TAYLOR COMMENTS

Geomorphic Recovery Processes Following Debris Flow Disturbances in Low-order Channel Systems of the Western Cascades

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***Introduction***

Sediment discharge rates from low-order stream channels are not constant. Water exports ~~transports~~ some material at regular discharge rates, while a large percentage becomes trapped in the channel. This stored material is then released in mass during infrequent debris flows events. Characterizing how much sediment accumulates in a channel over time is key to understanding debris flow cycles and their impacts on surrounding landscapes and biotic systems.

Debris flow impacts depend on flow frequency and on material volume because both parameters influence geologic and biologic changes in the channel and at the deposition sites. Many studies have examined factors affecting debris flow frequency, including landscape characteristics such as bedrock type and channel slope, as well as hillslope instability ~~weakness~~ due to land management (Snyder 2000, Swanson and Dyrness 1975, Sidel et al. 1985). Few studies have researched the rate at which channels refill with material and factors influencing that rate. Wood volume is expected to significantly influence sediment accumulation in low-order streams by acting as an obstruction where other storage mechanisms are lacking (Keller and Swanson 1978; May and Gresswell 2003).

NEED FIGURE 1 – base map WITH WATERSHEDS & REACH STUDY LOCATIONS IDENTIFIED

NEED TABLE 1 – SUMMARY OF STREAM REACH ~~data~~/WATERSHED CHARACTERISTICS

KEY IP'S

INCLUDE LAND USE TYPE, HARVEST HISTORY

quantifies

This study ~~begins to quantify~~ fill rates in 1st and 2nd order stream channels that have experienced debris flows in and near the HJ Andrews Experimental Forest (HJA) in the Western Cascades, Oregon. Specific objectives of the study are to:

1) Determine rates of wood and sediment accumulation in debris flow-scoured low-order stream channels, and

2) Identify primary factors influencing accumulation rates, quantitatively and qualitatively.

Project Results ~~were~~ are examined in the
~~In addition, for comparison purposes, study methods were designed for~~

Context of a ~~consistency with a~~ similar study in the Oregon Coast Range by May and Gresswell (2003).

Need Figure 1 → Location map with channel reaches & ID.

***Study Area***

The study was conducted along ~~in the~~ lower elevations at HJA ~~of the HJ Andrews Experimental Forest~~ and ~~at~~ two additional sites within two miles of the Forest boundary. The sites were 1st or 2nd order headwater streams as defined by the HJA ~~HJ Andrews~~ Interactive Map and corrected for observed tributaries in the field. Surveys were made in debris-flow scour zones, meaning that the last event ~~debris flow~~ scoured the channel down to bedrock in the study reaches. ~~that reach of the channel.~~

Bedrock ~~The~~ geology of the study area is comprised of lava flow and clastic volcanic bedrock (Swanson and Frederickson 1982). The overstory is primarily Douglass Fir (Pseudotsuga menziesii), western hemlock (Tsuga heterophylla), and other coniferous and a few deciduous species such as red alder (Alnus rubra) that often recolonize the scoured channels.

Italics

Use Italics

?? explain

The stream channels in this region experience debris flows with increased frequency relative to higher elevations (Swanson and Dyrness 1975). The dates of their last debris flows have been documented by direct observation or from historical notes and photographs (Snyder 2000). This study included channels with the latest debris flows occurring in 1996 or 1964, the two years accounting for more than 75% of all debris flows in the forest over the last 60 years (Snyder 2000). The abundance of debris flows in these years provided ample channels to study. In addition to those scoured by 1996 and 1964 flows, two channels were included that have not experienced a debris flow during d ~~the record of~~ the last century. The time since the last debris flow at these sites was approximated to 250 years.[1] These three different ages of 11 (1996), 43 (1964), and 250 years since the channels' last flushing events allow the study sites to represent different points in time during the geomorphic ~~along a channel~~'s recovery process.

The majority of the channels surveyed (7 of 9) were in unmanaged forested areas. These forested regions were prioritized because their characteristics would indicate the background rate of accumulation in a natural environment. Two channels surrounded by plantations were also surveyed. These areas were clear cut, burned, and replanted in the 1950's. One such channel's most recent debris flow was in 1964 and the other's was in 1996. Plantations and natural forests may yield different channel refill rates because of varying amounts of wood input. This study focused on channel recovery in natural forests but could be expanded with more plantation sites to compare rates in different management environments.

Return to (TABLE 1) Here → Summary of channel characteristics

[1] Trees growing along the lower banks of the channel and assumed to have seeded since the last debris flow can be used to assess the time since that event. Using a tree core, a Douglass Fir was estimated at 140 years in one channel, and a cedar was estimated at 95 years in the other. These ages represent minimum time since debris flow, and the last flows could have been as long ago as 1,000 years.

*Methods*

The study used a space-for-time representation of wood and sediment accumulation in stream channels after debris flow~~s~~. Volumes of wood and sediment were measured by methods specified below to quantify the increase in material over a known number of years.

Refer to Summary TABLE

Multiple channels with the same date of last debris flow were chosen to account for variations among channels ~~of~~ with the ~~same age.~~ recovery time. Three channels from 1996, two from 1964, and two from older flows, all of which exist in natural forest areas were selected from records of debris flow history i~~n the HJ Andrews Forest.~~ at HJA. In addition, two plantation sites, one from a 1996 debris flow and one from a 1964 flow were surveyed.

Once channels were selected, identification of scour zones was made based on channel gradient and exposed bedrock. The bottom of each survey zone was chosen as a location where gradient exceeded 15% or where long exposures of bedrock were observed. In some cases, deposits from the last debris flow remained ~~at intermittent parts~~ sporadic locations in ~~of~~ the scour zones. The study sites ~~zones~~ were also located out of range of road influence, ~~(at least 75m from the road).~~ positioned at least 75 m from access roads

refers to time

Avoid parenthetical statements, use punctuation

Each survey was conducted in 10m sections of channel length in order to observe local variation along ~~in the~~ channel reaches. ~~A sum of~~ total 10 to 15 consecutive sections per transect were ~~was~~ measured, totaling between 100m and 150m, in order to average out local variations and capture channel trends. A minimum of 10 sections were surveyed in each transect. In some cases, high variability along the channel called for extending the survey to improve the sample's representative validity.

Refer to DATA TABLE

The following ~~items~~ DATA were measured and recorded in each 10m section of channel.

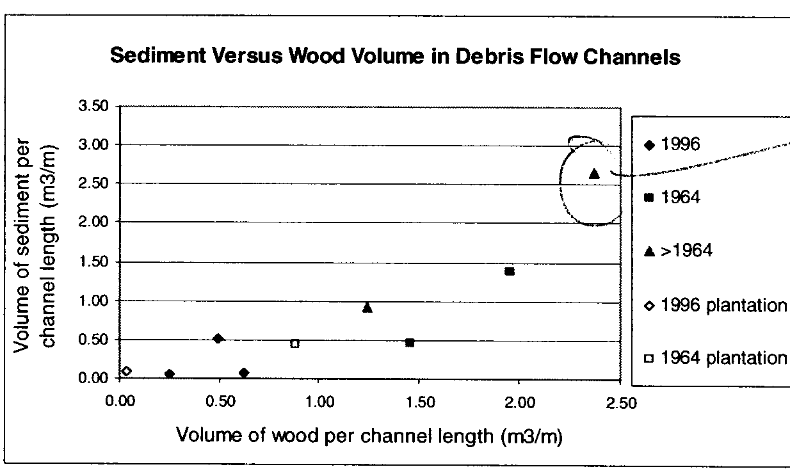
- Channel width: taken as the distance from one side bank to the other at a height of about 5m. above channel grade (?) ?
- Streambed width: the relatively flat region over which water flowed. (Active channel)
- Channel slope: measured with an Impulse laser.
- Wood vol. in the channel at least 0.2m in diameter and 2m in length: average diameter and average length in the channel were measured to calculate volume as a cylinder; in cases where wood was not cylindrical, a cross-sectional area was measured instead of diameter; wood entirely suspended more than 2m above the channel was not counted.
- Sediment volume accumulations at least 0.5m in length and width and at least 0.1m deep: average length, width, and depth were measured, and volume was calculated as a rectangular solid. When sediment formed terraces with a relatively flat surface but sloping bedrock base, volume of the wedge shape was calculated using the average depth assuming constant bedrock slope. Sediment refers to regolith transported by the stream. It excludes organic material from the sideslopes and boulders larger than 1m across. Sidelsope SP. input or hillslope volume remaining in the channel was approximated separately. Where sediment mixed evenly with organic sideslope material in accumulations, volumes were approximated to be half sediment, half hillslope. Each sediment accumulation was also characterized by the size of its pebbles as observed on the surface. Lastly, the object(s) or feature(s) ~~blocking~~ trapping each sediment accumulation were identified.

