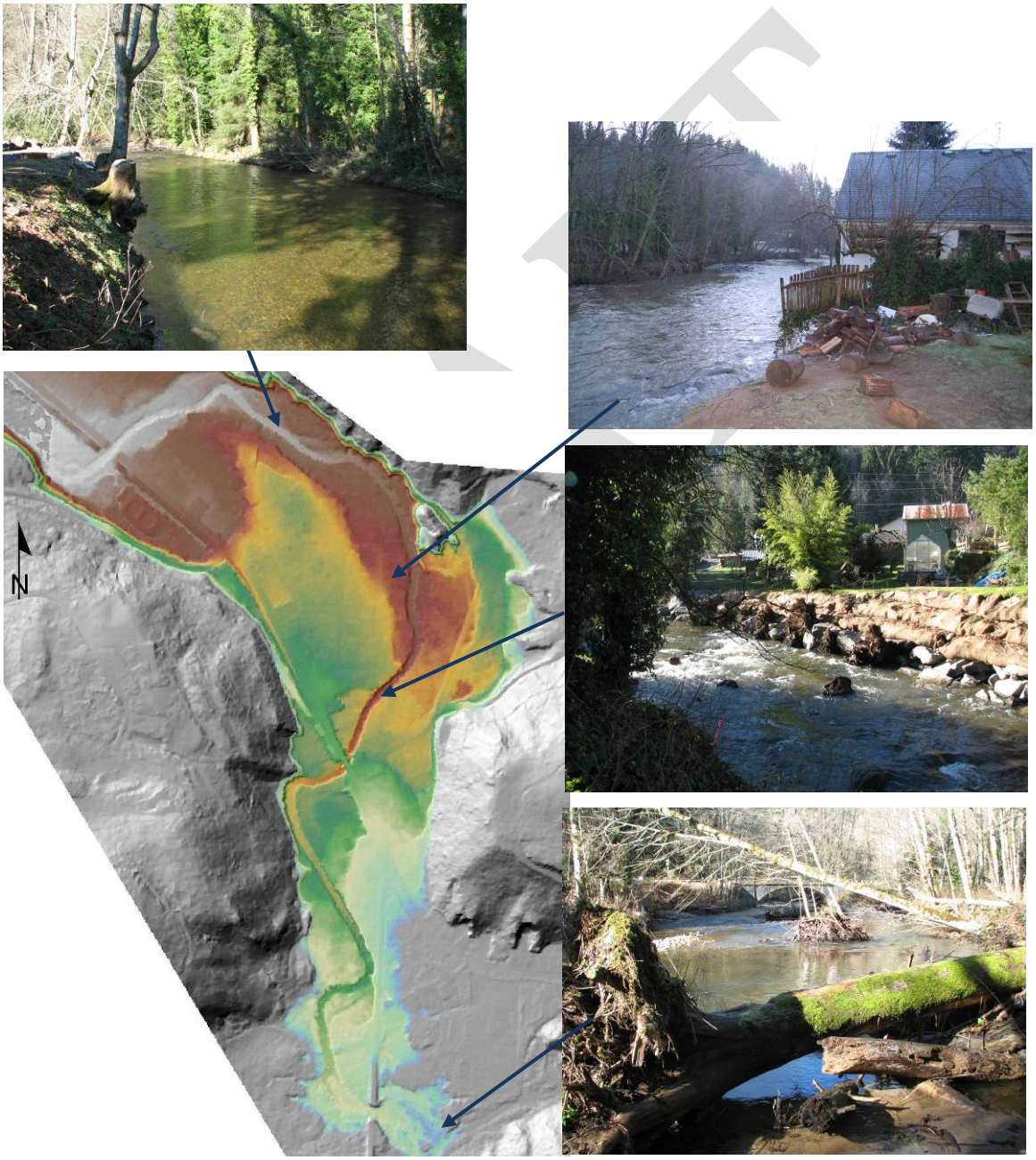
DEPARTMENT OF ECOLOGY, SHORELANDS AND ENVIRONMENTAL ASSISTANCE

# CITY OF WILKESON SMP UPDATE: CHANNEL MIGRATION ASSESSMENT




**03/16/2011**

## GENERAL CHANNEL MIGRATION MAPPING FOR SMP UPDATES

### BACKGROUND

Channel migration is a natural process associated with streams[1]. Streams may migrate across valleys due to a variety of reasons including channel and bank erosion, meander chute cutoff, avulsion, aggradation and incision. 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).

Channel migration is an important stream ecosystem process supporting habitat forming processes and ecological functions. The channel migration process is also an important risk factor for humans and infrastructure in that migration can result in property damage and change flooding dynamics.

Chapter 173-26 WAC requires that channel migration areas be generally identified during the inventory and characterization phase of Shoreline Master Program updates:

WAC 173-26-201(3) (c) (vii): Local government shall, at a minimum, and to the extent such information is relevant and reasonably available, collect the following information:

(vii) General location of channel migration zones, and flood plains.

WAC 173-26-221(3)(b) indicates that the assessment should be based on the historic record, geologic character and evidence of past migration over the past 100 years. Much of this information is collected for other inventory items as well. Existing relevant data include:

- Information on channel characteristics such as channel gradient and confinement.
- Existing GIS geology and soils data to evaluate erosion potential
- 2 to 3 time series of aerial photographs, maps, LiDAR or other spatial and temporal data that is available.

Channel migration zones are to be managed per the SMA to[2]:

- Reduce potential hazards to human settlements and infrastructure by guiding development near streams.
- Protect shoreline ecological functions.
- Not allow development including fill to interfere with natural channel migration processes.
- Restrict shoreline stabilization and armoring that could cause harm to other property or resources.

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

[2] Shoreline management code citations referring to channel migration can be found at http://www.ecy.wa.gov/programs/sea/SMA/st_guide/jurisdiction/CMZ.html

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## INTRODUCTION

The Washington Department of Ecology (Ecology), Shorelines and Environmental Assistance Program (SEA) are responsible for managing Shoreline Master Program updates and providing technical and policy assistance and guidance to local communities. The Shoreline Management Act (SMA) "*establishes a cooperative program of shoreline management between local government and the state. Local government shall have the primary responsibility for initiating the planning required by this chapter and administering the regulatory program consistent with the policy and provisions of this chapter. The department shall act primarily in a supportive and review capacity with an emphasis on providing assistance to local government and on insuring compliance with the policy and provisions of this chapter*" (RCW 90.58.05).

In response to the SMP channel migration requirements, the SEA program published a review of relevant literature and technical framework document (Rapp and Abbe 2003) and an interactive web-based technical guidance (http://www.ecy.wa.gov/biblio/0806013.html ). The web guidance provides:

- A decision chart for evaluating channel migration that is linked to the specific steps (Figure 1 and http://www.ecy.wa.gov/programs/sea/sma/cma/page2.html ).
- A decision chart to help identify when channel migration assessments are needed as part of the update (Step 1, pp 3-4, (http://www.ecy.wa.gov/programs/sea/sma/cma/page3-step1.html ).
- A range of approaches and methods to use depending on management objectives and importance of environment and infrastructure values (pp 9-11 of the Ecology web-based guidance http://www.ecy.wa.gov/programs/sea/sma/cma/page9-step2b.html ).
- Links to channel migration assessments that have been completed in Washington.

The approaches and methods were developed in an Ecology sponsored 1-day workshop (10/2005). The workshop included practitioners and scientists experienced and knowledgeable in channel migration processes and assessments.

Ecology developed a map showing stream reaches with potential to migrate for communities that began their updates in 2009-2012. Step 1 of the web guidance was used to determine migration potential and included data on:

- Channel and valley characteristics—confinement, gradient, entrenchment
- Geology and soils
- Channel processes and pattern
- Aerial photographs, orthophotos and maps to identify channel migration processes over time
- Digital elevation models and LiDAR where available.

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The map only shows reaches with potential to migrate and does not include channel migration area. Approximately 800 stream miles were identified. Approximately 550 of those miles occur within the Puget Sound region.

Many local communities do not have the resources (staff knowledgeable and experienced in fluvial geomorphology assessments and budget) to conduct channel migration assessments. The SEA program also had inadequate resources since it only had 1 staff person with the appropriate hydrologic and geomorphic experience to provide statewide technical assistance and no budget to hire other staff. So Ecology applied for grants to provide technical assistance in channel migration mapping. Ecology received a scientific and technical investigations grant from the Environmental Protection Agency (EPA), Region X. A major objective of the grant is to provide data and maps on "general" channel migration zones to the Puget Sound local governments who are updating their SMPs.

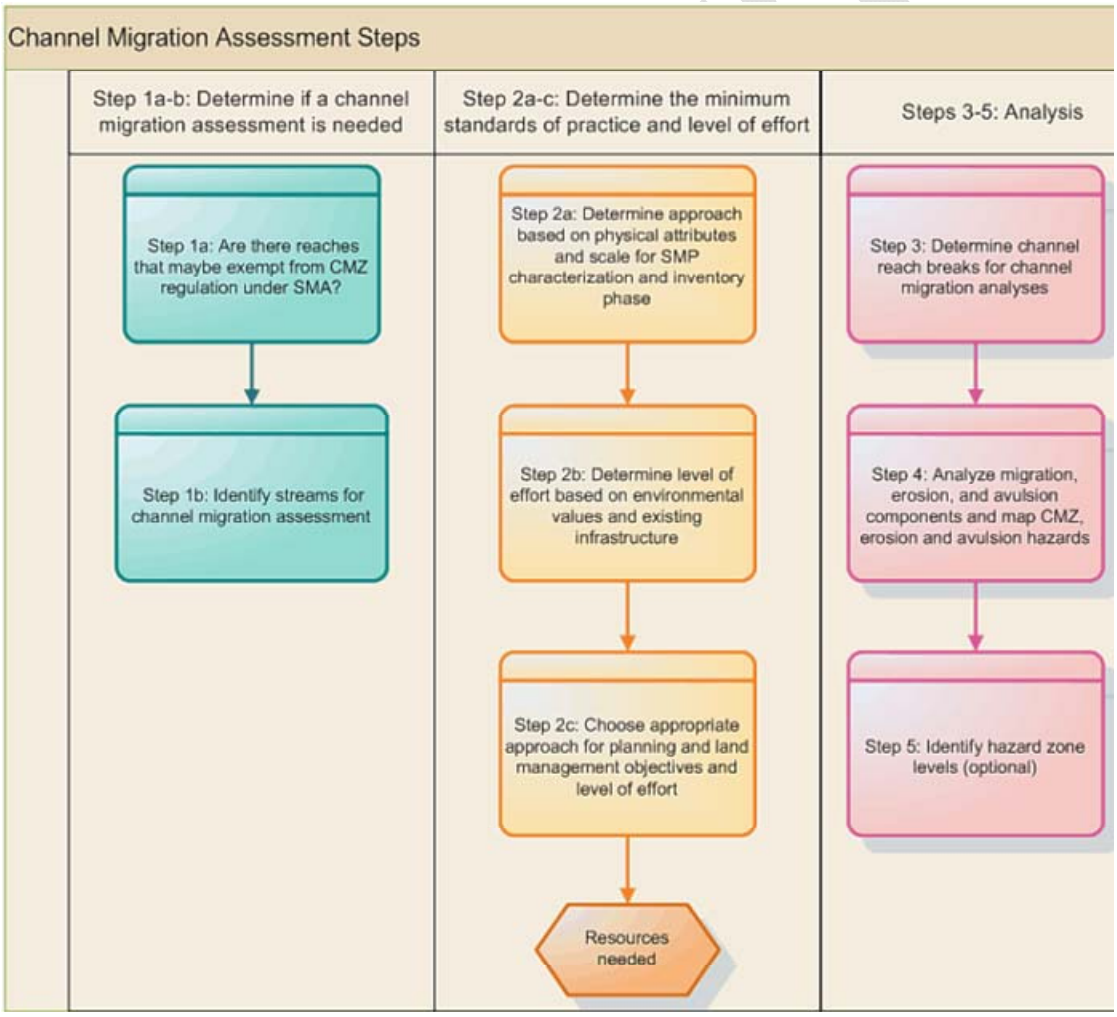


**Figure 1: Decision flow chart from web guidance showing a summary of recommended steps for a channel migration assessment.**

## GENERAL MAPPING METHODS

### *Introduction*

The SMP guidelines require that the channel migration zone be "generally" identified using existing relevant data. Since, channel migration areas vary over space and time; mapping provides a more efficient means to identify their location. Mapping occurs during the communities Shoreline Master Program updates if it hasn't already been done for other zoning purposes such as their Critical Area Ordinance.

