Relating Juvenile Salmonid Use and Channel Hydraulics to Full-Channel Engineered Log Jam Structures.

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Abstract

Two full-channel engineered log jams were surveyed on third-order streams in Western Oregon. The survey included profiling the bathymetry and velocities along transects in the streams. Snorkel surveys were conducted to collect observations on fish location, orientation and behavior. It was found that salmonids predominantly feed in areas with sharp gradients between high and low flow. It was also found that larger fish linger in deeper, higher flow areas, whereas the smaller fish preferred lower flow regions near the edges of the stream. Regarding the channel profile, velocities were observed to be highest toward the center of the channel and immediately downstream of the log jams where there was turbid water. Elaborate channel profiles were found most beneficial to the feeding behavior of fish.

1 Introduction

Streams in the Pacific Northwest lack the volume of in-stream wood that they had prior to European intervention for several reasons. Because of the area's old-growth forests and quantity of wood, humans have logged many of the region's forests for timber use. This logging caused a decrease of large woody debris in streams due to riparian forest removal. In conjunction with logging, splash-damming practices further wiped out naturally-occurring wood in streams. Splash-damming involved building a dam behind which logs were dumped. When these dams filled with water, they were opened and the resulting flood would carry the logs downstream. This build-and-release method had a long-term effect on streams in many ways, including the removal of natural log jams, widening of the channel, scouring of sediment often to the bedrock, and loss of habitat (Miller, 2010). In the 1950's and 60's, policymakers were fearful that wood in streams had negative effects, such as impeding fish migration (Burnett et. al., 2008) and increasing the channel-scouring power of floods (Sedell et. al., 1988). Wood was removed in large quantities, and when combined with logging, these practices created a large deficit of wood in streams. It was later realized that, rather than negatively impacting stream habitat, large woody debris actually plays an important ecological role, particularly in creating habitat for salmonids (Burnett et. al., 2008). In 1973, salmonid species were included in the Environmental Protection Agency's endangered or threatened species list, and as part of an attempt to comply with salmonid habitat and spawning ground reintroduction, adding large wood to streams became common practice throughout the Pacific Northwest (Katz et. al., 2007). One component of adding large wood to streams was the engineering of log jams. These Engineered Log Jams (hereafter ELJs) were designed for a variety of specific purposes, ranging between habitat creation, bank stabilization, and flood control. Although the importance of large wood in streams is now understood, the effectiveness of ELJs at creating complex flows that improve fish livelihood requires further study in order to make the best recommendations for policy makers in the future.

The purpose of this study was to contribute to the understanding of how ELJs function in a stream. To do this, we surveyed a full-channel jam on each of two third-order streams in Oregon, USA, to obtain data for channel bathymetry, velocity profiles, and fish behavior.

The quantity of organic matter present in streams is proportional to the water velocity (Fausch, 1984). Since salmonids feed by sight, it was hypothesized that salmonids would congregate in areas of low flow which are within a short visual distance of faster flowing water. This would maximize their food energy input while minimizing energy output. It was also hypothesized that full channel ELJs would create more complex channels, resulting in increased stream flow complexity. The more complex stream flow would result in preferred fish habitat, due to the increased quantity of gradients between low flow and high flow.

2 Materials and Methods

2.1 Site Descriptions

The first site is located on Quartz Creek, approximately 15 km upstream of where Quartz Creek flows into the McKenzie River (Figure 1). Quarts Creek has an average slope of 4%, with gradients of 8% or more for some reaches (Gregory and Wildman, 1999).Water temperature averaged 11.3-12.4° C and stream velocity averaged 0.32 m/s. The channel was approximately 21 m wide, and the stream-wetted width of the main channel was 6.7 m with an average depth of 0.53 m. There were three small additional channels flowing out from under the jam, but they were too shallow to be surveyed and no fish were observed in any of them. The focus pool immediately downstream of the structure was 11.1m long with substrate ranging from gravel to boulder. Data was collected at this site on July 11, 2011 and July 12, 2011, and between 10:00 am and 6:00 pm. This jam was part of the U. S. Forest Service's habitat restoration efforts by placing large wood in the stream, thereby increasing salmonid habitat and cover (Gregory and Wildman, 1999). It was originally built in 1988 with 20 pieces of wood. Since then, it has accumulated over 300 pieces of woody debris. Two major floods in 1996 drastically altered the stream channel, and with it the log structures. Substrate at this site ranged from cobble to boulder.

The second site is located about 4 km upstream of the Oregon Hatchery Research Center on a third-order section of Fall Creek, or 7.2 km upstream of where it flows into the Alsea River (Figure 2). Water temperature ranged from 14.9-17.8° C with an average velocity of 0.26 m/s and 0.24 m/s for the left and right channels respectively. Data was collected at this site between August 3, 2011 and August 11, 2011, and between 10:00 am and 6:00 pm. Prior to logging, this area has long been subject to controlled burns by Native Americans to harvest elk and deer. The area's forests have all been logged at various periods, and have been intermittently logged and seeded as a harvestable forest for over 100 years. The jam itself was constructed in 2005, in part to compensate for potential habitat loss caused by the building of the hatchery just downstream (Joseph O’Neil, Senior Technician at The Oregon Hatchery Research Center, personal communication). Substrate ranged from silt to cobble and included exposed bedrock.

Figure 1.Pin A marks the first site, Quartz Creek, near the McKenzie River in the Willamette Forest. (Google maps)

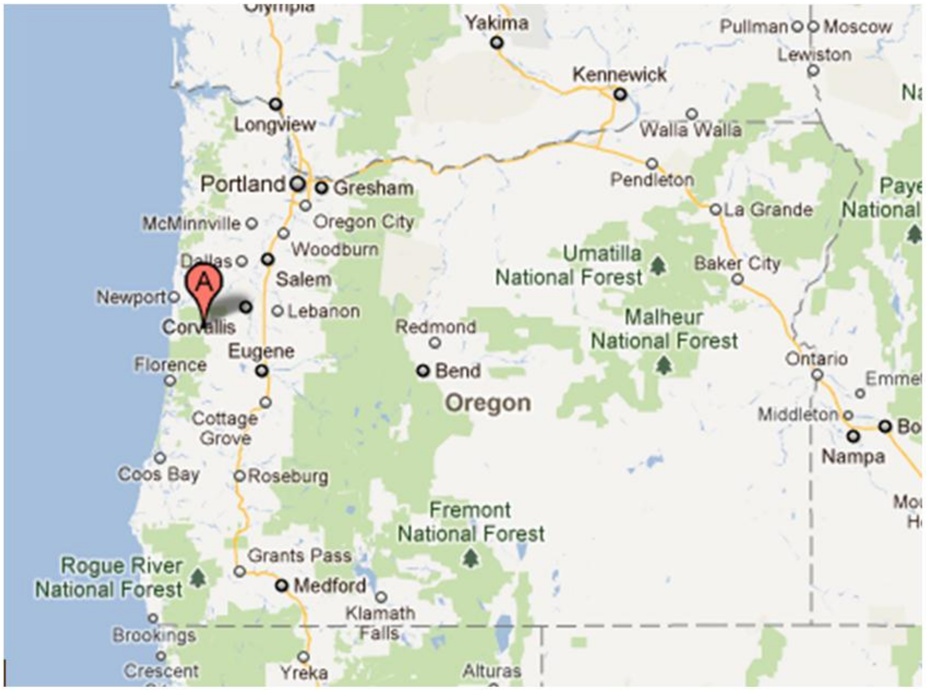

Figure 2. Pin A marks the second site, Fall Creek, at the Alsea River west of the city of Corvallis. (Google maps)

2.2 Data Collection

2.2.1 Channel Profiling

Transects were set up spanning pools downstream of the log jams, approximately perpendicular to stream flow. The number of transects was determined by the relative size of the pools downstream of the jams, the complexity of flow in certain areas, and the curvature of the streams. The last transect was set at the downstream edge of the ELJ. Each transect was designated with a stake on either side of the stream representing the river right and river left points of each transect. String was then tied to each stake to precisely determine the transect line.

Transect spacing ranged from 0.5m to 2m apart. The half-meter approximate distance between transects was chosen due to the way the Acoustic Doppler Current Profiler (ADCP, Teledyne Instruments) sampled and recorded velocity data. The transducer is the device on the instrument that sends out sound signals into the stream in a conical fashion. The “cone” extends 20-30° relative to vertical. Given that the maximum vertical depth in the streams surveyed ranged from 0.8-1.1m, the ADCP was able to collect data for a 0.46-0.63m radius cone in the deepest areas.