- Other notes: the percent of streambed covered by large wood (>0.2m diameter and >2m length), small wood (wood less than measurable threshold size), sediment, exposed bedrock, reaches and other material was approximated ? ? ? ? Finally, Quantitative observations were noted ~~that helped~~ to further characterize the channel environment, including size of the largest trees in the channel, evidence of sideslope failures after the last debris flow, and ~~descriptions of the~~ sideslope composition ~~makeup~~.

### *Results*

~~As expected,~~ Volumes of both wood and sediment are lowest in the channels that were most recently scoured (1996) and highest in channels with the longest time since a debris flow (before 1964). Because older scour zones exhibit more of both wood and sediment than younger ~~newer~~ ones, there is an observable correlation between the volume of sediment in a channel and the volume of wood in the channel (See Figure 1). While the sample number is too small to allow credible statistical analysis, there does appear to be a non-linear relationship between wood and sediment volume: doubling wood volume corresponds to more than a doubling of sediment volume.

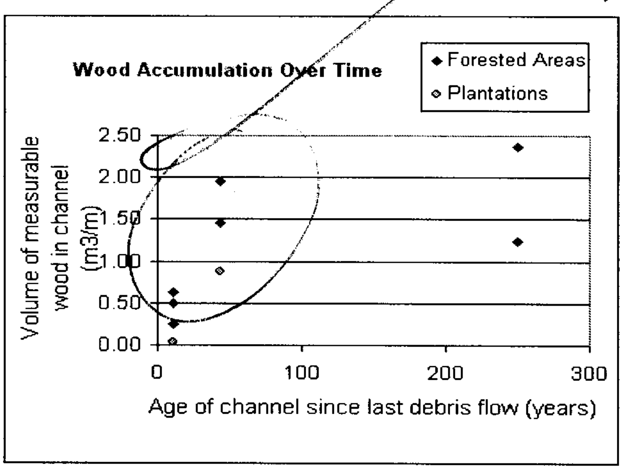
**Figure 1.**

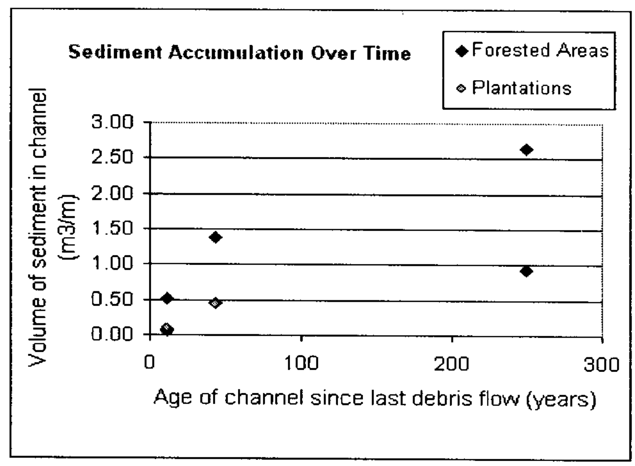



Label maybe ID's

The rate of wood and sediment accumulation in the study area can be calculated by relating the amount of wood and sediment to the time since the channel was scoured. Figures 2 and 3 display these two relationships. The amount of material found in 1996-scoured channels represents the accumulation over the first 11 years of recovery. The average wood from the three such sampled channels was $0.46 m^3/m$. The average sediment volume was $0.22 m^3/m$. The average amount of wood found in 1964-scoured channels, representing the accumulation during the first 43 years of recovery, was $1.7 m^3/m$. Sediment volume from these channels averaged $0.92 m^3/m$.

**Figure 2.** Label pts. **Figure 3.**




Sediment obstructions were divided into 8 categories, and the total volume of sediment stored by each type are displayed in Figure 4. The same data is shown as percentages in Figure 5. Large wood alone accounted for 45% of all sediment storage. In conjunction with small wood and boulders, large wood played an ~~obstruction~~ trapping role for 87% of the total sediment volume. Boulders alone blocked 9% of the sediment, while small wood alone, hill slump/bank, and a shallow channel slope (no obstruction) each ~~blocked~~ trapped less than 2% of sediment.

**Figure 4.**

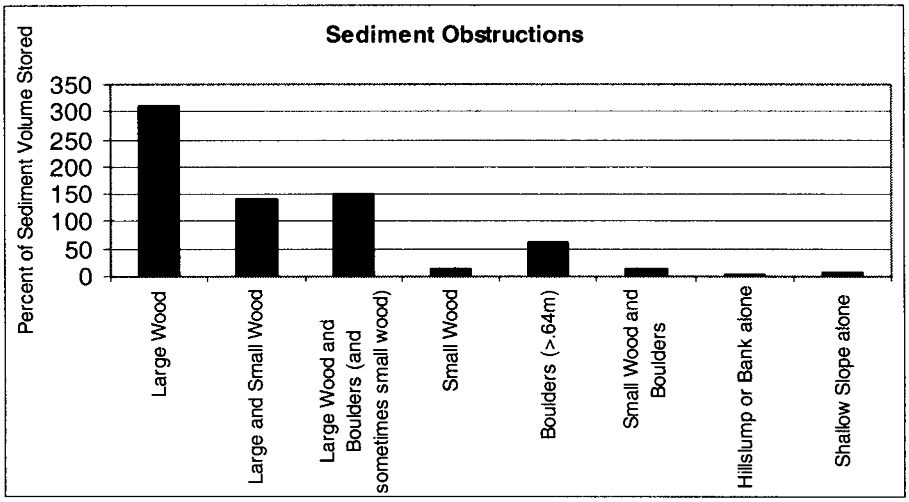
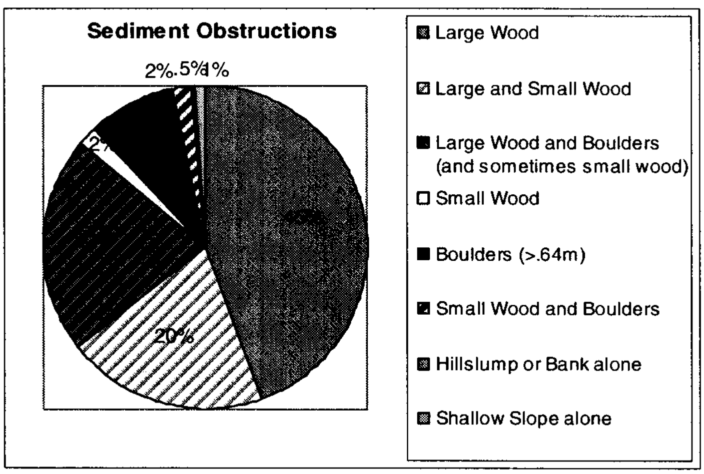



**Figure 5.**




Small wood and boulders commonly rested on flat reaches of bedrock along the channel. The gradient ~~slope~~ of the bedrock streambed varied considerably between 10m sections of most channels. GRADIENT ~~Slope~~ changes from one section to the next varied by an average of 6% ~~percentage gradients~~. Dramatic slope changes were also apparent within sections, usually in the form of a 2-5m bedrock ~~cliff waterfall~~ knick point followed by a flat scour pool. Small wood, boulders, hillslump, and no obstructions were more common sediment storage mechanisms in flatter sections than on steeper stretches. The two examples of remnant debris flow

explain? NOT A TERM

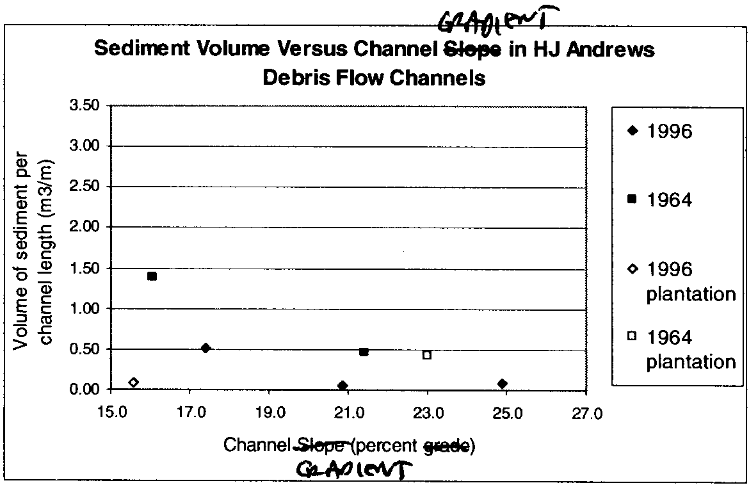
deposit~~ions~~s in the otherwise scoured channel reaches rested on flat bedrock sections. Large wood that entered the channel since the last debris flow, by contrast, exhibited no significant preference for shallow or steep channel ~~slopes~~ gradients.