The Ecology web guidance suggest that "general" mapping methods used are low to moderate level depending on scale and channel pattern (Figure 2). Using general methods leads to a higher uncertainty in CMZ location. The final map should be considered approximate and require more detailed assessment for proposed development as the SMP guidelines recommend.

**Step 2a:** Determine minimum approach and methods basd on physical attributes and scale for SMP characterization and inventory phase.

| | Basin Scale | | | | Reach Scale | | | | Site Scale | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel Pattern | M | B | A | W | M | B | A | W | M | B | A | W |
| Watershed Characterization | 1 | 1 | 1 | 1/2 | 2/1 | 2/1 | 2/1 | 2/3 | 3/1 | 3/1 | 3/1 | 3/2 |

**Figure 2: The numbers identify the linked summary of approaches and methods Table 4, Step 2c. M=meandered pattern, B=braided pattern, A=island braided pattern, W= wandering pattern. This table provides a list of minimum standards of practice approaches and methods for watershed characterization. The methods are organized by scale and channel type - meandering, braided, Island braided and wandering. Straight channel patterns that may have potential to migrate fall under meandering pattern. Channels with avulsion potential are included under island braided and wandering channel categories.**

The web guidance uses a decision flow chart to answer the question: "Is a channel migration assessment needed and where?" It includes steps for determining the channel migration zone based in part on Rapp and Abbe (2003). The SMP guidelines provide some exemptions where, areas may be removed from the channel migration zone. These areas are called disconnected channel migration areas (DMA). For incorporated cities and urban growth areas, the guidelines suggest that:

- Only within **incorporated municipalities** and **urban growth areas**, channel migration areas separated from the active river channel by **legally existing**, constructed channel constraints that limit channel movement, but not built to the 100-year flood standard, could be considered within the DMA.
- Artificial constraints must be publicly maintained structures based on SMA floodway definition (RCW 90.58.030)
    - Exempted only where flood control devices are maintained by or maintained under license from government

- Commitment to maintain.

- All other areas separated from the active channel by **legally existing** constructed structures that are likely to restrain channel migration and are built above and to **remain intact through the one hundred-year flood**, including transportation facilities, could be considered within the DMA.

Descriptions of constraints are listed on page 3 of the CMZ web guidance document (http://www.ecy.wa.gov/programs/sea/sma/cma/page3-step1.html ).

The general channel migration zone (CMZ) includes the historic channel migration area (HMZ), the probable floodplain and bank erosion hazard area (EHA) and the potential avulsion hazard area (AHZ) minus the disconnected migration area (DMA) (Figure 3). The Ecology general maps do not include the DMA except in obvious areas such as publicly maintained roads and railroads meeting the 100-year flood standard, and government maintained levees and revetments. Riprap is often placed by landowners and there is no public commitment to maintain. Also there is little to no information on bank stabilization and other hydromodifications. Local governments with technical assistance from Ecology may identify structures that meet the exemption criteria.

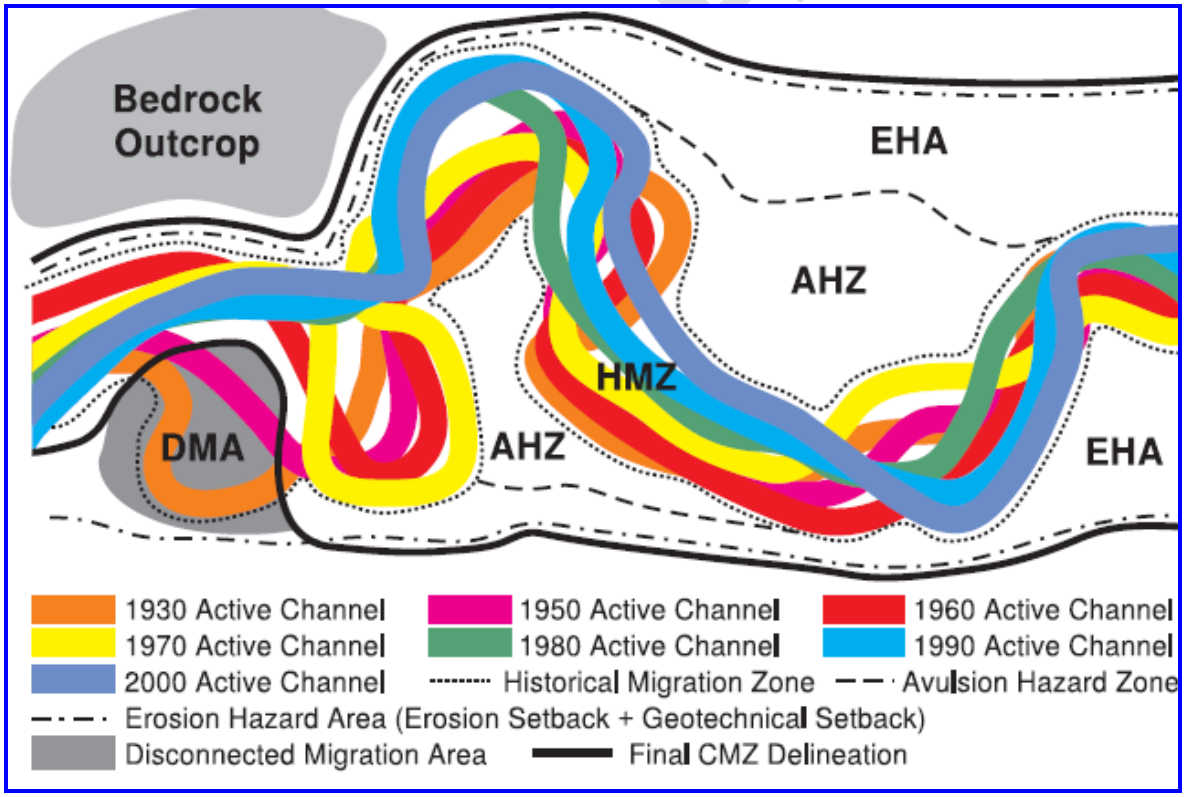


**Figure 3: Channel migration zone schematic showing the elements that create the CMZ. Figure from Ecology publication (Rapp and Abbe 2003), http://www.ecy.wa.gov/biblio/0306027.html.**

### *METHODS USED TO MAP A GENERAL CMZ FOR WILKESON.*

Low and moderate level methods were combined to generally map the channel migration zone along Wilkeson Creek using available data (Table 1). The assessment

relied mostly on GIS data and analysis. After a draft channel migration map was developed, we evaluated the boundaries and made changes based on field evidence.

**Table 1: Describes approaches and method used to map the migration, bank erosion and avulsion zones. The blue text summarizes data and analysis used for the Wilkeson Creek assessment.**

| Basin/watershed scale | Most applicable to basin or watershed Scale: all stream types |
|---|---|
| Approaches used | Synthesize available data to understand control or relevant basin-scale processes such as geology, soils, topography/gradient, hydrology, land use, vegetation<br>• GIS based with limited field verification which increases uncertainty<br>• GIS data used included USGS Lower Puget Sound 2004 LiDAR, UACOE 1941 aerial photograph (georectified), 1990 USGS orthophotos and the 2006 and 2009 NAIP orthophotos, NRCS Pierce County soil data, DNR 1:100,000 geology layers, 1:24000 NHD water course layer, Pierce County preliminary FEMA floodplain maps.<br>• Other information and data obtained from SMP inventory, characterization, WRIA reports, geologic reports, and USGS stream flow data from South Prairie Creek USGS gage.<br>• 1 day field verification using field evidence and Trimble GPS to evaluate draft channel migration area map and potential constraints to channel migration. |
| 1. Low accuracy method | Minimum Level of Effort<br>• Identify the purpose of the CMZ delineation<br>  o To generally map the CMZ for the shoreline update<br>• Use available tools such GIS, DEM, LiDAR and hydrologic data to minimize costs (Refer to approach)<br>• Determine the characteristics and processes operating within the basin, including sources of sediment, climate and land use changes by researching floodplain & geologic and soils maps, and historic stream flow data<br>  o Much of this information was obtained from GIS data, USGS stream flow data on SF Prairie Creek, NRCS Pierce County soil data, mining geology reports, and other historical information<br>• Identified possible channel migration areas using DEM, LiDAR, and multi-date orthophotos |
| 2. Moderate accuracy method | Minimum Level of Effort—Above plus the following<br>• Evaluate channel erosion and aggradation areas based on stream power analysis<br>• Trace the 2004 active channel and the 1941, 1990, 2006, 2009 channel lines<br>• Identify relative rate of migration by reaches<br>• Identify potential bank erosion hazard areas (EHA) from soils and geology and profiles derived from LiDAR DEM.<br>• Map potential avulsion hazards (AHZ) channels<br>• Map the CMZ as the historic migration zone (HMZ), probable migration area based on photo and map record plus the erosion hazard area and AHZ<br>• Remove areas (disconnected migration areas) landward of publicly maintained roads that are above the 100-year flood.<br>• Field verification on channel migration evidence and boundaries. |

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## GIS Method

Wilkeson Creek was divided into 2 reaches within the City's boundary. These reaches correspond with the reaches identified in the inventory and characterization. However, the 2 reaches were not sufficient for describing channel change and response. The reaches were subdivided into smaller reaches based on channel, bank, floodplain and riparian characteristics (Figure 4). These smaller reaches are used in describing channel conditions, processes and channel migration zone. The 1:24000 National Hydrography Data (NHD) layer was used as the base streamline layer (available publicly through USGS National Hydrography Dataset http://nhd.usgs.gov/data.html). The Washington layer was developed from 2006 or earlier data.

The Lower Puget Sound Pierce County2004 LiDAR bare earth elevation data (Puget Sound LiDAR Consortium 2004*)* were used to develop a DEM along Wilkeson Creek and valley and a hillshade model. The DEM was draped over the hillshade layer. This provides a visual image of channel locations within the valley (refer to Figures 10 and 12 stream power). The DEM was also converted into a relative elevation model which shows the elevation of adjacent land relative to water surface (Appendix A).

The LiDAR elevation data were also used to develop channel cross-sections. The cross-sections provide information on floodplain elevations relative to the channel and areas that have avulsion and erosion potential. The channel thalweg and banks were traced from the LiDAR to provide elevation data on banks and channel. The channel elevation data were used to calculate channel gradient and bank traces were used to calculate active channel width. Gradients and channel width were calculated using Ttools Version 7.56 (Kasper and Boyd 2009).

The channel gradient data were also used for a stream power analysis. Unit stream power (specific weight of water*channel gradient * discharge/active channel width) is an indicator of transport capacity that is the ability of the stream to transport sediment. High transport capacity can result in channel incision and bank erosion. Low transport capacity may cause channel aggradation. The USGS Streamstats program was used to estimate the 2-year recurrence flood discharge along the channel for the upstream and downstream boundaries as well as before and after tributaries (http://water.usgs.gov/osw/streamstats/Washington.html). The 2-year flood was used as an indicator of the discharge that initiates channel forming / changing processes.

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. Our definition for bankfull discharge is the discharge where sediment transport, channel movement and other geomorphic work is done.

*Historic Migration Zone (HMZ):* The LiDAR (2004) and 1941, 1996, 2006 and 2009 orthophoto layers were compared to determine channel changes over time. Only mid-channel streamlines were digitized for 1941, 1990, 2006, and 2009 channels

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because the canopy cover obscured much of the active channel on the orthophotos. Reach 1 posed the greatest challenge for locating side channels and main channel braids. For obscured reaches, the LiDAR DEM was cross-referenced to check stream locations. The GPS data obtained during our field reconnaissance provided additional information. The channel streamlines, visible secondary channels on 1941, 1990, 2006, and 2009 orthophotos, secondary channels from LiDAR DEM, and secondary channels identified during field observations were used to map the historic migration zone (HMZ).