The bathymetric profiles of the streams were surveyed with the ADCP and Total Station (Nikon 302, series DTM-352). The Total Station was used to set up a grid on which all points could be located relative to each other. It was also used to record the position in space of the endpoints of the transects, so the velocity and bathymetry data could be organized in a useable fashion. Bathymetry was interpolated in data analysis for areas not measurable with the ADCP – 30 cm was the minimum depth required for velocity data to be recorded. Coordinates of several key points were also recorded, including the thalweg, stream-wetted edges alongthe transect, and either end of the transects' segments captured by the ADCP, as elaborated in the next section.

2.2.2 Acoustic Doppler Current Profiler (ADCP) Overview

The ADCP uses a transducer to collect information about the stream. It saves the information into a file which contains packages, or ensembles, of measurements, each averaged over one second. For the purposes of this study, the ADCP was used to collect velocity data, depth information, and temperature. Depth information is collected from the acoustic signals, which is used to track movement along the bottom to produce the "Distance Made Good" value (DMG). The ADCP collects velocity data by sending acoustic signals from four sensors, all oriented at different planes, located on the transducer. Some signals reflect off of the particles in the stream, returning to the transducer. Based on the time lag and distortion of returning signals, the ADCP calculates the velocity of the particles, as well as the depth of the streambed.

By combining the velocity and depth information from each returning signal, the ADCP computes velocity of the particles in three Cartesian dimensions – northing, easting, and zenith. The ADCP then averages the velocities collected within depth slices of a specified thickness, called "bins," and then returns a single three-dimensional velocity vector for each bin. The ADCP then combines the velocity information, the DMG value, depth, temperature, and magnetic heading into each ensemble. In this study, the thickness of each depth slice was 5cm, because this was the minimum setting on the ADCP used and would result in the most dense data.

2.2.3 Velocity and Bathymetry Collection

The ADCP was oriented such that the transducer was upstream, and the flotation device downstream. After the transects were set up, the starting point of the ADCP was marked with a flag tied along the transect string. The ADCP has a blanking distance—a minimum depth required to produce average velocity information – of 30cm. As such, shallower regions of the stream along the transect could not be sampled properly. Thus, for every transect, only a segment of the stream was actually sampled and recorded by the ADCP.

After a starting point was determined and marked, the ADCP was positioned upstream of the person holding the instrument. The position of the transducer had to be maintained directly in line with the transect to collect consistent and accurate data for each pass. Once the position was established, the instrument was guided slowly across the stream, straight along the transect, until an ending point of the segment was detected – at a depth near 30cm. This ending point was marked with another flag tied along the transect string. After the first pass, more passes were accomplished, alternating starting and ending points after each pass. A total of 2-4 passes were made for each transect. To finalize, the starting and ending points of the segments were suitably marked and surveyed with the Total Station. The velocity measurements were later coordinated with the channel profiles in data analysis.

2.2.4 Salmonid Observations

To assist in salmonid observations, rocks were brightly spray-painted and numbered. Prior to observations, these rocks were placed in the stream at the sample site in a grid-like fashion. Each rock was then surveyed with the Total Station, to mark their positions relative to the rest of the site data. At each site, fish were observed with snorkel surveys. The surveys lasted about 45 minutes each, once every four hours, over a 24-hour time period. Recorded observations included relative fish size (smolt < 7cm, small = 7-11cm, medium = 11-16cm, large > 16cm), distance from the bottom of the stream, orientation relative to the transect furthest upstream, distance and orientation from the closest painted rock, and activity –feeding, resting, and/or showing aggression. Trout identification was based on the field identification guide written by Pollard et al. (1997).The number of fish present was not recorded because individual fish behavior was of primary concern, and fish may have been recorded multiple times if they held a different position during the survey.

2.3 Data Analysis

2.3.1 Mapping Velocity Data with Coordinates

A limitation of the ADCP is its inability to determine the locations of the starting and ending points of each transect relative to other transects or any other landmark of the stream. However, using the easting and northing coordinates collected from the Total Station, the position of starting and ending points of the ADCP transects were inputted into Mathematica 8.0.1.WinRiver II was used to collect DMG values of each transect from the ADCP data. Each ensemble was placed appropriately on the corresponding transect line at a distance determined from the DMG value from the transect starting point. Using the calculated ensemble locations, the three dimensional velocity, and depth of each bin per ensemble, an irregular grid of velocity vectors was generated for each site.

2.3.2 Coordinate Assignment for Fish Location and Orientation

As previously described, the transect furthest upstream was used as the reference transect in measuring the location and orientation of the fish. To determine the location of the fish, the angle and distance of the fish from the closest painted rock were recorded, which were then converted into a pair of northing and easting coordinates. This was done by rotating the location of the fish by the angle measured between the northing direction and reference transect, and then shifting relative to the recorded coordinates of the painted rocks. The northing and easting coordinates of the location of the fish were combined with their recorded depth to obtain three dimensional coordinates. The orientation of the fish was similarly determined using simple rotational trigonometry.

2.3.3 Combining Velocity, Bathymetry, and Fish Survey Data

To best visualize the velocity vectors and fish data, contour plots were generated for stream velocities averaged over recorded depth; stream velocities recorded at the bottom-most depth; and stream bathymetry. For each site, contour plots were generated with Mathematica's 'ListContourPlot' function. This function takes in a list of x, y, and f vectors, where x and y represent data values in two-dimensional Cartesian coordinates. f is the function of interest for the given x and y coordinates; depth and velocity data were used as f to visualize depth and velocity contour plots for different *x* and *y*, respectively. The ListContourPlot function proved useful for the bathymetry and velocity data, because neither set of data was spatially symmetric; the ADCP does not sample points uniformly, and the spaces between transects were not surveyed and/or sampled by the ADCP.

As discussed, each point in the transects was assigned three orthogonal velocity vectors – northing, easting, and zenith. The resultant total magnitude was calculated using the magnitudes of the three vectors, and was used to generate contour plots for the velocities in the stream. Two types of velocity contour plots were created: a depth-averaged velocity plot, and a bottom-depth velocity plot.

The depth-averaged velocity plot averaged the resultant magnitudes of the velocities over stream depth. The transects had variable stream depths. Thus, for every ensemble, the velocities collected between the bottom and surface of the stream were averaged over the bins of each ensemble (Figure 3). After averaging, each ensemble had a single velocity magnitude value. These values were inputted for interpolation in between transects with the 'ListContourPlot' function. The bottom-depth velocity plot linearly interpolated the velocity magnitudes obtained at the bottom-most depth of each vertical sliver. Note that the bottom-most depths were all variable, as the streambed was never flat, so the velocities obtained were not all on a single horizontal plane.

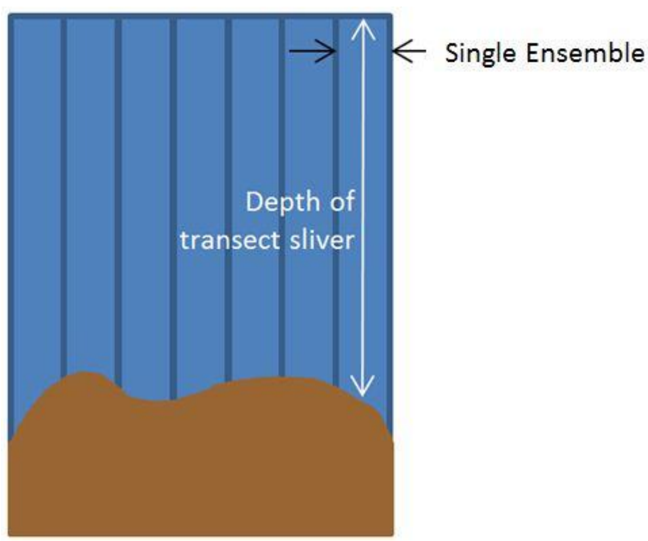

Figure 3. Each ensemble contained several bins of velocity data, which were averaged over the respective depth of the ensemble for depth-averaged velocities.

To determine how the velocity magnitudes were affecting the location and orientation of the sighted fish, the vectors which represented the fish were overlain on the velocity contour plots. Mathematica's 'ListVectorPlot' function was used to input the location coordinates and orientation angle of the fish. 'VectorPoints->All' was appended in the function to avoid automatic interpolation in between the inputted fish vectors. Once mapped, the fish vectors were overlain with the contour plots with the command 'show.'

