the channel migration delineation includes only that portion of the valley within a corridor that encompasses the active channel and a migration and erosion hazard buffer equal to one half of the meander amplitude.

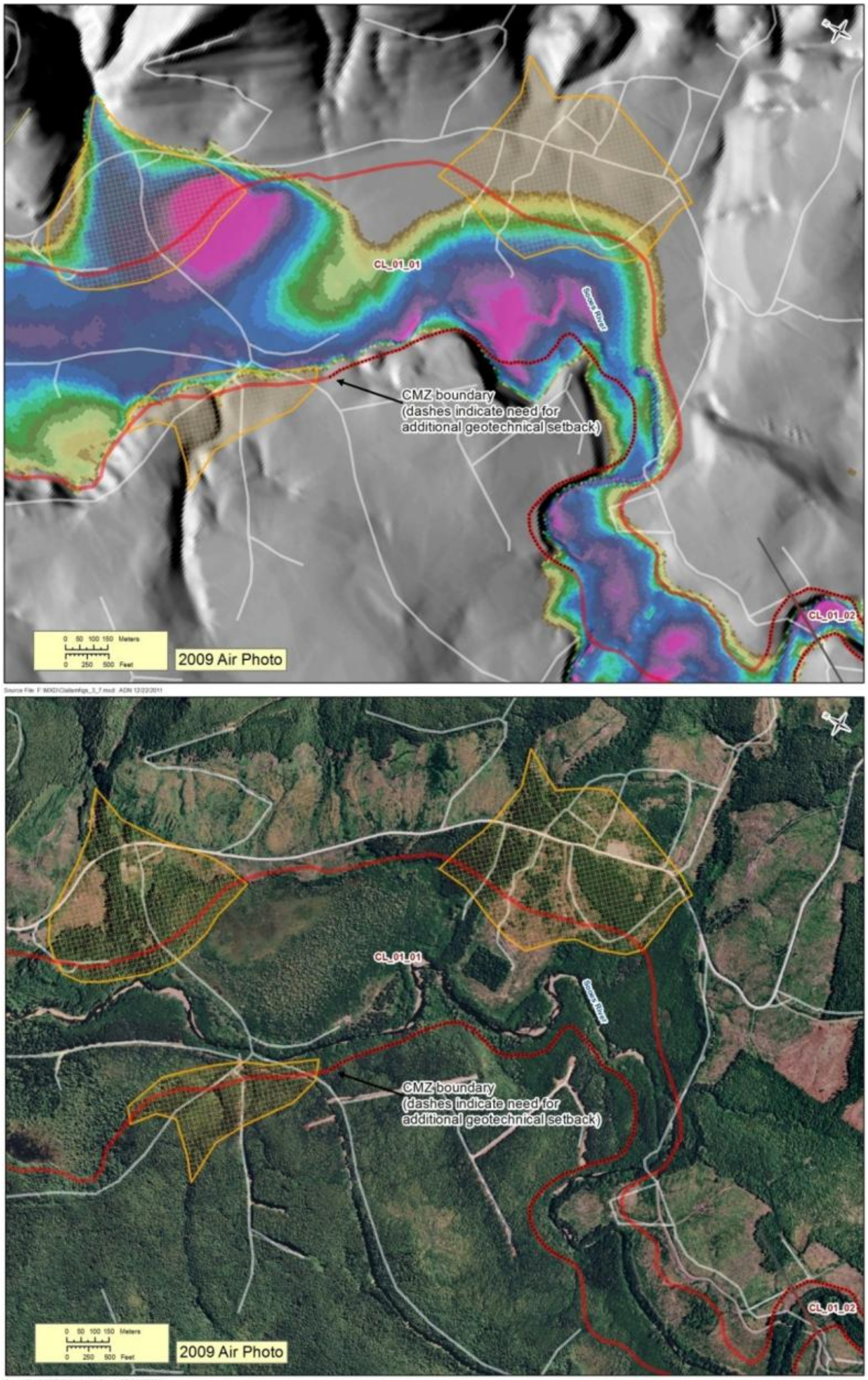


Figure 4.7 DEM hillshade with relative water surface elevation (from 10m USGS DEM) (above) and aerial image (below) for a reach of Sooes River that is considered underfit.

