A Probabilistic Model of Large Woody Debris Movement and Distribution in Small Mountain Streams

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Abstract

Streams with headwaters in steep mountainous terrain are constantly subjected to change because their dynamic spatial setting has such a high impact on encompassing processes. High-velocity flow, susceptibility to flashy discharges, and interruptions in flow patterns from foreign objects such as large woody debris (LWD) affect how and at what rate stream channels change.

Woody debris enters streams by means of wind throw, fire, logging operations, and most commonly debris flows from surrounding mountain slopes, and pieces or accumulations can have long residence times in small mountain streams up to 200 years[7]. The presence and accumulation of these logs produces many significant impacts for the stream and is an important subject of study in fields including hydrology, geology, and biology. Processes associated with LWD are complex and have many implications, so it is difficult to mathematically and accurately predict and represent the patterns of entry, transport, and deposition of wood in streams for practical applications and study.

This study aims to model the probability of the movement of LWD and the change in volume of wood at a given stretch of stream over time. Many assumptions must be made in this modeling process as to simplify the problem enough to make it approachable. In this study, data from the historical research site at Lower Lookout Creek (LOL) in the H.J. Andrews Experimental Forest near Blue River, Oregon, was used as a base for annual changes in wood volume as well as to define parameters for mountain stream characteristics to observe changes after a 5–year flood in January 2011.

By comparing the fluvial, wood, and cross sectional data before and after the 2011 flood, a model was developed for the distribution and change of the wood volume per unit length of the reach studied. This model accounts for the change in volume per year by parameterizing the methods in which wood moves in the system: entering, exiting, and staying within it. The probability model for the movement itself is utilized to develop a relationship for unknown values for the mean travel distance ($\frac{1}{\lambda}$) and input processes of floated and fallen wood ($\overline{r}$). An analysis of the relationship of these values was performed, which is essential for expanding the model to a larger scale.

1 Introduction

1.1 Study Site

The H.J. Andrews Experimental Forest (HJA) located within the Willamette National Forest holds a wealth of information and a great opportunity for scientists to study small–and large–scale, long-term processes with the availability of historical data dating back as far as its 1948 establishment[9]. The HJA is a National Science Foundation-funded Long-Term Ecological Research site lying on the west side of the Cascade Range. Heavily vegetated mountainous terrain covered with Douglas-firs, western redcedars, western hemlocks, and a variety of ferns and mosses[9] grade down to stream beds at approximately 20-80% slopes[4], making a complex drainage network.

Streams here run clear and cold as they are mostly fueled by groundwater that is seasonally recharged pristine melting snowpack that has accumulated in the highlands during the winter months. This meteorological setting also tends to mean flashy discharges for mountain streams that are capable of producing extremely powerful flooding events. At this study site, the stream gradient varies from 13% in the headwaters to 1.5% near the mouth[5], so a wide variety of bed sedimentation patterns can be observed in this highly weatherable Oligocene to Miocene volcanic bedrock setting[9]. Some bedrock channels have been carved in the stream bed at various narrow, quick-moving sections of stream, and other sections consist of bedloads ranging from sand to boulder sized clasts. The median grain size for this study's reach of stream is approximately 0.112 m (see Appendix A).

Near the H.J. Andrews Experimental Forest headquarters, a 470 m stretch of the 5th order stream Lookout Creek, referred to as Lower Lookout Creek (LOL), has been designated as a long-term study site with 14 irregularly spaced transects created for datum points to monitor cross-sectional changes in the stream[1]. For each transect number, an X post is designated on river left (in geologic terms, looking downstream) and a Z post on river right.

Transects were designated for areas of stream that would be representative of a variety of stream channel features and flow characteristics, and these sites have been surveyed annually since their creation in 1978 except in years without significant flooding events[1]. In 1986, some intermediate posts were put in place and became the new reference points in a effort to improve the quality of the measurements at the datum points by more closely matching the elevation between X and Z posts[1].

Lower Lookout Creek has an average channel width of 27.3 m and a 1.5% gradient[1]. The United States Geologic Survey (USGS) has a stream gauging station, Hydrological Unit 17090004, at the mouth of Lookout Creek where it empties into Blue River Reservoir. Its location is 44° 12′35″ latitude, 122° 15′20″ longitude[15], approximately 450 m downstream of the 14 LOL transects[1]. Thus, this gauge intercepts the total discharge of the greater H.J. Andrews Forest's Lookout Creek watershed with the exception of Watersheds 1, 9, and 10[1] for a gauged drainage area of approximately 62 km^2 [15].

1.2 Importance of Studying Woody Debris

Wood in streams has become an increasingly important field of study for scientists over the last few decades as it can have many implications for its surrounding ecosystems relevant to hydrology, geology, and biology fields. Wood can enter streams by many mechanisms, both natural and anthropogenic. Trees fall into nearby streams most commonly by means of debris flow and also wind throw, fire, disease, bank erosion, or channel migration as a result of flooding. Anthropogenic sources of wood entering a stream may be upstream logging operations and clear cuts, road construction, and building or landscape-altering operations[4].

