Cumulative Watershed Effects Bibliography

Prepared by the CFER program

Alila, Y., and J. Beckers. 2001. Using numerical modelling to address hydrologic forest management issues in British Columbia. Hydrological Processes 15:3371-3387.

This paper outlines how long-term statistical-deterministic physically based hydrologic modelling utilizing data from experimental watersheds in British Columbia (BC) can be used to fill knowledge gaps related to forest management in the BC Forest Practices Code, and discusses data and modelling issues that need to be considered in this context. Developing hydrologic model applications for these experimental watersheds will further provide insight regarding priorities for future data collection and will also advance our understanding of capabilities and limitations of physically based hydrologic models in addressing watershed management concerns in BC. Experience and expertise obtained in this fashion is a prerequisite for successful use of these hydrologic models in evaluating site-specific forest management issues at catchments with fewer data resources. Copyright © 2001 John Wiley Sons, Ltd.

Austin, S. A. 1999. Streamflow response to forest management: a meta-analysis using published data and flow duration curves. M.S. thesis. Colorado State University, Fort Collins.

The effects of forest management on streamflow have long been a concern for land managers. A clear understanding of this relationship is difficult because studies on the hydrologic influences of forests are highly variable in their conclusions. This project was undertaken to help reduce the confusion by evaluating results from these studies. An initial analysis of changes in peak and low flows was conducted using reported results from approximately 160 papers. The effects of logging on peak flows ranged from -36% to 563% relative to pre-treatment flows. Most changes were less than 35% and approximately one-third were reported as not significant. Large relative increases were uncommon and associated with severe site disturbance and smaller peak flows. The largest peak flows were typically little affected by timber harvest. Afforestation studies generally showed a decrease in the size of peak flows as the trees matured. Low flows typically increased after logging and decreased after afforestation. Mean daily flows from paired basins were used to generate flow duration curves for a second analysis of streamflow changes after forest management. Absolute and relative changes in flow were determined for 11 flow percentiles after adjusting for climatic differences between pre- and post-treatment periods. This consistent methodology was used to minimize variability between studies and to determine the changes in runoff over time due to forest management. The flow duration curve data showed that the highest flow had the smallest relative increase (median = 12%) while the lowest flow increased the most (59%). Low flows recovered within three to four years after logging while increases for larger flows persisted ten or more years. Afforestation studies again showed streamflow decreasing with regrowth. There were few strong relationships between the changes in flow after logging and basin characteristics or management activities. Significant basin characteristics included annual precipitation, hydrologic regime, mean elevation, mean basin slope, drainage density, and vegetation type. Significant management activities included percent area harvested, silvicultural method, yarding method, and the use of buffer strips around waterways. Insufficient data precluded a similar analysis using afforestation results. This study shows the complexity and variability of the hydrologic response to forest management. Despite the lack of strong predictive relationships, the results do show a difference in how high and low flows respond to logging and afforestation. The results also provide an indication of which basin characteristics and management activities influence the observed changes. This information should provide a better basis for determining the effects of forest management on streamflow.

Bartholow, J. M. 2000. Estimating cumulative effects of clearcutting on stream temperatures. Rivers 7:284-297.

The Stream Segment Temperature Model was used to estimate cumulative effects of large-scale timber harvest on stream temperature. Literature values were used to create parameters for the model for two hypothetical situations, one forested and the other extensively clearcut. Results compared favorably with field studies of extensive forest canopy removal. The model provided insight into the cumulative effects of clearcutting. Change in stream shading was, as expected, the most influential factor governing increases in maximum daily water temperature, accounting for 40% of the total increase. Altered stream width was found to be more influential than changes to air temperature. Although the net effect from clearcutting was a 4^{o}C warming, increased wind and reduced humidity tended to cool the stream. Temperature increases due to clearcutting persisted 10 km downstream into an unimpacted forest segment of the hypothetical stream, but those increases were moderated by cooler equilibrium conditions downstream. The model revealed that it is a complex set of factors, not single factors such as shade or air temperature, that governs stream temperature dynamics.

Available online at:
http://smig.usgs.gov/SMIG/features_0902/clearcut.html

Beckers, J., and Y. Alila. 2004. A model of rapid preferential hillslope runoff contributions to peak flow generation in a temperate rain forest watershed. Water Resources Research 40. W03501, doi:10.1029/2003WR002582.

A model for the 10 km(2) Carnation Creek watershed on Vancouver Island, British Columbia, is used to assess preferential hillslope runoff contributions to peak flow generation. The model combines the matrix flow algorithm of the distributed hydrology soil vegetation model with a Green-Ampt formulation for calculating matrix and by-pass infiltration, preferential hillslope runoff initiation controlled by rainfall depth, and downslope subsurface flow rates prescribed based on at-site tracer tests. Model evaluation using 1972-1990 hydrometeorological data reveals that this formulation is successful in simulating subannual and larger peak flows. Model results suggest that preferential flow contributions to streamflow generation become greater than matrix flow contributions for unit area discharge values in excess of 2.8 mm/hr, corresponding to a peak flow return period of 2-3 months. This transition from matrix flow dominated runoff to preferential flow dominated runoff is consistent with an observed upper limit of groundwater response to precipitation for return periods in excess of 2 months. A break in slope in peak flow frequency curves at a return period of about 20 months appears to correspond to a change in storm characteristics. Thus at least three physically distinct populations of peak flows may exist at Carnation Creek. The ability of the model to simulate peak flows and groundwater responses for small and large storms suggests that it may be useful for addressing runoff process considerations in the debate whether forest management effects for annual and larger peak flows are similar to those inferred from analyses dominated by subannual peak flows.

Benda, L., and T. Dunne. 1997a. Stochastic forcing of sediment routing and storage in channel networks. Water Resources Research 33:2865–2880.