Saltwater Deltas

Figure 4.8 presents an example of a saltwater delta. Many stream segments assessed in Clallam county flow directly into the Strait of Juan de Fuca. The delta environment at the mouth of these streams has a unique set of geomorphic processes operating and, therefore, unique channel migration characteristics. Delta environments are characterized by gradual aggradation of fine sediment. This aggradation causes the stream channel to become elevated above its floodplain and leads to a situation where avulsion is likely. Some erosion of valley walls is possible, but significant erosion is not likely over a 100-500 year time span. The position of the stream mouth is controlled by both fluvial and coastal geomorphic processes. Coastal processes that may influence the position of the streams mouth include movement of longshore bars, beach erosion, and possible future changes in sea level.

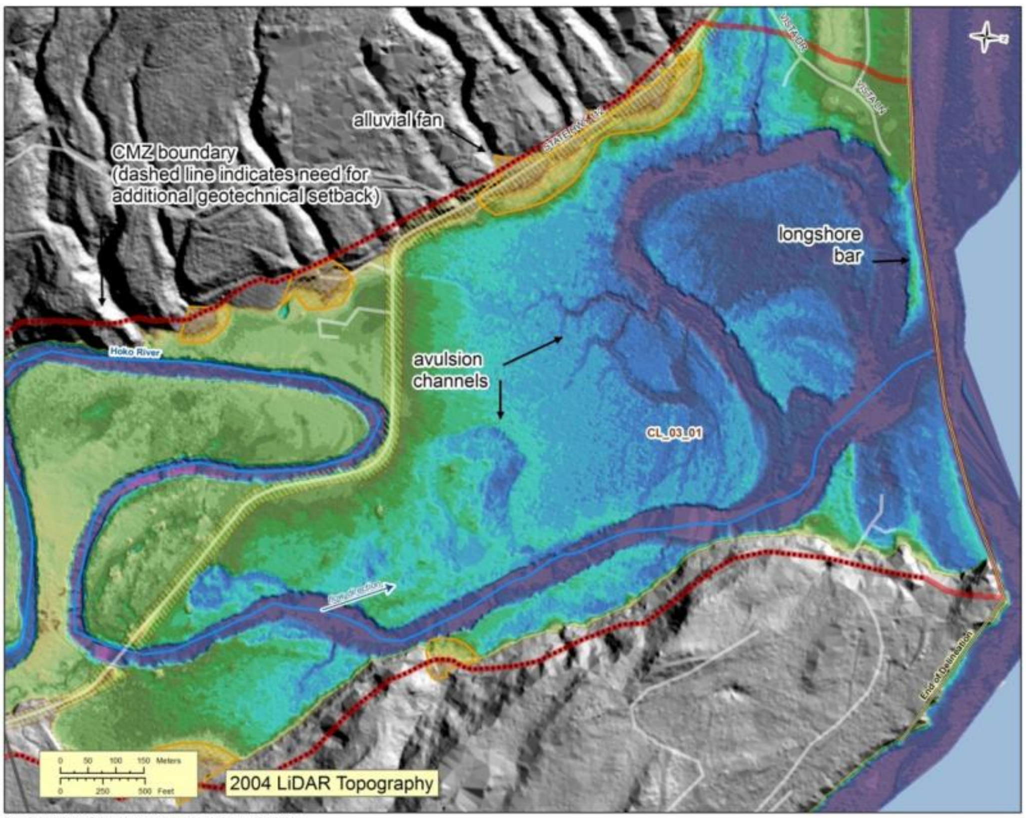


Figure 4.8 RWSE map of the delta of Hoko River showing a typical pattern of avulsion channels. A longshore bar has formed filling in the historical channel to the west of the current river mouth.

Identify infrastructure that is likely to affect migration and delineate Disconnected Channel Migration Zone (DCMZ)

Infrastructure construction and land development has commonly occurred in the floodplain and within the channel migration zone. Depending on the type of infrastructure and how it is constructed and the power of the stream, infrastructure can act as a barrier to channel migration or be susceptible to erosion and failure. In the event of a flood or failure, the infrastructure will often be repaired or replaced depending on the importance of the infrastructure and the extent of the damage. In general, only infrastructure with a public agency commitment for maintenance and that are substantial enough to withstand channel migration were considered barriers to channel migration. Levees that are certified by the U.S. Army Corps of Engineers and state highways are the two cases which we assumed to act as barriers to channel migration. In both these cases, we assume the facilities were built to withstand channel migration or will be repaired in place (though there are cases where facilities have been moved after being damaged). State highways and federal levees and the areas behind them were mapped as DCMZ. See Figure 4.9 for an example of a DCMZ.