LWD exists in-stream as fallen or floated in pieces from upstream, accumulating as lodged pieces in jams or serving as key pieces. Historically, wood snagging efforts have been made to remove LWD from streams to improve waterway navigation[13] or for lumber harvest. If mobilized in a large flood, LWD can also wreak havoc on waterway infrastructure such as bridges or gauging stations. Recently, however, scientists and environmentalists have encouraged ceasing, and in some cases reversing, removal processes of LWD in streams since its presence can greatly help river restoration efforts. Reversing the snagging process would include projects placing engineered log jams in small streams for fish habitat restoration.

Large woody debris provides diverse environments in streams that would not normally be found in mountain stream settings. For example, steep gradients and flashy discharges in mountain streams often results in high bedload transport ability and low sedimentation rates. Fallen or floated logs can span channel-wide and create log steps and scour pools. This allows smaller sediments to be trapped in the bedload, and gravel bars may also accumulate around jams creating dynamic channel features and cross-sectional profiles. Gravel bars along with LWD-facilitated bank erosion can largely contribute to channel migration as well.

In turn, LWD-forced geological stream features can result in positive ecological implications. Jams themselves can provide protective habitats and also help trap particulate organic matter for benthic organisms. Scour pools, gravel bars with hyporheic flow, and smaller median grain sizes of stream bedload provides fish with spawning and feeding habitat. Hence, LWD has become an integral part of river restoration efforts, especially when man-made dams must be removed for permit and safety reasons.

1.3 Research Objective

This study aims to 1) remap the Lower Lookout Creek stretch of stream for changes in wood distributions and channel feature migration as a result of the January 2011 flood, and 2) to develop a predictive model of how much total wood volume will move in a given flood event. We are particularly interested in how floods of certain magnitudes affect wood storage spatially and temporally. To design such a model, we must make many assumptions to simplify the complicated process of LWD movement in streams. We use wood dimensions from 2010 and our own data from 2011 to observe changes in wood volumes in Lower Lookout Creek and then develop a probability distribution of wood moving a certain distance along the stream given the January 2011 floods discharge.

Ultimately and ideally if we had more time, this model would develop into one that predicts where a log is in a given amount of years after experiencing a random series of discharges (from flood frequency analyses). This data would be represented as a Monte Carlo simulation, yielding a range of possible outcomes for how wood would be distributed in a stream over the course of many years.

2 Methods

2.1 Wood Mapping

For each section of Lower Lookout Creek, all pieces of woody debris larger than 1 m length and 0.1 m diameter were measured and located on a map image developed by the 2010 EISI group (see Appendix B) provided to us by Dr. Desiree Tullos. This image is not scaled to precision.

Lengths were taken using a regular long tape end-to-end of the wood pieces, and diameter-at-breast-height measurements were taken using a diameter tape approximately 1.3 m from the thickest ends of the pieces. Where pieces were not 1.3 m long, diameter was generally consistent for the entire length and was thus just taken at the thicker end. In the case of jams consisting of key pieces and lodged members or only lodged branch debris (such as upstream of rooted trees, gravel bars, etc.), length, width, and height measurements were taken to estimate volume with an associated porosity factor to account for air space.

A rudimentary compass was used to obtain approximate length-wise orientations for each of the pieces since orientation in relation to flow direction is often an important factor to consider when modeling the movement of wood debris[2]. In the case of jams, orientations were taken only if branches seemed to accumulate with a preferential settling direction.