At the Fall Creek site, eight fish that should have been on the river right side were located closest to rocks that were actually on the river left. These data points were removed from the data set.

3 Results and Discussion

The results illustrated are all contour plots described in the previous description. Note that lighter colors indicate relatively higher numerical values.

3.1 Channel Profiling

3.1.1 Quartz Creek

Quartz Creek displayed a relatively simple bathymetry. The flood event in winter of 2010 drastically simplified the channel by forcing the majority of the water through a single opening in the jam (Matthew Cox, EISI program director, personal communication). All water entering this pool flowed under and or through the jam structure. This main source caused a plunge pool of 0.97 m deep to be formed (Figure 4). The high spots next to and downstream of the root wad are boulders. The high spot in front of the log is unexplained, and is not accurately represented in this image as it was not present at the site.

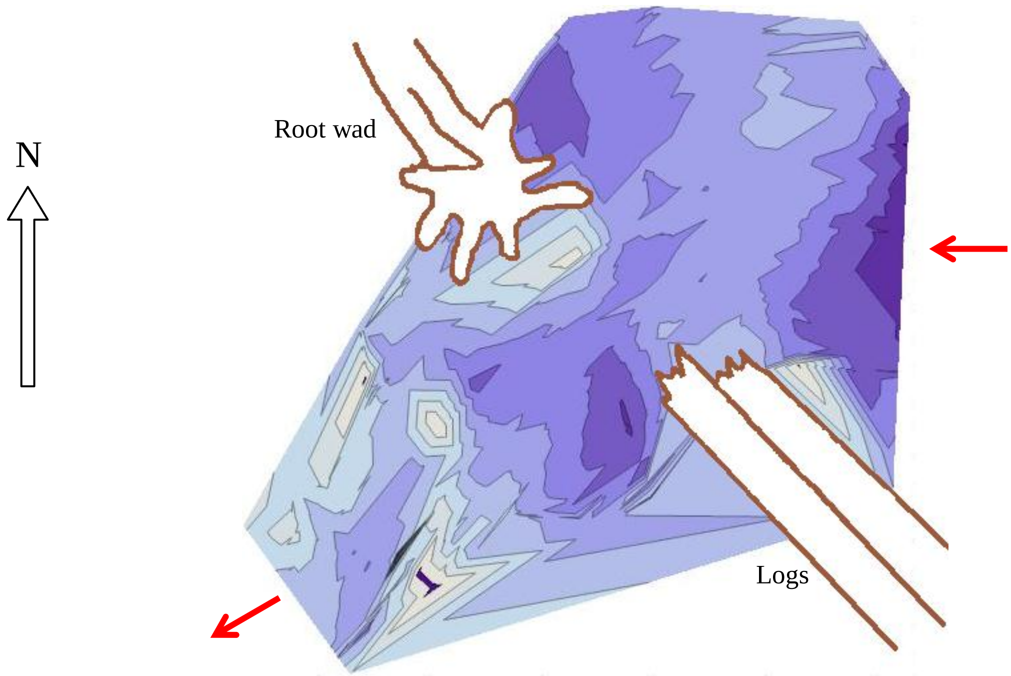

Figure 4

Figure 4.Bathymetry of the Quartz Creek site. This area represents the pool surveyed for this site. Darker colors represent deeper areas. Flow is moving from the right side of the image to the lower left, indicated by the red arrows. Note that the root wad and logs pictured interfered with the track of the StreamPro, so the depths represented at edges nearby the obstructions are mainly interpolated. The root wad is partially submerged and the logs are just barely in contact with the water.

Water flows in from the upper right-hand corner and moves downstream to the lower left. By observation, the deepest area is where the water first enters the pool. This is formed by water plunging through and under the jam structure, carving into the streambed. The water flows around the bend, and shallows out at the lower end of the pool.

3.1.2 Fall Creek

Fall Creek bathymetry is more complex than that of Quartz Creek. The jam is concentrated in the center of the stream (Figure 5). The channel splits into two at the top of the jam. The river left side consists of silt- to cobble-sized particles, and is relatively shallow with an average depth of 0.33 m, and maxes out at 0.60 m. Most of the water flowing into this side flowed left around the structure, with very little of it coming in contact with the jam. The river right side, however, is very different. It has little in the way of cobble, and primarily is composed of exposed bedrock and silt. Average depth is 0.42 m and the deepest pool is 0.98 m deep, although the lower half of this side is shallow bedrock that experiences little elevation change.

The two channels are split for approximately 30 meters by a gravel bar down the center of the stream. All of the water on the right side flows under the structure, creating a deep central pool with a larger backwater area next to it, too shallow for the ADCP measurements and no fish were found there.

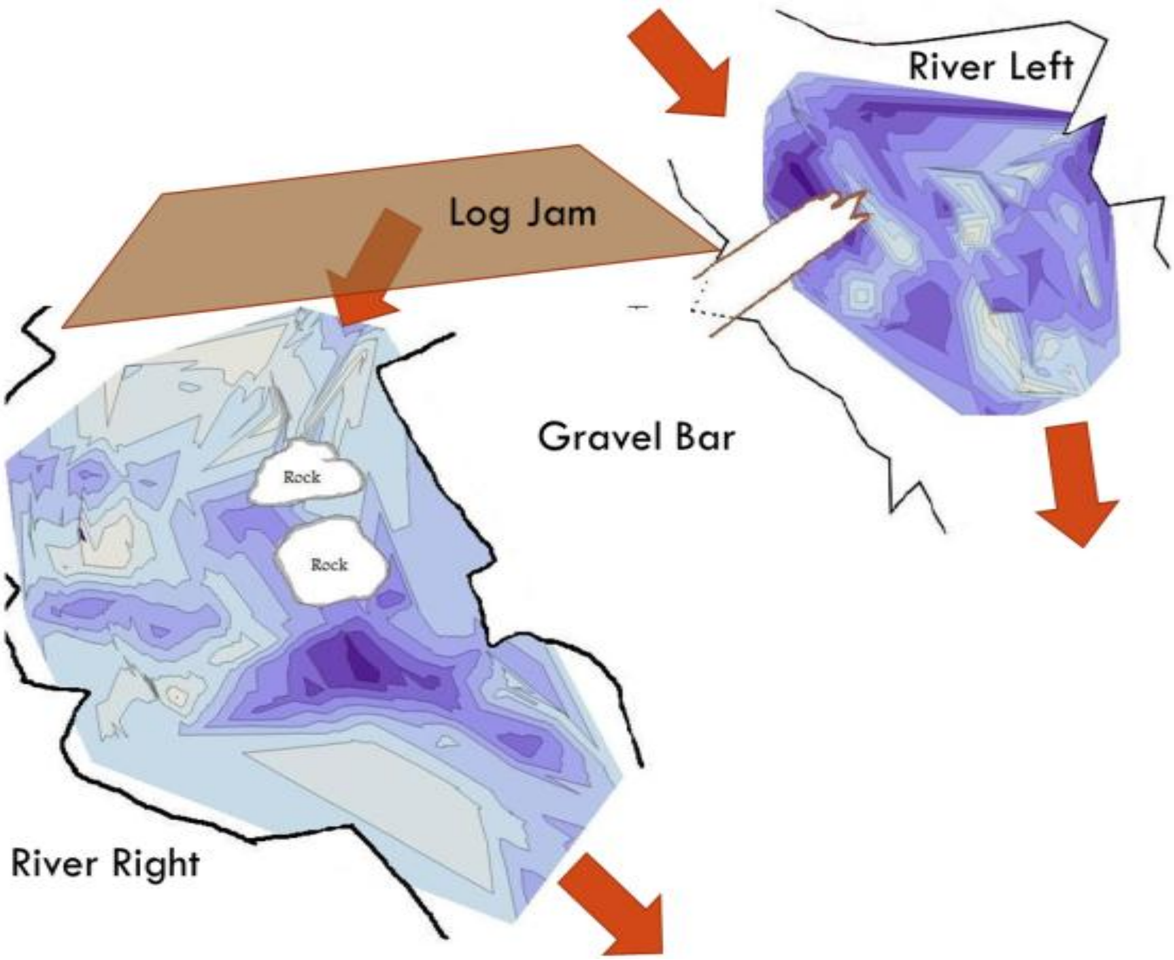

Figure 5. Bathymetry of the Fall Creek site. This image represents the area surveyed at the fall Creek site. Darker colors represent deeper areas. Note that the same colors do not correspond for same depths for river right and river left. Flow is moving from the upper left towards the lower right. The log jam is partially submerged, and the gravel accumulation is typical of this kind of jam.

