ENVIRONMENTAL IMPACT ANALYSIS TO SUPPORT NARA BIOFUEL DEVELOPMENT IN THE PACIFIC NORTHWEST – WATER RESOURCES COMPONENT

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EXECUTIVE SUMMARY

Land use and residuals management changes associated with biofuel growth, harvesting, and processing may pose unique environmental issues related to water quality. There is a need to investigate water quantity and quality impacts that biofuel harvesting may have on short- and long- term changes in sediment and nutrient loadings, hydrologic dynamics, and stream channel responses within the project watersheds at scales ranging from field scale to regional scale. The *specific objectives* of this project are:

(1) to examine tree harvesting options at field-scale test plots to examine potential alteration of the ecological environment through measurement of runoff and sediment erosion;

(2) to collect and examine microbial communities at the test plots to examine short-term changes related to biomass removal;

(3) to develop predictive water quantity and quality models that can be used to evaluate watershed-scale regional impacts; and

(4) evaluate the potential impacts of altered hydrologic conditions on stream channels.

Items 1-3 were conducted primarily by the University of Utah, and item 4 was conducted by Washington State University, although joint collaboration with field data collection occurred.

TASK 1: WATER RESOURCES AND SEDIMENT EROSION

Data for the investigations conducted in this task were collected from Weyerhaeuser's Long-Term Soil Productivity (LTSP) site in the southern Willamette Valley of Oregon near Springfield, OR. A total of 28 one-acre plots were selected by Weyerhaeuser to aid in this investigation and round out an existing regional study, to extend into warmer and drier parts of the Douglas-fir ranges, as to contribute more understanding into the broader LTSP network. Trees were harvested and treatments (biomass removal and compaction) were randomly assigned, and laid out in such that any plot could feasibly receive that particular random assignment. General LTSP "Core" Treatments consisted of a 3 x 2 factorial combination of compaction (C0, none; C1, moderate) and above ground OM removal (OM0, bole/trunk only; OM1, whole tree; OM2, whole tree plus forest floor removal). Three levels of organic matter removal and two levels of compaction in a 3 x 2 complete factorial design exist – totaling 7 different treatment plots (A-G) each having 4 replicates. Figure EIA-1.1 depicts each LTSP study plot location on the ArcMap model, including the location of the soil moisture sensor probes and weather stations.

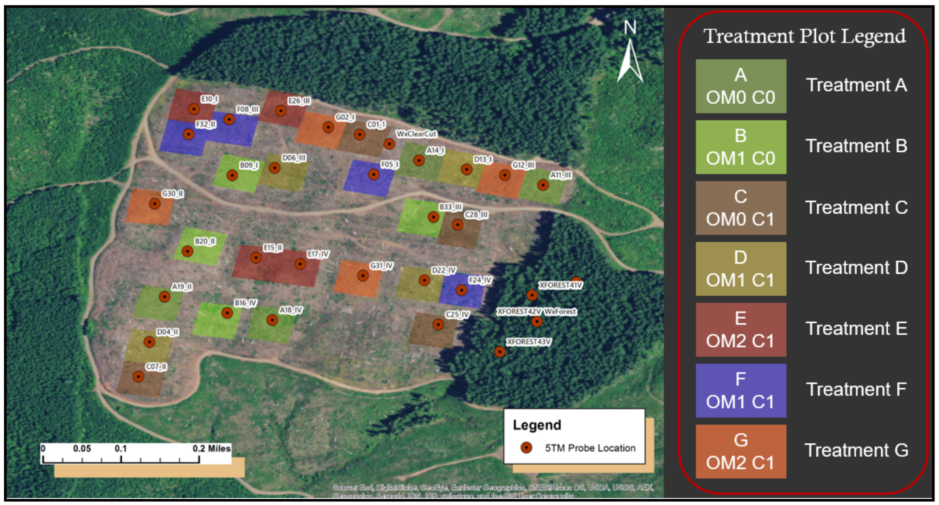

Figure EIA-1.1. Site location map.

Water balance and sediment erosion

Water resources model development

This task involved obtaining soil moisture and climate data collected at the Oregon field plots and calibrating a 1-dimensional unsaturated groundwater model (UNSAT-H) based this information. Soil moisture data from depths of 10, 20, 30, and 100 cm was modeled with local precipitation and climate data. Typically, four soil moisture measurement probes were installed at each plot location on the map, respectively, totaling to approximately 112 probes for the whole LTSP site. The 5TM Soil Moisture & Temperature Sensor by Decagon Devices® was the chosen soil moisture and temperature probe selected for installation.

UNSAT-H can use van Genuchten and Brooks-Corey water retention functions and the Mualem and Burdine hydraulic conductivity functions. The model simulates atmospheric interactions, plant transpiration, solute transport, heat transfer and vapor flow using modified forms of Richard's Equation. Calibration results favored the van Genuchten function and Mualem hydraulic conductivity model which has the form:

$$\theta = \theta_r + (\theta_s - \theta_r)[1 + (\alpha h)^n]^{-m} \qquad (1)$$

where *a*, *m*, and *n* are curve-fitting parameters, and where it is assumed that m = 1 – 1/n (Mualem, 1976), θ_r is the residual water content, θ_s is the saturated water content.

The conductivity function is based on the Mualem conductivity model and goes as follows:

$$K_L = K_S \frac{\{1-(\alpha h)^{n-2}[1+(\alpha h)^n]^{-m}\}^2}{[1+(\alpha h)^n]^{lm}} \qquad (2)$$

where K_L is the unsaturated hydraulic conductivity and K_s is the saturated hydraulic conductivity.

Modeled results versus measured results from the soil moisture probes were used as a basis for adjusting parameters in the model. Pedotransfer functions (PTFs) were used to predict the values of water retention as well as the saturated and unsaturated hydraulic conductivity. The computer model ROSETTA utilizes five hierarchical PTFs, where it interprets and translates basic soil data into hydraulic properties, and additionally provides the water retention parameters (θ_s, θ_r, K_L, and K_s) and curve fitting parameters (α, m, and n) according to van Genuchten. These parameters were averaged over 25 soil samples taken from each plot, where percentages were recorded over three depth profiles: 0-15 cm; 15-30 cm; and 30-100 cm below the soil surface. While too much information was generated for complete inclusion in this report, Table EIA-1.1 illustrates the results from the 0-15 cm deep soil horizon.