present tense — Past tense

While channel ~~slope~~ gradient alone plays a negligible direct role in sediment storage, it was related to total sediment volume in the 1964 and 1996 channels. Channel reaches with higher average ~~slopes~~ gradients exhibited lower sediment volumes (See Figure 6).

use parallel verb tense

**Figure 6.**




The above graph also shows the influence of time since debris flow on sediment volume, as the trend line of 1964 channels lies consistently above the 1996 trend line. The 250 year-old channels were ~~left off this graph~~ omitted because they do not show any relationship between channel ~~slope~~ gradient and sediment volume, ~~but only~~ however do emphasize the observation that sediment increases with time.

In the ~~younger channels~~ more recently scoured reaches, the interacting influence of channel ~~slope~~ gradient and large wood on sediment accumulation can be observed by profiling ~~the channels by~~ reaches in 10m ~~sections.~~ increments (fig. 7) Figure 7 shows measurements of sediment volume, wood volume, and channel ~~slope~~ gradient in each section of channel WS 2-3, ~~which was~~ last scoured in 1996. Section 1 is downstream, and section 10 is at the top of the study reach. By following the green and blue lines from right to left, one observes that an increase in ~~slope~~ gradient corresponds to or is closely followed by a decrease in sediment volume and vice versa. ~~, likewise, decreases in slope correspond to increases in sediment.~~ Spikes in wood volume have some effect on sediment ~~volume~~ accumulation as well. The 1964 channels also displayed a link between slope and sediment volume. One example is profiled in Figure 8 with channel WS 1-2. In these channels, increases in wood correspond strongly to increases in sediment. Shallow ~~slope~~ gradient and corresponding small wood, boulders, and hillslope accounted for only 10-15% of sediment storage in 1964 or older channels, while the same features ~~blocked~~ trapped 45% of sediment in 1996 channels.

**Figure 7.**

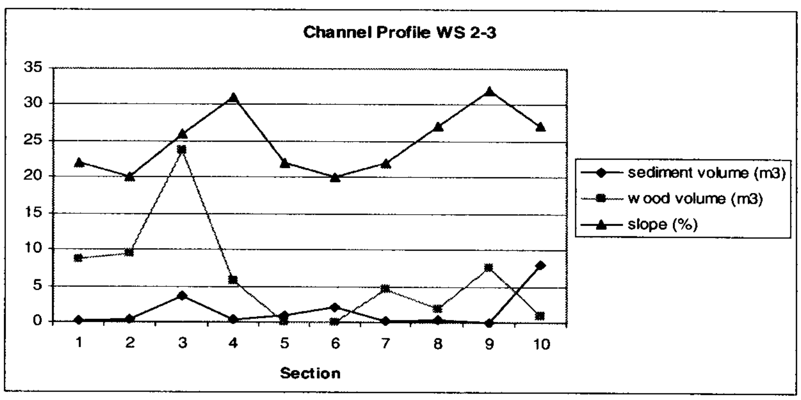
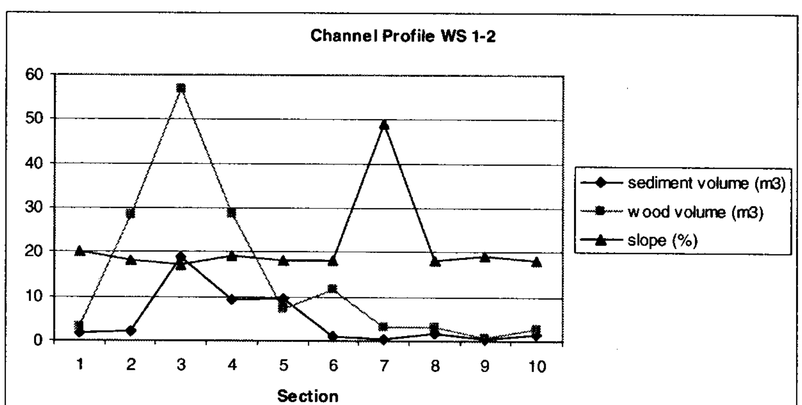



**Figure 8.**



### *Discussion*

The results of this study provide preliminary estimates of sediment and wood accumulation rates in low-order channels of unmanaged regions at HJA ~~in HJ Andrews Forest~~. The reliability of fitting a trend line to the data points is limited because only three time intervals were sampled, and the longest one is not known. Nevertheless, the average accumulation volumes in the first 11 (1996) and first 43 (1964 event) years indicate initial accumulation patterns in the study area, and these values can be compared to accumulation rates determined for ~~calculated in~~ other geographic regions.

May and Gresswell's (2003) study of wood and sediment accumulation rates in headwater streams of the Oregon Coast Range provides one basis of comparison. The two figures below (FIG X XX ??) compare the trends in wood accumulation between these two studies. Figure 9 is derived from ~~the same as~~ Figure 2 above, and Figure 10 is from May and Gresswell (2003).

Debris flow channels at HJA ~~in the HJ Andrews Forest~~ exhibited higher initial rates of wood accumulation than did the channels in the Coast Range. ~~In the HJ Andrews Forest,~~ low-order channels in the study area accumulate an average $0.46m^3/m$ of wood in the first 11 years and $1.7m^3/m$ in the first 43 years. IN ~~By~~ contrast, the equation that May and Gresswell derived to describe wood accumulation based on their measurements (see Figure 10) indicate accumulation volumes of $0.16m^3/m$ in the first 11 years and $0.25m^3/m$ in the first 43 years. These differences in wood volumes between the two study areas could be due to older forests and thus larger trees inputting wood to HJA ~~the HJ Andrews~~ streams compared to those in the Coast Range. ~~channels.~~

**Figure 9. Wood accumulation (HJ Andrews)**

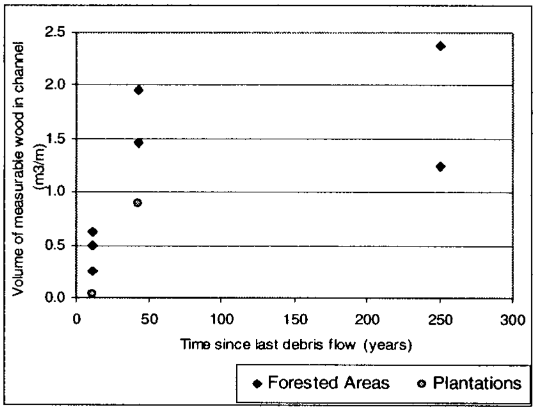
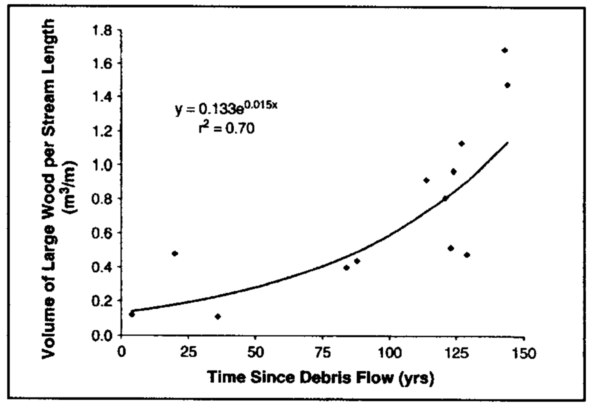



**Figure 10. Wood accumulation (Coast Range)**




Figures 9 and 10 also suggest different shapes to the wood accumulation trends between ~~the HJ Andrews Forest~~ HJA and the Coast Range. Measurements from ~~the HJ Andrews study~~ former indicate a faster accumulation rate during the first 50 years than during the next 200 years. ~~By~~ In contrast, ~~the~~ Coast Range data indicate~~s~~ a higher accumulation rate later in the recovery process rather than earlier. One explanation for this difference is the limited data for older channels in the ~~HJ Andrews~~ HJA study, both with respect to sample ~~number~~ size and date uncertainty. Another complication is that wood volumes in the 250 year-old channels at ~~in the HJ Andrews Forest~~ are underestimated. This is known because several (n = 8-12) large pieces of old wood were observed in these channels but were not measurable because of their degree of burial. Therefore, detailed comparisons of long-term accumulation rates (>50 years) between this study and the Coast Range ~~study~~ require ~~deeper~~ further investigation. Nevertheless, over all time intervals, ~~the HJ Andrews~~ HJA channels exhibit greater wood volume~~s~~ accumulation following debris flow.