3.2 Velocity Measurements

This section illustrates contour plots of velocity measurements taken at field sites. Figures in this section should be observed in parallel to those in the previous Section 3.1 for correlation among fish location, velocity, and channel profiles.

3.2.1 Quartz Creek

Quartz Creek had distinct correlations between bathymetry and velocity – depth and velocity were negatively proportional. Velocity contour plots showed that the shallower, more broad-channeled regions maintained higher flow (Figure 6).The deepest area was mostly beneath the log jam, while the shallowest area was relatively uncovered.

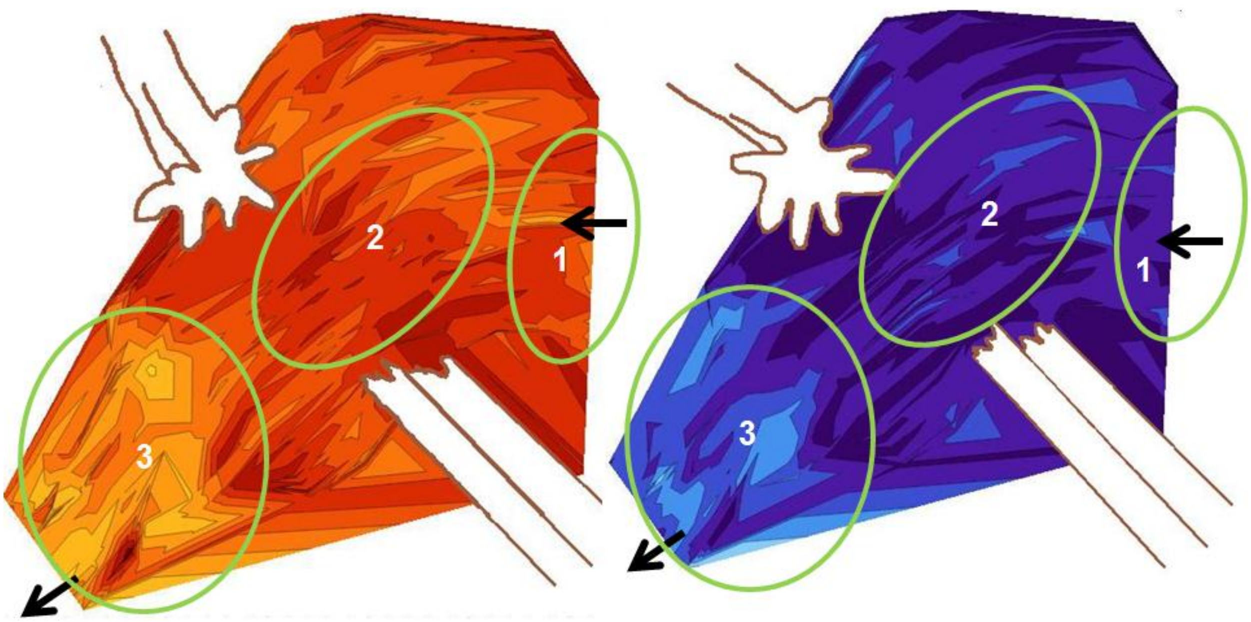

Figure 6. *Left*: Contour plot of depth-averaged velocity magnitudes with fish overlain. *Right*: Contour plot of bottom-depth velocity magnitudes with fish overlain. In both plots, depth progresses from maximum depth to minimum for regions 1 to 3 respectively. Flow is represented by the black arrows. The root wad and logs are also illustrated. In both plots, the shallowest regions demonstrated the highest velocity flow.

In region 3, the depth-averaged velocities were more variable than the bottom-depth velocities. At depths less than 1 meter, the averaged velocities were more similar to bottom-depth, albeit both demonstrated more complex flow due to bathymetry. This represents regions 2 and 3. It is interesting to note that the flow accelerated with decreasing depth as it progressed from region 2 to region 3, as stated previously. There was relatively high flow as it exited in a turbid state under the jam (region 1), and then slowed down as it turned the bend (region 2). The average velocity was measured to be 0.32 m/s at Quartz Creek. Based on the velocity streamlines in Figure 7, there seems to be lateral flow of water across the channel at the entrance (right edge) due to the shape and bend of the channel.

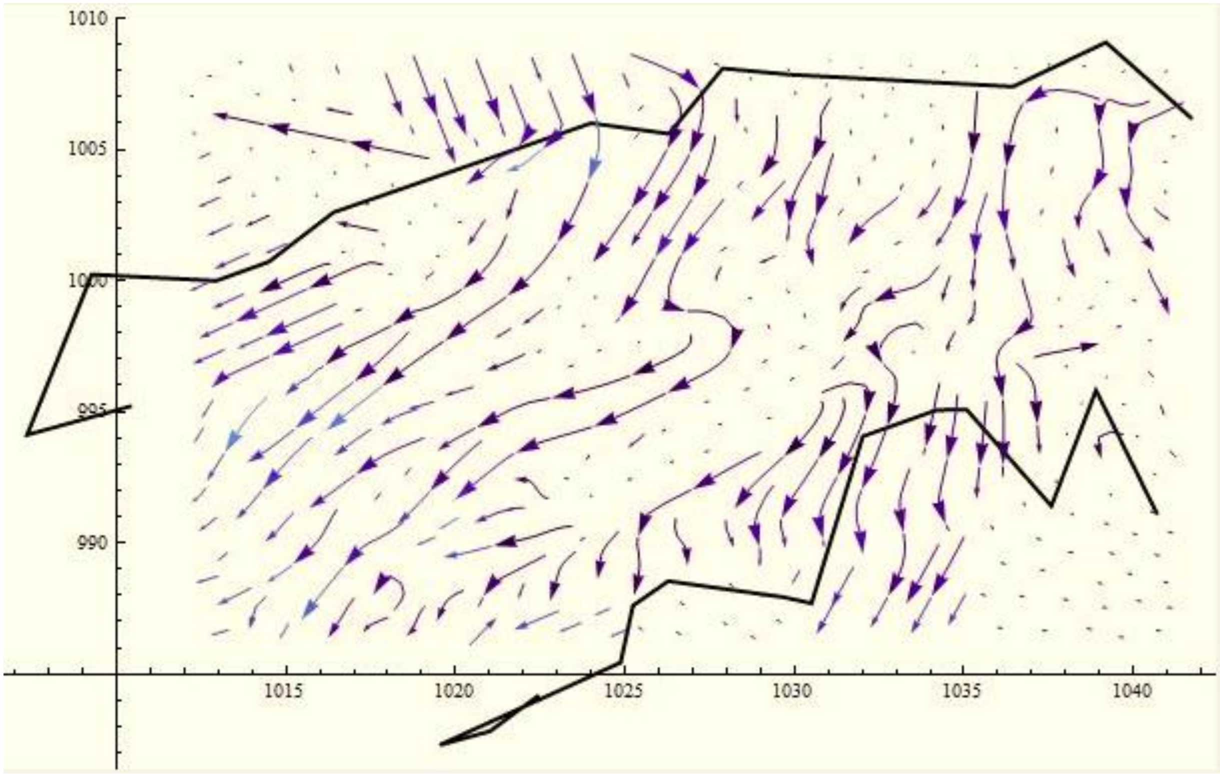

Figure 7. Streamline velocity plot at Quartz Creek. The velocities in spaces between transects were linearly interpolated, and then connected as streamlines. This gives a visual representation of the complexity of the flow. The regions outside the boundary of the channel should be neglected as they show overprocessed interpolation data.

3.2.2 Fall Creek

Compared to Quartz Creek, Fall Creek had more complicated channel profile and generally slower flow. The log jam split the channel into two separate sub-channels by means of accumulating gravel directly downstream. This accumulation of gravel caused for more formation of complex streambed profile, and in turn, more diverse types of flow. As noted previously, the colors on River Right and River Left do not correspond to the same numerical velocity values. The velocities at Fall Creek averaged between 0.24 and 0.26 m/s.