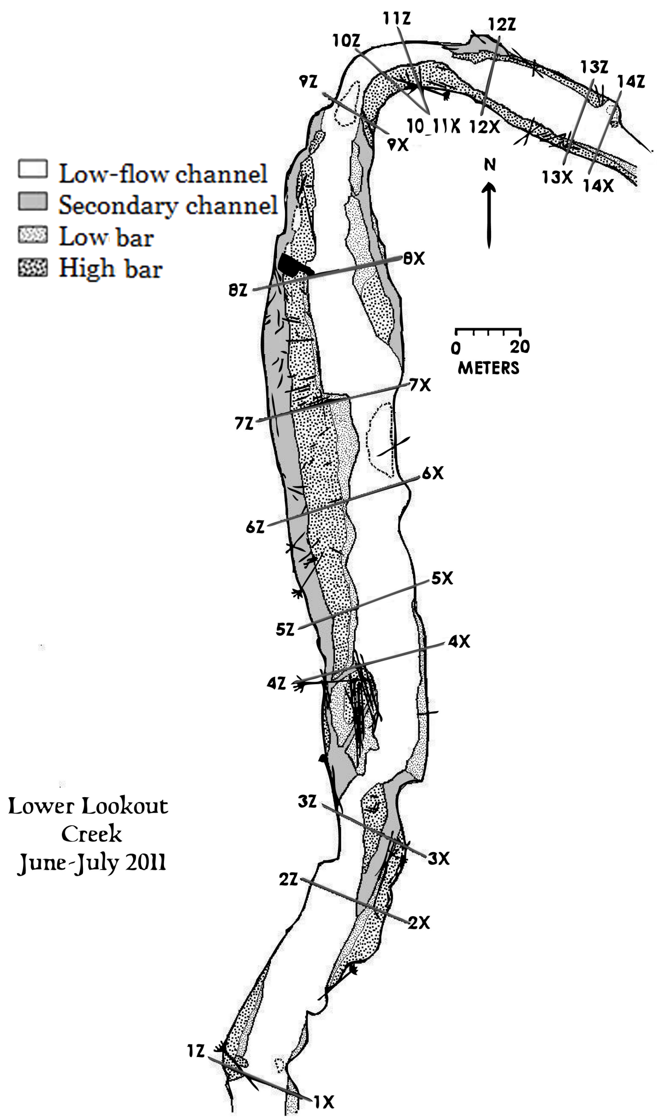

Fig. 1. A final mapping of the study area, including wood and channel features

2.2 Channel Mapping

For this entire stretch of Lower Lookout Creek, Transects 1-14, channel features including low gravel bars, high gravel bars, vegetated banks, deep pools, secondary channels, and abandoned channels were measured and spatially located on another blank 2010 EISI outline map of LOL. Particular care was taken in observation around large woody debris accumulations to correlate how the debris affects sedimentation rates.

Gravel bars were measured for length along stream and width across the channel. Where noticeably different elevations of the gravel accumulations were present, the bars were classified as low bars if less than 1 m above the lowest point in the stream bed and as high bars if more than 1 m above the lowest point in the stream bed. This classification system was used to settle discrepancies between observations that would exist at different times of year depending on stage height of the stream.

Length, width, and depth dimensions of pools of slower-moving or stagnant-like water were measured at several points in the stream, typically downstream of large gravel or wood accumulations. Secondary channels were considered where flow would not normally be present in lower-flow conditions due to gravel bars impedance. At the time of measurement, these channels had a significantly lower volume of water flowing through it. Abandoned channels were considered where elevation was more than 1 m below that of the surrounding gravel bars and historical maps indicated it was once an active channel but is now heavily vegetated with no flow.

The channel feature map was overlain by the wood map and touched up in Adobe Illustrator CS5.1 for the final 2011 LOL map (Fig. 1).

2.3 Cross-Sectional Profiles

Due to difficulty of crossing Lower Lookout Creek at certain cross-sections because of depth or quick-moving flow, profiles were only taken at Transects 2, 4, 8, 11, and 12. These particular transects were selected also because they are representative of a wide array of stream characteristics for this stretch of stream. Most importantly, these transects have wood accumulations across them, a helpful component for the modeling process to see how the stream bed and wood accumulations interact in response to flooding events.

A long tape was strung across each transect, beginning at the transect's X posts, or river left looking downstream, and ending at the Z posts. Slack was reduced as much as possible after tying off the tape at X and Z reference points so that the tape was approximately level across the stream. A PVC pipe with 0.1 m increments was used to measure the depth of the stream bed below the tape at 0.5 m intervals along the tape for the current water level and at 1.0 m intervals for gravel bars and points on the bank above flow. This method was most efficient and feasible for limited access to more professional, accurate instruments such as past profiles have been taken[1] and served the general purpose of getting rough estimates of how the channel changed since the January 2011 5-year flood.

GPS locations were also taken using a high-precision, submeter resolution Trimble ProXH GPS instrument with a Zephyr antenna. Data was taken in the NAD_83_HARN projection and downloaded to a Trimble Nomad handheld computer for each transect's X and Z datum points except for points 8Z, 9Z, 10Z, 11Z and 14Z which were too treacherous to access with given equipment. Approximately 50-100 points were collected for each datum for increased accuracy and precision. Theresa Valentine, Spatial Information Manager at the Corvallis Forest Science Laboratory in Corvallis, Oregon, processed this data for plotting in ArcGIS to provide an accurate, to-scale map of the bank-full stages of Lower Lookout Creek (see Fig. 1).

3 Mathematical Model

For the theoretical model of movement of wood in streams, the only previously existing literature involves modeling each piece of woody debris as a right-circular cylindrical log. In this case, a force balance on each log is analyzed, assuming that the log initially moves by sliding when the downstream forces (gravity and drag) are greater than the upstream (friction). Another important point of this previously existing model is that the lift force, which is commonly included in sediment transport is not involved as typically moving logs are not submerged[2].

To further simplify in our case, all logs are assumed to be parallel or perpendicular to the flow of the stream with no or negligible rootwads. From qualatitive observation, this is a fair assumption for our study site. These assumptions allow the force balance to be simplified to the following, relating the diameter, length, and area submerged of each log:

$$g\rho_{wood}\frac{\pi {D_{log}}^2}{4} = g\rho_{water}L_{log}A_{sub} \tag{1}$$

In equation (1), ρ_{wood} and ρ_{water} are the densities of wood and water respectively and the area submerged is a function of d_c, the critical depth of water (from the bottom of the log) required to mobilze the piece of wood.