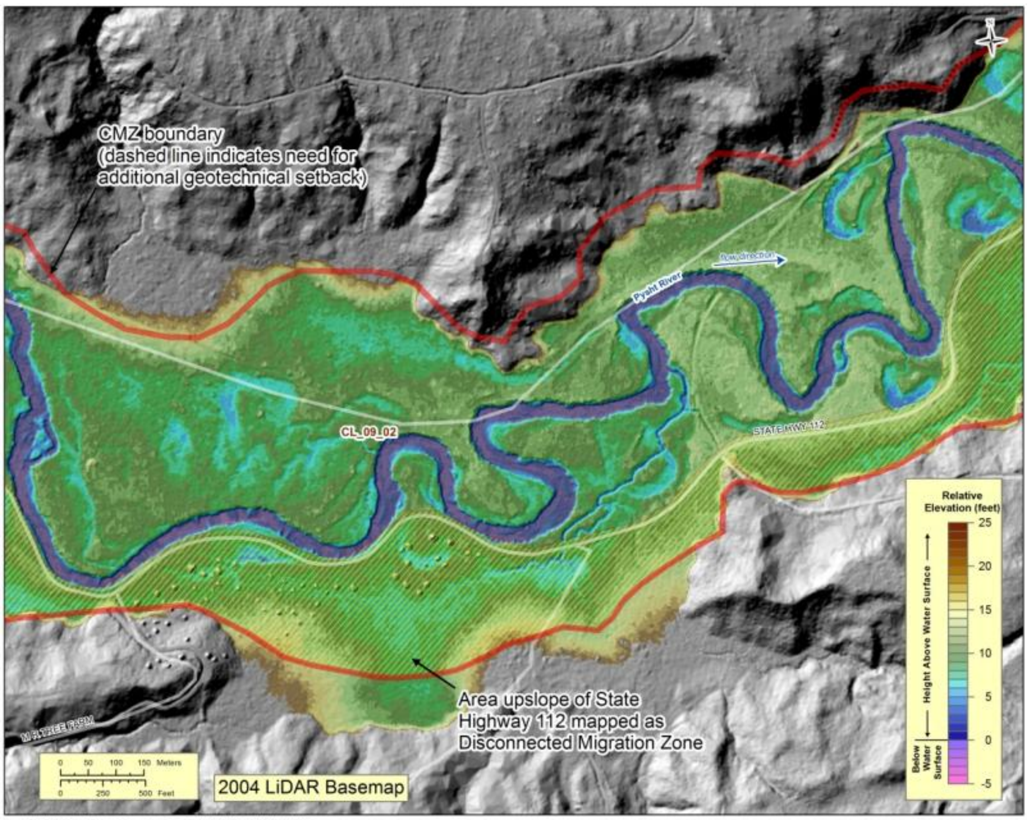


Figure 4.9 Disconnected CMZ along Physht River. This figure shows the same location as Figure 4.4

A disconnected CMZ identifies an area that would lie within the CMZ if not for the highway or levee, thus helps planners, landowners and others understand that areas in disconnected CMZs would be at risk if the river got through the highway or levee.

The SMP guidelines include infrastructure that may be considered to be barriers to channel migration. WAC 173-26-221(3)(b) provides criteria for barriers:

- *Within incorporated municipalities and urban growth areas, areas separated from the active river channel by legally existing artificial channel constraints that limit channel movement should not be considered within the channel migration zone.*

- *All areas separated from the active channel by a legally existing artificial structure(s)* (as defined in the Shoreline Management Act, RCW 90.58.030, text added for clarification)*, that is likely to restrain channel migration, including transportation facilities, built above or constructed to remain intact through the one hundred-year flood, should not be considered to be in the channel migration zone.*

In areas outside incorporated municipalities and urban growth areas, channel constraints and flood control structures built below the one hundred-year flood elevation do not necessarily restrict channel migration and should not be considered to limit the channel migration zone unless demonstrated otherwise using scientific and technical information.

Barriers to CMZs that would define disconnected CMZs include existing artificial structures are defined under the Shoreline Management Act definition for floodway (RCW 90.58.030): "...protected from flood waters by flood control devices maintained by or maintained under license from the federal government, the state, or a political subdivision of the state."

Little information was available concerning barriers to channel migration in Clallam County that meet the SMP and SMA criteria. Thus only state roads and active railroads were considered to be the only structures to constrain channel migration.