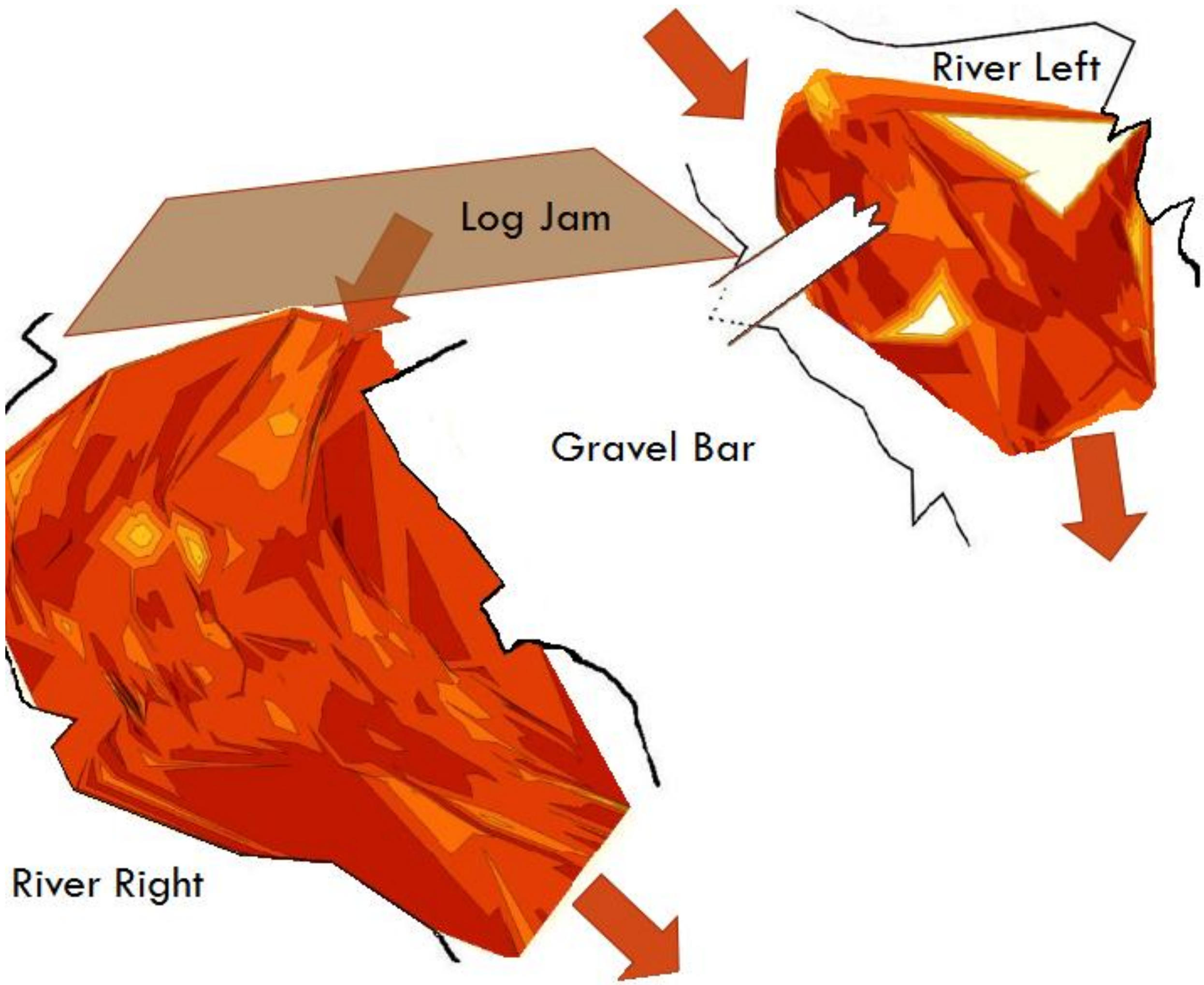

Figure 8. Depth-averaged velocity contour plot of Fall Creek. The large white gap in the plot of River Left should be neglected as it is an interpolation error. Velocities tended to be faster toward the center of the channels, especially River Right. This was expected, as were the slower flows near the shallower regions at the edges of the channel.

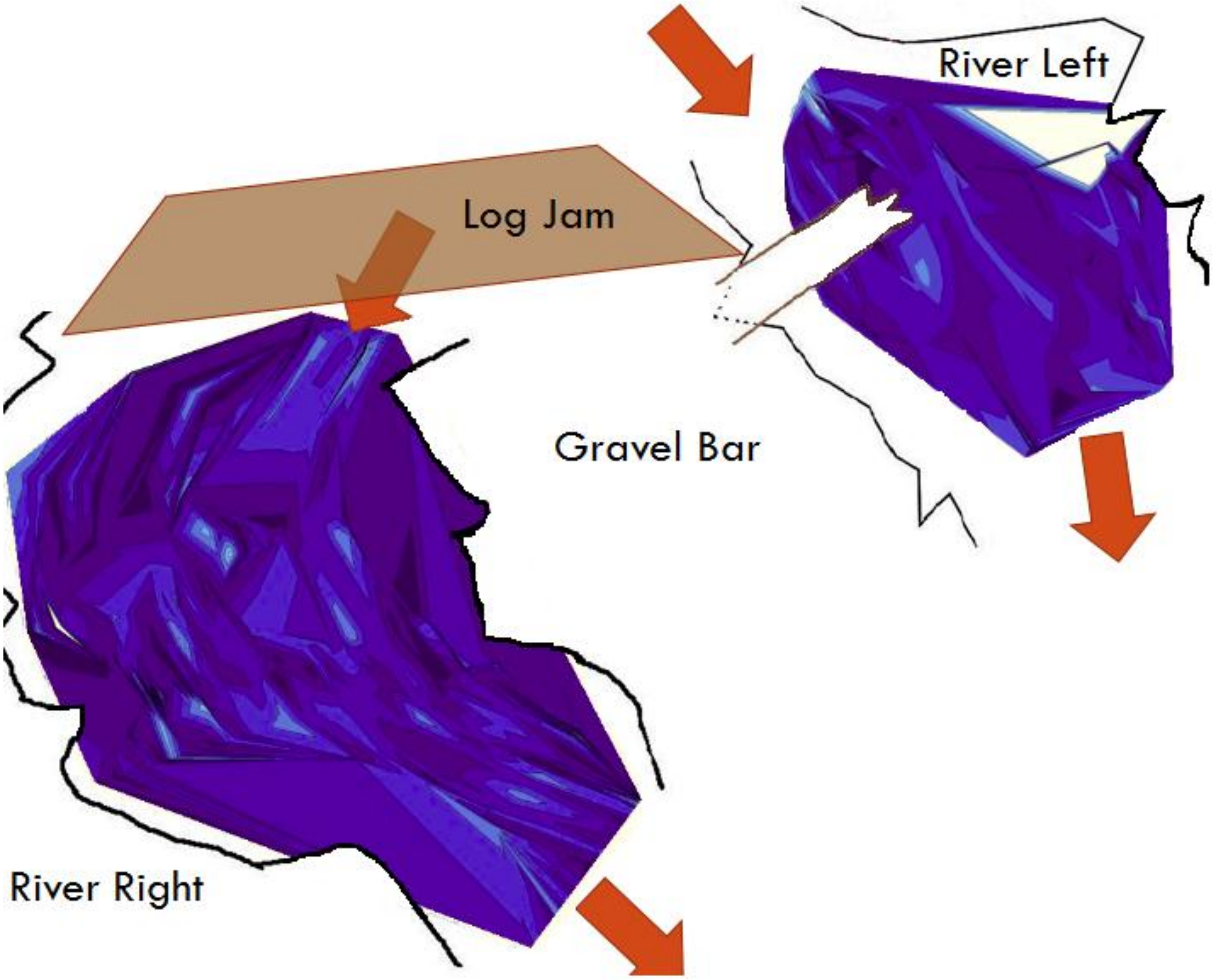

Figure 9. Contour plot of velocities from the bottom-most depth per ensemble. River Right demonstrates more variable velocities than did that in the depth-averaged velocity plot (Figure 7). The general trend is maintained in that the center of the channel shows higher velocities. The increased variability in bottom-depth velocities is perhaps accurate, as the channel profile was also variable, especially in River Right. As for River Left, bottom-depth velocities appear more consistent, whereas depth-averaged velocities appear more variable.