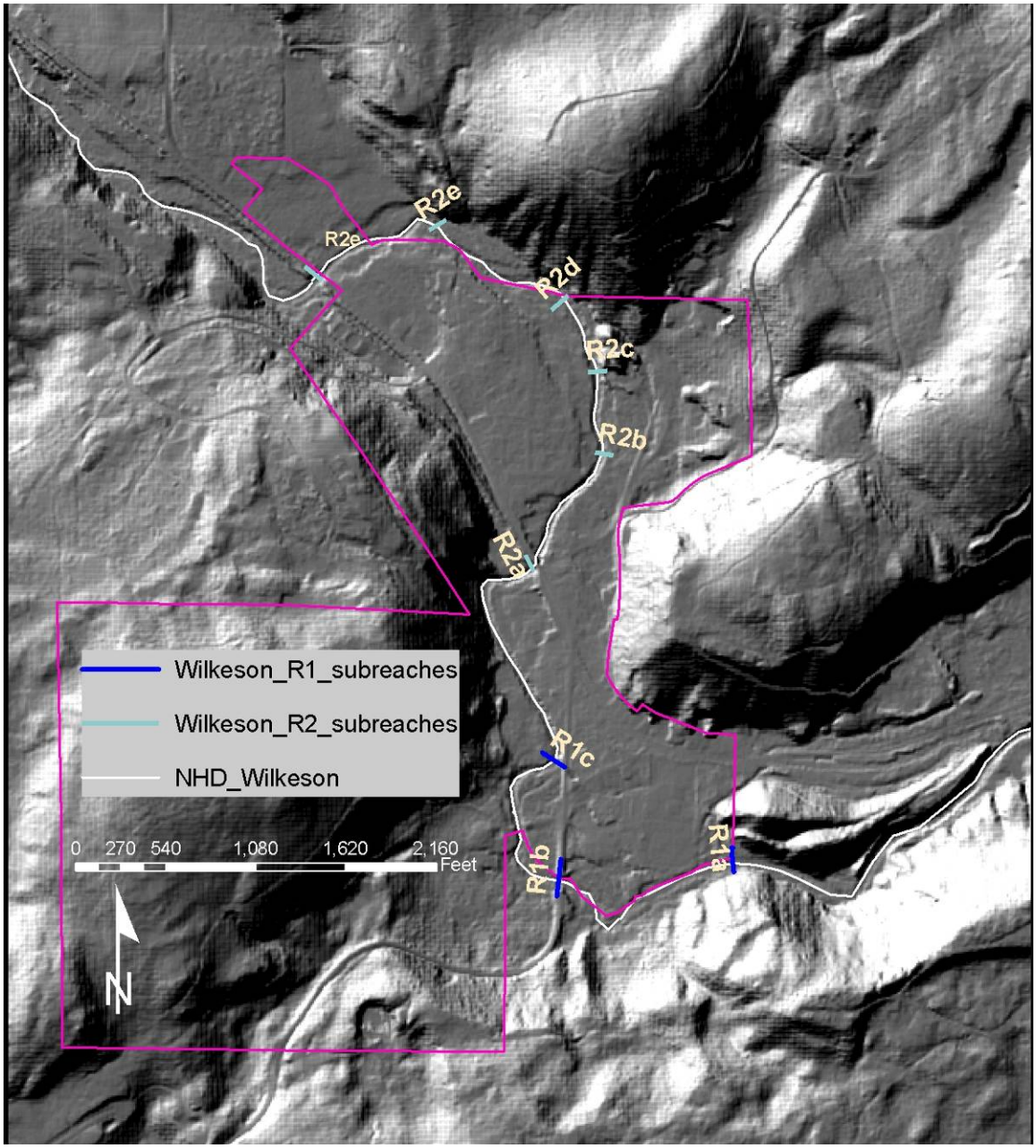


**Figure 4: Reach breaks on Wilkeson Creek shown on 2004 LiDAR hillshade layer.**

*Erosion hazard areas:* The erosion hazard area (EHA) includes the floodplain surface landward of the HMZ and the terraces and hillslopes bordering the floodplain and banks along the landward boundary of the HMZ. Migration rates and erosion potential were used to determine the EHA.

Migration rates were estimated by measuring distance between streamlines for 1941, 2004, 2006, 2009 streamlines. Migration rates were estimated using the Arc Toolbox\ analyst\proximity\near commands. The migration rates don't provide information on right or left channel migration because they aren't based on active channel locations. The most recent maximum annual migration rates (migration from 2006-2009) for each subreach were multiplied by 10 years and measured from the HMZ to estimate the landward extent of floodplain erosion hazard area. The EHA boundary was then adjusted based on LiDAR elevation data, location of public roads outside the floodplain, and field observations. The LiDAR elevation data and cross-section profiles were used to identify older channel features that have potential to be eroded or occupied.

Since erosion potential of soils and underlying geology influence bank and floodplain erosion and channel migration, shapefiles of geologic formations and soil characteristics that intersected with the SMP streams were created.

Geology: Lithology is considered an upland control as well as a local control on channel morphology and process. Bedrock along streams is generally considered a geologic control on channel migration. However, coarse sediment during transport can erode bedrock (e.g., Sklar and Dietrich 2001, 2004; Montgomery 2004). This erosion can occur within a 100-year timeframe. So rocks with low tensile strength are an indicator of areas that could potentially be eroded by flow and sediment transport. Local conditions may alter the potential. There are many factors that may influence fluvial erosion of bedrock such as uplift, knickpoint propagation, debris flows, sediment size, sediment supply, storm events versus long term averages.

Geology qualitative erosion potential (low-high) was assigned to surface geology classes (Table 2) and bedrock (Table 3). Geology erosion ratings were given for the Wilkeson area (Figure 5). The geology data were obtained from the WDNR geology GIS layer (<http://www.dnr.wa.gov/geology/dig100k.htm>)

**Table 2; Relative erosion ratings are assigned to surface geology umits.**

| Surface geology deposits | Erosion potential |
|---|---|
| Holocene alluvial and active alluvial fan deposits; landslides; peat; glacial deposits—recessional outwash, outburst flood, recent volcanic deposits—lahars, ash | High |
| Glacial—coarse undifferentiated drift and fractured till, terraces (coarse grained), advance outwash such as the Esperance sands, or coarse clasts | Moderate High |
| Undifferentiated glacial drift with clay matrix (Pleistocene or older alluvium and alluvial/debris fans, landslides), terraces with clay matrix | Moderate |
| Basal till, | Moderate Low |

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**Table 3: Bedrock strength classification is used to assign relative erosion ratings to bedrock.**

| Strength classification | Unconfined fracture strength (MPa) | Typical rock types | Fluvial erosion potential |
|---|---|---|---|
| Very weak | 10-20 | weathered and weakly-compacted; highly fractured; marine sedimentary rocks | Moderate High |
| Weak | 20-40 | weakly-cemented sedimentary rocks; tuffs, | Moderate |
| Medium | 40-80 | competent sedimentary rocks; tuff breccia | Moderate Low |
| Strong | 80-160 | competent igneous rocks; some metamorphic rocks and fine-grained sandstones, schists; some low-density coarse-grained igneous rocks | Low |
| Very strong | 160-320 | quartzite; dense fine-grained igneous rocks | Very Low |

Soils*:* Floodplain and bank sediments (soils) are local controls on channel morphology. NRCS SSURGO soil data were used to estimate the bank and floodplain erosion potentials [NRCS, http://soildatamart.nrcs.usda.gov/]. Soil texture was the primary variable used to create bank and floodplain erosion potential. Soil texture was chosen over other factors because knowledge of soil texture provides an indication of cohesive properties of the banks or floodplains. The soil data contains a soil erodibility factor. But it applies more too upland rill erosion and sediment detachment than to fluvial or shear-related erosion. For example, silt soils have the highest rill erodibility factor while sands are quite low. However, banks composed of coarser materials are less cohesive than clayey banks and thus more susceptible to fluvial erosion. Using the Bank-toe stability model (Simon and Langendoen 2006) and keeping all things equal except soil texture indicates that banks composed of clay with silt are less likely to erode than sandy soils with silt. Banks composed of clay with silt tend to have a steeper slope than sandy soils.

The 2 end point textures were used: clayey soils (lower erosion potential) and sandy soils (higher erosion potential). Many of the clay soils have high silt content also, so while these soils have lower erosion potential than sandy soils they are still erodible. Textural class tables were used to define the two textures where clayey soils were defined as having clay content > 15%. Sandy soils were classified as total sand>35%. There may be some overlap between sandy clay, sandy clay loam, clay loam and loam textures.

Areas with moderate to high erosion potential were included in the EHA. Along Wilkeson this includes the steep banks in Reaches 1c, 2a, 2b, 2c and terraces in Reach 1a and 1b. The fracture plan and erosion distance was estimated using the Using the Bank-toe stability model (Simon and Langendoen 2006).

Avulsion hazard zone: Avulsion hazard zones (AHZ) are identified using elevation elevation differential between historic and current channel as well as channel locations. The LiDAR DEM and cross-section profiles also provided information on potential avulsion hazards. The stream power analysis in combination with LiDAR

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elevation data and profiles indicate there are potential avulsion hazard areas within the city boundaries.

## FACTORS CONTRIBUTING TO CHANNEL MIGRATION ALONG WILKESON CREEK

### Hydrologic changes

A large portion of Wilkeson Creek watershed is located within the transient snow zone which is the area most influenced by rain-on-snow produced floods. The rain-on-snow storms produce larger floods and contribute substantial channel migration. Wilkeson Creek does not have a stream gage. We used the South Prairie Creek stream gage (USGS station) as a surrogate for evaluating high flow hydrologic regimes. Wilkeson Creek is a tributary to South Prairie Creek. A hydrologic analysis of high flows for South Prairie show there has been an increase in high flows. Since Wilkeson does not have a gage and is tributary to South Prairie Creek, we are assuming that similar increases have occurred for Wilkeson Creek. Both the daily mean discharge data (Table 4) and annual maximum peak data show increases in high water (Table 5, Figure 5).

The low magnitude, high frequency floods such as the flood that has a 50% chance of occurring in any given year have not changed significantly (Table 5, Figure 5). However lower frequency, higher magnitude floods such as the 10-year flood or greater show a significant change. For example, the flood that had 2% chance of occurring (50-year event) in any given year based on 1950-1979 record now has 7% chance (7.5 year flood) in any given year based on 1988-2009 record. The January 2009 flood at Prairie Creek had a 1.9% chance of occurring (53-year flood) based on the entire record (1950-1979; 1988-2009). However, the 2009 flood had a 4.5% chance of occurring (22.5 year flood) using the 1988-2009 peak flow record.