Comparatively, Sediment volumes between the ~~HJ Andrews sites~~ HJA and ~~the~~ Coast Range sites are more similar than wood volumes, but rates were again higher in the ~~HJ Andrews Forest~~ former.

Figures 11 and 12 compare sediment trends from the two studies. Figure 11 is ~~the same~~ derived ~~as~~ from Figure 3 above, and Figure 12 is from May and Gresswell (2003).

Average sediment volumes from the 1996 ~~channels and average volumes from the~~ and 1964 channels suggest that low-order channels in the study area accumulate an average of $0.22m^3/m$ of sediment in the first 11 years and $0.92m^3/m$ in the first 43 years following evacuation. May and Gresswell's (2003) derived equation for sediment accumulation rate (see Figure 12) indicates accumulation volumes of $0.05m^3/m$ in the first 11 years and $0.38m^3/m$ in the first 43 years. The volumes for the first 11 years differ by a factor of 4 ~~like wood volumes,~~ similar to the wood data, suggesting faster sediment accumulation in ~~the HJ Andrews~~ HJA channels; however both values are small enough to be within the range of sampling ~~inconsistency~~ error~~s~~. The sediment volumes for the first 43 years differ by a factor of 2.5, less than the difference in wood volumes ~~(a~~ with a factor of 7~~)~~. Avoid parenthetical statements

**Figure 11. Sediment accumulation (HJ Andrews)**

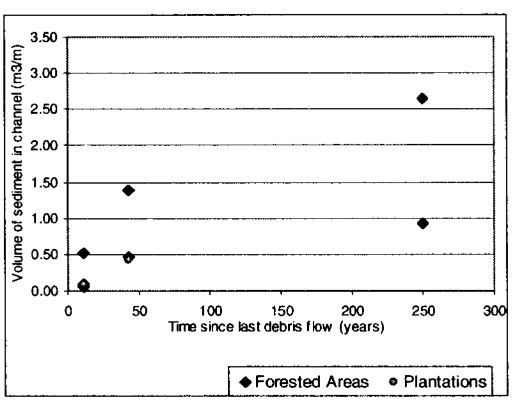
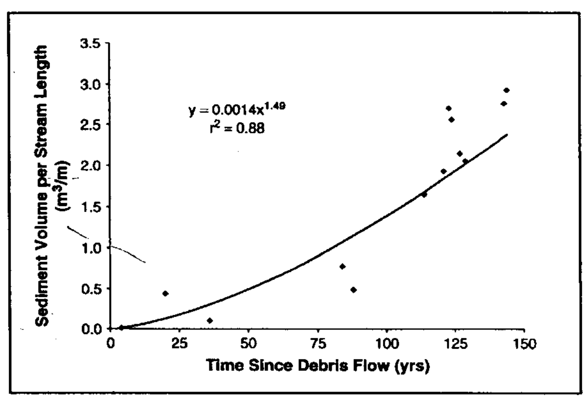



**Figure 12. Sediment accumulation (Coast Range)**




The higher values in the ~~HJ Andrews Forest~~ HJA DATA SET suggest that the correlation between wood and sediment volumes applies across study areas of otherwise similar environments. However, sediment volumes were relatively similar compared to wood volumes, signaling that other factors must be considered. Differences between the Coast

Do you mean HJA vs. Coast Range or between transect at HJA only?

and Cascade Ranges such as erosional processes and sediment input rates as well as channel slope would influence accumulation differently. These discrepancies make comparisons between sediment accumulation rates suspect ~~without~~ and require further research.

Awkward Sentence Rewrite

It is also important to note that May and Gresswell (2003) found a ~~steeper relationship~~ more rapid rate of increase between sediment volume and wood volume than was observed in this study (Figures 13 and 14). ~~The difference can be seen in Figures 13 and 14, the first of which comes from this study and the~~ second ~~from May and Gresswell (2003).~~

**Figure 13. Sediment and Wood (HJ Andrews)** (This Study)

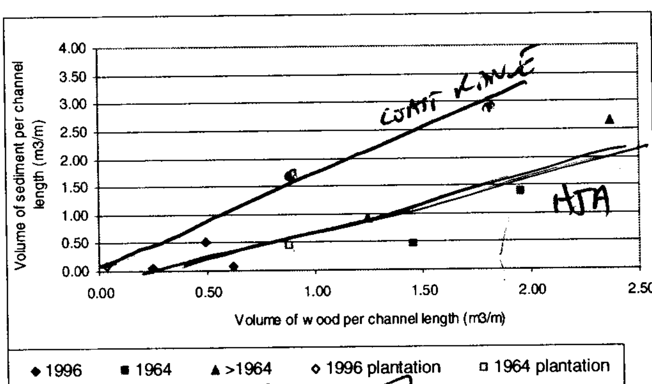
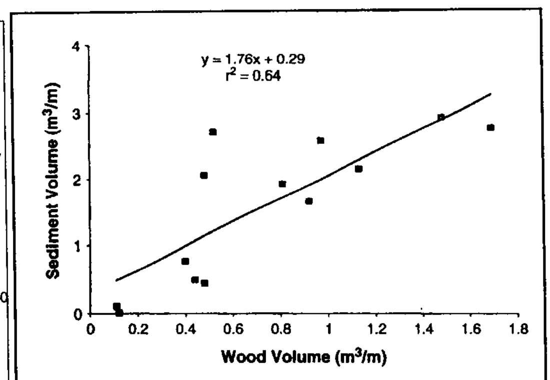



**Figure 14. Sediment and Wood (Coast Range)** May & Gresswell (2003)




The ~~steeper~~ more steeply sloping relationship in the Coast Range could indicate that wood plays a greater role in sediment storage there; but this hypothesis is weakened by the observation that both studies report wood ~~blocking~~ trapping 87% of all sediment. Another explanation is that the wood-based sediment storage in the Coast Range is much nearer its threshold capacity than ~~in the HJ Andrews Forest~~ at HJA. Only when sediment volumes become very high does the extra wood in ~~the HJ Andrews~~ HJA's channels become a crucial factor. This hypothesis is supported by the observation that sediment volumes increase nonlinearly with wood volume in the HJ Andrews Forest compared to the linear relationship in the

really what about fitting & checking $R^2$

Coast Range, and by the observation that wood becomes an increasingly important sediment obstruction in older, fuller channels.

While explaining the differences between the Coast Range ~~the~~ and ~~HJ Andrews Forest~~ HJA warrants further examination, the sediment volume data from this ~~HJ Andrews~~ study has valuable ~~applications by themselves~~ implications. The preliminary results help predict the amount of material accumulation in a channel ~~after a certain time~~ as recovery time progressed since its last flushing. If the frequency of debris flows in the area is also known, then one can predict both how often the channel flushes and how much material will be ~~discharged~~ evacuated.

Awkward rewrite sentence

Both the frequency and ~~the amount of material discharged~~ sediment transport volume by ~~a~~ debris flows have many known and unknown implications on the landscape and ecosystems of the channel and deposition areas downstream from the channel. For example, different ~~vegetation~~ forest biota ~~cycles~~ will ~~develop on~~ inhabit the downstream ~~alluvial fan~~ deposition zone depending on whether the channel transports small, regular ~~pulses~~ volumes of sediment ~~versus~~ or large infrequent ~~deposits~~ pulses. The different vegetation as well as direct impacts of different sediment flux patterns on animals will favor some species over others. Details of these ecosystem impacts are beyond the scope of this paper, but depend on the factors explained here.