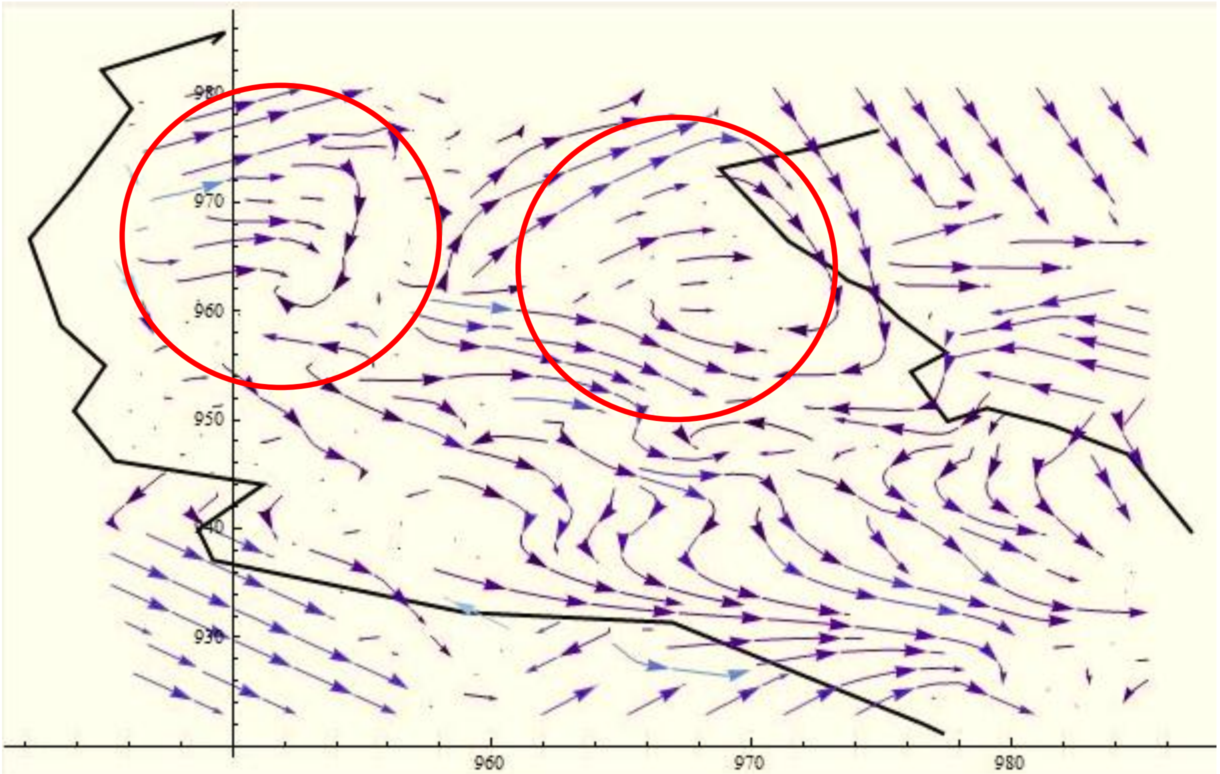

Figure 10. Streamline velocity plot at River Right of Fall Creek. The velocities in spaces between transects were linearly interpolated, and then connected as streamlines. There are eddies present at the right and left edges of the entrance, as circled. The regions outside the boundary of the channel should be neglected as they show overprocessed interpolation data.

3.3 Salmonid Observations

3.3.1 Quartz Creek

Cutthroat trout (*Oncorhynchus clarkii*) was the dominant fish species at this site. Rainbow trout (*O. mykiss*) were also present, although in fewer quantities – only two of 22 fish observations per survey block were rainbows. Feeding hierarchies were observed; however, the largest fish were not necessarily located the furthest upstream. This is contrary to our predictions, as we expected that the largest fish would hold a more dominant position with primary access to food brought by the stream. We observed positions that seemed preferable to the fish – if one fish moved out of a certain area, another fish would attempt to take its spot, often to be chased off by the returning original fish. The fish tended to congregate in medium to deep waters, although they were not as prevalent in the deepest, most upstream area. This may be due to the higher velocity and turbidity present at the upstream end of the pool.(Figure 11).

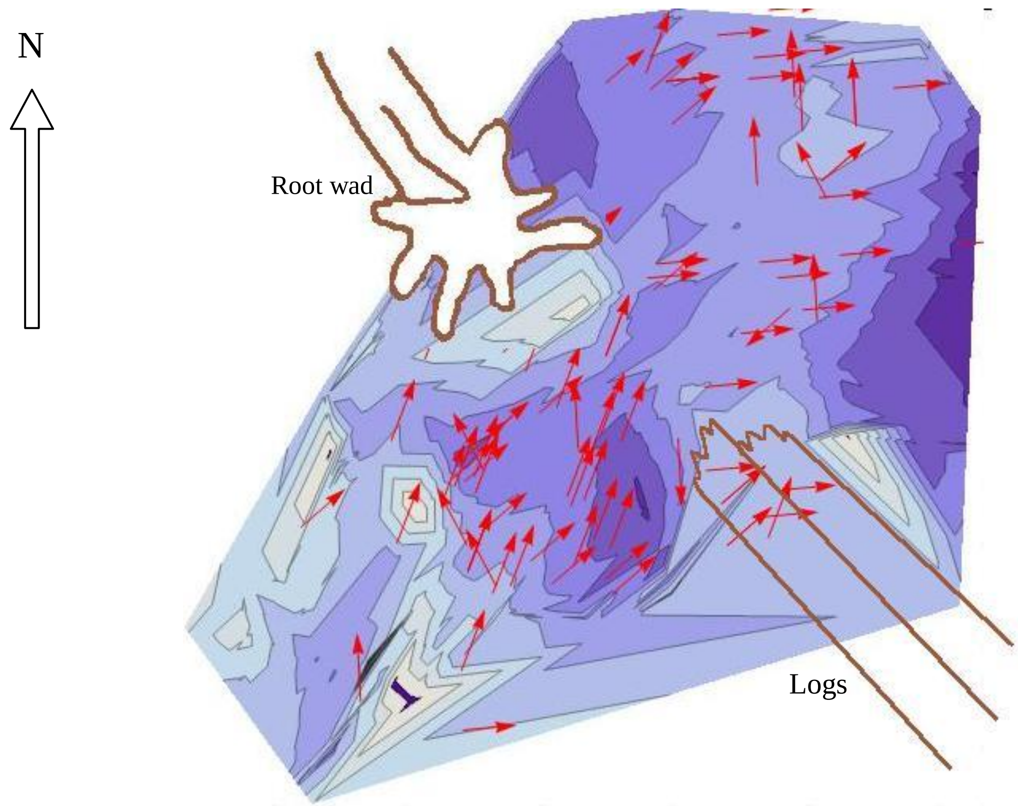

Figure 11. Bathymetry of Quartz Creek overlain with fish. The red arrow represent the orientation and location of fish sighted during snorkel survey. The fish are congregated in medium-depth and deeper areas downstream of the log jam.

Fish were rarely sighted in shallow areas with high velocities, or relatively deep areas with low velocities (Figure 12). They were predominantly found in medium-depth areas with lowest velocity and lower turbidity. At Quartz Creek, the shallow areas did not offer much cover (e.g. logs, roots, etc.) from predators, and had the fastest flowing water. Fish avoiding these areas was likely because of high energy expenditure due to maintaining position in high velocities, and to low cover levels. Additionally, since trout feed by sight, turbid flow would negatively impact feeding ability due to high opacity of the water. Fish were also found near the bottom, often at less than 10 cm from the bed. Since the boundary layer near the bed has much slower and smoother flow, energy expenditure to hold position in the boundary layer is lower for fish than at depths above the boundary layer where bulk flow exists. This gradient between boundary layer and bulk flow enables the fish to feed efficiently by quickly darting out of the boundary layer into the faster flow for food, without spending the energy to remain in high flow areas.