**Table 4: Mean daily discharge data from USGS Station—12095000 South Prairie Creek at South Prairie, WA were used to evaluate daily high flows. Flow statistics show there is an increase in daily high flows between 2 periods of record: 1950-71 and 1988-2010.**

| | MEANS | | COEFF. of VAR. | | DEVIATION FACTOR | | DEV. of C.V. | |
|---|---|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Magnitude | % | Magnitude | % |
| 1-day maximum | 2165 | 2609 | 0.3821 | 0.726 | 443.9 | 20.5 | 0.344 | 90.02 |
| 3-day maximum | 1575 | 1798 | 0.3554 | 0.6412 | 223 | 14.16 | 0.2858 | 80.41 |
| 7-day maximum | 1105 | 1141 | 0.313 | 0.5453 | 35.88 | 3.247 | 0.2323 | 74.22 |

**Table 5: The annual maximum peak flow data shows increases in the peak floods, most notable with the higher magnitude floods, when the 1950-1979 data are compared to the 1988-2010 data. The Red discharge numbers are estimates based on Bulletin 17b flood analysis methods.**

| Station - 12095000 South Prairie Creek at South Prairie, WA | 50% chance (2-year) (cfs) | 10% chance (10-year) (cfs) | 2% chance (50-year) (cfs) | 1% chance (100-year) (cfs) |
|---|---|---|---|---|
| 1950-1979; 1988-2009 | 3017 | 5794 | 8383 | 9511 |
| 1950-1979 | 3005 | 5230 | 7052 | 7790 |
| 1988-2009 | 3027 | 6493 | 10860 | 13150 |

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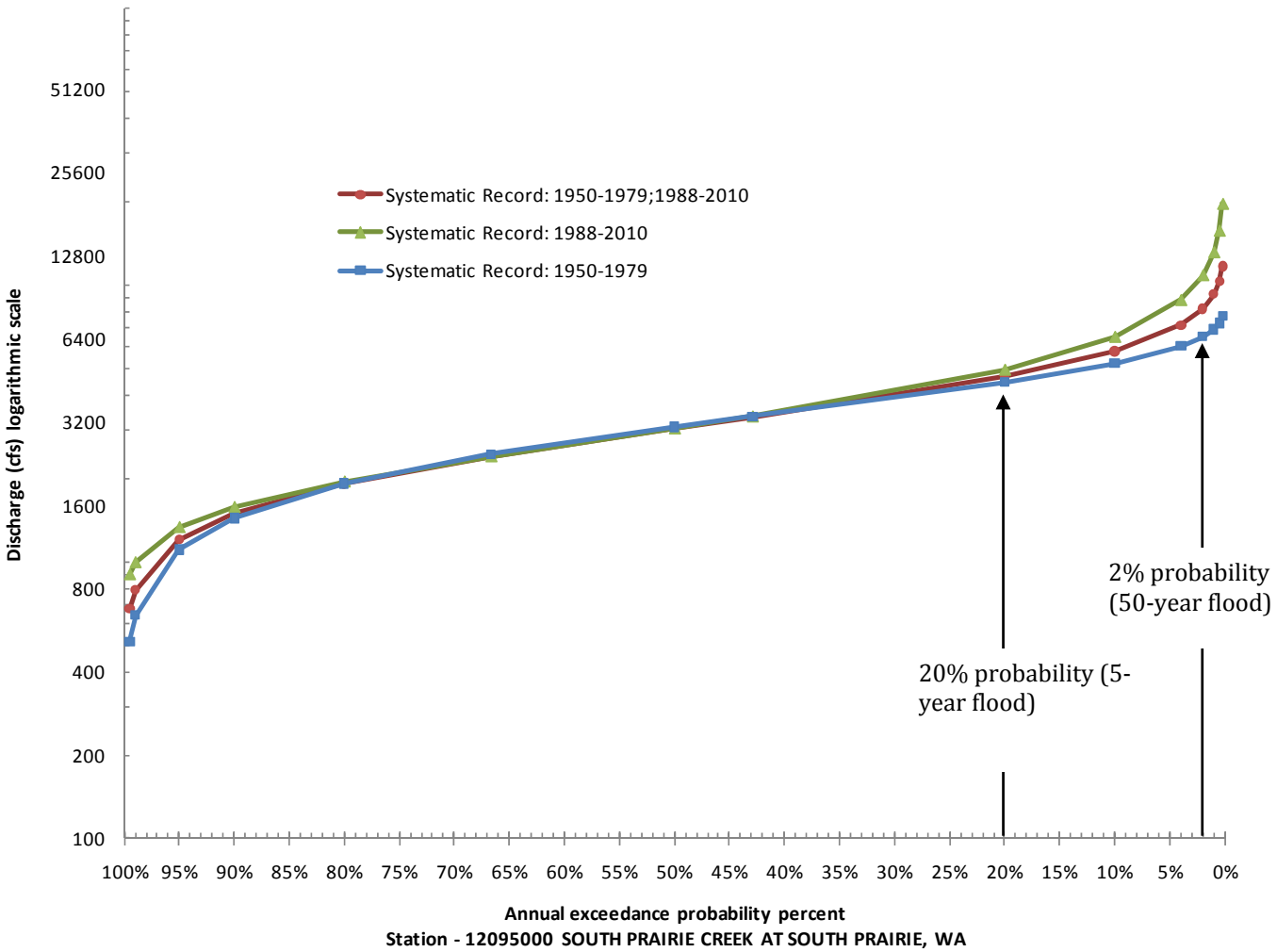


**Figure 5: The hydrograph shows the change in peak flows between 2 periods of record and the entire period of record. The 1988-2010 record**

## Soils and geology

Wilkeson Creek within City jurisdiction has two distinct reaches based on geology and soils. Both influence the channel pattern and response. Upstream of the City of Wilkeson's eastern boundary, Wilkeson Creek flows through a narrow bedrock valley with channel gradient ranging from 1.2 to 15%. Low falls and rapids occur in the ravine reach of Wilkeson Creek where the stream crosses resistant sandstone layers (Gard 1968). The stream gradient quickly decreases when it emerges from the incised ravine and enters the Puget Sound Lowlands where the stream is superimposed on alluvial fan, floodplain, and glacial drift deposits. The LiDAR DEM indicates that the stream in this reach exhibits characteristics similar to Holocene incised (e.g. multi-channel with low sinuosity) (e.g. Collins and Montgomery 2010).

The soil series in Reach 1 are aquic xerofluvents which are associated with floodplains and recent terraces. The soil in this reach is a sandy silt loam with silt (57.1%) being the major texture component. Sand follows at 32.9% while the remaining 10% is clay. Both the silt and sand components are erodible. Field observations indicate that there is a shallow subsurface water body that maintains

wetlands and produces seepage on the terraces and banks. Since this soil series has a higher soil erosion coefficient (kffact=0.37) and seepage, surface rills or gullies could increase bank erosion potential where the rills or gullies intersect with banks. The riparian vegetation reduces the erosion so should be maintained.

Where the large ice-marginal melt water channel (Gard 1968) intersects Wilkeson Creek valley near Reach 1c, the glacial geology changes to glacial drift with a high erosion potential (Figure 6). The soils also change to the Alderwood series which have high sand content (68.5%) and low silt and clay content. The high sand content increases the erosion hazard on stream banks.

The stream contacts the Carbonado Formation (Eocene, middle to upper, continental sedimentary deposits) on stream left in Reach 1a and 1c. The sandstones are relatively resistant and are geologic constraints to channel movement where the channel is bordered by the formation. The valley bottom is coarse glacial drift which has a moderately high to high erosion potential. Some material from the coal slag deposits are being delivered to the stream. These deposits are evident in Reach 1.

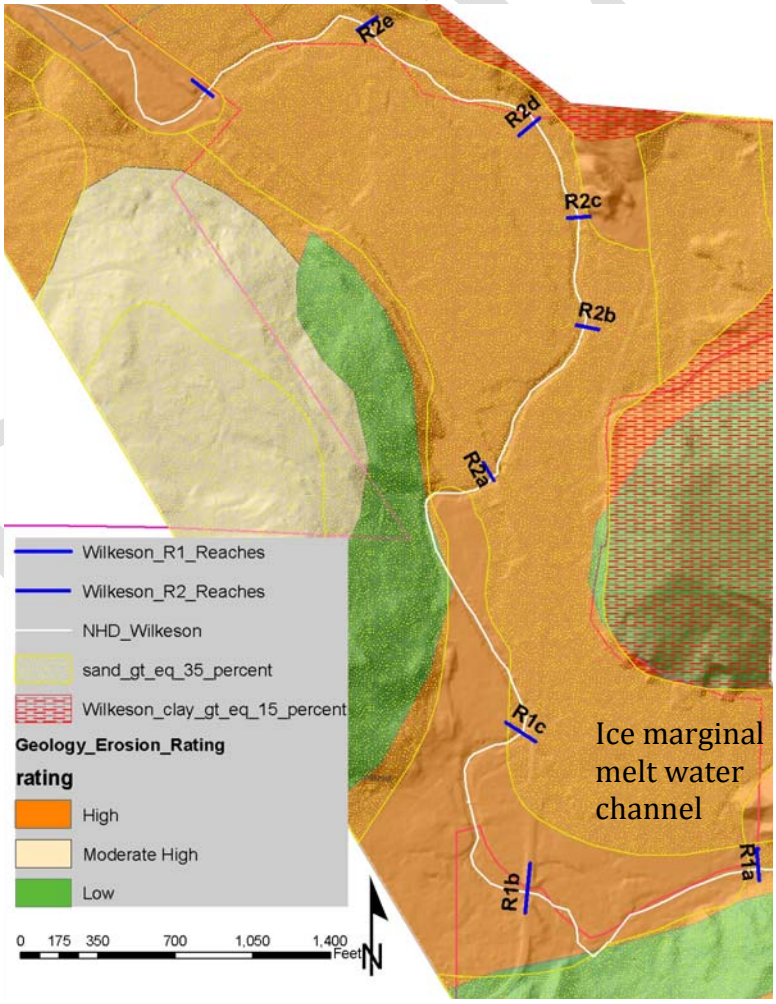


**Figure 6: Soil texture along Reach 2, Wilkeson Creek is mostly sand (high bank erosion potential) overlying glacial drift deposits (high erosion potential) associated with ice marginal channel.**

## *Channel migration: Wilkeson Creek*

Recent events show that channel migration processes, which include channel incision, bank erosion, aggradation, meander cutoffs and avulsions as well as lateral and translational movement, occurs along Wilkeson Creek. The channel migration that occurred during the 01/2009 flood was episodic with an approximate maximum of 61 feet of channel erosion during that event. However, a comparison of older orthophotos to 2006 orthophotos and 2004 LiDAR DEM in addition to onsite observations show that channel migration has occurred and is still active in other reaches (Figure 7, Table 6).

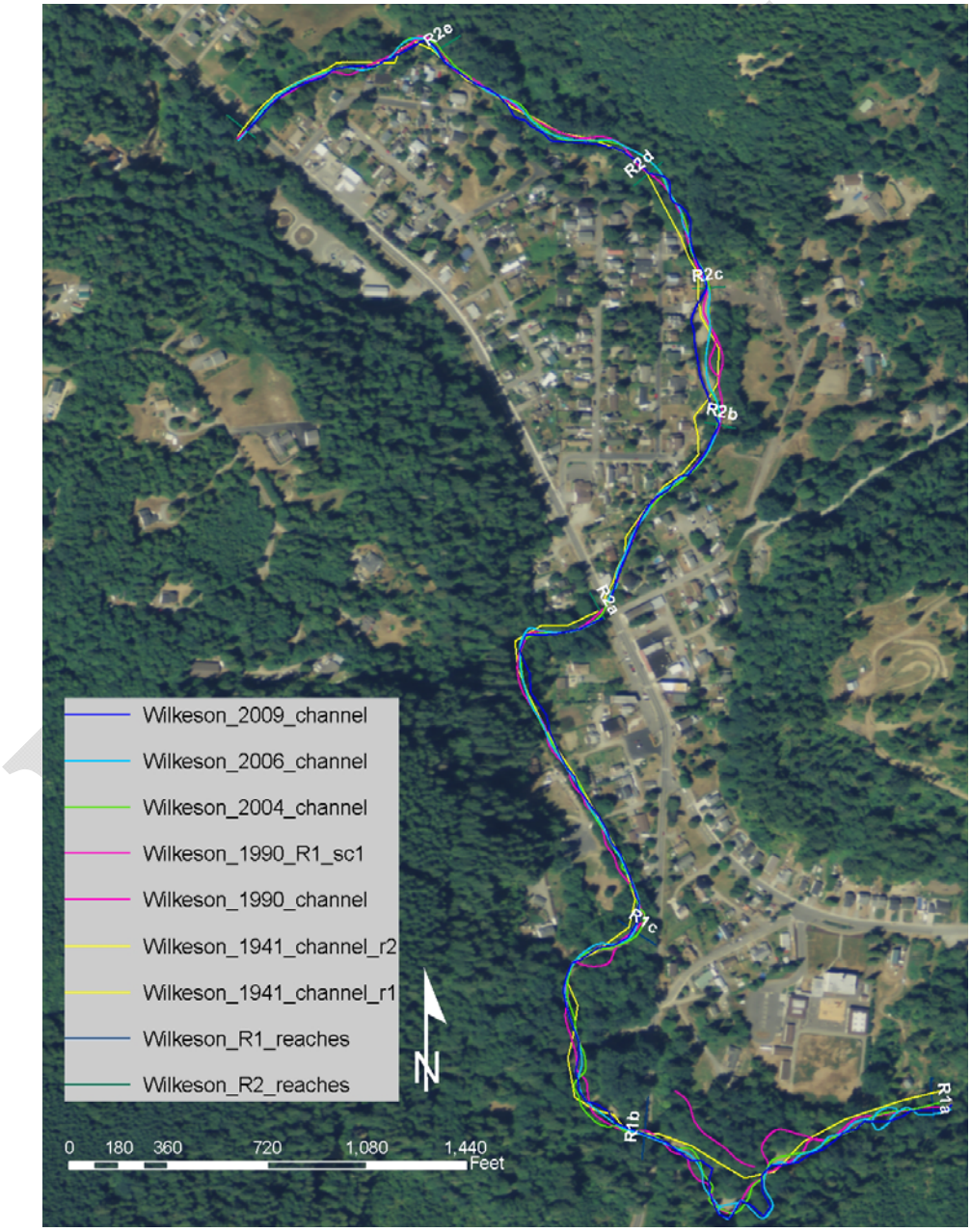


**Figure 7: Channel streamline traces show channel location from 1941, 1990, 2004, 2005, 2006 and 2009.**

**Table 6: Annual migration rates calculated by reach for 2 periods: 2006-2009 and 1990-2006. Since high flows appear to be increasing the maximum annual rates from the most recent period are used to map the channel migration area. The 1941 orthophoto was not used to estimate migration rates because geo-rectification error was higher than annual migration rates.**