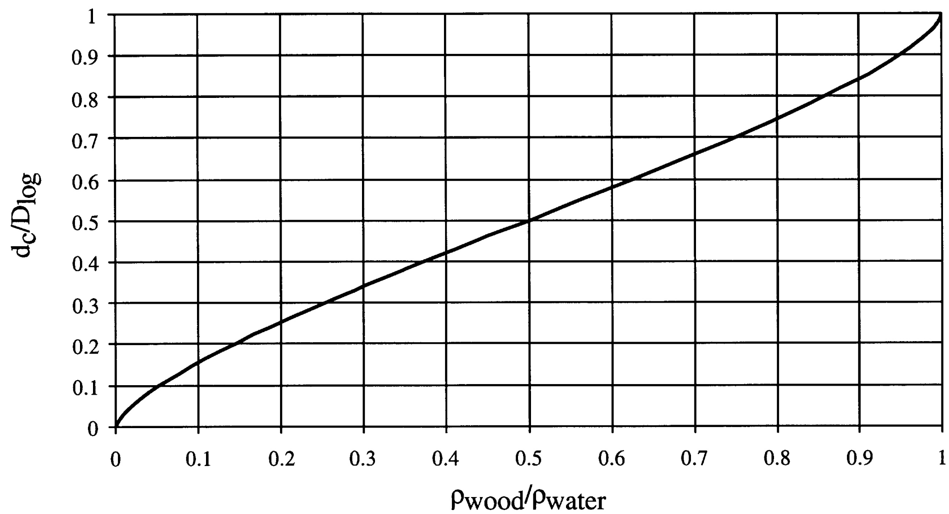

Fig. 2. Dimensionless plot of critical floating depth/log diameter versus wood density/water density)[3]

Solutions for the critical height of water in relation to the diameter of the log can be plotted against the ratio of the densities of wood and water.

As most of the logs in the field site analyzed were Douglas fir, a density estimate of 537 (kg m^{-3}) can be made[3]. Along with the density of water being approximated at 1000 (kg m^{-3}), a linear relationship develops (Fig. 2) and the following can be assumed:

$$\frac{d_c}{D_{log}} \approx \frac{\rho_{wood}}{\rho_{water}} \tag{2}$$

Therefore, since the diameter of each piece of wood analyzed is known, a critical flotation height can be calculated from each using the assumed density value and equation (2).

Accumulations of debris (for which all members could not be measured seperately) are treated as rectangluar prisms. The height of the measurement is used in place of the diameter. This special case will be addressed separately.

From the wood mapping of the reach and the cross sectional profiles surveyed, a rough estimate was made to place each piece of woody debris at a place on the cross section closest to where it was mapped. The wood was assumed to be on one point in the cross section, determined by the middle (diameter-wise if closer to parallel than perpendicular to flow or length-wise if otherwise) of the debris.

By placing each piece of debris at a specific point on a cross section, a critical stage height can be calculated. This is done by first taking the vertical coordinate of the point in which the debris is placed on the cross section and subtracting the coordinate of the lowest point in the cross section (assumed to be the bottom of the channel). The result of this subtraction is the stage height required for the water to reach the bottom of the log. The stage height to the bottom of the log plus the critical height for flotation in relation to the log. Using this method, a critical flotation stage height requirement can be calculated for all pieces of debris mapped in the creek.

Manning's equation relates the volume of a stream to the hydraulic radius and the gradient and is usually summarized as the following:

$$V = \frac{1}{n} R_h^{2/3} S^{1/2} \tag{3}$$

In Manning's equation, n is the Gauckler–Manning coefficient determined by physical characteristics of the streambed. In the case of the Lower Lookout Creek, several attempts have been made to estimate n. One estimation method uses the D_{50} particle grain size. The result of this method was an n value of approximately 0.03 and historical estimates have been approximately 0.05[8]. The value decided upon was 0.05, as the historical analysis was much more thorough than our own, including vegetation and other factors besides the particle size. The slope of Lower Lookout was approximated to be 1.5%, again from historical sources[5].

For each piece of debris and cross section associated with it, the stage height required for flotation was calculated using the aforementioned method. From that stage height, the hydraulic radius was calculated using the cross sectional data by assuming that the water was at the required stage height to determine the wetted perimiter and area of the water.

From this, all parts of Manning's equation are established for any given piece of woody debris and a velocity V can be determined. The discharge of the stream required for the mobilization of any debris can also be calculated by:

$$Q = AV \tag{4}$$

The area was previously calculated using the critical stage height. Therefore, the result of this is a critical discharge Q required to mobilize each piece of woody debris mapped in the reach of Lower Lookout Creek analyzed as a function of the horizontal position at a cross section and diameter or height of the debris.

This function was applied to the entirety of the wood data taken during the mapping, giving a distribution of the discharge required to critically float each debris. From this data, the goal was to determine the following stochastic equation:

$$\mu_V(Q, V) = P(movement|Q, V) \tag{5}$$

This function, μ_V, represents the probability that a given piece of woody debris of a volume V will move in a discharge Q. Although some previous literature attempts to model this as a function of length, this study took volume as a parameter instead, as it implicitly includes additional information about the debris.