Table EIA-1.1. ROSETTA hydrologic parameters for 0-15 cm soil horizon for each plot.

Code	Description	θ_r $[cm^3/cm^3]$	θ_s $[cm^3/cm^3]$	α [1/cm]	η	K_s [cm/day]	K_o [cm/day]
11	A11III	0.080	0.437	0.010	1.457	10.73	2.733
14	A14I	0.077	0.431	0.010	1.469	10.53	2.740
18	A18IV	0.086	0.453	0.012	1.403	10.21	3.012
19	A19II	0.084	0.447	0.011	1.437	11.04	2.763
9	B09I	0.086	0.454	0.011	1.422	11.32	2.804
16	B16IV	0.074	0.430	0.008	1.511	12.69	2.295
20	B20II	0.080	0.437	0.011	1.436	9.05	2.980
33	B33III	0.080	0.437	0.010	1.457	10.73	2.733
1	C01I	0.077	0.431	0.010	1.469	10.53	2.740
7	C07II	0.078	0.432	0.010	1.455	9.68	2.863
25	C25IV	0.085	0.450	0.011	1.430	11.17	2.782
28	C28III	0.076	0.430	0.009	1.490	11.92	2.503
4	D04II	0.082	0.444	0.011	1.444	10.92	2.749
6	D06III	0.085	0.448	0.012	1.403	9.02	3.108
13	D13I	0.081	0.438	0.012	1.422	8.34	3.107
22	D22IV	0.082	0.446	0.009	1.471	11.99	2.452
10	E10I	0.081	0.439	0.011	1.443	10.00	2.854
15	E15II	0.075	0.429	0.009	1.482	11.32	2.622
17	E17IV	0.085	0.448	0.012	1.403	9.02	3.108
26	E26III	0.068	0.412	0.011	1.472	8.10	3.276
5	F05I	0.078	0.432	0.010	1.455	9.68	2.863
8	F08III	0.068	0.414	0.010	1.481	8.78	3.077
24	F24IV	0.078	0.437	0.009	1.499	12.36	2.311
32	F32III	0.082	0.439	0.012	1.409	7.78	3.236
2	G02I	0.069	0.417	0.009	1.509	12.07	2.581
12	G12III	0.086	0.451	0.012	1.396	9.32	3.117
30	G30II	0.075	0.429	0.009	1.482	11.32	2.622
31	G31IV	0.084	0.446	0.012	1.416	9.67	2.987

Figure EIA-1.2 shows similarities and discrepancies between modeled and measured soil moisture with the green line indicating precipitation. Additional work was completed to refine and expand these procedures to all of the sample plots so we could develop a water budget model.

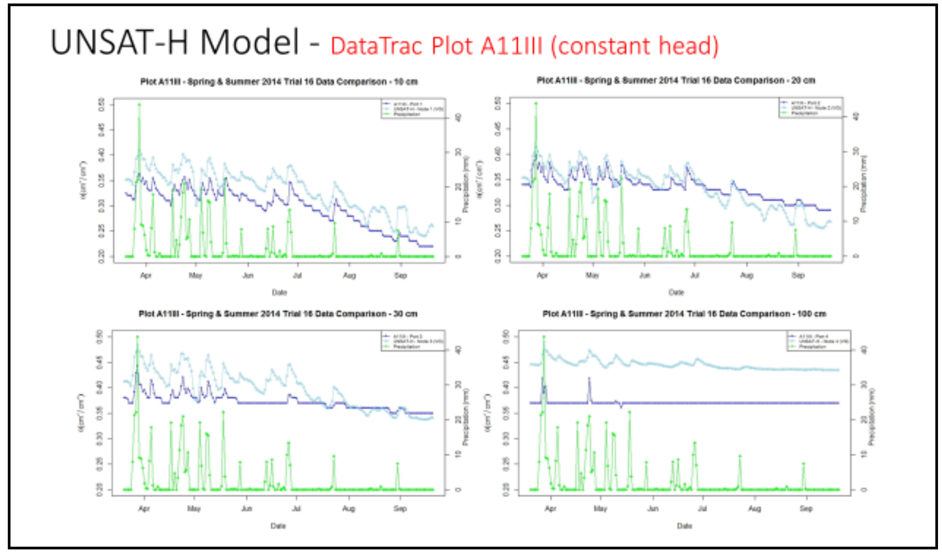

Figure EIA-1.2. Results from the UNSAT-H model

After calibration was complete, UNSAT-H was run for a 2-year simulation period for each of the 28 plots. Figure EIA-1.3 provides a typical simulation example. Precipitation that infiltrated the soil column to the 1-meter depth was assumed to constitute deep percolation (ground water recharge). Evaporation was the difference between the precipitation and the recharge as surface water runoff from the site was minimal due to the soil characteristics and precipitation patterns.

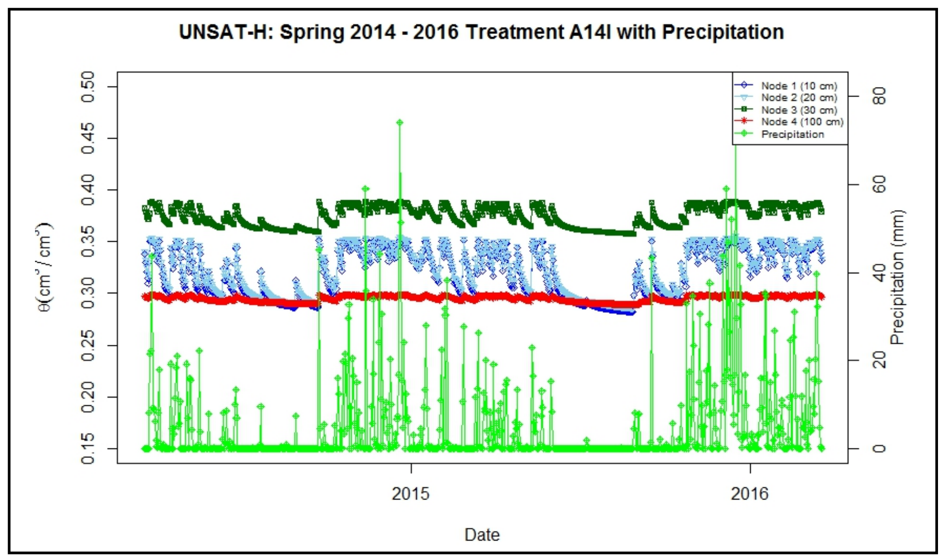

Figure EIA-1.3. UNSAT-H 2-year simulation of Plot A14I with precipitation

By comparing infiltration and evaporation values for various biomass treatment options, we were able to generate a model that examined the implications of biomass harvest and compaction. Table EIA-1.2 summarizes model results for plot types A-C including potential and actual evaporation, total infiltration (ground water recharge), and rainfall amounts for the entire 2-year simulation period. Similar information for plot types D-G were generated.