| | Average annual rate (ft $yr^{-1}$) | | Maximum annual rate (ft $yr^{-1}$) | |
|---|---|---|---|---|
| Reach 1 | | | | |
| Years | 2006-2009 | 1990-2006 | 2006-2009 | 1990-2006 |
| 1a | 1.8 | 3.7 | 6.7 | 12.9 |
| 1b | 1.0 | 2.5 | 4.6 | 7.1 |
| 1c | 0.53 | 3.1 | 1.6 | 9.8 |
| Reach 2 | | | | |
| Years | 2006-2009 | 1990-2006 | 2006-2009 | 1990-2006 |
| 2a | 2 | 0.34 | 3.6 | 0.77 |
| 2b | 11.1 | 1.61 | 21.7 | 3.87 |
| 2c | 3.4 | 0.51 | 10.9 | 2.1 |
| 2d | 4.8 | 0.68 | 11.9 | 2.4 |
| 2e | 3.3 | 0.61 | 8.9 | 1.7 |

Reaches 1a and 1b:

Wilkeson Creek has been highly disturbed through mining activities and development. Because of the disturbance, the channel migration processes have been altered and evaluating future channel response is complex. In Reach 1a, disturbance from mining activities is still somewhat evident in sediment deposition areas. Evidence of coal slag deposits (and petrified wood) indicates that the slag deposits are still being eroded and transported downstream to Reach 1a. However, Reach 1a and portions of Reach 1b appear to be recovering from past mining and other disturbances. The migration rates also suggest that Reach 1 conditions may be improving. Even though the flood of record occurred between the 2006-2009 orthophotos, the annual migration rates were less than rates estimated from 1990-2006 (Table 6). The opposite is occurring in Reach 2. The stream in Reach 1a and 1b exhibits characteristics similar to Holocene incised channel with multi-channels. There is much evidence of secondary channels that have conveyed recent high flows, main channel braiding and switching and large wood recruitment (Photos 1, 2, 4). Because of this the channel migration zone is larger in this area than further downstream (Figure 8).

The channel migration area consists of the historic migration area, avulsion hazard area and floodplain, terrace and bank erosion hazard area. Potential avulsion paths were identified in both Reach 1a and 1b (Figure 8). In Reach 1a, avulsions are to be expected because avulsions are commonly associated with multi-channel patterns such as Holocene incised streams. The side channel elevations in relation to the main channel (Photo 3. Figure 9) and the power analysis (Figure 10) support this assumption.

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**Photo 1: Reach 1a view downstream at large wood accumulations and active channel erosion.**

**Photo 2: Reach 1a view upstream at dry channel adjacent to main channel.**

**Photo 3: Side channel and potential avulsion path on right floodplain near school yard. Water in channel is mostly groundwater.**

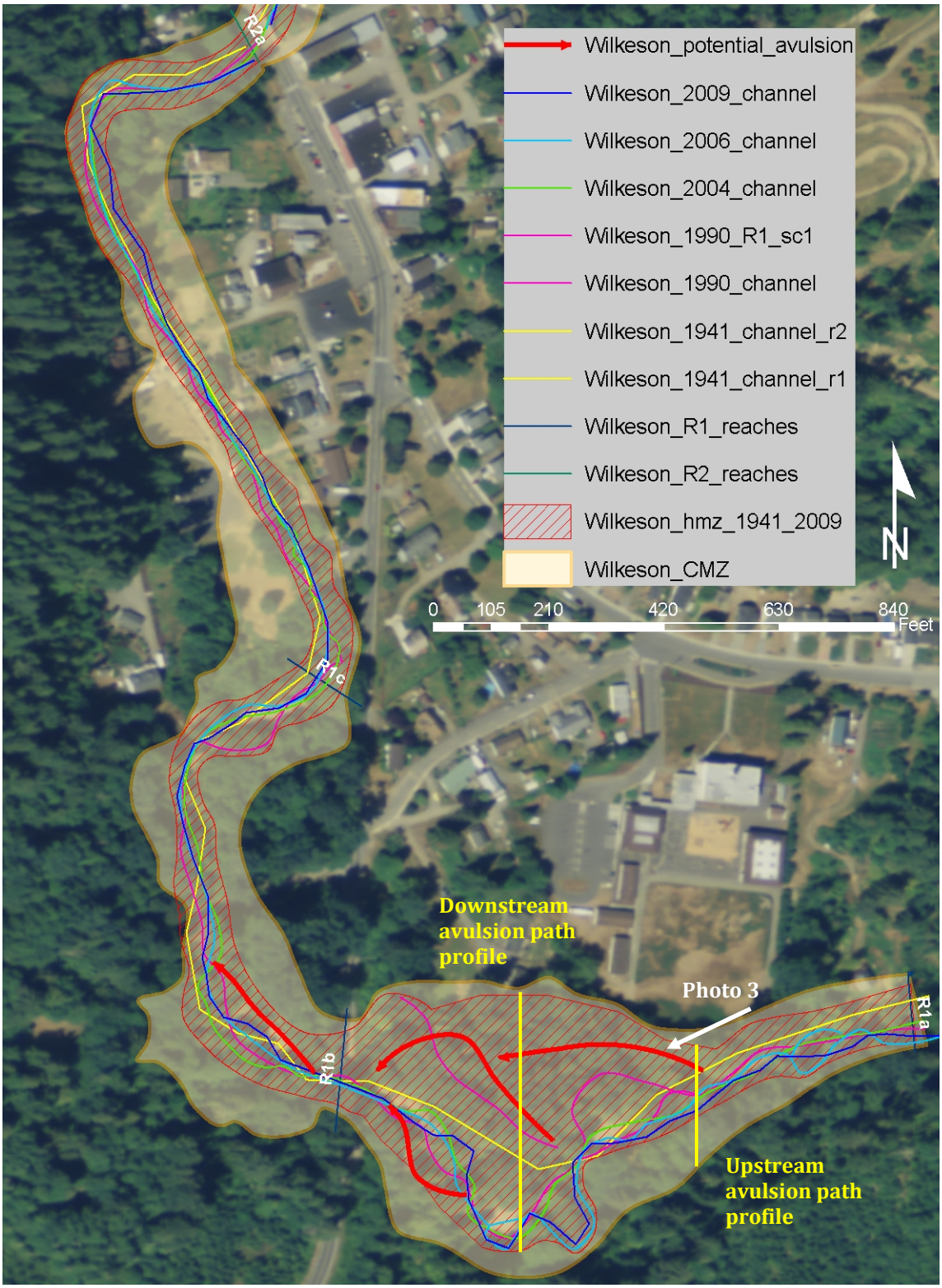


**Figure 8: The CMZ is the HMZ plus floodplain, bank and terrace EHA plus potential avulsion zones (Reaches 1a and 1b). The HMZ is based on stream locations from 1941, 1990, 2006, 2009 orthophotos and 1004 LiDAR. No disconnected migration areas (DMA) were included because there are no public roads within the CMZ and much of the channel constraints are privately maintained.**

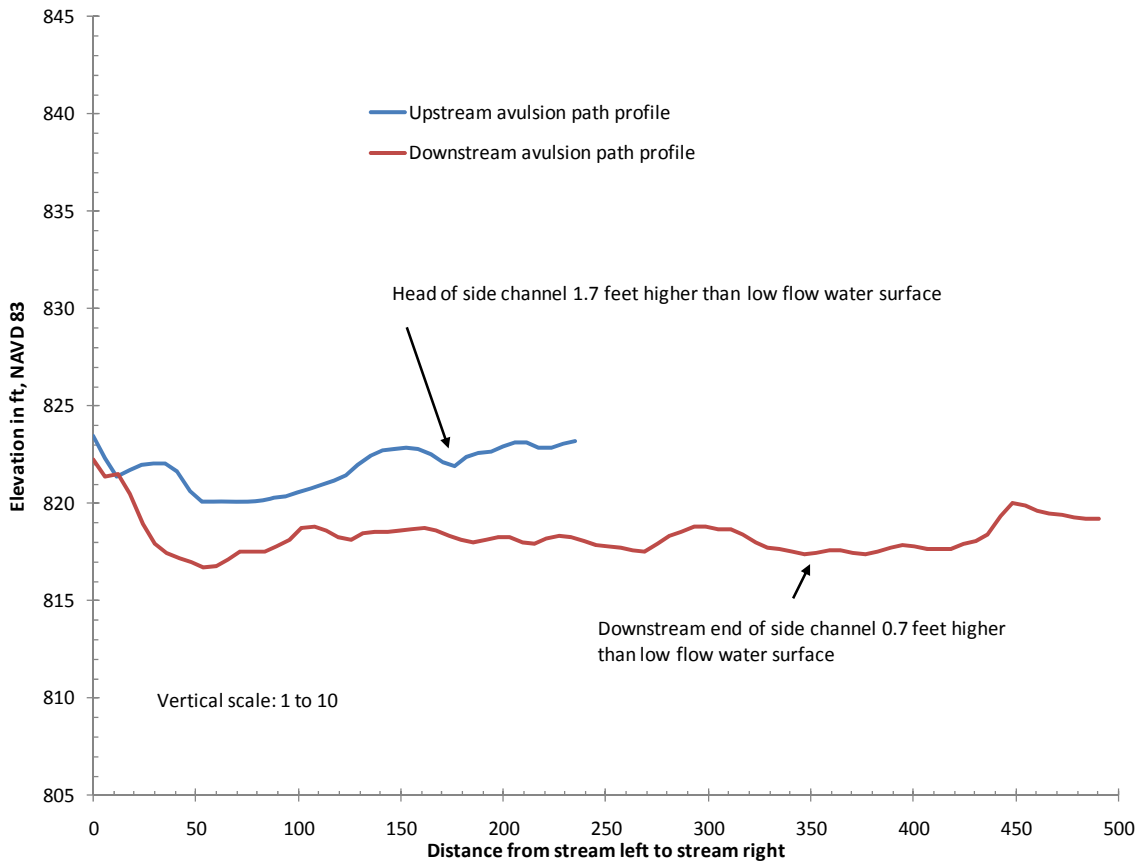


**Figure 9: Profiles of the upper and downstream avulsion path (Figure 8, Photo 3) show that side channel elevation is not much higher than water surface elevation at low flow. At higher flows, this channel will be occupied and become part of the main channel.**

The riparian vegetation and large wood jams in Reach 1a and 1b reduce floodplain, terrace and bank erosion (Photo 4). In Reach 1a, floodplain and terrace surface have active shallow groundwater seeps that create piping and channel initiation points. Removal of vegetation and wood would increase erosion hazards in both reaches. But removal would result in even a larger increase in the erosion near these seeps. The seeps on stream left are not within the City boundaries. However, vegetation removal in these areas will affect channel response of stream right which is within the city boundaries.