The volume of the debris was calculated in different ways depending on if it was classified as an accumulation or single member. For the single members, the volume was calculated simply as the volume of a cylinder of a given length and diameter. Rootwad was not included in the calculation. For the accumulations, which were measured as rectangular prisms, the volume of the prism was calculated and then scaled by a porosity factor. The scaling factor used was estimated to be approximately .55, as past studies have used porosity values around 45%, meaning the measured volume would be 55% of the actual[10].

To first determine μ_V, the critical discharges for all wood were fitted to probability distrubtions, ignoring the dependence on volume. p–values were used to assess most appropriate fit using the Anderson–Darling test. A fitted gamma distribution proved to result in the highest p-value, so the distribution was accepted (Table 1). From there, to make μ_V a function of V, the data was split into volume classes. In this case, a class is just a range of possible volumes determined by the data taken on Lower Lookout Creek. First, the data was split in half, resulting in two classes: one from 0 to 1 m^3 and the other from 1 to 55.08 m^3. When each of these volume classes were fit to a gamma distribution, the resulting p–value was averaged and compared to the process where the volumes were split up into 3 classes (splits at .25 m^3 and 3 m^3). As result was that the two splits were a better fit for the data (Table 2).

TABLE 1
Tested Distributions of Critical Discharge Data for Wood Movement

Distribution	p–value
Gamma	0.267
Logarithmic	0.012
Log-Normal	0.151

TABLE 2
Tested Volume Classes (assuming Gamma distribution)

# of Vol. Classes	Avg. p–value
2	0.693
3	0.468

Using the μ_V formulated with a gamma distribution, a general density distribution model can be applied, resulting in the following integro-differential equation[14]. This can be utilized to model dynamics of the large woody debris distribution on a river stretch of length $\Gamma : [0, L_\Gamma]$

$$\frac{\delta u}{\delta t}(x,t,V) = r - \mu_V(Q,V)u_V(x,t,V) + \mu_V(Q,V)\int_\Gamma \kappa_V(y,x,V)u_V(y,t,V)dy \tag{6}$$

Here, $r = \frac{\overline{r}}{L_\Gamma}$, which represents the percent of the volume of wood that both enters and exists the stream reach per unit length, $u_V(x,t,V)$ is the density of the volume of wood per unit length at point x and time t for a specific volume class, and $\kappa_V(y,x,V)$ is the probability that a log of a specific volume class will move from point y to point x in the stream reach. The next step is to integrate over the range of volumes to represent all of the volume classes observed on the Lower Lookout Creek.

$$\int_0^{V*} \frac{\delta u}{\delta t}(x,t,V)dV = \int_0^{V*} (r - \mu_V(Q,V)u_V(x,t,V) + \mu_V(Q,V)\int_\Gamma \kappa_V(y,x,V)u_V(y,t,V)dy)dV \tag{7}$$

The following equation is the result of integrating over the range of volumes:

$$\frac{\delta u}{\delta t}(x,t) = r - \mu(Q)u(x,t) + \mu(Q)\int_\Gamma \kappa(y,x)u(x,t)dy \tag{8}$$

where

$$\mu(Q) = \int_0^{V*} \mu_V(x,Q,V)f_V(V)dV \tag{9}$$

and

$$\kappa(y,x) = \int_0^{V*} \kappa(y,x,V)f_V(V)dV = \lambda e^{-\lambda(x-y)} \tag{10}$$

f_V was determined stochastically by fitting a log-normal distribution to measured wood. This distribution was selected because the sample data taken contained a large abundance of small volumes, which suggested such a distribution as seen in Fig. 3.