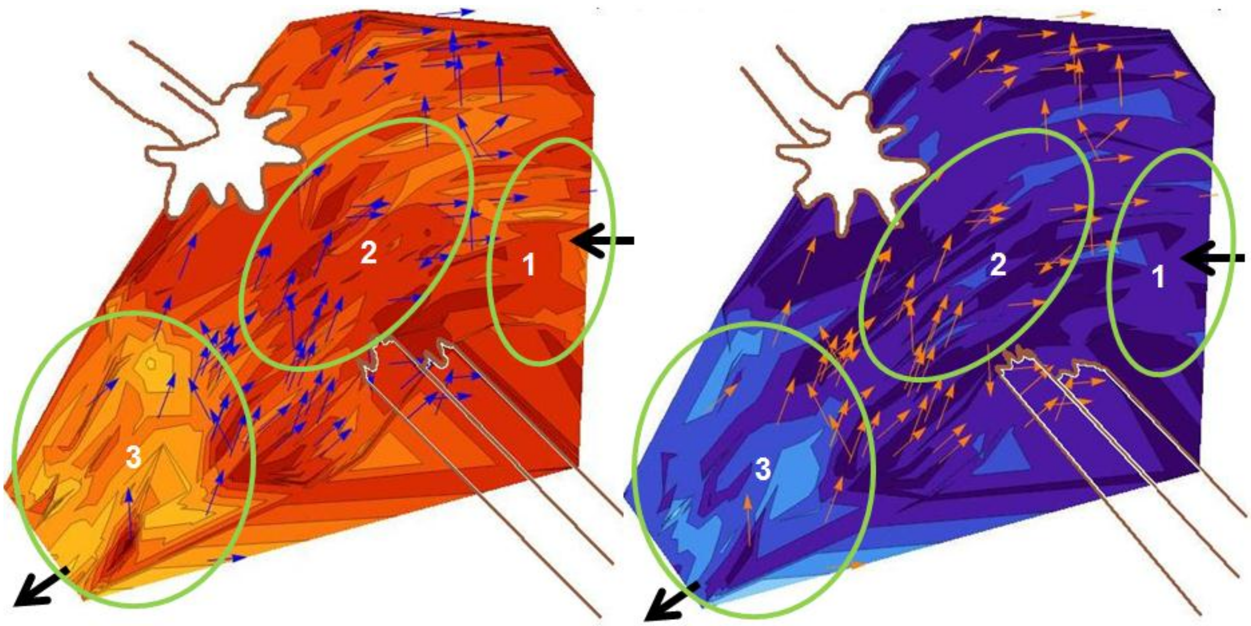

Figure 12. *Left*: Contour plot of depth-averaged velocity magnitudes with fish overlain. *Right*: Contour plot of bottom-depth velocity magnitudes with fish overlain. In both plots, depth progresses from maximum depth to minimum for regions 1 to 3 respectively. As shown, fish generally congregated in the medium-depth areas with the lowest velocities. This is demonstrated in both plots.

3.3.2 Fall Creek

The dominant fish at Fall Creek was the Coho salmon (*O.kisutch)*. The Coho smolt was the dominant size class in shallower areas of Fall Creek, while the small and medium size Coho dominated the deeper areas. As observed at Quartz Creek, fish seemed to take advantage of gradients between high and low stream velocities, especially on the River Right channel, where most areas in the lower half were flat exposed bedrock (Figure 13, Figure 14). Small and medium-sized fish were generally found in the areas of slower flow adjacent to fast flow – this allowed fish to conserve energy holding position in low flow areas while having the ability to quickly dart into high flow areas for food. The small and medium sized Coho positioned themselves near the center of the channel, where these gradients existed, while the smolt positioned themselves near the edge of the channel with shallower stream depth. In River Left, the largest size fish lingered in deeper regions with slower flow. Few fish were found in turbid or fast-flowing regions.

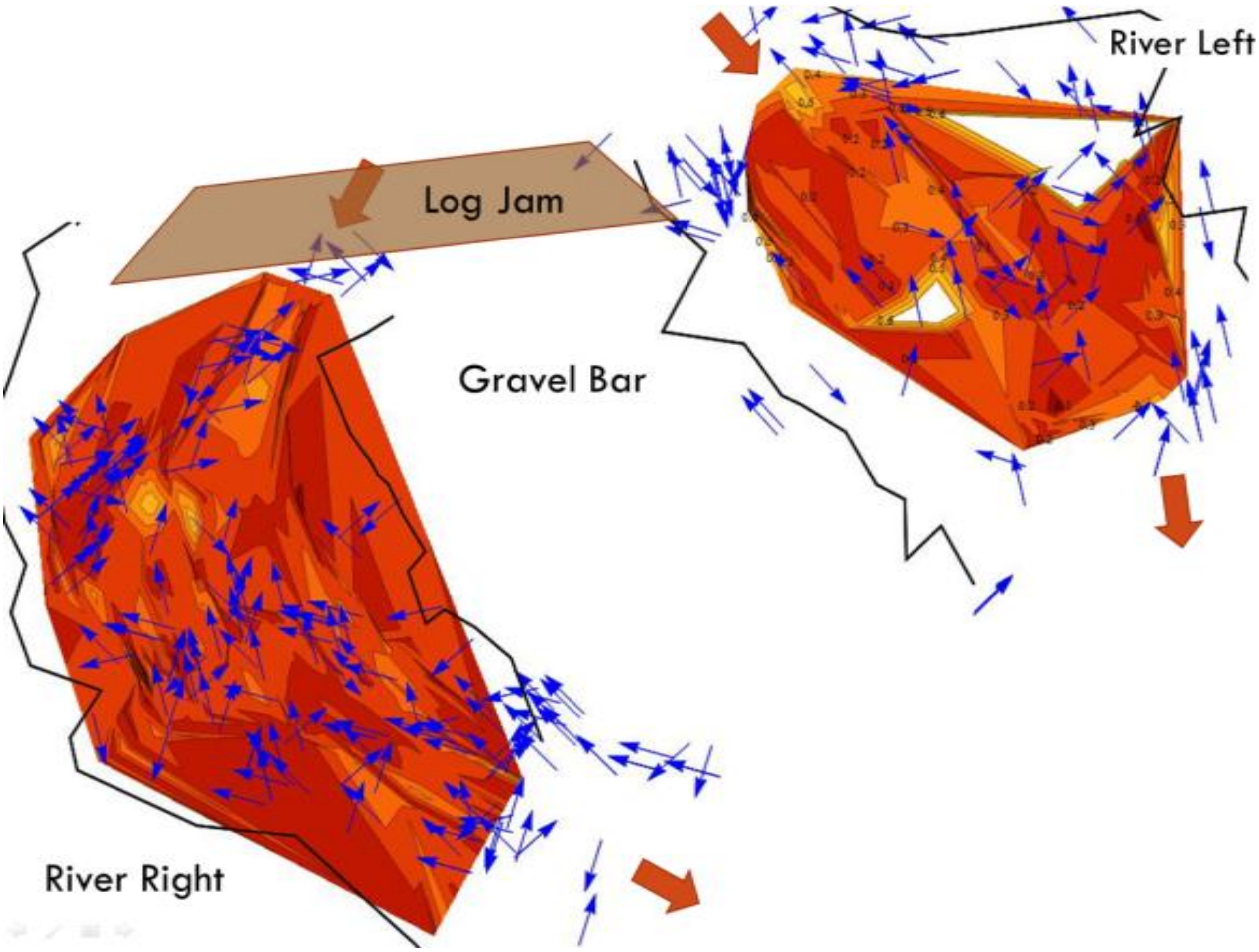

Figure 13. Depth-averaged velocity contour plot of Fall Creek with fish overlain. Lighter colors represent faster flows, while darker colors represent slower flows.