**Photo 4: View upstream in Reach 1b showing vegetation protection of banks.**

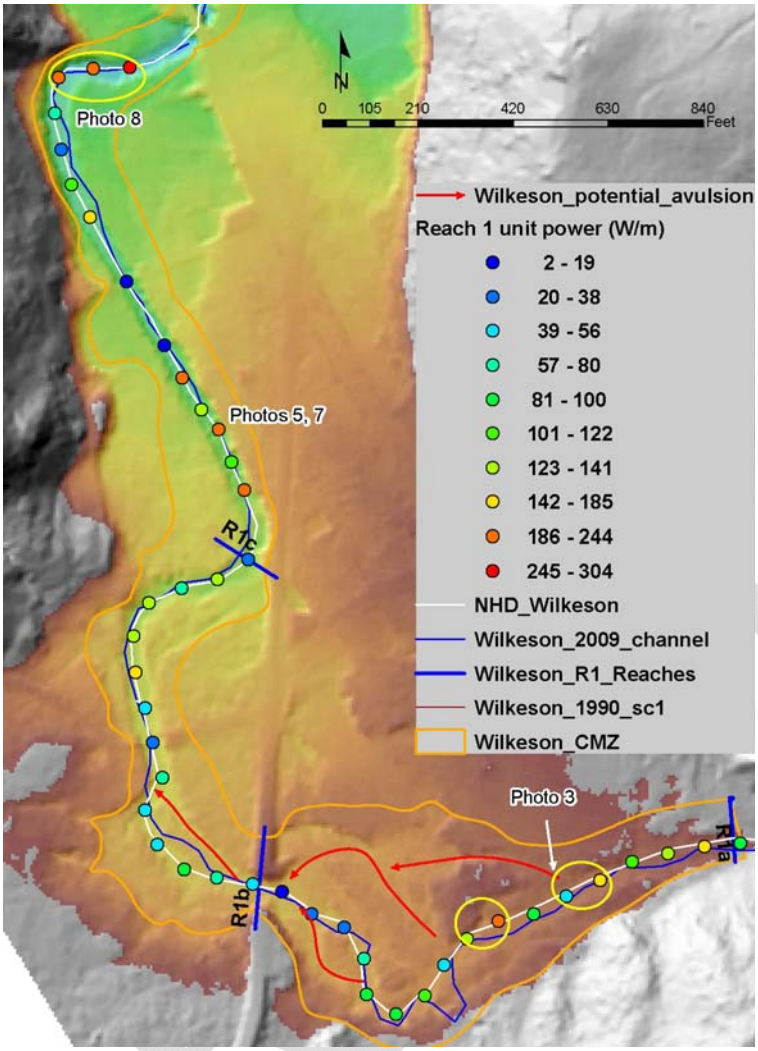


**Figure 10: Stream power analysis (unit power N $m^{-1}$ $s^{-1}$) shows that Reach 1a and 1b have lower unit stream power indicating that they are depositional areas. The yellow circles in Reach 1b highlight areas of high stream power to lower stream power at the head of potential avulsion paths. This condition can create avulsions.**

## Reaches 1c and 2b

Some incision has occurred in Reach 1c along Maple Street (Photo 5). However, Reach 2b is more incised (Photo 6). Incision can be caused by many factors including natural floods, increase in storm runoff (for example by loss of floodplain storage and increased runoff from impervious areas), an increase in high flow regime (e.g. Tables 4-5), a decrease in sediment, and hardening of stream banks through riprap, revetments and bridge abutments. Some empirical evidence indicate that the channel shape (width: depth ratio) is related to the percentage of silt and clay in the sediments forming the channel perimeter (e.g. Schumm 1977). Channels with higher silt-clay percentages may be narrower and deeper than those with high sand content. However, along Wilkeson Creek, the narrowest stream reaches with the steepest banks are occurring in soils with high sand content indicating that it is not naturally caused (Figure 11).

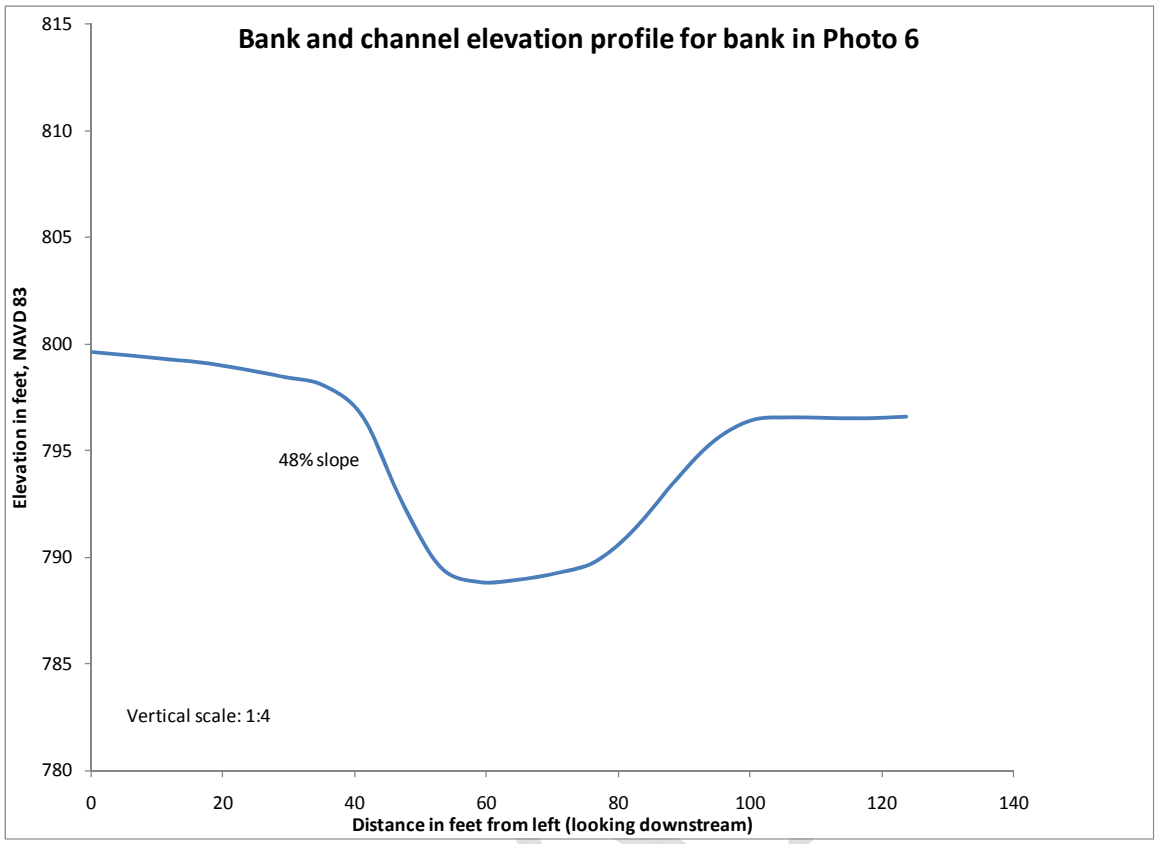


**Figure 11: Bank and channel elevation is from the 2004 LiDAR data. The bank slope is 48% which is overstep for sand. The profile is located near Photo 6 (also see Figure 12)**

When transport capacity (that is the ability of a stream to transport sediment) continually exceeds sediment supply, bank erosion, channel incision and entrenchment typically occurs. Erosion becomes the dominant channel process resulting in an increase in the mean size of bedload materials, lack of bed forms and reduction of channel complexity (Photo 5, 6). Channel pattern is often straight and incised with smaller width to depth ratios. In Wilkeson Creek, transport capacity likely increased in the constrained reaches as water velocity and stream power (a function of velocity and channel gradient) increased (Figures 10, 12). When a stream can no longer incise its channel bed, bank erosion will increase (Figure 14, Table 8). Consequently both incision and bank erosion occurs (Photo 5, 6, 7).

Some aggradation is occurring in Reach 1c. Photo 7 shows aggradation in the incised part of Reach 1c. The sand deposits are likely from bank erosion as the upstream channel sediment size ranges from gravels to cobbles. Bank erosion is also occurring in lower part of Reach 1c (Photo 8). This is occurring on in conjunction with increased stream power (Figure 10) likely due to Highway 169 bridge which confines the channel and high flow.

The channel migration area is dominated by the erosion hazard area in Reaches 1c and 2a (Figure 8, 15). The LiDAR data and orthophotos indicate that there has been limited lateral migration in these incised reaches but there is higher erosion potential (Photo 6, 7). Disconnected migration areas were not identified. There is

riprap within Reach 1c but it is privately maintained and some is failing so does not meet the SMP criteria as constraints to migration (Photo 5, 7). In subreach 2a, the left stream bank at the sewer pipe location has been stabilized and we assume will be maintained by the city but it does constitute a constraint for the entire Reach 2a.

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**Photo 5: Reach 1c: Photo on left is incised channel in Reach 1c. Riprap is evident on stream right. Some is failing.**

**Photo 6: Reach 2a: View downstream at incised channel. Bank erosion is occurring on stream left.**

**Photo 7: Reach 1c: Aggradation and bank failure occurring in incised channel.**

**Photo 8: Reach 1c: View downstream showing bank erosion downstream of the incised reach. Photo J from Wilkeson's first draft Inventory and Characterization**

Reach 2b

During the 01/2009 flood, the channel changed from straight to meander along Cothary Street with substantial lateral migration (approximately 61 feet maximum erosion). Likely there was evidence of bank erosion occurring before the channel moved during 2009. Human activity can cause significant channel change by creating a "threshold crossing" (e.g., Church 2002). Apparently, a threshold "crossing" occurred in Reach 2b. Channel migration in Reach 2b appears to be a response to upstream hardening. Incision often results in downstream aggradation (sediment deposition) as the eroded sediment from the incised reach is transported to a reach with lower stream gradient such as Reach 2b (Photo 9). Aggradation can increase bank erosion and subsequent lateral migration or cause avulsions (channel switching to a new location).

**Photo 9: Photo 9a on left shows flood deposits on channel left at head of channel migration section. Photo 9b on right shows older aggradation as bars on channel right as well as damage caused by channel migration.**

Thresholds are set by conditions that govern channel processes and response. The more important conditions include flow regime, sediment volume and size, and topographic setting ((Church 2002)Channel change from one pattern to another is closely related to transport capacity (ability of stream to transport sediment) and bank stability. Stream power provides a metric for transport capacity. A stream power analysis was done to evaluate the possible causes of channel change in Reach 2b (Figure 12).

The analysis suggests that an increase in stream power and downstream aggradation may have caused the channel to migrate during the 01/2009 flood. In 2004, just upstream of where the channel migration occurred stream power was much higher than at other stream points (Figure 12, Table 6). Stream power decreased substantially just downstream of the channel migration head. Channel aggradation was occurring before the 01/2009 (Photo 9b). Deposition of fines occurred during the flood (Photo 9a). Cross-section profiles indicate that the channel elevation in the area of higher stream power (Cross-section 3, Figures 12, 13) was lower than channel elevation at the downstream cross-section (Cross-section 5, Figures 12, 13) confirming that aggradation was occurring in 2004.

LiDAR elevation data and cross-section profiles from Reach 2b provide additional information for evaluating the incision effects on bank erosion and channel movement (Figure 13). The banks in Reaches 2a and b are steep for the soil type (sands) (Figures 11, 13). The bank steepness increases bank failure potential. The stream power analysis, bank profiles and recent events indicate that in the incised reaches, channel movement may be responding to channel incision and subsequent bank failure. The channel evolution model illustrates this response (Figure 14, Table 8). Reach 1b and 2a appear to be Type II-III channels. Reach 2b, where the channel moved, appears to be approaching Type IV which is more stable form than the Type II-III.