Table EIA-1.2. UNSAT-H results for 2-year simulation for Treatment Plots A-C

Plot	Treatment	Initial Water Storage [cm]	Potential Evap. [cm]	Actual Evap. [cm]	Total Basal Liquid Flux (drainage) [cm]	Total Final Moisture Storage [cm]	Total Runoff [cm]	Total Infiltration [cm]	Actual Rainfall [cm]
14	A-I	48.7	184.6	69.1	239.2	49.8	0	356.7	356.7
19	A-II	59.2	184.6	51.2	200.6	58.9	0	356.7	356.7
11	A-III	55.7	184.6	85.9	251.7	56.2	0	356.7	356.7
18	A-IV	63.8	184.6	76.3	246.2	64.0	12.1	344.6	356.7
9	B-I	58.0	184.6	78.2	186.0	57.6	0	356.7	356.7
16	B-IV	62.1	184.6	53.2	251.1	62.0	0	356.7	356.7
20	B-II	46.2	184.6	58.1	260.5	46.0	14.3	342.4	356.7
33	B-III	45.3	184.6	67.9	229.4	44.6	0	356.7	356.7
1	C-I	46.8	184.6	66.3	189.6	46.4	0.985	355.8	356.7
7	C-II	55.7	184.6	75.3	215.2	55.1	0	356.7	356.7
25	C-IV	64.7	184.6	73.1	258.4	64.3	0.112	356.6	356.7
28	C-III	74.7	184.6	74.3	247.5	74.7	0	356.7	356.7

Final results illustrated changes in water budgets as a function of percent watershed being harvested, level of biomass removal, and compaction. Our working hypothesis was:

Ho: Increased biomass removal from the LTSP site will have no impact on infiltration rates or the water budget of the subsurface.

After the analysis of the amount of evaporation from each Treatment Type A-G, it was observed that Treatment B exhibited the least average amount of evaporation compared to all other treatments. Treatment B sites were non-compacted and had the crowns removed. It can be noted that the lack of crowns impacts the amount of evaporation by reducing biomass surface area where evaporation can occur. There were statistically higher evaporation rates in Treatments C-F compared to Treatments A-B, ranging from 12%-32% increases. Treatments D-F fall in the C1 compaction category, as well as the OM1 and OM2 harvest categories.

Sediment model development

We examined soil erosion and runoff modeling to evaluate the impacts of additional biomass removal from logged areas and evaluated several model options before selecting the WEPP model. Processes in WEPP erosion include rill and interrill erosion, sediment transport, and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration and erodibility, climate, and effect of soil random roughness. The basic equation for sediment erosion:

$$\frac{dq_s}{dx} = D_r + D_i \quad (3)$$

where q_s is the sediment load (kg/s-m), x is the longitudinal downslope distance (x), D_r is the rill erosion rate (kg/s-m^2), and D_i is the interrill erosion rate (kg/s-m^2). Equations for the rill and interrill erosion can be expressed as:

$$D_r = K_{rb}(\tau_f - \tau_{cb})\left(1 - \frac{q_s}{T_c}\right) \quad (4)$$

and

$$D_i = K_{i\,adj}\ I_e\ \ \sigma_{ir}\ SDR_{rr}\ F_{nozzle}\ {}^{R_s}/_{W_e} \quad (5)$$

where $K_{r\,adj}$ is the adjusted baseline erodibility (s/m), τ_f is the shear stress of the flow (Pa), τ_{cb} is the baseline critical shear stress (Pa), T_c is the transport capacity (kg/s-m), $K_{i\,adj}$ is the adjusted baseline interrill erodibility, I_e is the equivalent rainfall intensity (m/s), σ_{ir} is the interrill runoff rate (m/s), SDR_{rr} is the interrill sediment delivery ratio, F_{nozzle} is the sprinkler nozzle energy factor, R_s is rill spacing (m), and W_e is the equilibrium rill width (m).

The interrill erodibility equation in (3) can be adjusted for local conditions including ground cover (Ki_{gc}) as follows:

$$K_{i\,adj} = K_{ib}K_{ican}K_{igc}K_{idr}K_{ilr}K_{isc}K_{isl}K_{ift} \quad (6)$$

The ground cover coefficient is given by

$$K_{igc} = e^{(-2.5 * Fgc)} \quad (7)$$

This study considers existing logging operations as the baseline for comparison and focuses on the changes directly related to the removal of slash materials. Other researchers have concluded that ground cover would impact erosion more than runoff although both parameters would respond in similar ways. Figure EIA-1.4 shows the exponential decrease predicted by Equation 7.

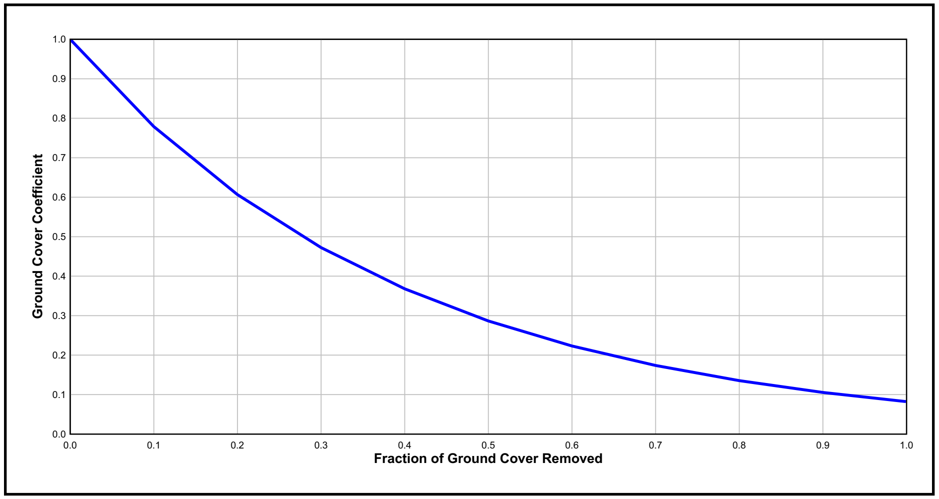

Figure EIA-1.4. Impact of ground cover on interrill erosion.