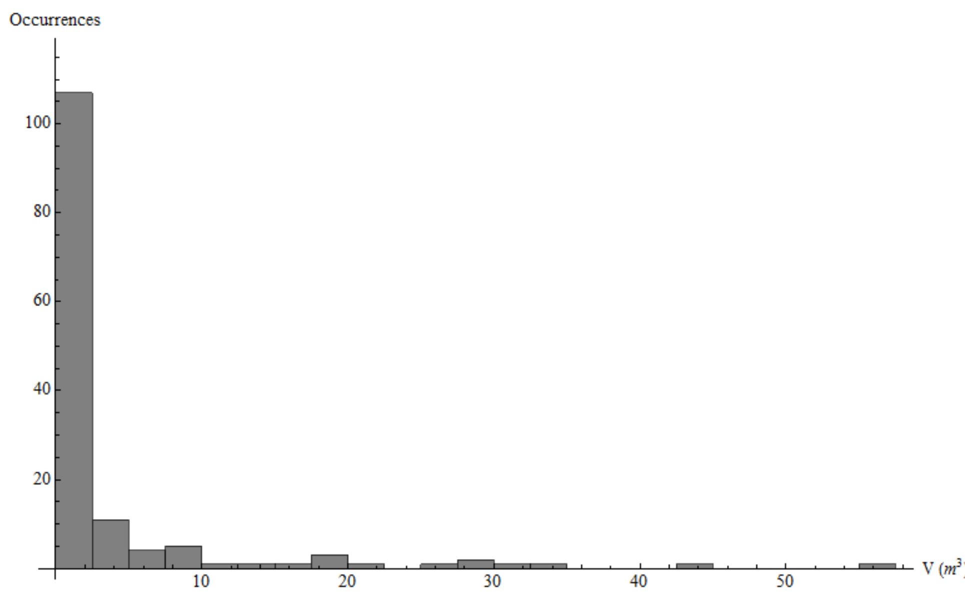

Fig. 3. Histogram of the occurrence of volumes of woody debris in LOL

Additionally, $\kappa(y,x)$ is assumed to be a negative exponential[12] where $\frac{1}{\lambda}$ represents average distance the wood moves in the stream for a given discharge, Q. The function $u(x,t)$ is quantified through the 2010 wood survey on the Lower Lookout Creek performed by Jung–il Seo and Kristen Kirkby. To do so, the normalized volume of wood in each cross section of the Lower Lookout Creek was calculated per unit length and defined as a piecewise function. The unit length in our calculation was a cross section, meaning the total volume of debris was calculated for each of the 14 cross sections and then divided by the length of the cross section, giving the volume per unit length. Then, to normalize the volume of wood, each value was divided by the total wood volume in the stream. To have the model represent change in wood volume in the entire stream reach, the equation is integrated over the length of the reach, Γ. Here, $\Delta t = 1$ year and $\Delta U(t)$ is the change of total volume over one year in the stream reach.

$$\int_\Gamma \frac{\delta u}{\delta t}(x,t)dx = \frac{\delta}{\delta t}\int_\Gamma u(x,t)dx = \frac{U(t+\Delta t)-U(t)}{\Delta t} = \int_\Gamma (r - \mu(Q)u(x,t) + \mu(Q)\int_\Gamma \kappa(y,x)u(x,t)dy)dx \quad (11)$$

$$\Delta U(t) = \overline{r} - \mu(Q)\int_0^{L_\Gamma} u(x,t)dx + \mu(Q)\int_0^{L_\Gamma} u(x,t)\int_x^{L_\Gamma} \kappa(y,x)dydx \quad (12)$$

The integration over the stream reach is performed such that the position y is upstream from x. Effectively, the probability represents the volume of wood moving from y to x in the stream.

$$\Delta U(t) = \overline{r} - \mu(Q) + \mu(Q)\int_0^{L_\Gamma} u(x,t)(-1 + e^{\lambda(L_\Gamma - x)})dx \quad (13)$$

Equation (13) is the total change of wood volume in the Lower Lookout Creek after one year given a specific discharge, in our case, the 2011 flood.

4 Results

4.1 Mapping

Comparing the two channel and wood maps from 2010 and 2011 for Lower Lookout Creek, a large observable volume of wood and sediments were redistributed throughout the study site. These changes are attributed to the January 2011 flood, a 5-year return period flood. A large jam at XS 11 washed out as well as channel-spanning logs at XS 1 and XS 4 being snapped and partially washed out. The most prominent new LWD accumulations and jams can be found at XS 4 and XS 8.

Gravel bars also show changes and migrations in the stream channel most noticeably between XS 7–8 and XS 3–4. Different sedimentation patterns are responses to both the flooding event and changes in wood debris distribution in the stream. Following large flooding events, erosion and deposition greatly affects the median grain size of the bedload[5], and LWD largely influences the location of new channel features.

4.2 Modeling

The result of the model for the change in total volume of wood in the reach (equation 13), was a function of λ and $\overline{r}$, neither of which were available from historical sources nor from the data we took. Because of this, we attempted to estimate each of these parameters and see how they relate.

To estimate λ and $\overline{r}$, the physical interpretation of each value was utilized. In this case, λ is the inverse of the mean distance traveled by debris in the 2011 flood. Therefore, because of our model, even wood that moves an insignificant amount (<1m) is considered ”moved”, so this was taken into account when estimating the mean travel distance. Our estimates for $\frac{1}{\lambda}$ were a range between 0 and 150 meters. One study in a nearby creek, Quartz Creek, which considered logs ”moved” after moving 10m, reported a mean travel distance of approximately 108m[7] over 14 years. Although wood is likely to move shorter distances in Quartz Creek as it is a smaller order stream, the criteria of moving resulted in our estimates of mean travel distance to be lower.

The significance of $\overline{r}$ is the volume of wood that entered the entire reach in a given year. This value includes fallen wood into the reach and wood that has floated into the system from upstream. We assume the fallen wood to be insignificant in a year’s span, so the volume of the floated wood was the deciding factor estimating $\overline{r}$. Our estimate of this value is between 0 and 20% of the total volume, as larger values would be unlikely as the same study in Quartz Creek indicated that a maximum of approximately 16% of the total wood was mobilized the 1996 flood, a much larger magnitude flood than the 2011 flood[7].