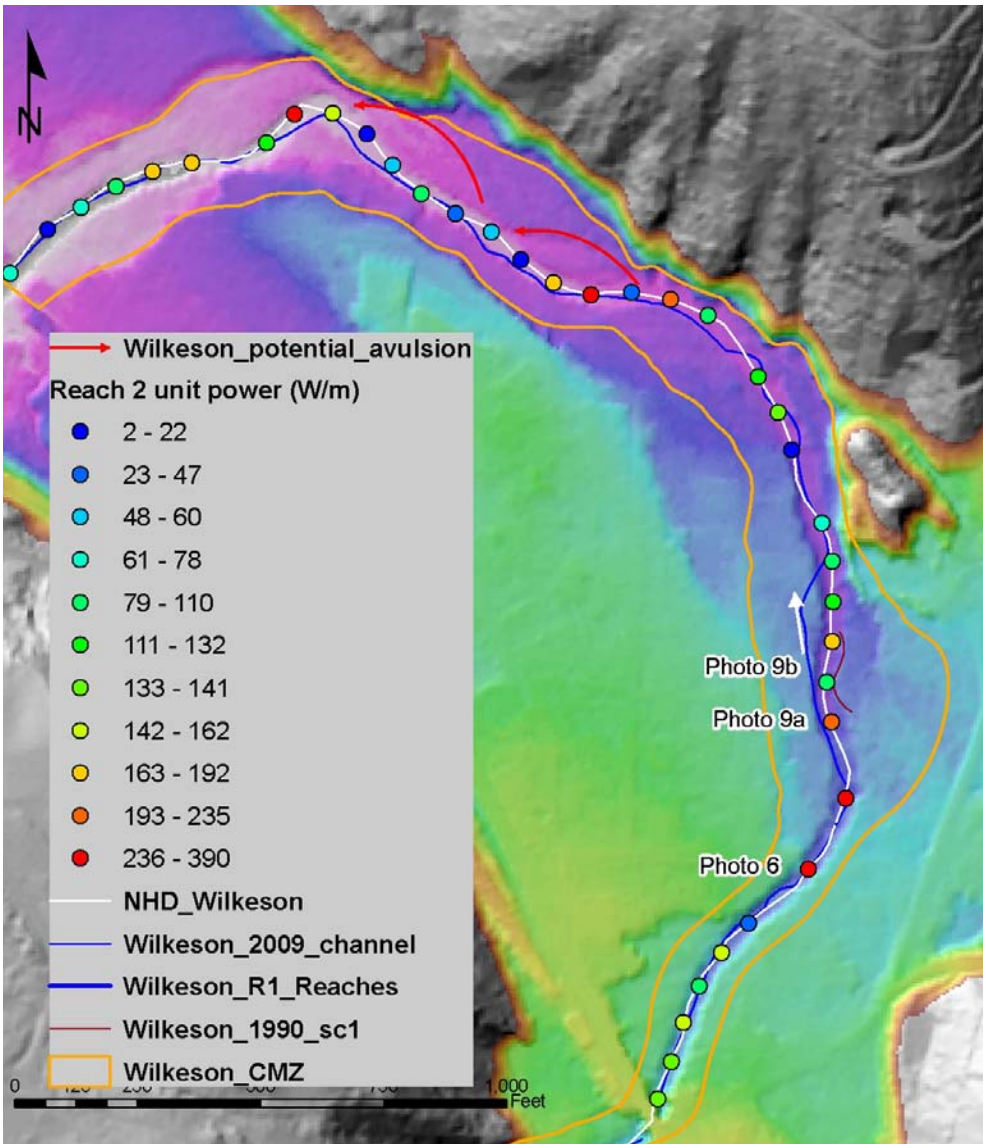
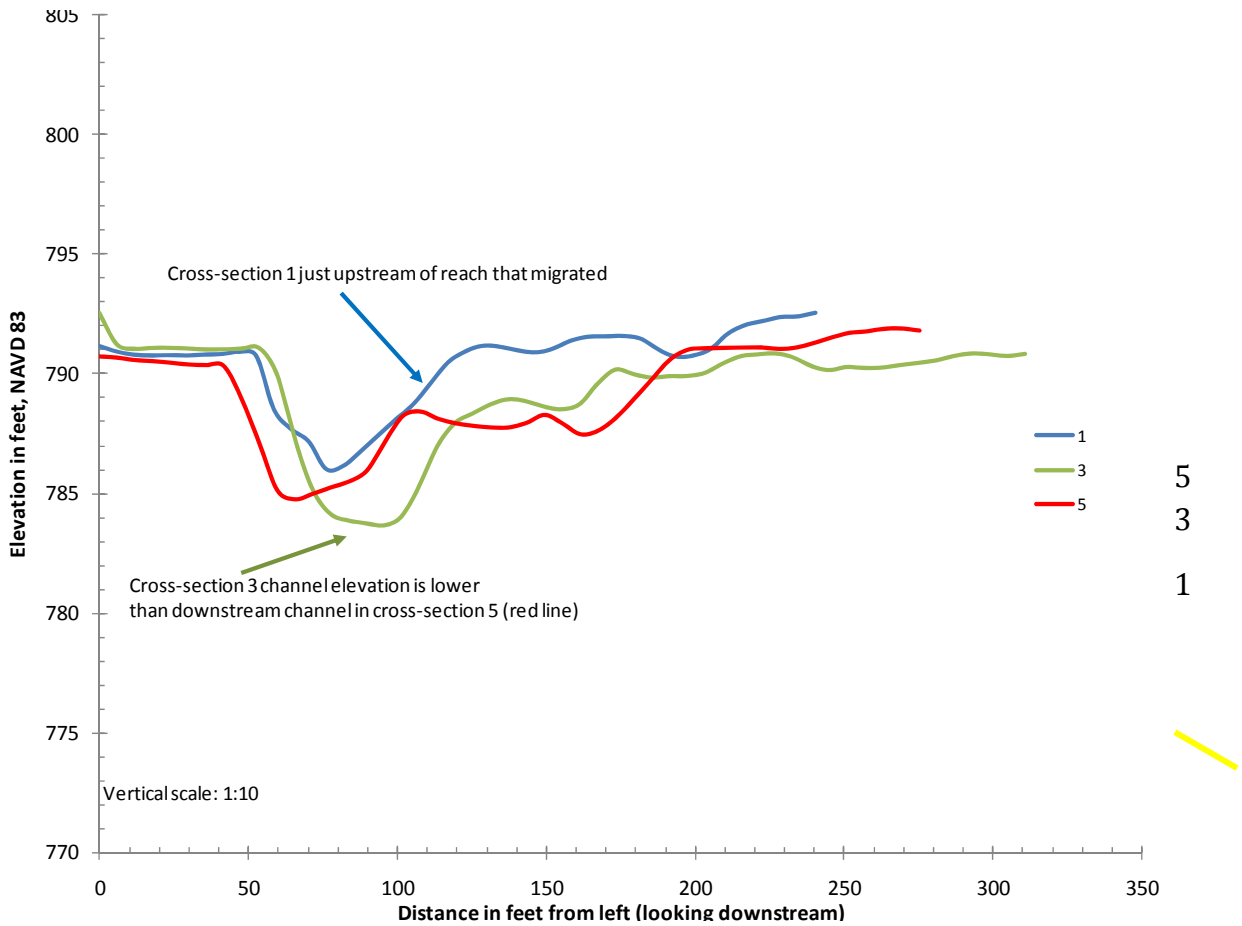



**Figure 12: : Stream power analysis (unit power N $m^{-1}$ $s^{-1}$) shows that Reach 2 shows areas of incision (orange to red colors) and aggradation (blue-green to blue colors). The cross-section profile shown in Figure 11 is yellow. The white cross-sections show locations in Figure 13.**




5
3
1

**Figure 13: Bank and channel elevation is from the 2004 LiDAR data. Cross-section profile locations are shown on Figure 12. Cross-section 1 is just upstream of where the channel migrated during the 01/2009 flood. Cross-section 3 is the downstream end of the incised stream in Reaches 2a, 2b. Cross-section 5 is in an aggrading reach. The aggrading reach channel elevation is higher than the upstream cross-section 3. Conditions like these can initiate an avulsion or substantial bank erosion may occur. Incision and downstream aggradation appear to be major contributors to channel migration in this reach.**

Stream power is directly related to discharge. The South Prairie Creek discharge data indicates that the frequency of higher magnitude flows is increasing. Increased flow results in higher stream power. Other factors can reduce the high flow effects on the channel and banks. Vegetated banks have greater strength especially where the channel bed is at or near the rooting zone. In the case of Reach 2 much of the vegetation with deeper roots (trees) has been reduced substantially and replaced by shallow rooted vegetation such as grass and shrubs. Off channel flood storage, such as wetlands and connected floodplains, also reduce high flow effects.

For example, Reach 1a and portions of 1b have more extensive riparian buffers as well as riparian wetlands and less artificial confinement and disconnection from the floodplain. This reach was much less affected by the 01/2009 flood indicating that artificial channel confinement, significant reduction in deeper rooted riparian vegetation, and loss of floodplain storage were major contributors to the incision and subsequent bank erosion and aggradation. The combination of factors created conditions favoring channel migration.

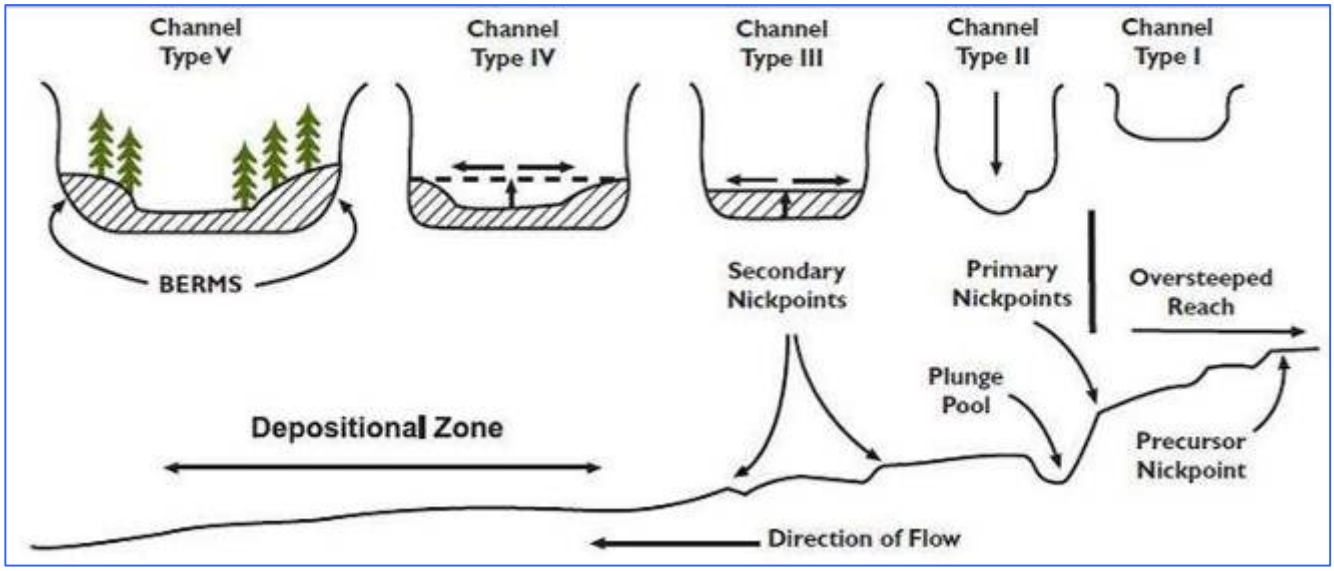



**Figure 14: Schumm et al (1984) developed a conceptual channel evolution model for degraded alluvial channels. The model describes the systematic response of a degraded channel over time.**

**Table 7: Descriptions for the channel evolution model schematic in Figure 10.**

| |
|---|
| Type I—<br>• Sediment transport capacity > sediment supply. For example, an increase in discharge increases sediment capacity.<br>• Bank height (h) < critical bank height (hc).<br>• U-shaped channel cross-section. |
| Type II—<br>• Immediately downstream of knickpoint. A knickpoint is an abrupt change in thalweg elevation, and may be visualized as a small rapid or waterfall.<br>• Sediment transport capacity > sediment supply.<br>• h< hc<br>• Bed slope < than Type I because water depth has increased |
| Type III—<br>• Sediment transport capacity varies with respect to sediment supply<br>• h>hc with bank erosion often due to slab failure<br>• Bank loss rates at a maximum<br>• variable sediment deposition may start forming bars<br>• Channel depth generally > Type II depth<br>• Channel widening due to bank failure |
| Type IV—<br>• Sediment supply>transport capacity resulting in bed aggradation<br>• h approaches hc<br>• Less bank failure than Type III & failure may change from slab to circular-arc failures<br>• Channel widened<br>• Berm, natural levees at the edge of the effective discharge channel may form |
| Type V—<br>• Sediment supply and transport capacity in balance—dynamic equilibrium<br>• h<hc<br>• vegetation is colonizing bank with decreased bank angle from accumulation of failed bank materials at toe slope<br>• aggraded channel<br>• channel sinuosity increases<br>• newly formed floodplain |

The channel migration zone in this reach is defined by recent and historic lateral migration as well as erosion hazard areas (Figure 15). The erosion hazard area extends landward of the Cothary Street. However, the SMP guidelines exempt areas that are landward of publicly maintained roads that are above the 100-year flood elevation. Cothary Street meets the exemption criteria so the channel migration zone is not mapped landward of the road.

