Title: Modeling geomorphic response to large wood introduction as a strategy to restore fish habitat in managed forest watershed

Investigators:
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Project duration:
July 1, 2014 – June 30, 2016

Objectives:

1) characterize the fluvial regime of three reaches before and after LW
2) classify channel types in the alluvial stream network of the Mill Creek Watershed
3) develop a watershed scale model of channel geomorphic response to LW additions,

Background:
Even though large wood (LW) additions are often part of fish habitat restoration efforts, the relative success of these efforts is rarely evaluated or reported in terms of ecological significance. Under natural conditions and adequate sediment supply the interaction of stream channels with their floodplain allows river systems to recruit wood and develop complex morphologies [1]. This high level of complexity is often associated with the best habitat for anadromous fish [2, 3]. Historic forest operations that allowed clear-cutting to the edge of river systems and in-stream clearing of stored LW strongly disturbed this interaction leading to riparian areas dominated by deciduous species such as red alder and simplified channel complexity. Prospects for natural recruitment of LW by this alder dominated forest are low because of their small size and rapid decay. The Mill Creek Watershed is a tributary of the Siletz River that drains both commercial and Tribal land (Fig. 1). This system is ideal to study the effectiveness of restoration efforts that includes LW not only because it is part of a large scale (over 7.5 miles of stream) restoration effort lead by the Oregon Department of Fish and Wildlife (ODFW) and funded by Oregon Watershed Enhancement Board (OWEB) but also because is one of the ODFW Life Cycle Monitoring sites with fish population data since 1997. Partners in the project with the Mid Coast Council and ODFW include Weyerhaeuser, Department of Environmental Quality, Oregon State University (Segura is in charge of the geomorphologic component), and the Confederated Tribes of the Siletz Indians[1].

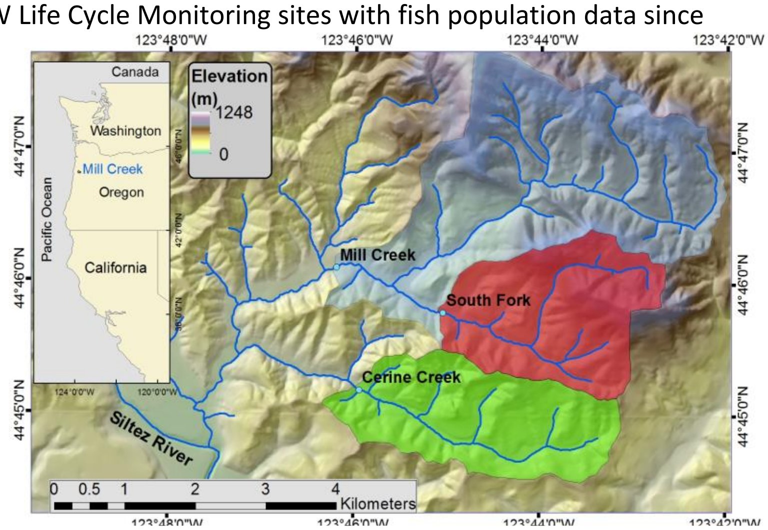

Figure 1: Location of Mill Creek watershed, OR. Study sites reaches Mill Creek, Cerine Creek, and South Fork are indicated.

Summary of accomplishments toward objectives:

Characterization of the fluvial regime in three reaches before and after LW: Using a two-dimensional flow model (Nays2DH), we were able to quantify the spatial and temporal changes in fish habitat triggered by the addition of LW in three sites (Fig. 1). This effort required a significant field campaign including topographic surveying, rating curve development, grain size characterization, etc. Here we focus on the hydraulic modeling results given that the field component of the project was presented in previous progress reports.

[1] http://www.midcoastwatersheds.org/in-progress/

Model: Nays2DH, a fully unsteady 2D flow model, was used in this investigation. This model solves finite differenced, depth integrated version of the Navier-Stokes equation assuming that the horizontal momentum transfer is larger than the vertical. Nays2DH inputs include: channel topography, discharge, channel bed roughness, downstream flow stage, and a characterization of the water surface initial condition at the upstream end of the model. Roughness in the model is expressed as a drag coefficient, which is typically adjusted during calibration. The model produces time variable distributions of velocity, shear stress, and wetted channel extend. We used the results of model runs considering bankfull flow (Q_{bf})conditions and bankfull flow events to develop metrics of geomorphic change relevant to fish habitat. These included vertical velocity, considering thresholds associated to the ability of fish to maintaining swimming position, and substrate stability, under the premise that juvenile fish bury during high flow as a survival strategy.