The stochastic field of sediment supply to the channel network of a drainage basin depends on the large-scale interactions among climatically driven processes such as forest fire and rainstorms, topography, channel network topology, and basin scale. During infrequent periods of intense erosion, large volumes of colluvium are concentrated in parts of a channel network, particularly near tributary junctions. The rivers carry bed material and wash load downstream from these storage sites at different rates. The bed material travels slowly, creating transient patterns of sediment transport, sediment storage, and channel morphology along the channel network. As the concentrations of bed material migrate along the network their waveforms can undergo changes by diffusion, interference at tributary junctions, and loss of mass through temporary sediment storage in fans and terraces and through particle abrasion, which converts bed material to wash load. We investigated how these processes might influence the sediment mass balance in channels of third and higher order in a 215-km2 drainage basin within the Oregon Coast Range over a simulated 3000-year period with a climate typical of the late Holocene. We used field measurements and a simulation model to illustrate interactions between the major controls on large-scale processes functioning over long periods of time in complex drainage basins.

Benda, L., and T. Dunne. 1997b. Stochastic forcing of sediment supply to channel networks from landsliding and debris flow. Water Resources Research 33:2849-2864.

Sediment influx to channel networks is stochastically driven by rainstorms and other perturbations, which are discrete in time and space and which occur on a landscape with its own spatial variability in topography, colluvium properties, and state of recovery from previous disturbances. The resulting stochastic field of sediment supply interacts with the topology of the channel network and with transport processes to generate spatial and temporal patterns of flux and storage that characterize the sedimentation regime of a drainage basin. The regime varies systematically with basin area. We describe how the stochastic sediment supply is generated by climatic, topographic, geotechnical, and biotic controls that vary between regions. The general principle is illustrated through application to a landscape where sediment is supplied by mass wasting, and the forcing variables are deterministic thickening of colluvium, random sequences of root-destroying wildfires, and random sequences of rainstorms that trigger failure in a population of landslide source areas with spatial variance in topography and colluvium strength. Landslides stop in channels or convert to scouring debris flows, depending on the nature of the low-order channel network. Sediment accumulates within these channels for centuries before being transferred downstream by debris flows. Time series of sediment supply, transport, and storage vary with basin scale for any combination of climatic, topographic, and geotechnical controls. In a companion paper [Benda and Dunne, this issue] we use simulations of timing, volumes, and locations of mass wasting to study the interaction between a stochastically forced sediment supply and systematic changes of storage and flux through channel networks. © 1997 American Geophysical Union

Berg, D. R. 1995. Riparian Silvicultural System Design and Assessment in the Pacific Northwest Cascade Mountains, USA. Ecological Applications 5:87-96.

Active management of riparian zones can be economically as well as ecologically beneficial. Restoration of riparian forests is simulated with forest growth models. Logs were generated using the model to be of sufficient size to resist annual floods in salmon habitat streams on the west side of the Pacific Northwest Cascade mountains. The economic feasibility is reported at real interest rates. Economic viability depends on the initial volume removed, costs of regeneration and monitoring, volume of thinnings, and interest rate. Harvest operations allow for the restoration of forest structure and composition that is beneficial for salmonid habitat in areas where the primary forest has been replaced with early seral hardwood species and fiercely competitive shrubs. This silvicultural system restores natural functions of riparian forests of watersheds in the Pacific Northwest. Copyright © 1995 by the Ecological Society of America.

Berg, N. H., K. B. Roby, and B. J. McGurk. 1996. Cumulative watershed effects: applicability of available methodologies to the Sierra Nevada. Pages 39-78 in Sierra Nevada Ecosystem Project: Final Report to Congress, Vol. III, Assessment, Commissioned Reports, and Background Information. University of California, Centers for Water and Wildland Resources, Davis.

This project has two primary objectives: (1) to review and evaluate existing CWE analysis methodologies for their applicability to foothill and forested areas of the Sierra Nevada and (2) to identify and recommend one or several promising methodologies for further development or site-specific modification for use in the Sierra Nevada. A four-step approach was taken to address the objectives: (1) review and evaluate the literature on existing CWE methodologies, (2) obtain, review, and compare recent case studies of

CWE analyses used (a) on national forests in the Sierra Nevada, and (b) by state and local officials for instream flow requirements and effects of multiple water diversions, (3) identify unique or critical biogeoclimatic and socio-economic elements of the Sierra Nevada pertinent to the applicability and use of specific CWE methods, and (4) interview experts in the development and application of CWE assessment procedures. Watershed Analysis methodology is recommended as being most suitable for adaptation and use in the Sierra Nevada.

Available online at:
http://ceres.ca.gov/snep/pubs/web/PDF/VIII_C02.PDF

Beschta, R. L., J. R. Boyle, C. C. Chambers, W. P. Gibson, and others. 1995. Cumulative effects of forest practices in Oregon: literature and synthesis, Report to the Oregon Department of Forestry. Salem, Oregon.

Beschta, R. L., M. R. Pyles, A. E. Skaugset, and C. G. Surfleet. 2000. Peakflow responses to forest practices in the western cascades of Oregon, USA. Journal of Hydrology 233:102-120.

The effects of clearcut silviculture (road building, clearfelling, cable logging, and site preparation) were evaluated using long-term peakflow records for three small watersheds (60–101 ha) and six large basins (62–640 km^2) in the western Cascades of Oregon, USA. After a calibration period, two of the small watersheds were treated while the third remained untreated (control). Analysis indicated that peakflow increases following treatments were dependent upon peakflow magnitude. Peakflow increases averaged approximately 13–16% after treatment for 1-yr recurrence interval events, and 6–9% for 5-yr recurrence interval events. For the six large basins, multiple linear regression analyses of peakflows relative to: (1) peakflow magnitude; and (2) difference in percent area harvested provided mixed results. While significant ($p<0.05$) relationships were found in half of the analyses, the explained variance (delta r2) due to harvesting was generally small (1–7%).

Bowling, L. C., and D. P. Lettenmaier. 1997. Evaluation of the effects of forest roads on streamflow in Hard and Ware Creeks, Washington. Technical Report 155, University of Washington, Seattle.