- Delineate tributary alluvial fans

Alluvial fans often form along the margins of larger valleys where tributaries enter the valley. Alluvial fans develop over time as the tributary deposits sediment at the location of a sharp reduction in channel gradient such as where a channel comes down from a hillslope into a much flatter valley. The loss in gradient reduces the sediment transport capacity of the tributary and it deposits the coarse sediment it is carrying and aggrades the channel. As the channel aggrades, flows are more likely to leave its banks and find new pathways down to the valley bottom. Sometimes the active channel on an alluvial fan can be 10's of feet above other portions of the fan (a cross-section of a fan shows a convex shape with the stream typically at the highest spot). Given the relief between the stream and the surrounding area, a channel flowing over an alluvial fan is prone to suddenly jump to an entirely new pathway. Once a new channel forms, it may undergo short-term down-cutting, but will eventually begin to aggrade and the process repeats itself, building a convex "fan" on the valley bottom with its apex where the tributary comes out of the confined channel within the adjacent hillslope. Given the process of how alluvial fans form, they are very dynamic landforms subject to frequent and sometimes catastrophic channel migration. The entire surface of an active fan is considered to lie within a CMZ, and thus the streamlined delineation delineated large alluvial fans where they occurred within the valley where a stream was being delineated. The DEM and RWSE maps are usually excellent in revealing the fans. No field surveys or other data were used to delineate alluvial fans, so these streamlined delineations should be considered approximate.

Identify areas requiring geotechnical analyses for a geotechnical setback buffer

Once the erosion hazard buffer was delineated, the boundary was evaluated to determine if a geotechnical review was warranted. These areas occur where the edge of the channel migration area intersects a valley wall, terrace, or landform that is greater than approximately 25 feet above the water surface (Figure 4.10). Since 'erodible' high ground is no impediment to channel migration, when a channel cuts into high ground it will, by definition, over-steepen the slope. This sets up conditions to destabilize the slope and trigger a slide that can impact a much greater proportion of the hillslope than the toe erosion done by the stream. Since toe erosion can set up the conditions to impact a much greater area, it is important to recognize how channel migration can pose a threat to property located far above the stream (Rapp and Abbe 2003). The Lyre River example of valley expansion (Figure 4.6) was observed in many streams evaluated by this study. Many examples included obvious examples of shallow or deep-seated landslides, both recent and prehistoric that had occurred along stream valleys. The potential channel migration boundary in reaches where evidence of valley widening is occurring includes the entire valley bottom plus a portion of the valley wall. The streamlined CMZ delineations were not intended to be precise, simply call out areas where a more detailed assessment, including a geotechnical analysis, is needed to determine the geographic extent of the hazard. The area where geotechnical setback buffer is needed is indicated on the maps with black dots in the CMZ boundary line.

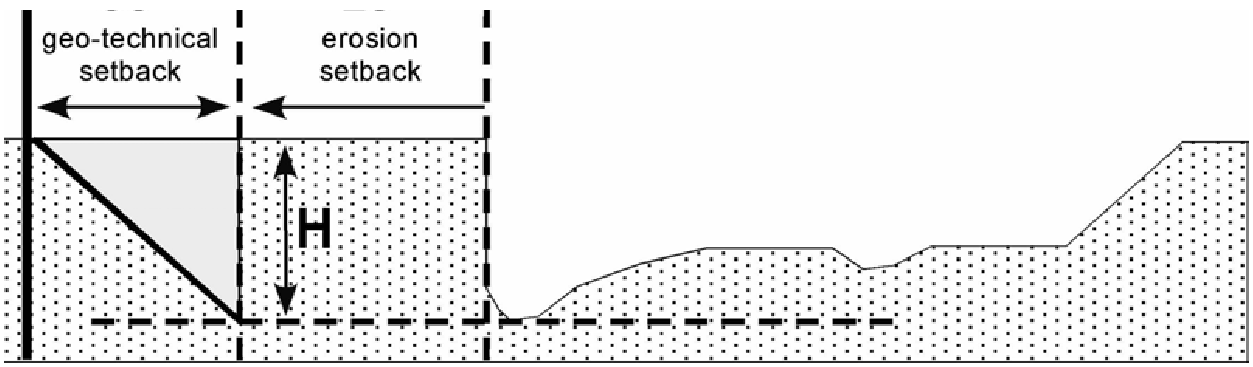


Figure 4.10 Illustration showing the basis for the geotechnical setback buffer. For purposes of this study, a geotechnical buffer was recommended any time H (height) was greater than 25 feet. The width of the geotechnical setback buffer was not determined for this study since it requires additional field data. (From Rapp and Abbe 2003).

QA/QC review

The final step in the general CMZ delineation consisted of review by 3 senior geomorphologists. Each reviewer individually reviewed the maps and then met to discuss the draft channel migration maps comments and recommendations for map changes. Once changes were agreed upon, the changes were made and the maps finalized in draft form.