Velocity: At Q_{bf}, the addition of LW increased the area of habitat with acceptable velocity for juvenile Coho Salmon in all study sites. We considered 3 velocity ranges: below a critical velocity (v_{crit}=0.5 m/s) for winter-time ~8-10cm long Coho Salmon in the advanced fry to early smolt phase [4], above v_{crit} but below the burst swim speed (v_{burst} =1 m/s) of juvenile Coho Salmon [5] , and those greater than v_{burst}. Critical swimming speed is the maximum velocity at which a fish can maintain position in the flow stream for extended periods of time under a given set of environmental conditions.

LW jams backed up flow, increasing the width of channel as additional low velocity flow occupied areas near the channel margins (Fig. 2 presents an example). As a result, average velocities in the wetted channel decreased by 23-36% across all three sites. Increased floodplain connectivity upstream of LW jams created most of the additional area of acceptable habitat (dark blue in Fig. 2). This change was also evident in the shape of the frequency distributions of velocity, which became wider. Thus, further indicating that the heterogeneity of the flow field. The change in the velocity distribution show that after the addition of LW the area of long-term acceptable habitat ($v < v_{crit}$) increased by 17-26% (Fig. 2). ($v \leq v_{crit}$ where v_{crit} = 0.5 m/s [4])

We also consider temporal variability in habitat availably by modelling flow conditions over the duration of a bankfull discharge (Q_{bf}) event in all sites. Acceptable habitat area increased after LW addition for the entire storm duration in all three sites (Fig. 3, presents an example). The area of long-term acceptable habitat ($v < v_{crit}$) increased in average 23-29% over the hydrograph after the addition of LW. Wetted area increased 24-35% at Q_{bf} and additional floodplain connection occurred over 20-80 m of the banks for 33-57% of the hydrograph duration (Fig. 4, presents an example). This additional low velocity area should provide acceptable habitat locations for juvenile Coho Salmon.

Substrate stability: In order for bed material to provide acceptable shelter for juvenile salmon, we assume it must remain stable during high flow events. We calculated the critical shear stress for the motion of the median grain size of the bed as a metric to quantify the likelihood of substrate stability. We then quantify the area of the bed likely to remain stable during a storm event. At $Q_{bf,}$ the addition of LW caused reach-average shear stress values to decrease by 23-36%. This resulted in a 31-39% increase in the stable bed area, a 6-32% decrease in the area likely to be in partial transport, and a 7-25% decrease in the area likely in full transport. Areas of high shear stress, generally in the channel thalweg were disrupted as LW deflected flow laterally creating slower, deeper pools. Additionally, connected floodplain areas provided low shears stress habitat that was not previously available. The areas of low shear stress upstream of LW additions correspond to possible areas of sediment deposition. Further, areas of high shear stress in the immediate and downstream vicinity of LW additions indicate where scour is likely to occur over time. The changes to the distributions of shear stress, as in the case of velocity, showed that the area of acceptable habitat increased.