Road networks in mountainous forest catchments may increase peak streamflow by replacing subsurface flow paths with surface flow paths. Forest roads affect runoff generation via two mechanisms: capture of subsurface water by road incisions, and generation of infiltration excess runoff from road surfaces. The quantity of runoff intercepted by the road network was monitored in two small Western Washington catchments, Hard and Ware Creeks (drainage areas 2.3 and 2.8 square km, respectively). Road densities in both catchments are approximately 5.0 and 3.8 km/square km, respectively. Observations indicate that the highest peak culvert discharges in Hard and Ware Creeks are associated with subsurface flow interception rather than road surface runoff. A total of 111 culverts in the two catchments were located using GPS. For each of the road segments defined by the culverts, road widths, slopes and the fraction of the road surface draining to the culvert were measured, and each of the culvert outlets was field checked to determine whether the culvert was hydraulically connected to the channel system. Based on the field study, the effective channel network density was found to have increased by 64% in Hard Creek and 52 % in Ware Creek due to road construction. The Distributed Hydrology-Soil-Vegetation Model (DHSVM) is an explicitly distributed hydrological model that simulates the land surface water and energy balance at the scale of a digital elevation model (DEM). DHSVM represents water movement through the unsaturated zone and the vegetation canopy in one dimension, as well as subsurface and surface lateral flow. It accounts for interception of precipitation as both rain and snowfall in the forest canopy. A new scheme represents the effects of forest roads on runoff generation in DHSVM via two mechanisms: capture of subsurface water by road incisions, and generation of infiltration excess runoff from road surfaces. Runoff produced by both mechanisms is routed through an expanded (roads plus pre-existing channels) channel network using a Muskingum-Cunge scheme. DHSVM-simulated flows with and without roads were compared to continuous recording gauges at the outlets of each of the basins, and to crest-recording gauges installed on 12 culverts for selected storms during the winter of 1995-96. Simulated basin conditions indicate that the roads redistribute soil moisture throughout the basin, resulting in drier areas beneath the road right-of-way relative to the simulation without roads. Based on retrospective simulations using eleven years of data, the mean annual floods in Hard and Ware Creeks were predicted to have increased by 11%, and the mean of 4 peaks over threshold were predicted to have increased by 8 and 9%, respectively.

Available online at:
http://www.ce.washington.edu/pub/WRS/WRS155revised.pdf

Bowling, L. C., and D. P. Lettenmaier. 2001. The effects of forest roads and harvest on catchment hydrology in a mountainous maritime environment. Pages 145-164 in M. S. Wigmosta and S. J. Burges, editors. Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas. AGU Water Science and Application.

Bowling, L. C., P. Storck, and D. P. Lettenmaier. 2000. Hydrologic effects of logging in western Washington, United States. Water Resources Research 36:3223-3240.

Possible changes in streamflow associated with logging were analyzed for 23 western Washington catchments with drainage areas from 14 to 1600 km. Statistically significant trends in annual streamflow minima, uncorrected for climatic influences, are all decreasing and are apparently dominated by a regional climate signal associated with the Pacific Decadal Oscillation, rather than land cover change. Using paired catchment analysis, the number of statistically significant trends detected for the peak flow series is largely within the range of statistical noise. Only in the case of the annual minima were more trends detected than could be attributed to chance, owing in part to the lower relative variability, hence greater detectability of trends in low flows. Investigation of the effect of return period on peak flow changes shows an apparent increase in flood peaks for treatment relative to control catchments, the mean magnitude of which decreases with increasing return interval up to about the 10-year return period. In large part, owing to the small number of catchment pairs available, this analysis cannot be considered conclusive. An alternative approach to evaluating trends in peak flows based on time series residuals of observed flows from hydrology model predictions detected increasing trends in peak flow series, which were largely absent in the paired catchment analysis. This is attributed both to the ability of the model, which acts as the control, to filter out natural variability and to a larger trend "signal" in the residuals analysis resulting from the ability of the method to fix the vegetation condition in the model control.

Bunte, K., and L. H. MacDonald. 1999. Scale considerations and the detectability of sedimentary cumulative watershed effects. Technical Bulletin 776, National Council for Air and Stream Improvement, Research Triangle Park.

Available online at: http://www.cnr.colostate.edu/frws/people/faculty/macdonald/publications/ScaleConsiderations_full.pdf

Buttle, J. M., I. F. Creed, and R. D. Moore. 2005. Advances in Canadian forest hydrology, 1999-2003. Hydrological Processes 19:169-200.

Understanding key hydrological processes and properties is critical to sustaining the ecological, economic, social and cultural roles of Canada's varied forest types. This review examines recent progress in studying the hydrology of Canada's forest landscapes. Work in some areas, such as snow interception, accumulation and melt under forest cover, has led to modelling tools that can be readily applied for operational purposes. Our understanding in other areas, such as the link between runoff-generating processes in different forest landscapes and hydrochemical fluxes to receiving waters, is much more tentative. The 1999-2003 period saw considerable research examining hydrological and biogeochemical responses to natural and anthropogenic disturbance of forest landscapes, spurred by major funding initiatives at the provincial and federal levels. This work has provided valuable insight; however, application of the findings beyond the experimental site is often restricted by such issues as a limited consideration of the background variability of hydrological systems, incomplete appreciation of hydrological aspects at the experiment planning stage, and experimental design problems that often bedevil studies of basin response to disturbance. Overcoming these constraints will require, among other things, continued support for long-term hydroecological monitoring programmes, the embedding of process measurement and modelling studies within these programmes, and greater responsiveness to the vagaries of policy directions related to Canada's forest resources. Progress in these and related areas will contribute greatly to the development of hydrological indicators of sustainable forest management in Canada.

Connelly, B. A., and T. W. Cundy. 1992. Cumulative effects of forest management on peak streamflows during rain-on-snow events. Pages 470-484 in Interdisciplinary approaches in hydrology and hydrogeology. American Institute of Hydrology.

DeWalle, D. R. 2003. Forest hydrology revisited. Hydrological Processes 17:1255-1256.

Forest hydrology is that specialized part of hydrological sciences that emphasizes the influence of trees and forests and their management on the regimen, quality and quantity of water. In the USA the specific role of trees and forests has been elucidated over the past century in early treatises such as Zon's (1927) Forests and Water in the Light of Scientific Investigation and Kittredge's (1948) Forest Influences. The US Forest Service, in an era of concern over the effects of forest management on the hydrologic functioning of watersheds, established many experimental areas with names like Hubbard Brook, Coweeta, Fernow, Fraser, and H. J. Andrews, that have become legendary to students of forest hydrology. Based upon early studies, we have come to regard the natural forested watershed as the ideal in hydrologic functioning with the most moderate flow regime and best water quality (with early emphasis on temperatures and suspended solids), albeit at the expense of some reduction in water yield due to higher evapotranspiration rates. By the mid- to late- 20th century, we seemed to achieve the knowledge needed to meet current needs, and forest hydrology and watershed management research was de-emphasized. However, no sooner had we turned away to face hydrologic challenges elsewhere, than some old issues were again being raised.