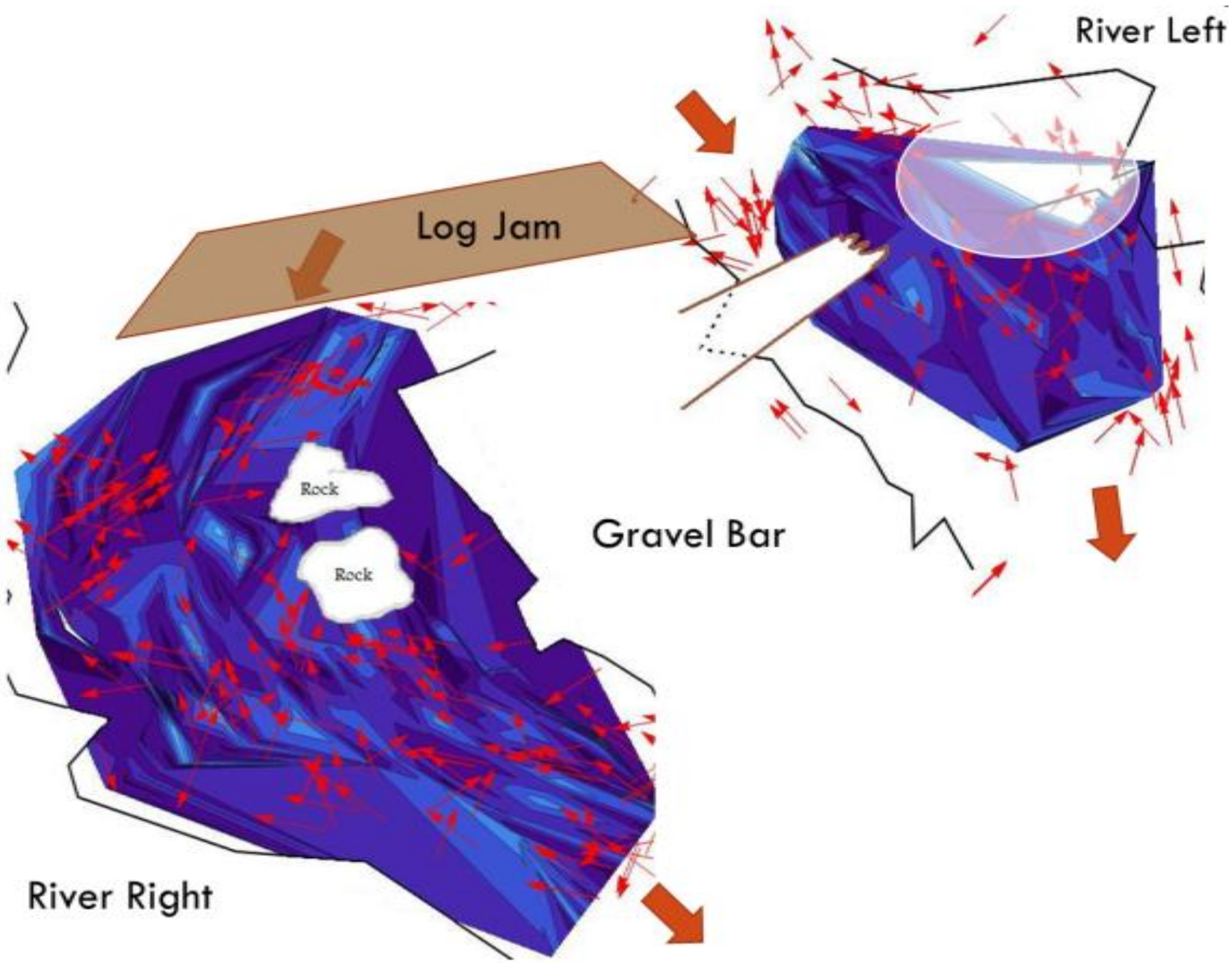

Figure 14. Bottom-depth velocity contour plot of Fall Creek with fish overlain. The transparent white oval represents a gap in velocity data due to interpolation error. Lighter colors represent faster flows, while darker colors represent slower flows.

3.4 Comparison of Field Sites

3.4.1 Stream Channel

Fall Creek had much more diverse and complex bathymetry in addition to a wider range of substrates than Quartz Creek. The deepest part of the Fall Creek channel was not immediately below the structure, as was the case at Quartz Creek, but rather midway down the pool where there was more flat, exposed bedrock. Because Fall Creek was a much wider channel with more diverse bathymetry and bedrock, it had higher quantities of fish. The log jam itself had smaller pieces of wood which added to the complexity of the jam, and thereby the underlying channel profile. As for nature of flow, Quartz Creek had more variable averaged flow among ensembles, especially in the center of the channel.

3.4.2 Physical Comparison of Jams

Quartz Creek had a key piece of wood that spanned the entire width of the channel, causing accumulation of wood immediately upstream. Therefore, all flow had to go through or under the accumulation. There was also a sharper change in elevation as the flow transitioned through the jam. Fall Creek had smaller pieces of wood comprising the jam. During dry periods, the jam is not a full channel jam at Fall Creek because the key piece was elevated in the jam above the flow of water. The small pieces of wood were mostly concentrated at the right channel, acting more as a half-channel jam. During the winter months, with higher discharge, the jam would act as a full-channel jam. The jam at Quartz Creek was larger in both number of pieces of woody debris and total woody debris volume than the Fall Creek jam. Quartz Creek is located in a system with higher energy and more forested land surrounding the jam, likely causing greater woody debris input than the Fall Creek jam. Although the system differences between both sites may account for total amounts of woody debris differences between the sites, the Quartz Creek jam was built 23 years ago while the Fall Creek jam was built only 5 years ago so the age difference may also contribute to the difference in woody debris accumulation.

3.4.3 Salmonid Comparison

The Quartz Creek jam, being a cold stream in the Western Cascades, contained primarily Cutthroat trout with some Rainbow trout. In contrast, the Fall Creek jam, being a warmer coastal stream, contained primarily Coho with some Cutthroat trout. At the Quartz Creek jam, the Cutthroat positioned themselves at the boundary layer, making greatest use of the gradient between boundary layer flows and bulk flows. Like the Cutthroat, the Coho also preferred to position themselves near flow gradients, but seemed to prefer lateral gradients—ones where flow changed when the fish darted horizontally—rather than the vertical gradients between boundary and bulk flows. This is consistent with our knowledge of the physical differences between Cutthroat and Coho. Cutthroat and rainbow trout have rounder, more powerful bodies than Coho, making them more capable of holding their position in faster-flowing waters. This allows them to feed throughout the water column. Coho salmon have thinner bodies with larger fins, making them more capable of rapid turns and quick, darting movement (Bisson et al., 1988). The tradeoff for this body type, however, is that the Coho are not able to maintain a position in fast-flowing water the same way the trout do. Body shape differences may also account for the apparent observations of the trout in lateral scour and plunge pools but avoided riffles, while the majority of smaller salmon were observed in the riffle areas.

3.5 Error and Limitations

There were some limitations and causes for error during data collection and data processing. In field data collection, the main source of error was inconsistency in the manner that the ADCP was guided along each transect. Because the bedrock was highly variable and slick in some areas, the person guiding the ADCP was prone to slipping out of transect line and/or moving it too fast. One compensating feature on the ADCP was that it tracked the bottom bathymetry of the location that it was in, so it took into account any areas where it slipped out of line.

During the fish snorkel surveys, underwater divelights were used during the night hours. It was found that fish were strongly attracted to the light, and were prone to follow the snorkeler's light. After this change in behavior was observed, the diver attempted to diffuse the light by shining it on rocks behind the fish, and making observations based on the weak light cast on the fish. This resulted in fewer behavioral changes due to light, but once the fish noticed the light we were unable to make quality observations about them, and therefore did not include subsequent observations of the same fish. However at the second field site, Fall Creek, transparent red film was used to diffuse the light as an attempt to mitigate the curious fish behavior; regardless, this did not seem to make a significant difference in the way that fish were attracted to the light. The fish behaved the same way as they did at the first site – they were initially startled at the sudden flash of light, and then accustomed to it by either congregating toward the light or starting to feed. As with the first site, once a fish reacted to the light we were unable to include subsequent observations of it.(Brignon et. al., 2011).

4 Conclusion

Velocity and fish data were obtained at two field sites, Quartz Creek and Fall Creek. These two locations had different ecological and geographical characteristics, and provided varied results on fish behavior associated with stream flow and ELJs.

There was always turbidity immediately upstream, thru, and downstream of the log jam. This pushed the fish more downstream of the actual jam, disabling the fish from effectively using the jam for cover and protection – areas downstream of the jam had decreasing amounts of wood in streams, banks with root wads, large rocks, etc. Turbid water also contains higher mixing of food in the water column, one benefit of ELJs.

Fish preferred to conserve energy by feeding where there were relatively sharp velocity gradients. They generally lingered in slower flow regions to conserve energy, then quickly darted into fast flow to feed, after which they darted back into their original positions. Larger fish occupied prime positions and often repelled smaller fish away – often these locations were deeper areas with higher flow, perhaps for higher volume of oncoming food. In channels with complex profiles, fish would not have to compete as much for ideal feeding positions, as there would be ample locations with velocity gradients.

An important consideration for future ELJ construction is the system in which the ELJ will be built. In systems like the Quartz Creek jam—mountainous, forested, with low water temperatures—throughout the Pacific Northwest it is important to realize the likely addition of large amounts of woody debris to the jam. Because of this, the initial placement of small pieces of wood and woody debris primarily placed for cover is less important than large key pieces that will snag woody debris in the future. Furthermore, in systems dominated by Cutthroat, the primary velocity gradients created by the ELJ should be between the boundary layer and bulk flow. In coastal, warm water systems like the one surrounding the Fall Creek jam, the initial placement of woody debris flow complexity is more important. Also, given the lateral darting of Coho feeding habits, the creation of lateral velocity gradients in stream flow should be a primary concern of ELJs in Coho dominated systems.

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