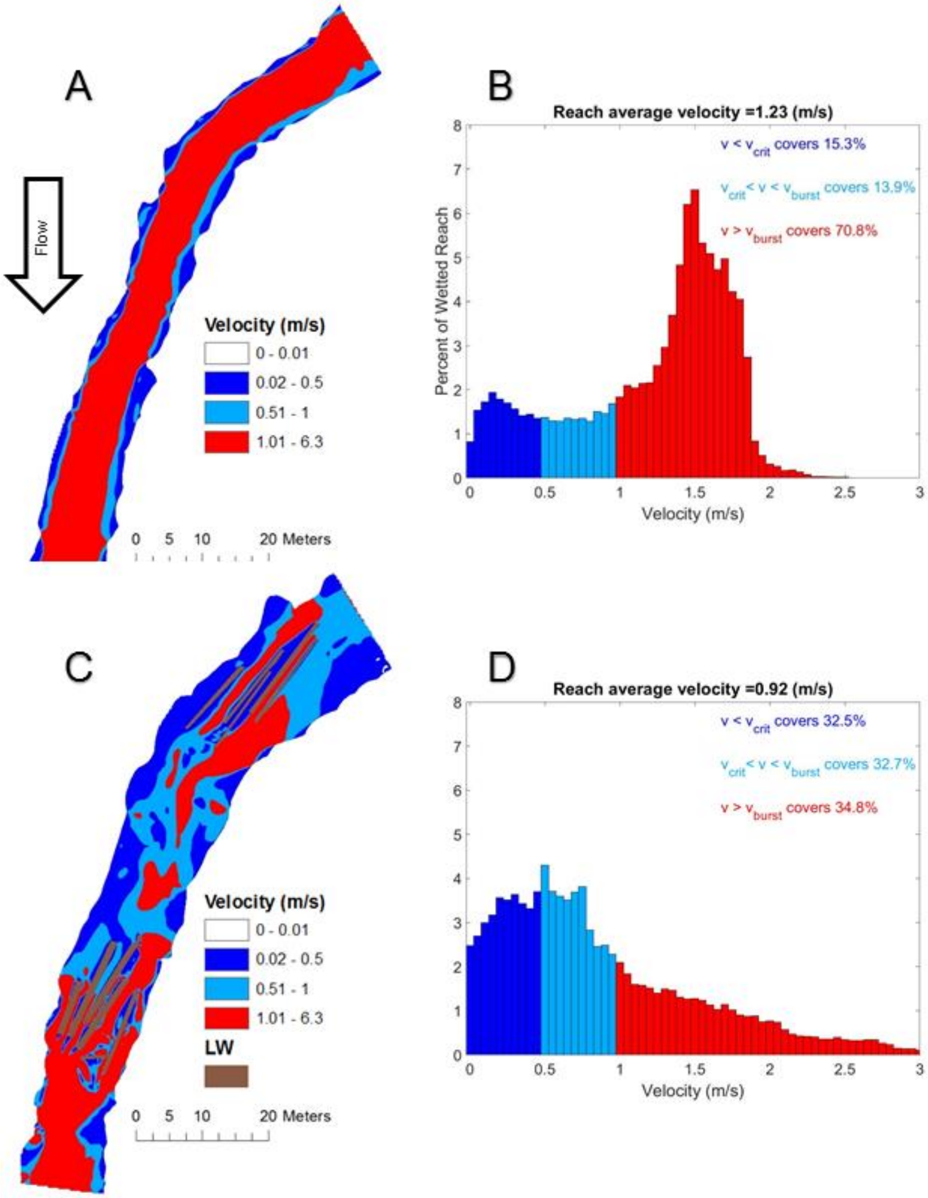

Figure 2: Spatial and frequency distributions of velocity at bankfull discharge before (A and B) and after (C and D) the addition of large wood (LW) in Mill Creek. Colors correspond to thresholds of velocity relevant to the ability of juvenile Coho Salmon to maintain position in the stream (dark $v < v_{crit}$ where $v_{crit} = 0.5$ m/s, light blue $v_{crit} < v < v_{burst}$ where $v_{burst} = 1$ m/s, and red $v > v_{burst}$).

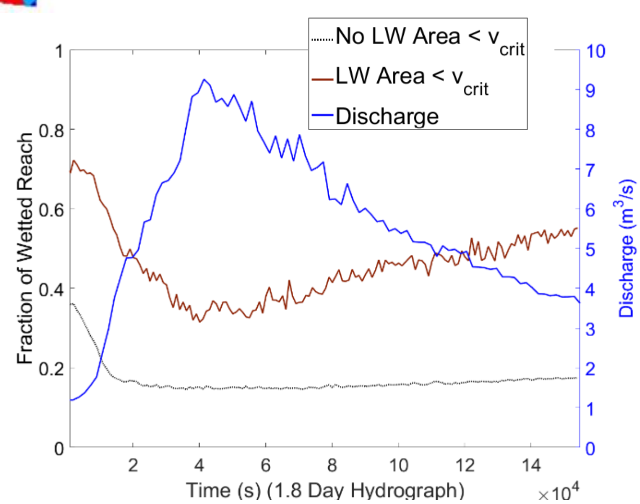

Figure 3. Fraction of wetted reach for Mill Creek, that has acceptable flow velocity ($v < v_{crit}$) over the entire 1.5 day bankfull storm hydrograph before and after LW addition.