Dhakal, A. S., and R. C. Sidle. 2004. Pore water pressure assessment in a forest watershed: Simulations and distributed field measurements related to forest practices. Water Resources Research 40:W02405, doi:02410.01029/02003WR002017.

A distributed shallow groundwater model related to slope stability is described to assess the spatial distribution of pore water pressure in steep forested terrain in British Columbia. Additionally, effects of timber harvesting and roads on measured changes in pressure head during rainstorms were evaluated for the first time to assess the need for incorporating different hydrological components in the event-driven distributed model. Although explicit spatial quantification of pore water pressure requires many measurements for accurate prediction, model performance using average parameter

values was reasonable when compared with pressure heads measured at nine spatially distributed sites. Increases in maximum pressure head (varying from 9 to 28 cm) between preharvesting (after road construction) and postharvesting rainstorm events were observed in seven of nine sites. The remaining two sites showed either a small decrease (approximate to 5 cm) or similar peak pressure heads following harvesting. Peak pressure head evaluated at one piezometer located 46 m downslope of the road decreased substantially (approximate to 50 cm) after road construction during moderate rainstorms and then recovered following harvesting. Piezometric responses in sites upslope of the road were not affected by road construction but did increase after harvesting. Moderate storms caused the largest relative increases in pressure head between preharvesting (after roads) and postharvesting conditions; such increases were small during large storms, lending support to the idea that timber harvesting in temperate forests enhances hydrologic response only during small and moderate storms. Since landslides in coastal Pacific Northwest are typically caused by large winter rainstorms, it appears more justified to include better spatial representation of soil physical and engineering parameters in the distributed shallow groundwater model compared to specifying evapotranspiration; road hydrology may, however, need to be included. © 2004 American Geophysical Union. Reproduced by permission of American Geophysical Union.

Doten, C. O., and D. P. Lettenmaier. 2004. Prediction of sediment erosion and transport with the distributed hydrology-soil-vegetation Model. Water Resources Series Technical Report 178, University of Washington, Seattle.

Erosion and sediment transport in a temperate forested watershed are predicted with a new sediment module linked to the Distributed Hydrology-Soil-Vegetation Model (DHSVM). The DHSVM sediment module represents the main sources of sediment generation in forested environments: mass wasting, hillslope erosion and road surface erosion. It produces failures based on a factor-of-safety analysis with the infinite slope model through use of stochastically generated soil and vegetation parameters. Failed material is routed downslope with a rule-based scheme that determines sediment delivery to streams. Sediment from hillslopes and road surfaces is also transported to the channel network. A simple channel routing scheme is implemented to predict basin sediment yield. We demonstrate through an initial application of this model to the Rainy Creek catchment, a tributary of the Wenatchee River which drains the east slopes of the Cascade Mountains, that the model produces plausible sediment yield and ratios of landsliding and surface erosion, when compared to published rates for similar catchments in the Pacific Northwest.

Available online at:
http://www.ce.washington.edu/pub/WRS/WRS178.pdf

Dunne, T., J. Agee, S. Beissinger, W. Dietrich, D. Gray, M. Power, V. Resh, and K. Rodrigues. 2001. A scientific basis for the prediction of cumulative watershed

effects. University of California Wildland Resource Center Report 46, The University of California Committee on Cumulative Watershed Effects, Berkely.

Available online at:
http://nature.berkeley.edu/forestry/curr_proj/cwe/cwe_i.html

Guillemette, F., A. P. Plamondon, M. Prevost, and D. Levesque. 2005. Rainfall generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 world-wide basin studies. Journal of Hydrology 302:137-153.

Increase in bankfull peak flows and a reduction of lag and base times of the storm hydrographs were the only change in stormflow characteristics observed after harvesting balsam fir stands over 85% of the area of basin 7A (122 ha) at Montmorency Forest (Quebec, Canada). The maximum peak flow increase by 63% and occurred when harvesting had reached 61% of the basin area. For the five-year period after harvesting 85% of the basin area, the maximum increase of bankfull flow was 57% while the average change derived from the regression between the treatment and control basin during the pre-harvest period was 54%. These peak flow changes were compared with results from harvesting effects on bankfull peak flow from 50 paired watershed studies. The maximum increase in peak flow of 63% (basin 7A) was at the upper end of published results for harvesting 45-70% of a basin area while a 54% peak flow increase corresponded to the average value (49%) of published results for the 70-100% harvesting intensity. The relatively high peak flow response of basin 7A was mainly attributed to the connections of skid trails and road ditches with two branches of the stream. Considered globally, the results from watershed studies indicate that logging should not cover more than 50% of a basin area to minimise the occurrence of peak flow increases above 50%, which are deemed to affect stream morphology significantly.

Harr, R. D. 1983. Potential for augmenting water yield through forest practices in western Washington and western Oregon. Water Resources Bulletin 19:383-394.

Harr, R. D., and B. A. Coffin. 1992. Influence of timber harvesting on rain-on-snow: a mechanism for cumulative watershed effects. Pages 455-469 in Interdisciplinary approaches in hydrology and hydrogeology. American Institute of Hydrology.

Ice, G., C. Loehle, J. Beebe, and T. Cundy. 2003. Calibrating and Validating Hydrologic Model Performance for a Forested Watershed in a Snow Regime: The Dueling Model Mica Creek Watershed Study.

In 1990 Potlatch Corporation, along with numerous cooperators, initiated a forest watershed study in northern Idaho. The goal of the Mica Creek Study is to assess the effectiveness of the Idaho forest practice rules in protecting water quality. The study uses a series of nested gaging stations to measure both on-site and cumulative impacts of forest operations. The Mica Creek Study provides unusually dense and detailed hydrological, meteorological, water quality, biological, and channel data. Detailed watershed data are available in a Geographical Information System (GIS) database. These attributes make Mica Creek a logical site for calibration and validation of hydrologic models that are being applied to forest watersheds. Models that have been or are in the process of being tested include Hydrologic Simulation Program-FORTRAN (HSPF), Distributed Hydrology-Soil-Vegetation Model (DHSVM), and Watershed Analysis Risk Management Framework (WARMF). An application of SEDMODL2 may also be tested. Because models are becoming increasingly important in comparing management options on forest lands, the performance and cost of applying these models is being critically reviewed by the forest products industry.