Reaches 2c-e

Some aggradation occurs within these reaches (Photo 10). The channel movement in Reach 2b added additional sediment available for transport downstream to Reaches 2 c-e. For now, the sediment mostly has stayed within Reach 2b and upper Reach 2c.

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**Photo 10: View downstream at channel aggradation, Reach 2d. Photo in Wilkeson's 12/2010 draft Inventory and Characterization taken 9/30/2010 by The Watershed Company.**

The channel migration zone in this reach is defined by recent and historic lateral migration as well as erosion hazard areas (Figure 15). The erosion hazard area extends landward of Brierhill Boulevard and Short Street. However, the SMP guidelines exempt areas that are landward of publicly maintained roads that are above the 100-year flood elevation. Cothary Street meets the exemption criteria so the channel migration zone is not mapped landward of the road. While the avulsion hazard zone in Reach 2d is not within the city's boundaries, an avulsion in this location will affect channel response within the city

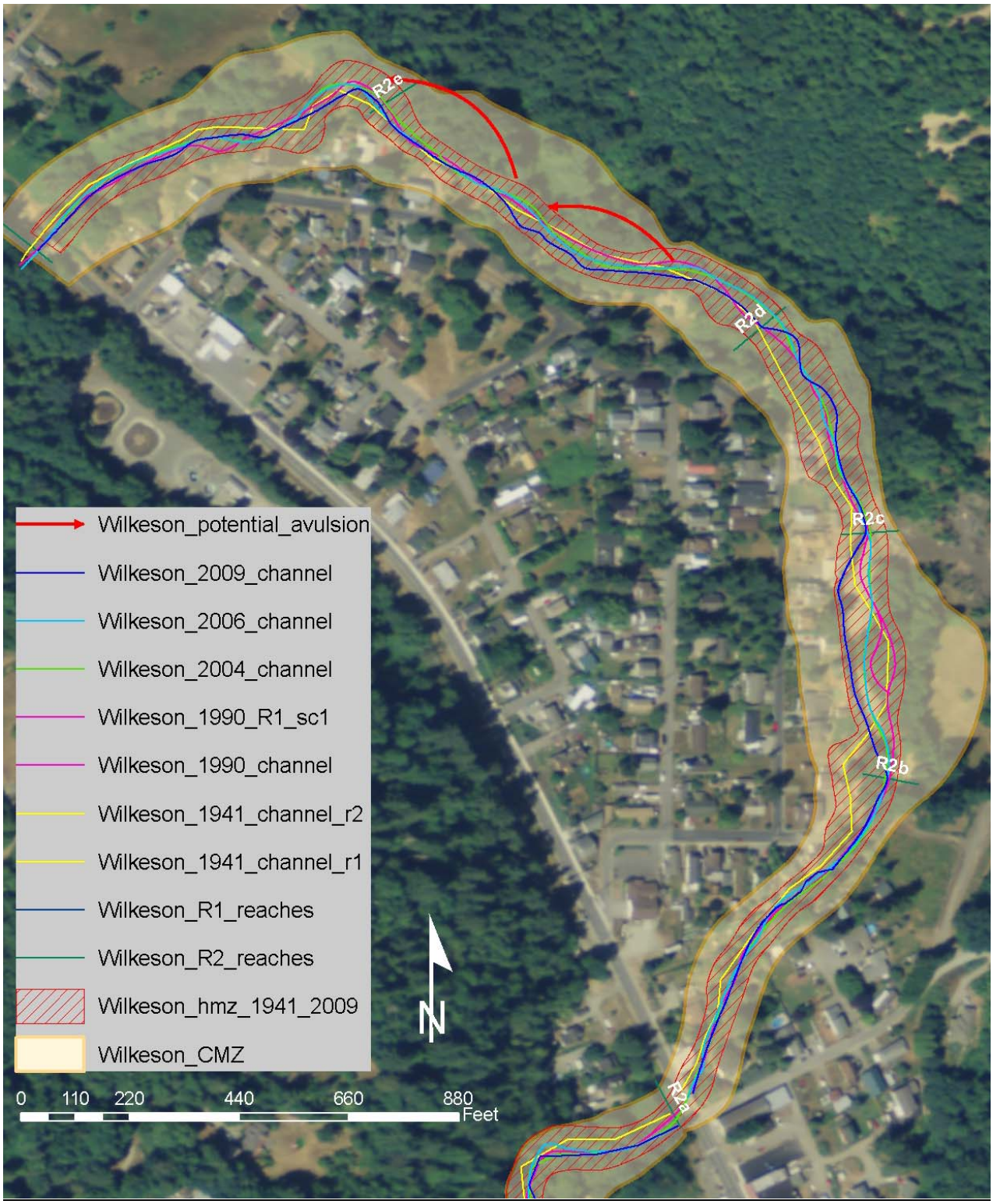


**Figure 15: The CMZ is the HMZ plus floodplain, bank and terrace EHA plus potential avulsion zones (Reach 2d). The HMZ is based on stream locations from 1941, 1990, 2006, 2009 orthophotos and 1004 LiDAR. Disconnected migration areas are located landward of Cothary and Short Streets and Brierhill Boulevard.**

## Conclusion

The evidence suggests that artificial channel confinement, loss of flood water storage and removal of channel wood are likely major contributors to changing Wilkeson Creek's transport capacity and subsequent bank erosion and channel migration. Increased frequency of higher magnitude floods will also contribute to increased bank erosion, channel migration and possible avulsions. Under this scenario, maintenance of riprap and other bank protection structures will be require more diligence and will be more expensive. For example in Reach 1c, some riprap appears to be unmaintained (so not a legal constraint to channel migration) and appears to be failing. While structures can be flood proofed, there are no standards to "channel migration proof" structures.

The SMP guidelines allow existing primary structures to be protected by bank stabilization when need is shown. However, geotechnical reports by qualified and licensed people (for example geotechnical engineer or engineering geologist) are required.

- WAC 173-26-231(3)(a)(iii)(B): *New structural stabilization measures not allowed except when need is demonstrated to protect an existing* ***primary*** *structure and meets criteria outlined in WAC 173-26-231(3)(a)(iii)(B)(I-IV).*
- WAC 173-26-231(3)(a)(iii)(C): *Existing structures can be replaced if there is a demonstrated need to protect principle use or structures from erosion based on criteria listed in this section*
- WAC 173-26-231(3)(a)(iii)(D): *Geotechnical reports are needed to demonstrate need to prevent damage to primary structure. The report must show time frames and rates of erosion, and urgency for stabilization. Stabilization methods using Hard armoring solutions (defined in WAC 173-26-231(3)(a)(ii)) should not be permitted except if the structure will be damaged within 3 years.*
- WAC 173-26-231(3)(a)(iii)(E): *Standards for new stabilization structures (besides geotechnical reports) when found to be necessary include limiting the size to minimum, using measures to assure no net loss of shoreline ecological functions, using soft approaches, and mitigating for impacts.*

However, new development within channel migration areas such as on vacant lots along Reach 2b and 2c on channel left should not be placed were future flood or channel migration measures will be needed:

- WAC 173-26-221(3)(c)(i): *New development or new uses in shoreline jurisdiction, including the subdivision of land, should not be established when it would be reasonably foreseeable that the development or use would require structural flood hazard reduction measures within the channel migration zone or floodway.*

Increasing flood water storage, adding more riparian vegetation with larger buffers, and maintaining the character of Reach 1a and 1b will help reduce, but not eliminate, the potential impacts. In incised reaches, grade control and large wood

could possibly reverse the effects of incision on the channel and stream side structures. However, they should be designed by qualified persons with much experience in fluvial geomorphology and channel response as well as hydraulic dynamics.

## Errors and Disclaimer

Data error from geo-rectification and digitizing channel traces can lead to under or over estimated migration rates. In this lower level assessment method, error is assumed but not quantified. The primary limitation is the maps will have lower accuracy than a more detailed assessment. We assume that the assessment only provides a general map of the channel migration areas. More detailed assessments, conducted by qualified, and preferably licensed, geomorphologists, hydrologists, geologists (including engineering and hydrogeology specialties) or engineers with at least 5 years of fluvial geomorphology experience should be required for regulatory purposes and future development.

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APPENDIX A: Wilkeson CMZ

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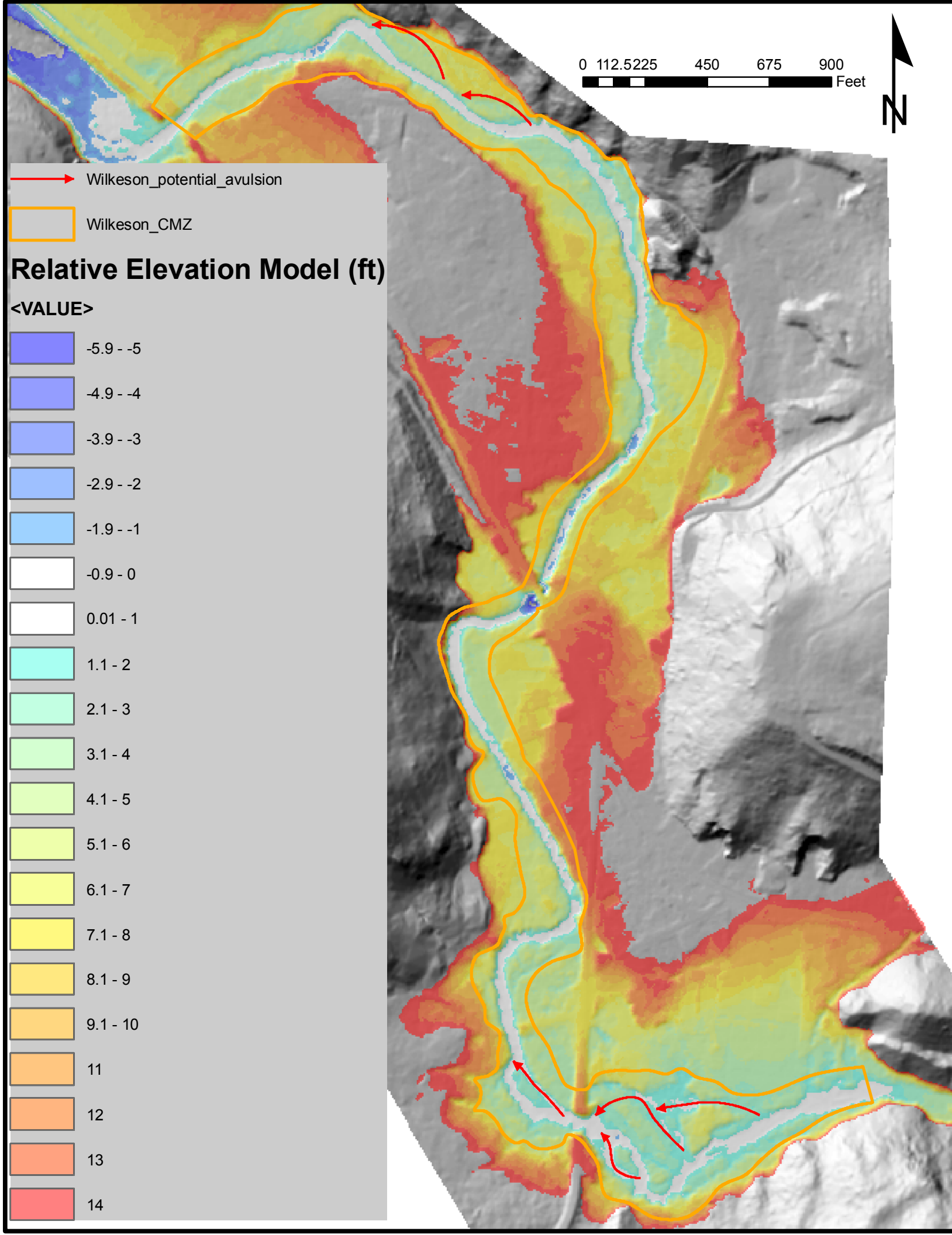
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