Awkward, repetitive

Changing either the debris flow frequency or the amount of material discharged will impact the ecosystem adapted to the channel's natural patterns. Certain Forest management practices ~~has~~ have been found to increase debris flow frequency by undercutting hillslopes and destabilizing the soil when building roads or removing old trees (Swanson and Dyrness 1975). This study offers preliminary ~~data~~ results suggesting that forest management ~~has~~ plays an additional role by also affecting how channels accumulate material. Because wood is a primary sediment ~~storage~~ trapping mechanism in low-order channels, and ~~because~~ sediment

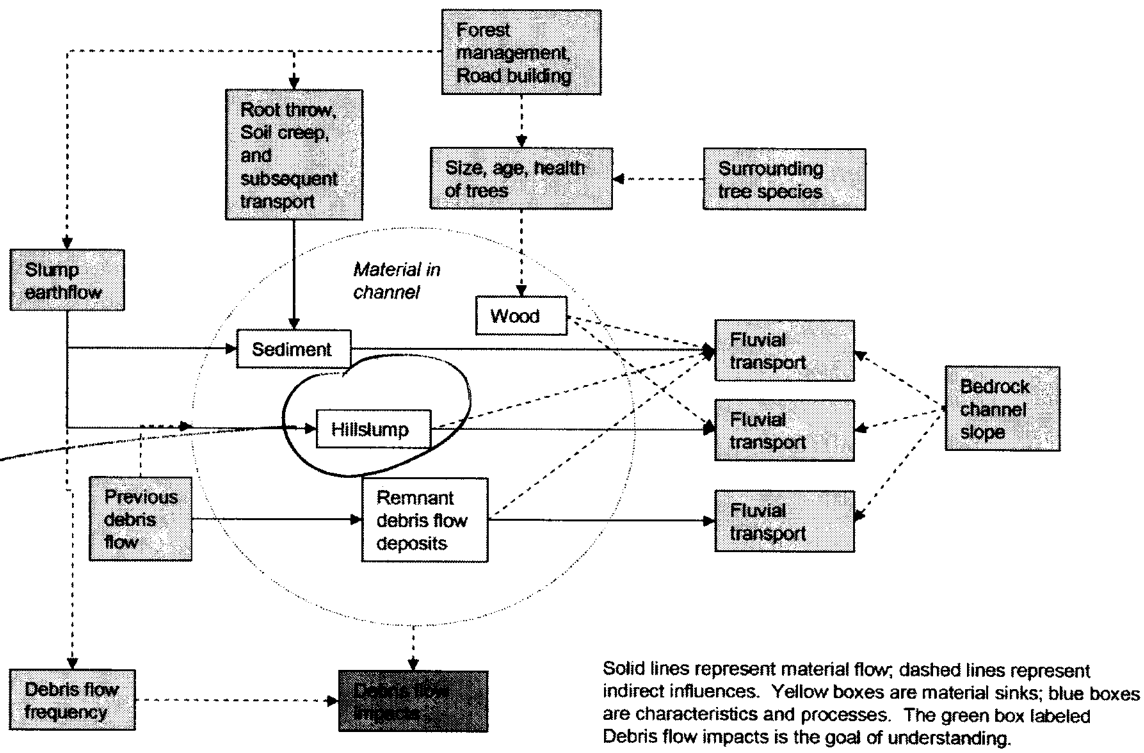
(FIGURE x 8X)

volume is positively correlated to wood volume, management practices ~~such as clear-cutting~~ that reduce wood input to channels are also likely to reduce sediment ~~accumulation rates~~ retention and increase the ~~regularity~~ rate of sediment ~~transport.~~ export.

While this study does not include a large enough sample of plantation sites to compare the rates of wood accumulation ~~between~~ in natural ~~forests~~ and managed forests, it is reasonable to expect that cutting and planting trees on a typical management cycle would reduce wood input unless ~~wood next to the channel were left or artificially increased~~ mitigation techniques were employed. (Swanson and Fredriksen 1982). Initial findings from the two plantation~~s~~ sites in this study ~~exhibit~~ show less wood ~~than natural channels in corresponding years, so far supporting that hypothesis.~~ accumulation rates compared to natural channels.

The ~~above-mentioned~~ aforementioned connections between forest management and debris flows are shown in the ~~influence~~ flow diagram ~~of~~ on Figure 15. This figure portrays the primary sources of material to a refilling channel, the sinks of material within a channel, and the processes that block or remove the material. Developing quantitative measures for each of these sources, sinks, and transfer processes in a particular region such as the western Cascades ~~Mountains~~ will improve predictions of debris flow cycling and ~~the flows'~~ impacts on ~~biota.~~ biotic communities. This study begins to assign numbers to the four material boxes within the channel. ~~That~~ This data can be combined with past and future studies to ~~complete the model~~ contribute quantitative measures to the model. ~~A quantitative~~ link be~~tween road building and sediment storage, for example, follows~~ the diagram.

**Figure 15. Land transfer processes affecting debris flow cycles.**




SNYDER'S (2000) WORK

Data from ~~Kai Snyder's master's thesis (2000)~~ on debris flow activity ~~in the HJ Andrews Forest~~ at HJA can be used to quantify one influence pathway from forest management to material in 2nd order channels. According to Snyder's (2000) analysis of all debris flows ~~in~~ at ~~the HJ Andrews Forest~~ HJA since 1946, basins disturbed by roads experience debris flows with 11 to 50 times the frequency of natural forest areas. The factor of 11 is associated with 1996 debris flows, and the factor of 50 refers to 1964 flow activity. The following analysis uses the recent 11-fold figure.

CONFUSING STATEMENT REWRITE & CLARIFY POINT

A sediment accumulation rate for low-order channels is derived from this study as $0.009 m^3/m$ per year. This is a simple calculation of the average sediment volume after 43 years ($0.38 m^3/m$) divided by 43 years.

Which Study yours or Snyder's?

Assum~~ing~~ that debris flows occur in low-order ~~HJ Andrews~~ HJA channels at the natural rate of X years ? between flows, the channels will have 0.009X $m^3/m$ of material in them at each flow event. If roads have influenced the area, debris flows may happen every X/11 years. Then the channels will store 0.0008X$m^3/m$ of material between flows or 1/11 the natural volume. The result is more frequent and less massive releases of sediment downstream. However, roads may also induce increased sediment input to the channel, which would likely increase sediment accumulation based on the evidence that sediment storage in HJ Andrews channels is under capacity.

I'm not getting the connection between Snyder's road work & yours??

Is this necessary?

Furthermore, Snyder's research reveals that debris flow impacts in $2^{nd}$ order channels are disproportionately higher than in $1^{st}$ order channels. This is attributed to the dendritic nature of stream networks, with multiple $1^{st}$ order streams feeding the same $2^{nd}$ order stream. Approximately twice the percentage area of $2^{nd}$ orders streams experience debris flows compared to ~~the percentage area~~ that of $1^{st}$ order channels (Snyder 2000). If flow frequency in $1^{st}$ order channels translates to twice the frequency in $2^{nd}$ order channels because the upstream events trigger flows downstream, then roads built across $1^{st}$ order basins will have a two-fold impact on $2^{nd}$ order streams. The frequency becomes X/22 years between flows, and the amount of material becomes 0.0004$m^3/m$. Again, sediment accumulation might be somewhat faster due to more input from the unstable slopes upstream.

This discussion doesn't add anything to your story??

The volume of sediment trapped between debris flows also depends on the storage capacity of the channel, ~~which depends on~~ as a function of wood. Therefore, if a $2^{nd}$ order channel is surrounded by a plantation downstream of a road, the reduced wood input is likely to decrease sediment accumulation. The result is even more regular discharge and smaller

(anyway) This needs to be recast with a different angle to be effective debris flows. The frequency of debris flows will not necessarily increase as much as predicted because flow inducement may require a certain degree of material volume in the channel, and the stated factors greatly reduce stored volumes (Swanson and Fredriksen 1982). Understanding this final influence requires further research on accumulation rates in plantation channels and on threshold forces that trigger debris flows relative to material volume in the channels.