To accommodate our sampling plan to the WEPP model, the ground cover adjustment factor (CK_{igc}) used in WEPP was changed to accurately predict forest conditions.

While theoretically this should have produced a considerable amount of additional erosion, field observations found no evidence of rills, gullies, or even overland flow for the slopes, soils, and climate conditions found at the Oregon field station.

TASK 2: MICROBIAL COMMUNITIES

Soil samples were collected in May 2014 from LTSP plots to perform DNA extraction test in the laboratory. Nine samples were collected from each plot. The samples were taken at a depth of 0-20 cm using a hand shovel.

The soil samples were kept in 8-ounce, air tight jars and were preserved in coolers at a temperature of less than 4°C to keep the microbial community safe. Dry ice was used to maintain the temperature of the coolers. A total of 252 samples were collected from plots for subsequent DNA Extraction testing in the laboratory. The samples were kept in a -20°C temperature freezer in the laboratory to preserve them for a long time.

MO Bio's Power Soil DNA isolation kit was used in the laboratory to extract DNA from the collected soil samples. Results of the DNA extraction tests by type of ground treatment are summarized in Table EIA-2.1. These values represent the averages of 8-9 samples per plot.

Table EIA-2.1. Results of the DNA Extraction Tests for the LTSP Sites

Treatments		Plots	Average DNA (ng/µl)
A	- No Compaction Bole only	P#14	51.84
		P#19	37.14
		P#11	29.06
		P#18	12.08
B	- No Compaction Total tree	P#9	37.85
		P#20	63.77
		P#33	20.69
		P#16	31.75
C	- Compaction Bole Only	P#1	56.40
		P#7	38.48
		P#28	45.84
		P#25	20.27
D	- Compaction Total tree	P#13	35.14
		P#4	33.08
		P#6	24.70
		P#22	21.49
E	- Compaction Total tree+ FF	P#10	14.64
		P#15	20.35
		P#26	28.92
		P#17	23.19
F	- Compaction Total tree	P#5	49.06
		P#32	30.07
		P#8	19.31
		P#24	27.51
G	- Compaction Total tree + FF	P#2	27.60
		P#30	28.32
		P#12	16.13
		P#31	15.01
	No treatment	Unharvested Site	15.44

Two sample t-tests assuming equal variances has been performed to find out the correlation between DNA concentration and different treatments. The results from the hypothesis tests were not able to make any decision about the null hypothesis for which a biological analysis has been performed using finger printing analysis (ARISA).

Forty samples out of 1024 DNA samples, 5 from each treatment including the control one has been selected for the ARISA finger printing analysis, in such a way so that those can be considered as the representative sample for each treatment. Community fingerprinting is used to profile the diversity of microbial community. These techniques show how many variants of a gene are present instead of counting individual cells in a sample. The results of ARISA tests are shown in Figure EIA-2.1 and Table EIA-2.2.

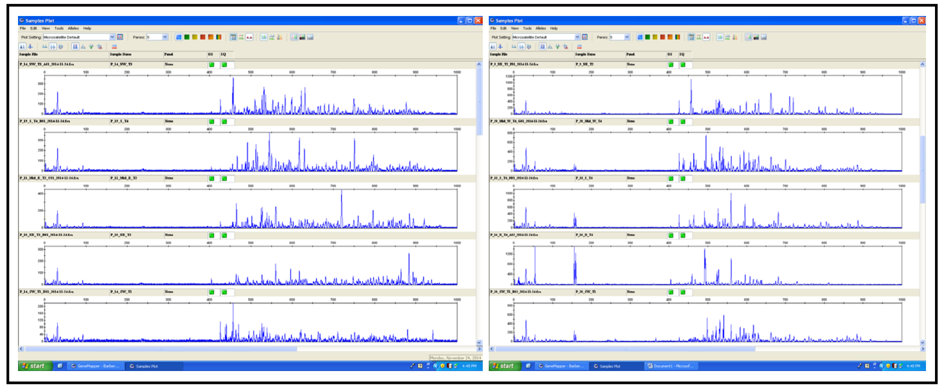

Figure EIA-2.1. ARISA test run result for treatment A and B

Table EIA-2.2. Range of Peak Number and sizes in the ARISA Profiles for Different Treatments

Treatments	No. of Peaks	Range of peak size (bp)	Range of spacer size (bp)
Treat A	397	208.46 – 920	86.46 – 798
Treat B	464	208.46 – 950.59	86.46 – 828.59
Treat C	404	208.48 – 917.79	86.48 – 795.79
Treat D	442	226.69 – 1002.1	104.69 – 880.1
Treat E	288	220 – 934.01	98 – 812.01
Treat F	337	208.62 – 921.7	86.63 – 799.7
Treat G	438	208.59 – 971.53	86.59 – 849.53
No Treatment	441	208.58 – 941.52	86.58 – 819.52
Total	3211		

1197 intergenic spacer sequences out of 3211 were examined and 56 genera were found; the majority of which are from taxa belonging to either the gram positive or gram negative phyla. Diversity indices were then calculated by Shanon–Weaver and Simpson's Diversity Index methods the results of which are shown in Table EIA-2.3.

Table EIA-2.3. Diversity Index Results

Treatments	A	B	C	D	E	F	G	Unharvested
Shanon – Weaver Index (H)	2.98	3.13	3.03	3.30	3.21	3.19	3.30	3.22
Shanon's Equitability Index (E_H)	0.85	0.84	0.83	0.87	0.86	0.86	0.86	0.85
Simpson's Index (D)	0.084	0.075	0.084	0.059	0.069	0.074	0.065	0.071

Work continued on evaluating possible techniques that could be used to reduce or otherwise quantify the results of the microbial analysis shown below. The literature has some suggestions and we are currently evaluating these to see if they would be beneficial.

TASK 3: WATERSHED SCALE IMPACTS

This objective was aimed at expanding the plot modeling results from the water runoff and sediment erosion models to watershed scales that would be applicable throughout potential biomass harvest locations in the Pacific Northwest. The original concept was developed when the study treatment areas were proposed to each be approximately 25-acres rather than the 1-acre size they ended up. Acknowledging the challenges associated with scaling from such small plots to the entire watershed, we still attempted to complete the task. Unfortunately, the results of both the runoff model and the sediment erosion model were less than satisfactory. Figure EIA-3.1 shows slopes for the study site. It was difficult to find correlations between infiltration and evaporation to slope, aspect, and cover that could be reasonably extrapolated to the entire basin or to other sites in the Pacific Northwest.