Available online at:
http://www.ncasi.org/Publications/Detail.aspx?id=2620

Jones, J. A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. Water Resources Research 36:2621-2642.

The magnitude, seasonality, and duration of peak discharge responses to forest removal and regrowth and roads in 10 pairs of experimental basins in the western Cascade Range of Oregon are consistent with fundamental water balance and routing concepts in hydrology. Hypothesized effects of forestry treatments on evapotranspiration, cloud water interception, snowpack dynamics, and subsurface flow interception vary predictably by season, geographic setting, amount of forest canopy removal, stage of canopy regrowth, and arrangement of roads in the basin. Post-treatment responses of selected subpopulations of matched peak discharge events were examined over 10- to 34-year post-treatment periods in treated-control basin pairs in a range of geographic settings. Changes in evapotranspiration associated with forest canopy removal and regrowth apparently accounted for significant increases (31-116%) in peak discharges during the first postharvest decade in 8 of 10 treated basins, but the events that were affected were small (,0.22- or 0.28-year return periods) and occurred in the fall (September-November), when soils are in moisture deficit, rather than in spring (March-May), when soils are in moisture surplus. For a given amount of forest canopy removal, initial increases in small, fall events were greater in drier basins than wetter basins, and increases tended to disappear as forest canopies regrew. Changes in cloud water interception apparently offset changes in evapotranspiration in two partially cut basins.

Changes in snowpack dynamics apparently accounted for significant increases (25-31%) in winter rain-on-snow events, but other types of winter events did not change, in four of five basins at the H. J. Andrews Experimental Forest. Changes in subsurface flow interception apparently accounted for significant increases (13-36%) in large (.1-year return period) events in seven of eight basins with roads, and, controlling for geographic location, the magnitude of increases was related to the density of midslope roads. © 2000 American Geophysical Union. Reproduced by permission of American Geophysical Union.

Jones, J. A., and G. E. Grant. 1996. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon. Water Resources Research 32:959-974.

This study quantified long-term changes in streamflows associated with clear-cutting and road construction and examined alternative hydrologic mechanisms to explain stream hydrograph changes in the Cascades Range, western Oregon. We examined differences in paired peak discharges for 150 to 375 storm events for five basin pairs, using 34-year records from two pairs of 60-to-101-ha experimental basins in the H. J. Andrews Experimental Forest, and 50-to-55-year records from three pairs of adjacent basins ranging from 60 to 600 km2. Forest harvesting has increased peak discharges by as much as 50% in small basins and 100% in large basins over the past 50 years. These increases are attributable to changes both in flow routing due to roads and in water balance due to treatment effects and vegetation succession. © 1996 American Geophysical Union. Reproduced by permission of American Geophysical Union.

Jones, J. A., and G. E. Grant. 2001. Comment on “Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon”. Water Resources Research 37:179-180.

Jones, J. A., and D. A. Post. 2004. Seasonal and successional streamflow response to forest cutting and regrowth in the northwest and eastern United States. Water Resources Research 40:W05203, doi:05210.01029/02003WR002952.

This study examined daily streamflow response over up to four decades in northwest conifer forest and eastern deciduous forest sites in the United States. We used novel methods to analyze daily observations of climate and streamflow spanning more than 900 basin years of record at 14 treated/control basin pairs where forest removal and regrowth experiments were underway in the period 1930-2002. In the 1 to 5-year period after forest removal, maximum daily increases ranged from 2 to 3 mm at deciduous forest sites, to 6 to 8 mm at conifer forest sites. Significant spring surpluses persisted for up to 35 years in conifer forest basins, but winter and spring streamflow deficits appeared after 10 to 15 years of forest regrowth in eastern deciduous forest basins. In all 5-yr posttreatment periods, absolute changes in daily streamflow were significantly more likely during moist, warm seasons, or during snowmelt seasons, but relative changes were more likely during warm seasons irrespective of moisture status. Both relative and absolute streamflow changes in the 1 to 5 and 15 to 25-year periods after forest removal were significantly positively related to the age of the forest at the time it was cut. Eastern deciduous forests had been disturbed by logging or hurricane 12 to 56 years prior to forest removal, while Pacific Northwest conifer forests had been not experienced logging or wildfire for 90 to 450 years. Paired basin experiments provide a continuous, and continuously changing, record of vegetation structure, composition, and climate, and their effects on streamflow.

Jones, J. A., and F. J. Swanson. 2001. Hydrologic inferences from comparisons among small basin experiments. Hydrological Processes 15:2363-2366.

The hydrologic community is poised to make important advances in basic hydrology through comparative analysis of small basin experiments around the world. Existing long-term records from small basins have already enriched our knowledge of fundamental processes and important societal issues, and yet they contain a wealth of untapped information about hydrologic and biogeochemical responses to climate change, natural disturbance and human activities over a wide range of climate, geophysical and vegetation settings.

Keppeler, E. T., and R. R. Ziemer. 1990. Logging Effects on Streamflow: Water Yield and Summer Low Flows at Caspar Creek in Northwestern California. Water Resources Research 26:1669-1679.

Streamflow data for a 21-year period were analyzed to determine the effects of selective tractor harvesting of second-growth Douglas fir and redwood forest on the volume, timing, and duration of low flows and annual water yield in northwestern California. The flow response to logging was highly variable. Some of this variability was correlated with antecedent precipitation conditions. Statistically significant increases in streamflow were detected for both the annual period and the low-flow season. Relative increases in water yield were greater for the summer low-flow period than for annual flows, but these summer flow increases generally disappeared within 5 years.

LaMarche, J., and D. P. Lettenmaier. 1998. Forest road effects on flood flows in the Deschutes River basin, Washington. Water Resources Series Technical Report 158, University of Washington, Seattle.