### *Summary* AND CONCLUSION

- The effects of debris flows on the landscape and biotic systems depend on their frequency and scale. Their scale (~~amount~~ VOLUME of material carried) depends on their frequency and ~~their fill~~ ACCUMULATION rate between flows. ~~Their~~ Frequency may also depend on fill rate.
- This study measured fill volumes of wood and sediment in channels with varying time intervals since their last debris flow to determine accumulation rates.
- Within ~~the HJ Andrews Forest~~ HJA, channels with higher wood volumes correspond to channels with higher sediment volumes, both of which also correspond to older channels. Plotting ~~these~~ volumes ~~over~~ time provides a visualization of accumulation rates. ~~As stated throughout this report,~~ Additional sites need to be surveyed to verify the preliminary results of this study and ~~to fit a statistical curve to~~ TO QUANTITATIVELY DESCRIBE FUNCTIONAL RELATIONSHIPS BETWEEN wood and sediment accumulation rates.
- Wood plays a role in ~~storing~~ trapping 87% of sediment in low-order channels. Channels ~~in the HJ Andrews Forest~~ at HJA accumulate wood more quickly than channels in the Oregon Coast Range, as studied by May and Gresswell (2003). This is

likely due to the older forests and larger trees that surround ~~the HJ Andrews~~ HJA ~~channel~~s compared to ~~the~~ those in the Coast Range ~~channels.~~

MOVE SECTION TO BEFORE SUMMARY

- Sediment accumulation rates are slightly higher in the HJ Andrews Forest than in the Coast Range, but they are more similar than wood accumulation rates between the regions. Sediment accumulation rates may differ between the areas partly due to more wood in the HJ Andrews channels. Explaining this comparison requires further research on sediment input processes, channel slope and other ~~differences~~ variables ~~between~~ in the study areas.
- Forest management affects the frequency of debris flows and is likely to affect the accumulation rates between debris flows, contributing to a two-fold impact on the debris flow environment. If a practice reduces wood input to a channel, then less wood and sediment will accumulate than ~~would naturally.~~ in an unmanaged forest. Sediment transport will be more regular and debris flows less voluminous. Increased frequency of debris flows due to the same or other disturbance would add to that shift. UNCLEAR REPHRASE/ EXPLAIN??
- NEW BULLET ~~Expansion of this study needs to~~ ~~Additional work is needed~~ including more plantation sites in ~~complete~~ enhance the quantitative comparison between ~~debris flow effects in~~ natural and managed environments.

~~Should~~ THIS SECTION SHOULD BE MOVED IN FRONT OF THE "SUMMARY & CONCLUSION"

### RELEVANCE TO *Ecosystem Informatics*

While this project ~~was predominantly~~ focused on ecosystem field research and data analysis, it contributed to a larger objective that abounds with ecosystem informatics components. That goal is to understand and model debris flow systems. Through this specific study, a conceptual model was developed from other models in literature and by observing material Storage ~~transfer processes~~ in the field. Values from this study and others were assigned to some of the model's components, and preliminary conclusions about debris flow behavior as influenced by forest management were ~~deer~~ derived, ~~calculated.~~

This project has high potential for explicitly expanding its ecosystem informatics component, ~~abundant room for ecosystem informatics expansion.~~ The data base needs more field measurements of both forested and plantation sites so that more robust statistical analy~~sis~~ses can be performed. Determining if a general equation for accumulation rates in the HJ Andrews Forest can be derived is the next step, followed by comparing that finding to May and Gresswell's (2003). Filling in the conceptual model or reworking it would require analytical compilation of existing data and new results from expanded field work. ~~this study's expansion~~. Comparing accumulation rates with debris flow frequency under different environmental conditions is one avenue to explore. This could be pursued in conjunction with biotic responses to large infrequent debris flows versus incremental ~~consistent~~ sediment transport. Field researchers, statistical modelers, and ecologists could all therefore contribute to this project's future.

Awkward sentence re-write

Ecosystem informatics means applying ecosystem research to larger concepts? ~~understandings~~ through mathematical and/or computer modeling tools. Qualitatively and quantitatively linking data from multiple sources to explain processes yields the best predictive capabilities available. ~~Credible~~ predictions of environmental and economic outcomes of land management alternatives is crucial for making policy decisions and ensuring proper ~~their~~ implementation. Improving the scientific basis for models and refining them to match historical records increases credibility and planning abilities. Finally, grasping the limitations of models and the complexity of natural processes is as important as making science-based predictions.

## Appendix

**Figure 16. Summary of Debris Flow Channel Characteristics in the HJ Andrews Experimental Forest**

| | | | | | | % of surface area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Channel L | Time since last debris flow (years) | Stream Order | Avg. stream-bed width (m) | Avg. Channel width (m) | Avg. Channel Slope (%) | bed-rock | large wood | small wood | sedi-ment | other: | volume of wood in channel per length ($m^3/m$) | volume of sediment + hillslope input in channel per length ($m^3/m$) | volume of sediment in channel per length ($m^3/m$) | volume of hillslope input in channel per length ($m^3/m$) |
| Forested areas: | | | | | | | | | | | | | | |
| sec 7 | 11 | 2 | 1.9 | 5.1 | 17.4 | 50.1 | 6.5 | 6.9 | 34.6 | 1.9 | 0.49 | 0.82 | 0.52 | 0.30 |
| 2-3 | 11 | 1 | 1.8 | 6.4 | 24.9 | 79.5 | 4.0 | 8.0 | 8.5 | 0.0 | 0.62 | 0.08 | 0.08 | none noted |
| 3a | 11 | 1 | 1.8 | 6.4 | 20.9 | 77.0 | 3.0 | 5.7 | 6.3 | 8.0 | 0.25 | 0.13 | 0.05 | 0.08 |
| 1-2 | 43 | 1 | 2.1 | 7.0 | 21.4 | 31.0 | 18.0 | 17.5 | 28.0 | 5.5 | 1.46 | 0.46+ | 0.46 | some noted |
| gate | 43 | 2 | 3.7 | 10.4 | 16.1 | 33.3 | 12.7 | 11.3 | 30.3 | 11.7 | 1.95 | 2.29 | 1.39 | 0.90 |
| 9 | >43 | ? | 2.6 | 4.8 | 38.5 | 25.0 | 14.5 | 13.5 | 28.5 | 16.5 | 1.24 | 1.32 | 0.92 | 0.40 |
| 11 | >43 | 2 | 2.7 | 7.9 | 39.0 | 1.0 | 8.5 | 9.0 | 75.0 | 5.5 | 2.37 | 3.21+ | 2.65 | 0.056+ |
| Plantations: | | | | | | | | | | | | | | |
| 3c | 11 | 2 | 2.6 | 8.9 | 15.6 | 79.5 | 1.5 | 5.0 | 10.0 | 3.5 | 0.04 | 0.25 | 0.10 | 0.15 |
| 402a | 43 | 2 | 2.7 | 7.0 | 23.0 | 47.7 | 6.8 | 5.9 | 28.6 | 10.9 | 0.88 | 0.86 | 0.43 | 0.42 |

Data collected July-August 2007

NOT APPENDIX MATERIAL

THIS IS A TABLE NOT FIGURE

↓

THIS SHOULD BE TABLE 2

TABLE 1 SHOULD INCLUDE A SUMMARY OF STREAM CHANNEL & WATERSHED CHARACTERISTICS

*Acknowledgements*

Frederick Swanson and Steve Taylor helped design and guide this research. The HJ Andrews Experimental Forest facilities and staff provided the necessary resources, along with a generous grant from the National Science Foundation. Desiree Tullos directed the research program, Ecosystem Informatics Summer Institute, which supported this project and will continue in 2008. Kristin Mowry provided field assistance for part of the study.

***References*** Cited

Keller, EA. and Swanson, FJ. 1979. Effects of large organic material on channel form and fluvial processes. *Earth Surface Processes* 4: 361-380.

May, CL. and Gresswell, RE. 2003. Processes and rates of sediment and wood accumulation in headwater streams of the Oregon Coast Range, USA. *Earth Surface Processes and Landforms* 28: 409-424.

Sidle, R. C., A. J. Pearce, and C. L. OÕLoughlin. 1985. Hillslope stability and land use. American Geophysical Union. Water Resources Monograph No. 11.140 pp.

Snyder, Kai. 2000. Debris flows and flood disturbance in small, mountain watersheds. Master of Science Thesis, Oregon State University.

Swanson, FJ. and Dyrness, C.T. 1975. Impact of clearcutting and road construction on soil erosion by landslides in the western Cascade Range. *Geology*. Vol. 3 no. 7: 393-396.

Swanson, FJ. and Fredriksen, RL. 1982. Sediment routing and budgets: implications for Judging Impacts of Forestry Practices.