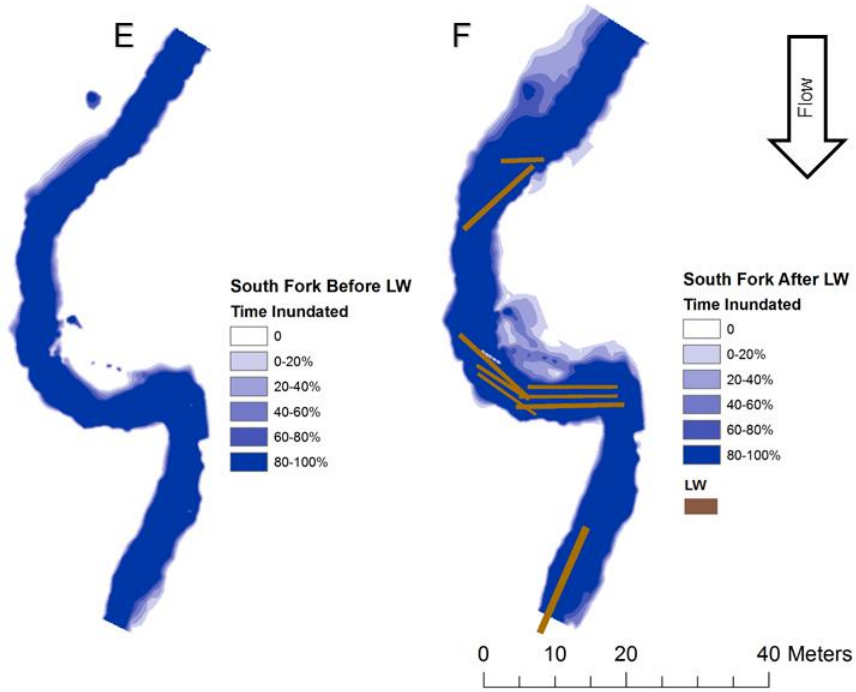

Figure 4: Timing of spatial increases in floodplain connectivity in South Fork before and after the addition large wood (LW). Colored areas show the percent of time during the storm hydrograph that an area was inundated.

<u>Classify channel types in the alluvial stream network of the Mill Creek Watershed:</u> We used the Netmap tool (http://www.terrainworks.com/) to classify all the stream network in Mill Creek considering reaches with stream order above 2 (Fig. 5). The results indicated that out of the 54 km of streams (order >2) 19% correspond to plane bed reaches; 14% are step pool; 7% are pool riffle; 2% are dune-ripple; and 58 % of the network is unclassified. In order to test the accuracy of Netmap we collected ground truth data along 5.5 km of Cerine Creek. The level of agreement was strong for plane bed reaches, which are the key interest in this study. However, Netmap was unable to classify about 2 km (or 36% of the comparison length) of channels that according to the field observations corresponded to either plane bed or forced pool riffle morphologies. In addition, Netmap incorrectly classified ~0.25 km of forced pool riffle reaches as plane bed. This inaccurate classification is not surprising considering that forced pool riffle morphology is generally triggered by the interaction of the flow with in-stream LW in reaches with slopes that could otherwise be associated with plane bed morphology [6]. The idea behind the channel calcification was to investigate how similar are the 3 sites we