Our working hypothesis was:

Ho: Data from the site-scale regional impacts can be applied to watershed-scale regional impacts of large-scale biomass removal through the Pacific Northwest.

The null hypothesis in summary is rejected. Through research and investigation, site-scale regional impacts cannot be applied to watershed-scale regional impacts of large-scale biomass removal through the Pacific Northwest. There are many factors as to why scaling up a site-scale regional impact to a watershed-scale, such as: differing soils, differing slopes, and differing aspect direction of sunlight.

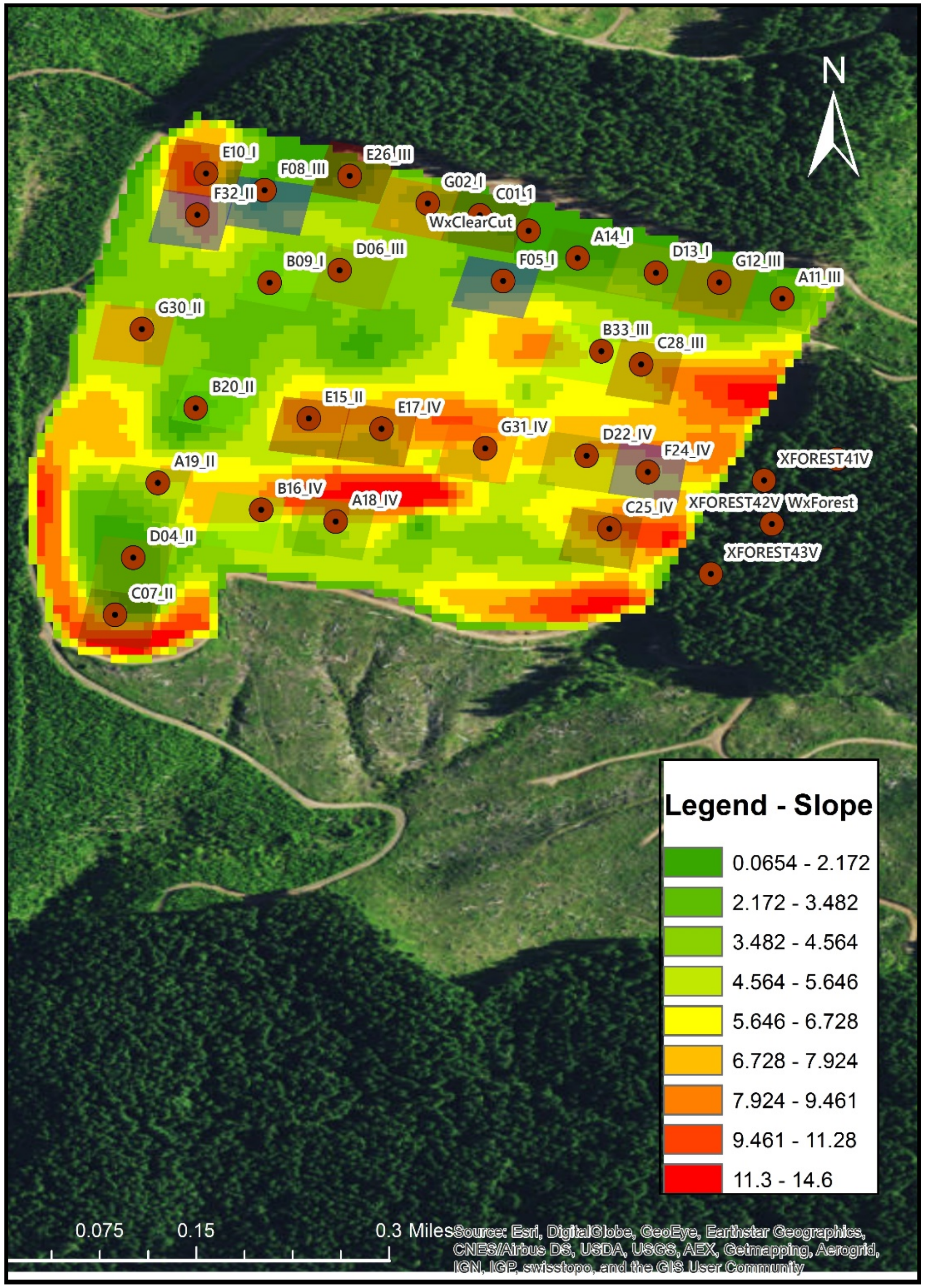

Figure EIA-3.1. Site characteristics related to slope.

TASK 4: CHANNEL IMPACTS

Site selection

To examine stream erosion impacts of logging, a site in northern Idaho, Cat Spur Creek was selected due to its proximity to Washington State University, previously collected data by the US Forest Service, and tree harvest impacts (Figure EIA-4.1). Additional properties of the Cat Spur Creek watershed are listed below.

Cat Spur Creek watershed characteristics:

- 10.8 mi^2 drainage area
- Approximate location: 46.959111 N, 116.259111 W
- Only land use change has been tree harvesting and forest road construction
- Located on land administered by Idaho Panhandle National Forest
- Sediment transport (bedload and suspended load) and streamflow data available from 1987 to 1995
- Additional data available collected in 1994, including:
    - Cross section and longitudinal profile measurements collected over 425 ft. study reach
    - Surface substrate bed material measurements

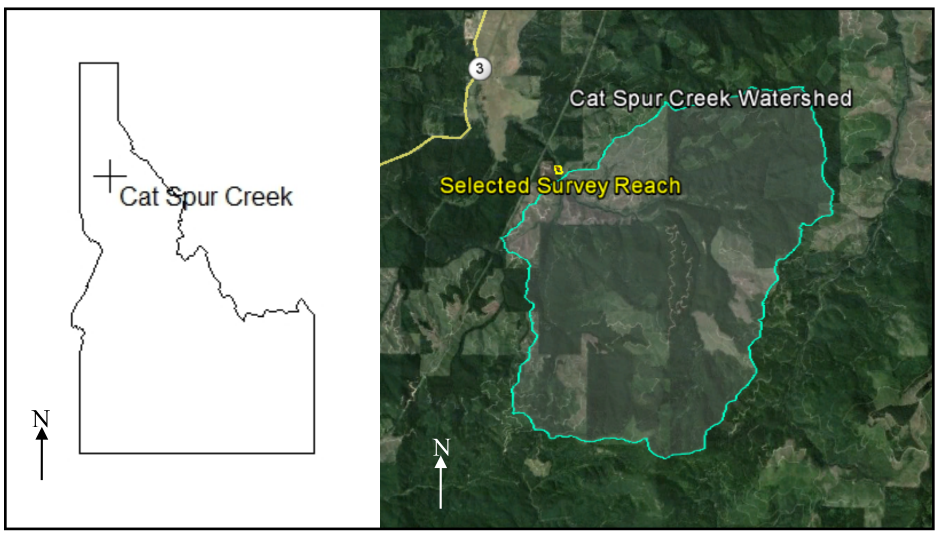

Figure EIA-4.1. Cat Spur Creek study site location.