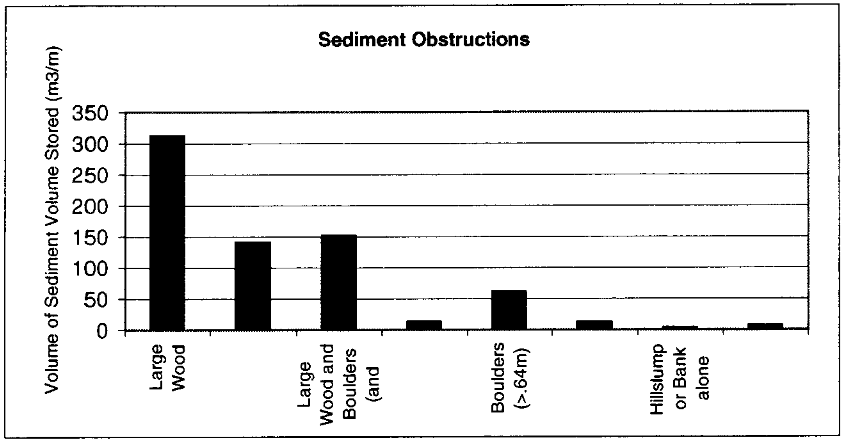
Check & make sure all are cited in text.

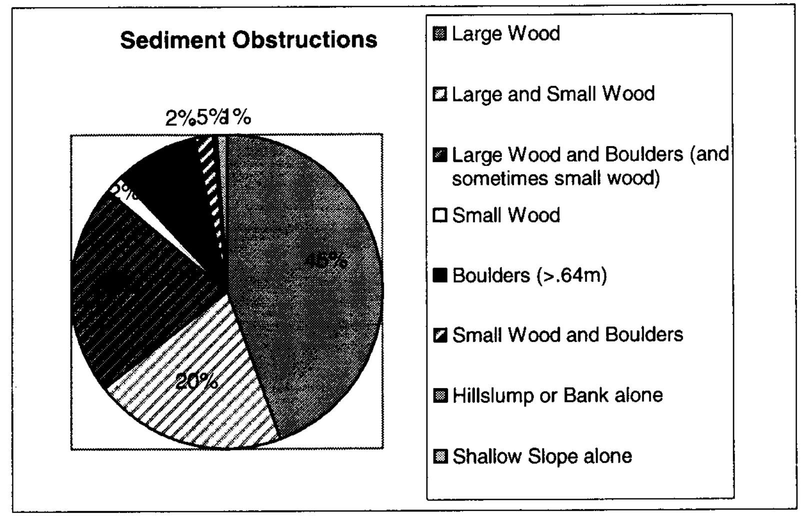
Check text to make sure all citations are listed here

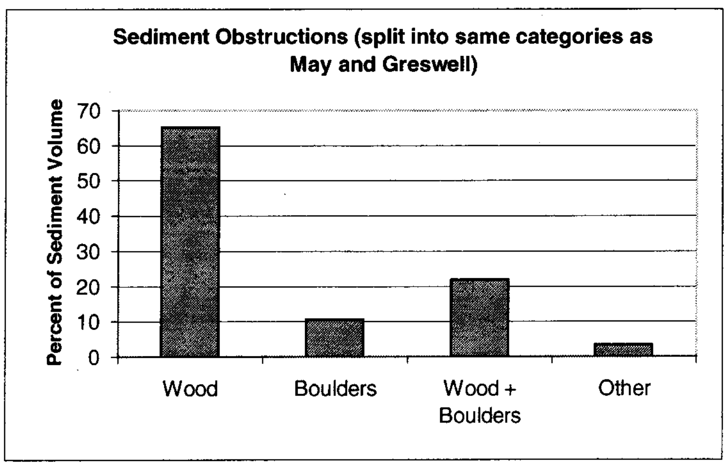
**Lambie Summary Data**

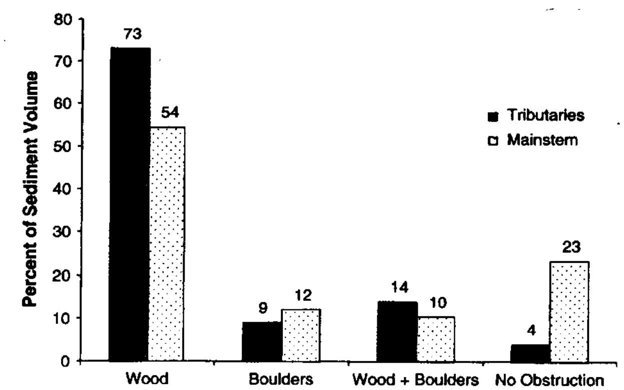
| Channel | Time since last debris flow (years) | Stream Order | Avg streambed width (m) | Avg Channel width (m) | Avg Slope (%) | % of surface area: bedrock | large wood | small wood | sediment | other: | volume of wood in channel per length ($m^3/m$) | volume of sediment + hillslope input in channel per length ($m^3/m$) | volume of sediment in channel per length ($m^3/m$) | volume of hillslope input in channel per length ($m^3/m$) | predominant sediment type | sediment stored by: Large Wood | Large and Small Wood | Large Wood and Boulders (and sometimes small | Small Wood | Boulders (>.64m) | Small Wood and Boulders | Hillslump or Bank alone | Shallow Slope alone | | sediment + hillslope column for graph | time since debris flow for graph |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Forested areas: | | | | | | | | | | | | | | | | | | | | | | | | | | |
| sec 7 | 11 | 2 | 1.9 | 5.1 | 17.4 | 50.1 | 6.5 | 6.9 | 34.6 | 1.9 | 0.49 | 0.82 | 0.52 | 0.30 | gravel, cobble | 11.64 | 5.11 | 51.86 | 0.00 | 1.79 | 1.89 | 0.00 | 5.28 | | 0.82 | 11 |
| 2-3 | 11 | 1 | 1.8 | 6.4 | 24.9 | 79.5 | 4.0 | 8.0 | 8.5 | 0.0 | 0.62 | 0.08 | 0.08 | none noted | gravel | 0.41 | 1.58 | 0.00 | 2.83 | 0.00 | 3.02 | 0.00 | 0.17 | | 0.08 | 11 |
| 3a | 11 | 1 | 1.8 | 6.4 | 20.9 | 77.0 | 3.0 | 5.7 | 6.3 | 8.0 | 0.25 | 0.13 | 0.05 | 0.08 | gravel | 2.26 | 0.00 | 0.00 | 0.59 | 0.34 | 0.00 | 1.47 | 0.28 | | 0.13 | 11 |
| 1-2 | 43 | 1 | 2.1 | 7.0 | 21.4 | 31.0 | 18.0 | 17.5 | 28.0 | 5.5 | 1.46 | 0.46+ | 0.46 | some noted | gravel | 35.68 | 3.41 | 0.00 | 5.04 | 0.47 | 0.00 | | 1.38 | | 0.46 | 43 |
| gate | 43 | 2 | 3.7 | 10.4 | 16.1 | 33.3 | 12.7 | 11.3 | 30.3 | 11.7 | 1.95 | 2.29 | 1.39 | 0.90 | gravel | 157.71 | 30.57 | 5.38 | 0.00 | 12.77 | 0.00 | 1.96 | 0.00 | | 2.29 | 43 |
| 9 | >43 | ? | 2.6 | 4.8 | 38.5 | 25.0 | 14.5 | 13.5 | 28.5 | 16.5 | 1.24 | 1.32 | 0.92 | 0.40 | soil, fine sediment, gravel | 23.66 | 35.18 | 18.04 | 4.63 | 9.56 | 1.00 | 0.00 | 0.00 | | 1.32 | 250 |
| 11 | >43 | 2 | 2.7 | 7.9 | 39.0 | 1.0 | 8.5 | 9.0 | 75.0 | 5.5 | 2.37 | 3.21+ | 2.65 | 0.056+ | cobble, boulder, gravel | 80.70 | 64.80 | 76.46 | 0.00 | 36.69 | 6.50 | | 0.00 | total | 3.21 | 250 |
| | | | | | | | | | | | | | | | total: | 312.05 | 140.65 | 151.74 | 13.10 | 61.62 | 12.41 | 3.43 | 7.11 | 694.98 | | |
| | | | | | | | | | | | | | | | total percentage: | 44.90 | 20.24 | 21.83 | 1.88 | 8.87 | 1.79 | 0.49 | 1.02 | 100.00 | | |
| Plantations: | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3c | 11 | 2 | 2.6 | 8.9 | 15.6 | 79.5 | 1.5 | 5.0 | 10.0 | 3.5 | 0.04 | 0.25 | 0.10 | 0.15 | gravel, cobble | | | | | | | | | | | |
| 402a | 43 | 2 | 2.7 | 7.0 | 23.0 | 47.7 | 6.8 | 5.9 | 28.6 | 10.9 | 0.88 | 0.86 | 0.43 | 0.42 | fine sediment, gravel | | | | | | | | | | | |