The first method of solving equation (13) numerically was to use the known change in volume from the previous year. From this, the left hand side of the equation is known and $\frac{1}{\lambda}$ can be solved for as a function of $\overline{r}$. The result of this is that our estimates of the mean travel distance are feasible, as the range for the estimates of $\overline{r}$ yield a range of $\frac{1}{\lambda}$ of about 0 to 140 m as anticipated. (Fig. 4). The relationship was that as the input rate increased, a larger mean travel distance was required to sustain the measured change in volume after the 2011 flood.

The next method was to attempt to predict the change in volume based on our estimates of the two parameters. This can be visualized as a contour plot with values representing the normalized change in volume in one year. The actual value measured after the 2011 flood was -0.1, a 10% decrease in volume. This plot reveals that large input rates result in a net increase in the change in total volume of wood while an increase in the mean travel distance results in a lower net change in volume of wood per year (Fig. 5).

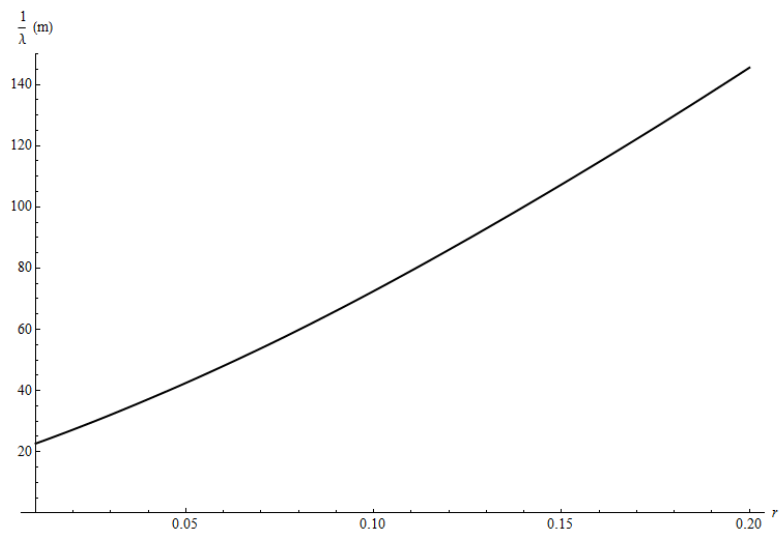

Fig. 4. Solutions for the relation between the mean travel distance ($\frac{1}{\lambda}$) and the input rate($\overline{r}$) using the known change in volume for 2011

5 Discussion

The implications of our modeling assumptions cause uncertainty in the accuracy of the model. The assumption that logs are right-cylinders will skew the actual volume of the log since the diameter tends to taper over the length of the log. Also, the volume of the rootwads was not accounted for in the calculations since the proportion of logs with rootwads versus those without was small. The total volume of wood in the Lower Lookout Creek is 462 m^3 and the volume of the dismissed rootwads is less than 20 m^3. G iven the over estimate from the right-cylindrical assumption, this can be considered negligible.

Furthermore, assuming the woody debris accumulations are rectangular prisms with a porosity of 45% only provides a rough estimate of the volume of the jams. The literature available about the porosity of wood accumulations is limited and varies with the style of the accumulation, which causes uncertainty in the volume calculations. It is a fair assumption that all of the wood in the stream is Douglas fir with a density of 537 $\frac{kg}{m^3}$ with 12% saturation[3], given the observed vegetation on the stream banks. However, the actual density of the wood varies with the saturation and 12% water content is a lower limit. As a result the critical height for flotation will vary. The critical stage height for flotation is a function of the density of wood, and with our density, the height must reach 50% of the diameter of the log. However, if the water saturation of the wood increases, the critical flotation height will change and this was not considered in the model.

The calculated stage height was used to calculate the cross sectional area of the stream to determine the discharge necessary for mobilizing the wood. The resulting discharges are an underestimate compared