An initial site visit was conducted on June 19, 2014. The purpose of the visit was to determine the suitability of the site, potential study reaches, and any site-specific issues associated with data collection. Due to previous logging activities, there are many fallen logs spanning the channel, creating difficult working conditions. A reach was selected with minimal fallen logs and a safe access route for transporting equipment.

Field sampling

Data collected from Cat Spur Creek include stream channel bathymetry bed material samples, streamflow velocity, and possibly sediment transport rates. The surveying uses a traditional total station and bed material samples use a gridded selection method, developed to minimize the user bias in bed material sampling (see Figure EIA-4.2). The gridded sample collection allows for a total of 121 surface particles to be measured in a relatively small area. The methodologies selected for the data collection are outlined in Table EIA-4.1.

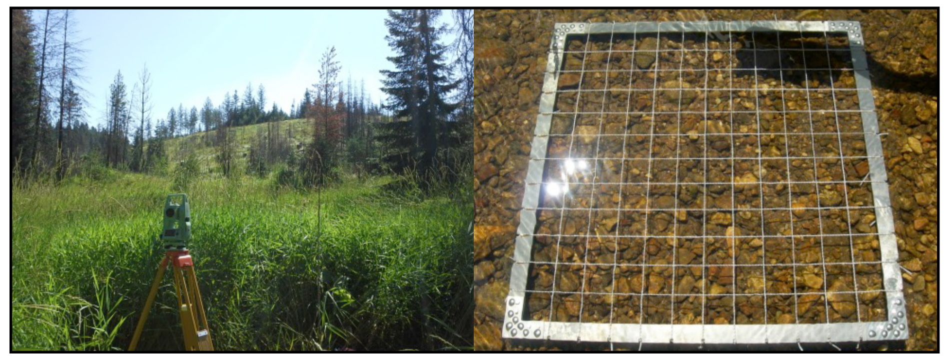

Figure EIA-4.2. Total station on tripod (left) and bed material sampling grid (right)

Table EIA-4.1. Data Collection Methodologies

Data	Methodology	Collection Date
Stream channel bathymetry	Survey cross sections using total station	7/16/14
Bed material grain size	Gravelometer with gridded sample selection	7/22/14
Soil samples of fines from bed and banks	Grab soil samples	7/22/14
Streamflow velocity	Acoustic Doppler Velocimeter (ADV)	10/28/14
Suspended Sediment	UH-DH-48 Depth Integrating Suspended Sediment Sampler	10/28/14

Data collection of the bed surface elevation and bed material grain size occurred during site visits on July 16, 17, and 22, 2014. The streamflow velocity measurements are anticipated to be conducted between late August and late September. Using the surveyed elevation data, the stream channel is defined as shown in Figure EIA-4.3.

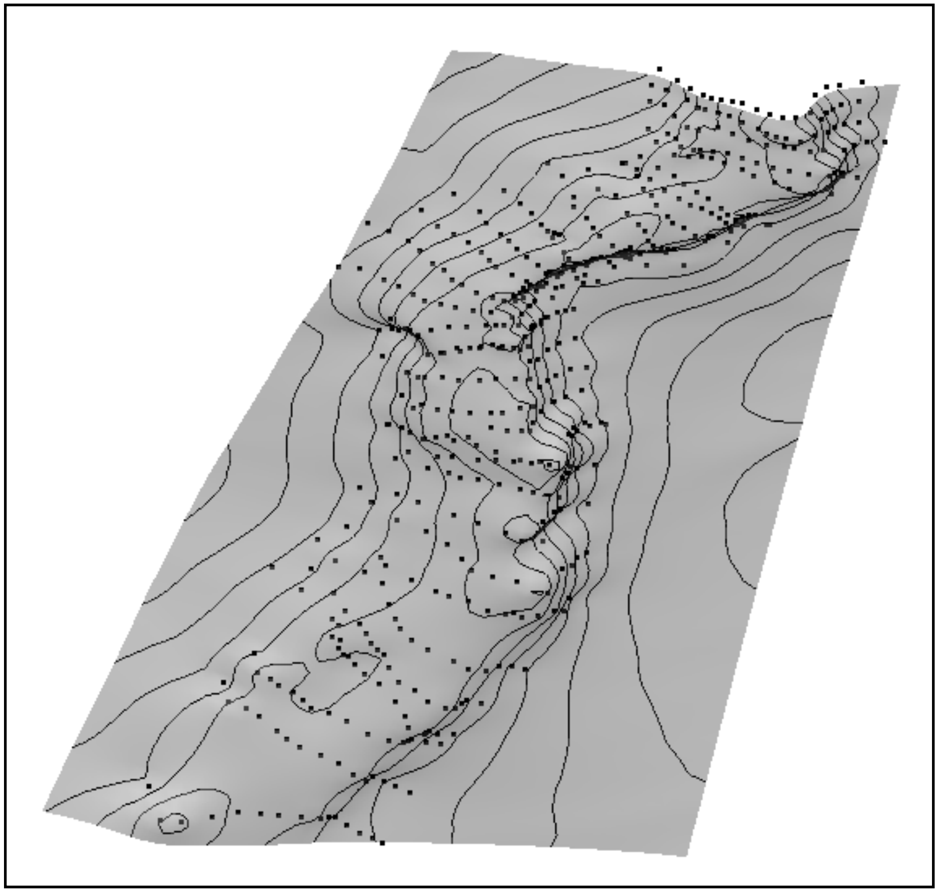

Figure EIA-4.3 Three-dimensional projection of processed bed elevation data. Dots indicate individual survey cross section measurements. Flow is from bottom to top.