Forest harvesting in maritime mountainous watersheds is thought to affect flood flows by two primary mechanisms. The first mechanism is through reduction of canopy interception and ablation of snow prior to rain-on-snow storms, and subsequently, by enhanced melt due to increased turbulent energy transfer during warm storms. The second mechanism is through increased runoff brought about by increased effective stream drainage density resulting fiom forest road drainage systems. To assess connectivity of the road drainage and stream network, the locations of 2 171 forest road culverts were identified during summer, 1997 in the extensively logged 150 km2 Deschutes River Basin, WA. Road characteristics, including cutslope height, culvert connectivities to the natural stream network, and hillslope position were identified for 140 culvert locations within 38 road segments. A logistic regression model based on topographic and vegetation attributes at these locations indicated that hillslope curvature and distance to the natural stream could be used to predict connectivity resulting fiom gullies below culverts extending to the stream channel. The model was applied to culverts classified in a previous study in Hard and Ware Creeks, two headwater subcatchments in the Deschutes Basin, and was found to accurately predict channel connectivity below 8 1 percent of the ditch relief culverts. The algorithm was then used to predict connectivity for all ditch relief culverts within the Deschutes Basin. Approximately 24 percent of the culverts were connected to the stream network. In addition, 33 percent of all culverts were identified as stream crossing culverts in the field study and, therefore, were connected to the stream network. Runoff monitored in roadside ditches during winters 1996-97 and 1997-98 indicated higher flows occurred in ditches draining clearcut compared to forested areas. Valley bottom and mid-hillslope roads had a higher response than ridge top roads. Road segments with higher cutslopes did not have an increase runoff response. The Distributed Hydrology-Soil-Vegetation Model (DHSVM) was used to evaluate road effects on peak flows, using the field data and algorithm predictions of culvert connectivity to the natural channel. The influence of topographic slope, road connectivity, vegetation, and road location on peak flows were investigated by comparing simulated discharge in nine sub-basins (2.2 to 21 krn2 in area), as well as the Deschutes basin outlet. Model results predicted increases in the mean annual flood due to forest roads alone in the sub-basins from 2 to 10 percent, and from 3 to 12 percent for the 10-year event. The corresponding changes at the Deschutes River outlet gauge were 4.6 and 5.2 percent, respectively. The largest predicted increases due to roads were roughly equivalent to the predicted effect of harvest (mature forest compared with current vegetation state) for the mean annual flood. Predicted road effects on peak flows were essentially independent of the vegetation state in all sub-basins. In general, predicted road effects increased with flood return period, while vegetation effects decreased. Simulated ditch flows using DHSVM were higher below immature forests than mature forests, which concurred with field results. However, no synergism between forest harvest and roads was predicted by the model at the scale of the nine sub-basins. This apparent inconsistency between hillslope and catchment scale response was attributed to desynchronization of the hillslope responses at the sub-basin scale.

Available online at:
http://www.ce.washington.edu/pub/WRS/WRS158.pdf

Lamarche, J., and D. P. Lettenmaier. 2001. Effects of forest roads on flood flows in the Deschutes River basin, Washington. Earth Surface Processes and Landforms 26:115-134.

The effects of forest roads on peak flows were examined through a combination of field data collection and modelling in the extensively logged 149 km2 catchment of the Deschutes River, Washington, USA.Based on a field survey, the connectivity of culverts to the channel network was related primarily to hillslope curvature and distance to the natural stream channel. Culvert crest stage recorders operated during winters 1996/97 and 1997/98 demonstrated that higher flows occurred in ditches draining clearcuts compared to forested areas. Contrary to expectation, road cutslope height did not seem to affect culvert peak runoff.Adistributed hydrologic model was used to evaluate road effects on peak flows in nine subcatchments (2.2 to 21 km2) of the Deschutes River as well as the Deschutes main stem. The model-predicted increases in the mean annual flood due to forest roads alone ranged from 2.2 to 9.5 per cent, and from 2.9 to 12.2 per cent for the 10 year event. These increases are roughly equivalent to slightly smaller than those predicted for harvest effects alone. Simulated road effects on peak flows were independent of forest harvest state. However, at the hillslope scale, modelled as well as fieldmonitored road ditch response was dependent on harvest state. Modelled road effects generally increased with flood return period, while vegetation effects decreased. Copyright 2001 John Wiley & Sons, Ltd.

Link, T. E., G. N. Flerchinger, M. Unsworth, and D. Marks. 2004. Simulation of water and energy fluxes in an old-growth seasonal temperate rain forest using the simultaneous heat and water (SHAW) model. Journal of Hydrometeorology 5:443-457.

In the Pacific Northwest (PNW), concern about the impacts of climate and land cover change on water resources and flood-generating processes emphasizes the need for a mechanistic understanding of the interactions between forest canopies and hydrologic processes. Detailed measurements during the 1999 and 2000 hydrologic years were used to modify the Simultaneous Heat and Water (SHAW) model for application in forested systems. Major changes to the model include improved representation of rainfall interception and stomatal conductance dynamics. The model was developed for the 1999 hydrologic year and tested for the 2000 hydrologic year without modification of the site parameters. The model effectively simulated throughfall, soil water content profiles, and shallow soil temperatures for both years. The largest discrepancies between soil moisture and temperature were observed during periods of discontinuous snow cover due to spatial variability that was not explicitly simulated by the model. Soil warming at bare locations was delayed until most of the snow cover ablated because of the large heat sink associated with the residual snow patches. During the summer, simulated transpiration decreased from a maximum monthly mean of 2.2 mm day(-1) in July to 1.3 mm day(-1) in September as a result of decreasing soil moisture and declining net radiation. The results indicate that a relatively simple representation of the vegetation canopy can accurately simulate seasonal hydrologic fluxes in this environment, except during periods of discontinuous snow cover.

Loftis, J. C., L. H. MacDonald, S. Streett, H. K. Iyer, and K. Bunte. 2001. Detecting cumulative watershed effects: the statistical power of pairing. Journal of Hydrology 251:49-64.