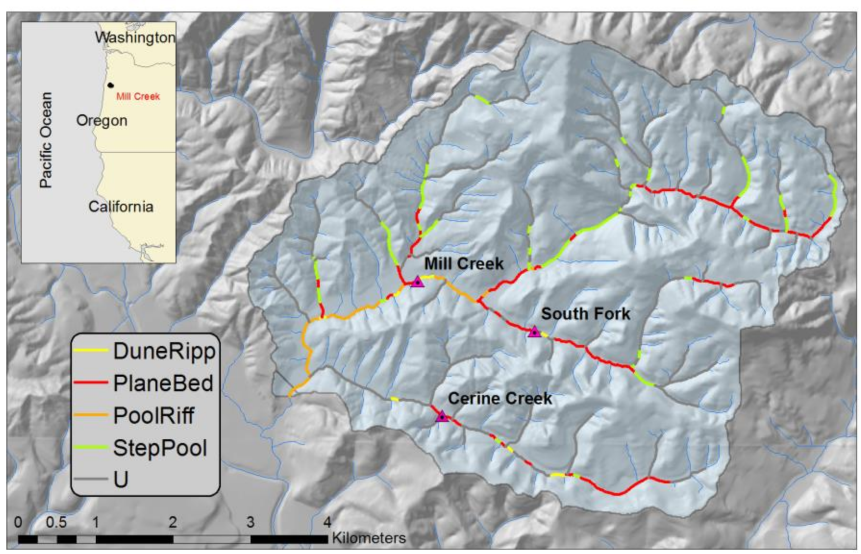

Fig. 5: Channel classification [1] of stream orders above 2 in the Mill Creek watershed. Three study reaches are also indicated.

intensely studied to the rest of the watershed. According to our results it is likely that our results are transferable to all other plain-bed reaches which occupied, according to NetMap 20% of the catchment.

Develop a watershed scale model of channel geomorphic response to LW addition: Our modelling results are one of the first attempts to include wood in a hydraulic model at the reach scale. While we were able to characterize in detail the geomorphic changes triggered by the wood over three sites, we are not yet able to estimate the overall basin response to the restoration effort nor the long term success. The results from the 3 study reaches indicated very similar responses. However, 3 reaches are not sufficient to generalize. For now, we anticipate very similar results in other plane bed sections of the stream network in Mill Creek.

Problems, barriers, proposed changes to objectives:
None to report.

Comprehensive summary of project results and impacts over life of project:
Large wood (LW) pieces are recognized as an important habitat component for salmon freshwater habitat. As such, they are often used in stream habitat restoration practices despite a lack of knowledge about their impacts on spatial and temporal hydraulic characteristics relevant to fish habitat. We use a hydraulic model to identifying patterns and magnitudes of change in aspects of the flow field that are relevant to juvenile Coho Salmon after an addition of LW. The Nays2DH model was used because of its capacity to model unsteady flows around LW structures in-stream. Flow conditions after LW addition were modeled in three alluvial plane bed gravel reaches of Mill Creek in the Oregon Coast Range, a long term salmon life cycle study site. Study streams are small, with a bankfull discharge between 2.2 and 8.7 m^3/s and bankfull widths varying from 5.5 to 10.6 m. Survivable habitat was characterized for the flow field in terms of a) velocity (v) less than critical swim speed of juvenile Coho Salmon (v_{crit} = 0.5 m/s); b) and bed refuge estimated based on the likelihood of the movement of the reach median bed particle size (D_{50}). Spatial and temporal increases in wetted area were also determined. After the addition of LW, the area of acceptable habitat increased 17-26% in terms of velocity, 31-39% in terms of substrate stability, and 24-35% in terms of wetted area at Q_{bf}. Similar magnitudes of increase were observed over an entire storm hydrograph in each site. Patterns of change in the flow field showed deep pools of slower water forming upstream of LW jams which agreed with initial field observations of geomorphic change. Newly inundated flood plains and bars represented large portions of the additional habitat after the addition of LW. These areas had low velocity and shear stress values indicating that their contributions to additional habitat will be resilient to fluctuation even if acceptable habitat metrics were to be adjusted. We found that 2D unsteady hydrodynamic flow models are a robust alternative to study the effects of LW additions to streams. Our results demonstrated that the introduction of LW to reaches in Mill Creek will increase the local area of acceptable habitat during high flow conditions. This effects could eventually lead to improved fish carrying capacity of the stream.

Preliminary results from this project were fundamental in the success of additional funding from OWEB ($17,500) and the National Science Foundation ($419,000)[2]. As part of these efforts we will monitor topographic changes in the 3 reaches for the next 3 years to assess long term restoration success. In addition, a new graduate student will complete her Masters also in Mill Creek around the question: *Where is most cost effective to conduct restoration efforts in a watershed.*

[2] Assessing the influence of lithology on the temporal-spatial variability of sediment transport and its relation to primary production in mountain streams. NSF, EAR Division.