For the bed material, a total of 18 grids were collected from the selected reach of Cat Spur Creek. The grain size distributions are shown in Figure EIA-4.4. Each individual frame establishes a grain size distribution that is assumed to be representative of the sample location.

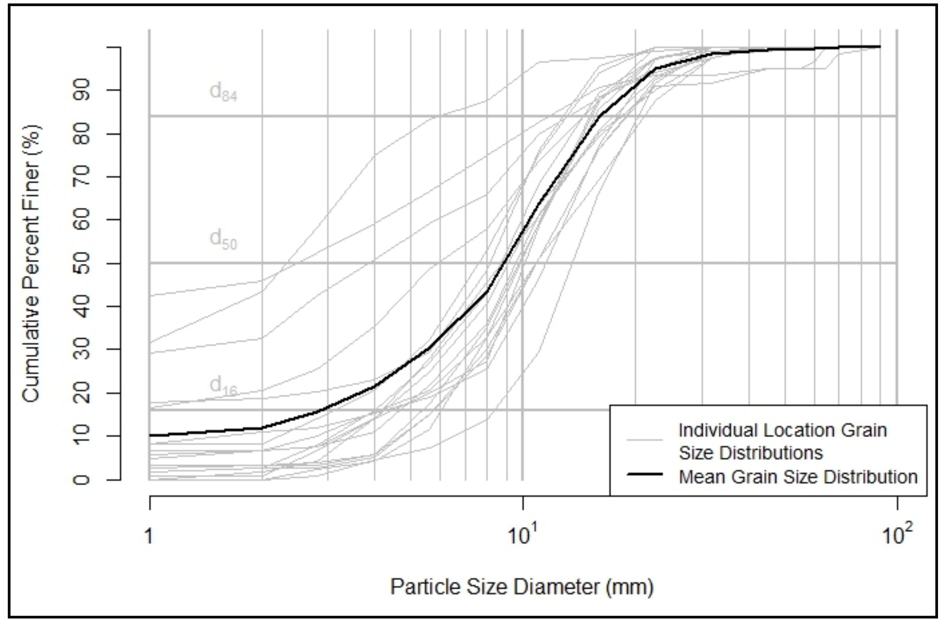

Figure EIA-4.4. Individual and mean grain size distributions

Stream erosion model of study sites

After data collection, the next task was to develop a stream erosion model to elucidate any impacts of tree harvestings on stream sediment transport. An essential component of the model development is the initial parameterization of the bed roughness. Hydraulic models are particularly sensitive to changes in roughness. A discretization method was used to parameterize the stream bed roughness (Figure EIA-4.5). Using this method, the bed surface was divided into similar zones by a statistical comparison of the grain size distributions.

Statistical analyses were performed on grain size data and methods for mapping stream channel roughness were explored.

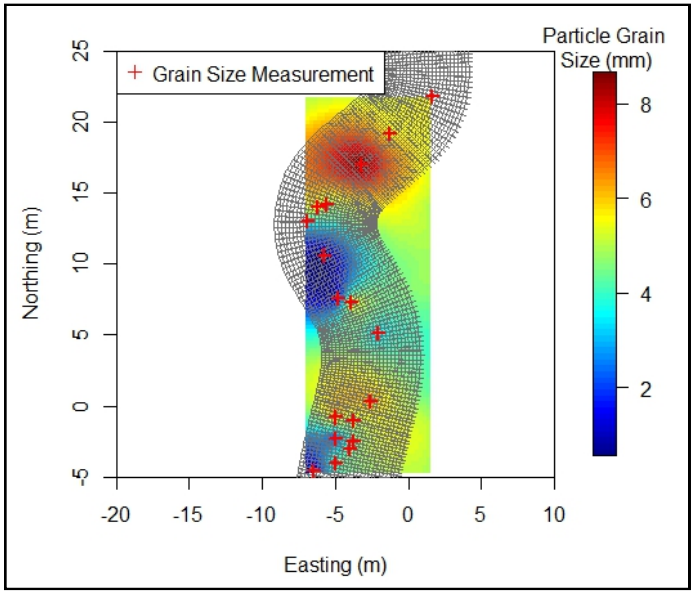

Figure EIA-4.5. Hydraulic model numerical grid underlain by surface roughness map

Additional work has been conducted to examine the stream erosion model sensitivity to grid resolution (Figure EIA-4.6). Results indicate that a definite relationship exists between the grid resolution and model parameters, with finer resolution creating greater velocities.

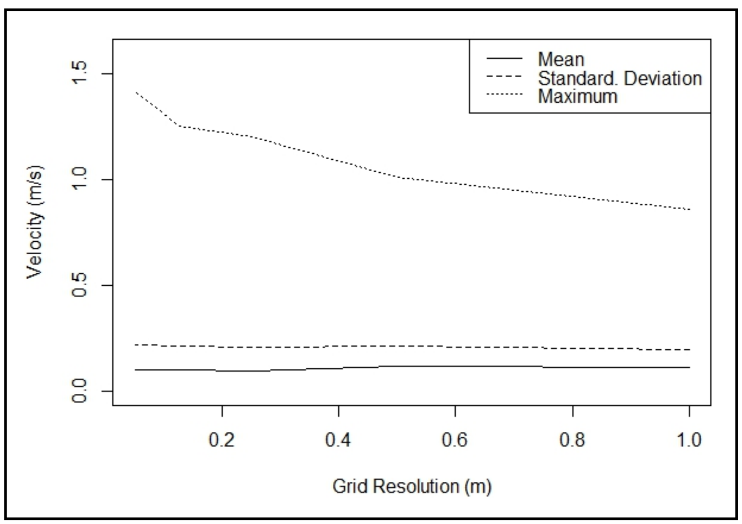

Figure EIA-4.6. Sensitivity of the hydraulic model velocity to grid resolution

Following the literature review, field data collection, and preliminary numerical modeling, we are investigating approaches to generalize the findings for a range of sites. Additionally, we are developing a preliminary tool to assess the response of stream channel to biomass removal using basic stream and watershed variables such as channel width, bankfull discharge, bed material grain size, drainage area, and vegetative cover. These data elements are being compiled for sites throughout the NARA region and Pacific Northwest. Currently, 376 watersheds are represented in the database. Much of this data focuses on streams in forested watersheds experiencing hydrologic disturbance given the lack of data specific to biomass removal. The database is being used to investigate the feasibility of accurate regional equations, which empirically relate various channel characteristics to one another for watersheds in similar terrain. We are primarily using the Analysis of Covariance (ANCOVA) statistical approach to develop and test these relationships. Once completed this generalized tool can be used to characterize streams at representative sites as a basis to estimate the channel response for a given watershed following alterations to its sediment supply and flow characteristics. Additionally, we are developing a process-based numerical model also aimed at predicting long-term changes to a typical, forested stream channel. This model includes a robust suite of hydraulic flow, sediment transport, and bank failure equations. Because the model operates in a one-dimensional scheme; it is ideal for conducting long-term simulations of channel morphology based on a range of sediment inputs and possible disturbances to the hydrologic inputs of the system.