Appendix E. Glossary, Acronyms, and Abbreviations

Glossary

Channel migration: Channel migration is a natural process associated with streams[3]. Streams may migrate across valleys due to a variety of processes including channel and bank erosion processes, meander chute cutoff, avulsion, and vertical movement. The **channel migration zone** represents the area within which a given stream may migrate over time and includes avulsion hazard and erosion hazard zones (Rapp and Abbe 2003).

Datum is a surface or point relative to which measurements of height and/or horizontal position are reported. A vertical datum is a horizontal surface used as the zero point for measurements elevation; a horizontal datum is a reference for positions given in terms of latitude-longitude, State Plane coordinates, or Universal Transverse Mercator (UTM) coordinates.

Detailed channel migration assessment and/ or delineation: Channel migration studies that include intensive archival historical analysis from maps and aerial photography and geomorphic field data collection. Some may include hydrologic and hydraulic modeling.

Instantaneous Annual Peak Flow: The maximum instantaneous peak discharge that is the highest discharge at an instant in time in a water year.

Parameter: A physical, chemical or biological property whose values determine environmental characteristics or behavior.

Planning level channel migration delineation methodology: A rapid channel migration assessment and mapping method developed for mapping channel migration zones for Washington State Shoreline Master Program update requirements.

Reach: A specific portion or segment of a stream.

Recurrence interval (return period): The average interval of time within which the given flood will be equaled or exceeded once (USGS).

Regime: 1) "Regime theory" is a theory of the forming of channels in material carried by the streams. As used in this sense, the word "regime" applies only to streams that make at least part of their boundaries from their transported load and part of their transported load from their boundaries, carrying out the process at different places and times in any one stream in a balanced or alternating manner that prevents unlimited growth or removal of boundaries. 2) A stream, river, or canal of this type is called a "regime stream, river, or canal." A regime channel is said to be "in regime" when it has achieved average

[3] The term stream encompasses all sizes of flowing water bodies.

equilibrium; that is, the average values of the quantities that constitute regime do not show a definite trend over a considerable period--generally of the order of a decade. In unspecialized use "regime" and "regimen" are synonyms (USGS).

Riparian: Relating to the banks along a natural course of water.

Streamflow: Discharge of water in a surface stream (river or creek).

Shoreline Management Act: In Washington State, the Shoreline Management Act (SMA) was passed by the State Legislature in 1971 and adopted by voters in 1972. The overarching goal of the Act is "to prevent the inherent harm in an uncoordinated and piecemeal development of the state's shorelines."

The Act applies to all 39 counties and more than 200 towns and cities that have "**shorelines of the state**" (RCW 90.58.030(2)) within their boundaries. These shorelines are defined as:

- all **marine waters**;
- **streams and rivers** with greater than 20 cubic feet per second mean annual flow;
- **lakes** 20 acres or larger;
- upland areas called **shorelands** that extend 200 feet landward from the edge of these waters; and
- the following areas when they are *associated* with one of the above:
    - biological **wetlands** and river deltas; and
    - some or all of the 100-year **floodplain** including all wetlands within the 100-year floodplain

Shoreline Master Program: Local Shoreline Master Programs (SMP) apply the Shoreline Management Act at the community level. SMPs are local land use policies and regulations designed to manage shoreline use. These local programs protect natural resources for future generations, provide for public access to public waters and shores, and plan for water-dependent uses. They are created in partnership with the local community and Ecology, and must comply with the state Shoreline Management Act and Shoreline Master Program Guidelines.

Shoreline Master Program Guidelines: The Shoreline Master Program (SMP) Guidelines are state standards which local governments must follow in drafting their shoreline master programs.

Water Year: In Washington, the water year is the 12-month period extending from October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ended September 30, 1959, is called the "1959 water year."

Watershed: A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

Acronyms and Abbreviations

Following are acronyms and abbreviations used frequently in this report.

CMZ	Channel migration zone
DEM	Digital Elevation Model
e.g.	For example
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
et al.	And others
GIS	Geographic Information System software and data
GPS	Global Positioning System
i.e.	In other words
QA	Quality assurance
RCW	Revised Code of Washington State
RM	River mile
RWSE	Relative Water Surface Elevation
SMA	Washington State Shoreline Management Act
SMP	Washington State Shoreline Master Program
SOP	Standard operating procedures
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Washington State Water Resource Inventory Area

Units of Measurement

cfs	cubic feet per second
cms	cubic meters per second, a unit of flow.
ft	feet
kcfs	1000 cubic feet per second
kg	kilograms, a unit of mass equal to 1,000 grams.
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mm	millimeter