The statistical power for detecting change in water quality should be a primary consideration when designing monitoring studies. However, some of the standard approaches for estimating sample size result in a power of less than 50%, and doubling the pre- and post-treatment sample size are necessary to increase the power to 80%. The ability to detect change can be improved by including an additional explanatory variable such as paired watershed measurements. However, published guidelines have not explicitly quantified the benefits of including an explanatory variable or the specific conditions that favor a paired watershed design. This paper (1) presents a power analysis for the statistical model (analysis of covariance) commonly used in paired watershed studies; (2) discusses the conditions under which it is beneficial to include an explanatory variable; and (3) quantifies the benefits of the paired watershed design. The results show that it is beneficial to include an explanatory variable when its correlation to the water quality variable of concern is as low as about 0.3. The ability to detect change increases non-linearly as the correlation increases. Power curves quantify sample size requirements as a function of the correlation and intrinsic variability. In general, the temporal and spatial variability of many watershed-scale characteristics, such as annual sediment loads, makes it very difficult to detect changes within time spans that are useful for land managers or conducive to adaptive management.

Luce, C. H. 2002. Hydrological processes and pathways affected by forest roads: what do we still need to learn? Hydrological Processes 16:2901-2904.

Forest roads are an important environmental issue. While many scientists interested in hydrology recognize climate-altering processes as an important global issue, there are problems that are similar in scope and magnitude because human industriousness has brought them to so many parts of the world. Almost everywhere people live and work they build and use unimproved roads, and wherever the roads go, a range of environmental issues follows. Among the environmental effects of unimproved roads, those on water quality and aquatic ecology are some of the most critical. Increased chronic sedimentation, in particular, can dramatically change the food web in affected streams, lakes, and oceans and reduces the effectiveness of drinking water treatment, which compounds problems of access to safe drinking water in developing regions. Low-standard roads accessing agricultural and forest lands comprise much of the extent of roads and probably affect the greatest area.

Luce, C. H., D. G. Tarboton, E. Istanbulluoglu, and R. T. Pack. 2005. Reply to comment by Jonathan J. Rhodes on "Modeling of the interactions between forest vegetation, disturbances, and sediment yields". Journal of Geophysical Research-Earth Surface 110:10.1029/2004JF000279.

Luce, C. H., and B. C. Wemple. 2001. Introduction to special issue on hydrologic and geomorphic effects of forest roads. Earth Surface Processes and Landforms 26:111-113.

MacDonald, L. H. 2000a. Evaluating and managing cumulative effects: process and constraints. Environmental Management 26:299–315.

Cumulative effects (CEs) result from the combined effect of multiple activities over space or time. This implies a persistence through time and often a transmittal mechanism through space. Environmental legislation often requires a broader CE assessment in addition to the more direct, project-specific impacts. Current efforts to evaluate and manage CEs are hampered by the conceptual problems of defining the key issues, specifying the appropriate spatial and temporal scales, and determining the numerous interactions and indirect effects. These problems can be greatly alleviated by following an explicit process. The process proposed in this paper includes a scoping phase, an analysis phase, and a planning and management phase, with each phase consisting of two to five discrete but interrelated tasks. Numerous approaches have been developed to assess CEs, and these range from simple checklists to complex, physically based models. The utility of each approach depends on the resource of concern, relative risk to those resources, information available, and time frame for the evaluation. In nearly all cases the assessment and regulation of CEs is severely hampered by the variability in site conditions and management effects, inability to predict secondary or indirect effects, lack of data on recovery rates, difficulty of validating predictive models, and uncertainty of future events. Since any proposed activity could contribute to a wide range of potential CEs at different spatial and temporal scales, a tiered or nested approach should be followed to assess CEs. The difficulty of assessing and predicting CEs also suggests that in many cases the most efficient approach is to focus on minimizing on-site impacts. Under some circumstances adaptive management can also be a viable alternative to detailed CE assessments. Regular monitoring and feedback is critical to the successful management and regulation of CEs. © 2000 Springer-Verlag New York Inc.

MacDonald, L. H. 2000b. Predicting and managing cumulative watershed effects. in M. Flug and D. Frevert, editors. Watershed Management 2000 Conference. American Society of Civil Engineers, Fort Collins, CO.

Nonpoint sources of pollution are an increasingly important cause of water quality impairment, and this is forcing water quality regulation towards a more integrated, watershed-scale approach. Nonpoint sources are the dominant source of pollution in forested areas, and large landowners, such as the U.S. Forest Service, are required to assess and minimize adverse cumulative effects on aquatic resources. This paper argues that the current emphasis on changes in runoff is largely unjustified, whereas forest management activities can have relatively large effects on erosion and sediment yields. Although the relative importance of sediment is recognized, current models must be revised to account for the potentially larger, but less persistent, changes in erosion and sediment loads. Geographic information systems can improve our ability to assess cumulative watershed effects (CWEs). However, the accuracy of any assessment will be limited by: (1) the uncertainty of quantifying the effect of each disturbance; (2) the inability to predict indirect effects; (3) unknown recovery rates; (4) problems of validation; and (5) the uncertainty of future events. Adaptive mangement is one alternative approach, but this is unlikely to provide a sufficient level of protection to aquatic resources. Minimizing the local effect of each activity is probably the most efficient means to reduce CWEs, but this should be coupled with focussed downstream monitoring. The assessment of cumulative effects will continue to be a difficult and contentious issue .

Megahan, W. F., and J. Hornbeck. 2000. Lessons learned in watershed management: a retrospective view. Pages 177–188 in Land stewardship in the 21st century: the contributions of watershed management. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Post, D. A., and J. A. Jones. 2001. Hydrologic regimes of forested, mountainous, headwater basins in New Hampshire, North Carolina, Oregon, and Puerto Rico. Advances in Water Resources 24:1195-1210.

This study characterized the hydrologic regimes at four forested, mountainous long-term ecological research (LTER) sites: H.J. Andrews (Oregon), Coweeta (North Carolina), Hubbard Brook (New Hampshire), and Luquillo (Puerto Rico). Over 600 basin years of daily streamflow records were examined from 18 basins that have not experienced human disturbances since at least the 1930s and in some cases much longer periods. This study used statistical methods to systematically evaluate the relationship between precipitation and streamflow at a range of spatial and temporal scales, and draw inferences from these relationships about the hydrologic behavior of the basins. Basins in this study had fundamentally different abilities to store and release moisture at a range of time and space scales. These different hydrologic regimes are the result of different types of forest canopies, snow, and soils in the study basins. Through their influences on interception and transpiration, forest canopies appear to play a very important role in the hydrologic regimes at Andrews and Luquillo, but at Coweeta and Hubbard Brook, the current deciduous forest plays a more limited although seasonally important role. Because of the timing of melt and its interaction with soils, seasonal snowpacks at Hubbard Brook and Andrews have quite different effects upon streamflow and vegetation water use. A variety of water flowpath types in soil, from macropore flow to long flowpaths in deep soils or fractured bedrock, appear to operate at the four sites. Hydrologic regimes may help predict the temporal scales of biogeochemical cycling and stream ecological processes, as well as the magnitude and timing of hydrologic response to disturbance and climate change in headwater basins.