CONCLUSIONS

- From all these analyses it has been found that the biomass removal from the field does not have any detrimental impact on the long-term flux of nutrient populations and microbial ecology.

- To find out the impact on water quantity specifically on runoff, infiltration and evapotranspiration a water balance model was developed using a Windows version of UNSAT-H model. Results indicate that ground water recharge can be enhanced using Treatment B and minimizing compaction.

- Future work is needed to improve hillslope sediment and runoff predictions from watersheds impacted by traditional logging and biomass removal. Our results indicate that extrapolation from one specific location to another will not be possible given the variability of factors effecting sediment erosion. We instead focused our modeling efforts on sensitivity analysis. Current work focus on sites representative of expected field conditions for biomass harvest sites. Additional data collection within the stream channel will also provide further insight into stream channel processes. A sustained monitoring and measurement campaign through cycles of watershed disturbance would be most beneficial. Such a dataset would provide important validation data for numerical models as well as quantitative metrics for stream channel impacts.

- Initial modelling results suggest that biomass removal may decrease the average bed material grain size and increase bedload transport. However, these results contain a high level of uncertainty, particularly for the sediment supplied to the stream. We continue to investigate the sources of uncertainty and approaches to reduce uncertainty in the model results.

- Based on discussions with others in the Sustainability team, future work is needed to expand results to differentiate between sites on the west- and east-side of the NARA region.

NARA OUTPUTS

Conference Proceedings and Abstracts from Professional Meetings

Hasan, M.M., Barber, M.E., Goel, R., and Mahler, R.L. Understanding the consequences of land use changes on sustainable river basin management in the Pacific Northwest, USA. Wessex Journal, England.

Wickham, R. and J. Petrie, Quantifying the spatial variability of stream bed grain size distributions and the influence on sediment transport modeling, ASCE EWRI Congress 2015, World Environmental & Water Resources Congress, Austin, TX, May 2015.

Research Presentations

C. Taylor Smith, M. Barber & R. Mahler, "Hydrologic assessment of woody biomass removal for biofuel production." 9th International Conference on Sustainable Water Resources Management, Prague, invited presentation, Czech Republic, July 2017.

C.T. Smith, S. Burian, J. Weidhaas, & M. Barber, "Evaluating the hydrological impact of removing woody biomass for biofuel production through unsaturated zone modeling." American Water Resources Association Specialty Conference on: Aquatic System Connectivity, Snowbird, UT, May 1-3, 2017.

M. Barber, M. Hasan, J. Petrie, & R. Goel, "Impacts of woody biomass biofuel production on sustainable river basin management." 2016 UCOWR/NIWR Annual Conference, Oral Presentation, Pensacola Beach, FL, June 2016.

Madsen, K., R. Wickham, and J. Petrie, "*Impacts of Biomass Removal on Flow and Sediment Transport in Forested Streams*." 2016 Pacific Northwest Water Research Symposium, Poster Presentation, Corvallis, OR, May 2016. (Winner of "Best Overall Poster" award)

Madsen, K., R. Wickham, and J. Petrie, "*Flow and Sediment Transport in Small Streams in Forested Watersheds*." Climate, Land Use, Agriculture and Natural Resources: Activities in Interdisciplinary Research, Education and Outreach Symposium, Poster Presentation, Pullman, WA, February 2016.

Hasan, M.M., M.E. Barber, R. Goel, and R. Mahler. Understanding the consequences of land use changes on sustainable river basin management in the Pacific Northwest, USA. River Basin Management 2015, 8th International Conference on River Basin Management including all aspects of Hydrology, Ecology, Environmental Management, Flood Plains and Wetlands, A Coruna, Spain, June 15-17, 2015.

Madsen, K., R. Wickham, and J. Petrie, "*The Effects of Biomass Removal on Small Streams in Forested Watersheds*." Water Initiative for the Future (WatIF) Conference, Oral Presentation, Kingston, ON, July 2016.

Wickham, R. and J. Petrie, "*Quantifying the spatial variability of stream bed grain size distributions and the influence on sediment transport modeling*." ASCE EWRI Congress 2015, World Environmental & Water Resources Congress, Oral Presentation, Austin, TX, May 2015.

Thesis and Dissertations

Hasan, M.M. Evaluating the Environmental Impact of Woody Biomass Removal for Biofuel Production, MS Thesis, Dept. of Civil and Environmental Engineering, University of Utah, successfully defended on April 24, 2015.

Wickham, R. The Effect of Grain Size Heterogeneity on Sediment Transport Modeling, MS Thesis, Dept. of Civil and Environmental engineering, Washington State University, successfully defended on April 20, 2015.

Smith, C.T. MS Thesis, Role of Woody Biomass Removal in Watershed Water Budget and Runoff Calculations, Dept. of Civil and Environmental Engineering, University of Utah, successfully defended on March 6, 2017.

In progress: Madsen, K. Stream Channels Changes Due to Biomass Harvesting, MS Thesis, Dept. of Civil and Environmental engineering, Washington State University, expected defense in September 2017.

NARA OUTCOMES

Our results demonstrated that reasonable biomass harvesting is not likely to result in significant negatives impacts beyond what is expected from traditional forest management practices. This conclusion is based on changes is water balances, microbial analysis, sediment transport modeling, and examination of downstream erosion impacts as well as economic discussions about the extent of biomass harvesting likely to occur with respect to distance from logging roads.

It should be pointed out that these results are based on data from a limited number of sites. Given the complex interactions between soil, water, and forest practices, site-specific studies are recommended for all proposed biomass harvesting sites.

LIST OF REFERENCES

Mualem, Y. (1976). A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water resources research,* 12(3), 513-522.