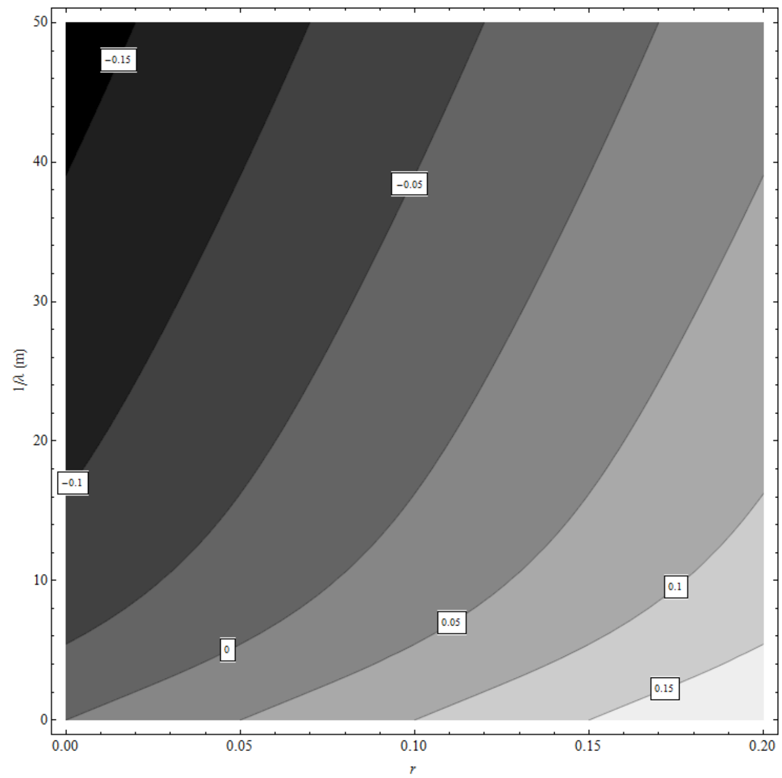

Fig. 5. Values for the total change in volume (normalized) in one year as a function of the mean travel distance ($\frac{1}{\lambda}$) and the input rate($\bar{r}$)

to historically observed discharges with equivalent stage heights, and this may be caused by the lack of up–to–date cross section profiles. All of the cross section profiles that were not surveyed through our methods are dated from 2006. This is problematic because there have been many flood events since 2006 that have greatly changed the morphology of the stream bed and are not accurate representations of the stream today.

Additionally, the cross sectional area is calculated with a trapezoidal approximation which neglects some of subtle changes in the profile. Another potential cause for the underestimation of discharge is our approximate value for Manning's coefficient for roughness of 0.05, which is a standard for mountain streams disregarding the specific morphological features of the Lower Lookout Creek. Lastly, our model assumes all of the logs lie parallel to the stream bed and have uniform contact with the ground. This will cause an underestimate for the critical discharge for mobilization since some of the logs were observed to be deposited at angles to the stream bed without uniform contact with the ground and would require a larger discharge than our calculations will estimate.

6 Conclusion

6.1 Study Significance and Continuing Study

This study and the resulting model can be used by scientists in many different fields including fish biology, civil engineering, geology, and hydrology. For example, knowing when LWD will move and where it will be in-stream at future points in time can allow biologists to predict and study fish populations and how the dynamics will change in the stream with large flooding events. Predicting movement of LWD as a function of flooding recurrence intervals can provide civil engineers with better-informed decisions on how and where to construct bridges over waterways and anticipate the possibility of mobilized LWD damaging infrastructure. In geologic and hydrologic fields, LWD can impact sedimentation rates and channel migration, also an important study for civil engineering if there are buildings near the stream banks.

The model itself holds significance of potentially expanding the scale. Specifically, only one year (in which the discharge was known) was used to solve for the distribution of wood in the reach. Future studies can develop a simulation performed for a longer term (several year) analysis of the distribution of wood in the stretch by each year. This could be done by selecting a theoretical peak discharge from a distribution (using flood frequency analysis) and from that discharge selection, λ and $\bar{r}$ can be selected accordingly, providing a new value for $u(x,t)$. This process that can be repeated for several years in a Monte Carlo simulation and the long term patterns of the distribution of wood volume could be analyzed.

6.2 For Future EISI Students

Wood dynamics is a very important study and would make a great continued project at the HJ Andrews Experimental Forest for future EISI participants. With this being the first year for the project, we found it difficult to attain and compile all the historical data and journal sources that ultimately pushed for our progress along on the project. The most problematic discrepancies were that historical data was taken by many different scientists who used several differing methods, especially for mapping woody debris, and it was hard to define and keep sight of a very specific question we wanted to answer with our research.

We have thus compiled a folder of important sources along with our most recent data and historical data to pass along to the next group. Our advice would be to take as much data as possible about the in-stream wood pieces, including two diameters (one at each end) in order to model the wood volume more accurately and treat each piece as a cone rather than right cylinder. Accurate cross-sectional data is also vital for the modeling process, so we suggest taking profiles with a stadia rod and transit level next year rather than our rudimentary methods. This could provide a better way of calculating discharge and stage height as to not grossly underestimate the total volume of wood moving in the stream.

Most importantly, we want to stress the importance of timely and efficient communication, both between group members and with project mentors. We found that much of our project would not have gone so smoothly if we were afraid to ask for more data, more sources, or meeting times to discuss concepts that were not clear. Many scientists associated with the Andrews are willing to help groups find historical data, and it is important to get as much information as possible even if it is unclear exactly how that data might relate to the project.

7 Acknowledgements

This study was a part of Oregon State Universitys Eco-Informatics Summer Institute (EISI) internship program funded by the National Science Foundation. We would like to thank the writers of the grants that gave us this opportunity including Dr. Desiree Tullos and Dr. Julia Jones who were also key mentors on our project. We owe a great thanks to Dr. Jorge Ramirez for helping us develop the model that is the heart of this study. Other project mentors include Dr. Fred Swanson, Travis Roth, and Matt Cox. Chris Gabrielli assisted in field data collection, and a cast of scientists associated with the H.J. Andrews Experiemental Forest provided a wealth of data, data processing, and equipment and for our study, including Dr. Mark Schulze, Theresa Valentine, Dr. John Faustini, Dr. Stan Gregory, Greg Downing, and Don Henshaw.

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