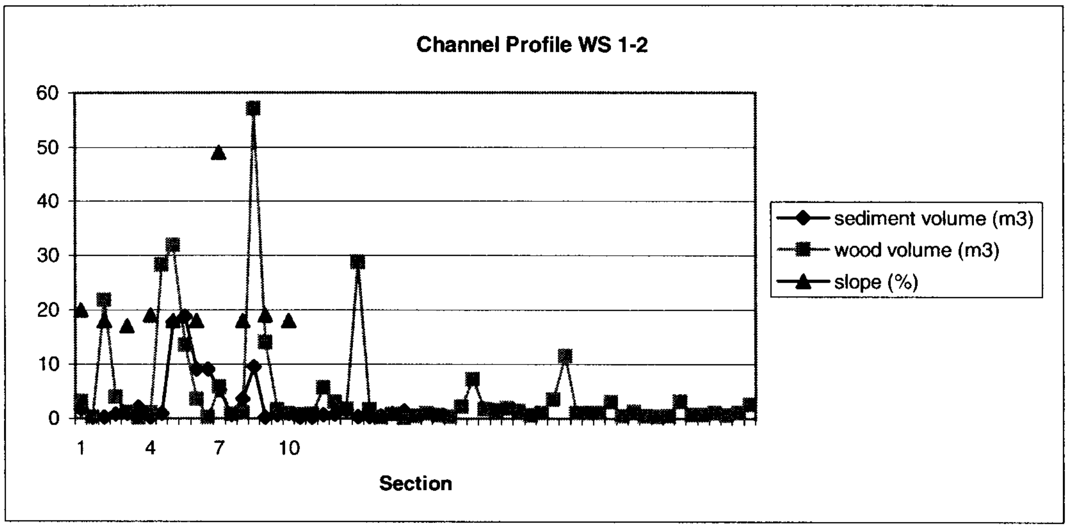
| | |
|---|---|
| Width of c | generally defined as the width between the banks at about 5m above streambed |
| Sediment | refers to pebbles (fine sediment to boulders) that likely originated upstream and are transported by stream |
| Hillslope in | refer to soil and rock input from the side slopes |
| Large woo | >.2m in diameter and >2m in length; Wood that was >2m above channel floor was not measured |
| Small woo | anything smaller than large wood |
| Lettered w | too burried and decayed to meausure, but are clearly >2m in length and >.2m in diameter |
| Boulders | less than one meter unless otherwise noted |
| + signs | indicate that more than that value was observed, but not measured |

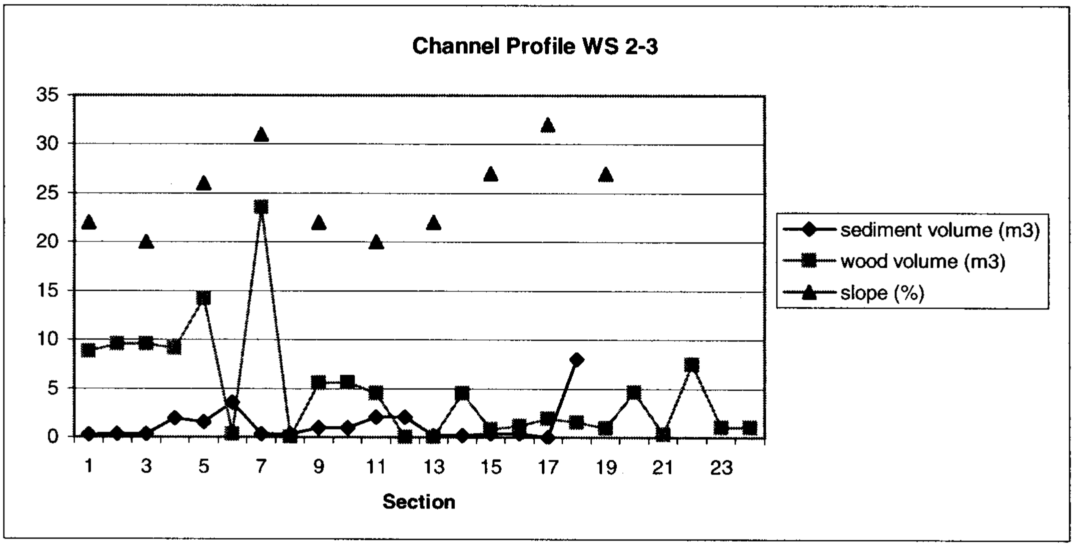

Sediment Obstructions
Volume of Sediment Volume Stored (m3/m)
350
300
250
200
150
100
50
0
Large Wood
Large Wood and Boulders (and
Boulders (>.64m)
Hillslump or Bank alone

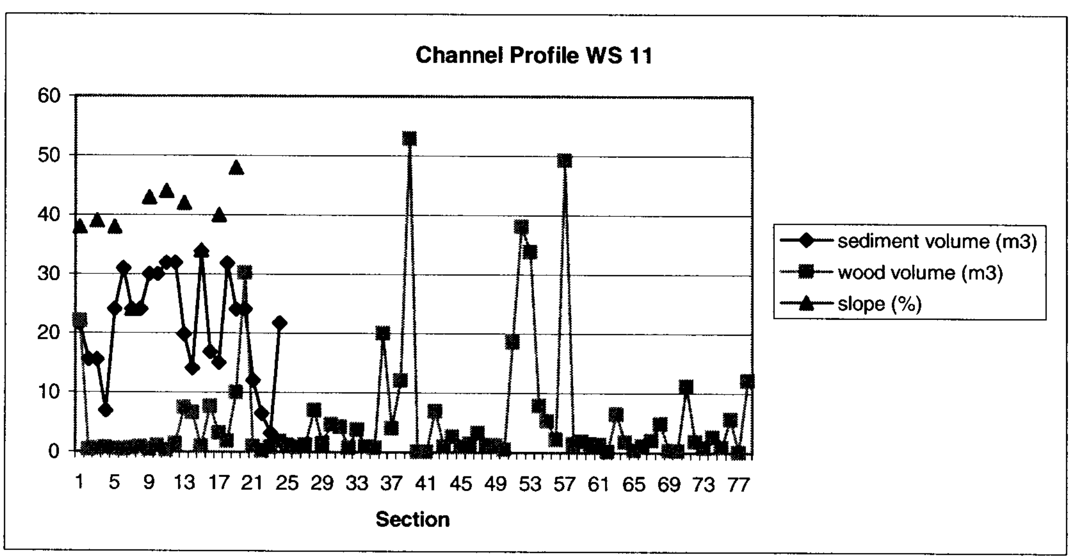

Sediment Obstructions
2%5%1%
45%
20%
Large Wood
Large and Small Wood
Large Wood and Boulders (and sometimes small wood)
Small Wood
Boulders (>.64m)
Small Wood and Boulders
Hillslump or Bank alone
Shallow Slope alone


Sediment Obstructions (split into same categories as May and Greswell)
Percent of Sediment Volume
70
60
50
40
30
20
10
0
Wood
Boulders
Wood + Boulders
Other


Percent of Sediment Volume
80
70
60
50
40
30
20
10
0
73
54
9
12
14
10
4
23
Tributaries
Mainstem
Wood
Boulders
Wood + Boulders
No Obstruction


Channel Profile WS 1-2
60
50
40
30
20
10
0
1
4
7
10
Section
sediment volume (m3)
wood volume (m3)
slope (%)


Channel Profile WS 2-3
35
30
25
20
15
10
5
0
1
3
5
7
9
11
13
15
17
19
21
23
Section
sediment volume (m3)
wood volume (m3)
slope (%)


Channel Profile WS 11
60
50
40
30
20
10
0
1 5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73 77
Section
sediment volume (m3)
wood volume (m3)
slope (%)