List of names and brief overview of graduate and/or undergraduate engagement in project:

- Russell Bair, Master Student in Water Resources Engineering [7]. Russell graduated last May.
- Amelia Yeager, Master Student in Water Resources Engineering, conducted field work the summer of 2016.
- Jon Sanfilippo (field support 2014); Michael Griffith (field support 2015), Joey Tinker (field support 2015 and 2016). Part of the funds to support these students was provided by the College Mentorship Program.

List of presentations, posters, etc:

- Segura C, Bair R, Yaeger A: Qualifying fish relevant hydraulic changes triggered by Large Wood Additions, EP51D-04 American Geophysical Union, Fall Meeting, San Francisco, CA, Dec 2016 (Oral).
- Bair R, Segura, C Sticks'n'Cricks: Hydrodynamic Modeling of Salmon Habitat Around Restoration Projects, 6th Annual Water Research Symposium. Corvallis, Oregon. April 18 -19, 2016 (Oral).
- Segura C, Katz S, Bair Russell. 2016 Interactions between fluvial geomorphology and stream ecology. Geology Seminar Series PSU. Feb 10 (Oral).
- Bair R, Segura C, Modeling the Effect of Geomorphic Change Triggered by Large Wood Addition on Salmon Habitat in a Forested Coastal Watershed 2016 River Restoration Northwest symposium, Stevenson, WA, Feb 1 – 4, 2016 (Oral).
- Segura C, Katz S, Bair Russell. 2016. Sediment transport modeling. Water Resources Seminar. Feb 24 (Oral).
- Bair R, Segura C, Lorion, C, Modeling the Effect of Geomorphic Change Triggered by Large Wood Addition on Salmon Habitat in a Forested Coastal Watershed, EP43B-0972 American Geophysical Union, Fall Meeting, San Francisco, CA, Dec 2015 (Poster).
- Bair R, Segura C, Modeling Effects of Large Wood on Spatial and Temporal Distribution of Salmon Habitat, 5th Annual Water Research Symposium. Corvallis, Oregon. April 26-28, 2015 (Poster).
- Bair R, Segura C, Modeling Geomorphic Response to Large Wood Addition and Habitat Implications for Fish in a Managed Forest Watershed. Western Forestry Graduate Research Symposium. Corvallis, Oregon. April 27-28, 2015 (Poster).

List of publications, thesis citations:

Bair, R., Modeling Large Wood Impacts on Stream Hydrodynamics and Juvenile Salmon Habitat, in Water Resources Engineering Graduate Program. 2016, Oregon State University: Corvallis. p. 155.

We are currently in the process of summarizing our results in a journal publication to be submitted in 2017.

References: **1.** Montgomery, D.R. and J.M. Buffington, Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin, 1997. 109(5): p. 596-611. **2**. Beechie, T.J. and T.H. Sibley, Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams. Transactions of the American Fisheries Society, 1997. 126(2): p. 217-229. **3**. Flitcroft, R., et al., Riverscape Patterns among Years of Juvenile Coho Salmon in Midcoastal Oregon: Implications for Conservation. Transactions of the American Fisheries Society, 2014. 143(1): p. 26-38. **4**. Glova, G.J. and J.E. McInerney, Critical Swimming Speeds of Coho Salmon (Oncorhynchus kisutch) Fry to Smolt Stages in Relation to Salinity and Temperature. Journal of the Fisheries Research Board of Canada, 1977. 34(1): p. 151-154.

5. Taylor, E.B. and J.D. McPhail, Variation in Burst and Prolonged Swimming Performance Among British Columbia Populations of Coho Salmon, Oncorhynchus kisutch. Canadian Journal of Fisheries and Aquatic Sciences, 1985. 42(12): p. 2029-2033. **6**. Montgomery, D.R., et al., Pool Spacing in Forest Channels. Water Resources Research, 1995. 31: p. 1097-1105. **7**. Bair, R., Modeling Large Wood Impacts on Stream Hydrodynamics and Juvenile Salmon Habitat, in Water Resources Engineering Graduate Program. 2016, Oregon State University: Corvallis. p. 155.