Putz, G., J. M. Burke, D. W. Smith, D. S. Chanasyk, E. E. Prepas, and E. Mapfumo. 2003. Modelling the effects of boreal forest landscape management upon streamflow and water quality: Basic concepts and considerations. Journal of Environmental Engineering and Science 2:S87-S101.

Modelling and predicting potential impacts of forest harvest operations and wildfire on water quantity and quality are critical tools for forest managers. To make these predictions, the impacts of harvest operations and wildfire on model input parameters must first be quantified with measurements. In addition, output data are required to validate the model before any meaningful predictions can be made. This component of the Forest Watershed and Riparian Disturbance (FORWARD) project will closely associate hydrologic and water quality simulation modelling with intensive field monitoring of disturbance effects in forests of the Boreal Plain subregion of western Canada. The goal is to develop modelling procedures that can be used for predicting the impacts of forest operations and wildfires on water quantity and quality of stream runoff on the Boreal Plain.

Reid, L. M. 1993. Research and cumulative watershed effects. General Technical Report PSW-GTR-141, Pacific Southwest Research Station Forest Service, U.S. Department of Agriculture, Albany, CA.

The mandate for land managers to address cumulative watershed effects (CWEs) requires that planners evaluate the potential impacts of their activities on multiple beneficial uses within the context of other coexisting activities in a watershed. Types of CWEs vary with the types of landuse activities and their modes of interaction, but published studies illustrate both descriptive and predictive evaluations of many of these types. Successful evaluations have generally used geomorphological and ecological approaches based on the understanding of the processes involved. In contrast, most generalized "cookbook" analysis procedures are shown to be unable to assess accumulations of impacts through time, usually cannot evaluate the range of activities and uses that are necessary, and are rarely validated. A general approach to evaluation is proposed, and the types of information available for assessments are reviewed.

Available online at:
www.fs.fed.us/psw/publications/reid/reid_141.pdf

Reid, L. M. 1998. Cumulative watershed effects and watershed analysis. Pages 476-501 in R. J. Naiman and R. E. Bilby, editors. River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer-Verlag, N.Y.

Cumulative watershed effects are environ- mental changes that are affected by more than one land-use activity and that are influenced by processes involving the generation or transport of water. Almost all environmental changes are cumulative effects, and almost all land-use activities contribute to cumulative effects. • An understanding of cumulative water- shed effects is necessary if land-use activities and restoration projects are to be designed that accomplish their intended objectives. Cumulative effects first must be evaluated to decide what actions are appropriate. The likely direct and indirect effects of the planned actions must then be assessed. • Technical issues that complicate analysis of cumulative effects include the large spatial and temporal scales involved, the wide variety of processes and interactions that influence cumulative effects, and the lengthy lag-times that often separate a land-use activity and the landscape's response to that activity. • Analysis strategies contain implicit assumptions about the role of humans on the landscape, the limits of responsibility, and how the natural world functions. Controversy over methods often revolves around philosophical differences concerning these assumptions. • Cumulative effects analysis requires a non-traditional approach to information: patterns are usually more important than details; an interdisciplinary focus is more useful than multiple monodisciplinary foci; and a large area is more than the sum of its parts, so it must be evaluated as a unit. • Ad hoc methods for evaluating cumulative effects are well developed and have been widely used for nearly a century. An ad hoc method is designed to address a particular kind of problem in a particular place and often cannot be applied elsewhere without modification. • Standardized analysis methods were developed in the 1970s and 1980s to fulfill requirements of the National Environmental Policy Act, but most of these methods lack technical credibility or are limited in the kinds of problems they can address or the areas in which they can be applied. Examples include use of index values, mechanistic models, and checklists for applying expert judgment. • More recently, methods of watershed analysis were developed to provide the back-ground information needed for evaluating cumulative effects. • The watershed analysis method employed in Washington state uses an understanding of past environmental changes to develop prescriptions for land-use practices, but it does not assess the likely cumulative effects of future activities. • The ecosystem analysis method used on federal lands in much of the Pacific Northwest provides background information about eco-system and landscape interactions that can be used for later cumulative effects assessment. when projects are being planned.

Available online at:
http://www.treesearch.fs.fed.us/pubs/viewpub.jsp?index=8492

Schnorbus, M., and Y. Alila. 2004. Forest harvesting impacts on the peak flow regime in the Columbia Mountains of southeastern British Columbia: An

investigation using long-term numerical modeling. Water Resources Research 40:W05205, doi:05210.01029/02003WR002918.

Numerical hydrologic simulation, in combination with synthetic weather generation, was used to assess the sensitivity of the peak flow regime for hourly, daily, and 7-day discharge to hypothetical harvesting scenarios in Redfish Creek in southern British Columbia. Simulation was based on stationary vegetation cover, thus representing potential peak flow regime adjustments during the first few critical years following harvesting. The relative difference between preharvest and postharvest peak discharge quantiles (DeltaQ(T)), estimated by comparing GEV distributions fit to the simulated preharvest and postharvest annual maximum series, tended to increase with increasing harvest area; however, the relationship was strongly influenced by the elevation distribution of harvest blocks. Although rainfall was determined to be a factor in roughly three quarters of all peak discharge events, the flood frequency of Redfish Creek is fundamentally a function of the frequency structure of snowmelt runoff. Consequently, changes in runoff synchronization between various elevation bands largely drove the magnitude of DeltaQ(T), and the degree of increased synchronization was found to be greatest following harvesting above H60 (elevation above which lies 60% of basin area) and least following harvesting below H60. As a result, only harvesting schemes that incorporated cut blocks above H60 tended to generate significant (alpha = 0.05) DeltaQ(T) for a wide range of return periods (T), regardless of discharge timescale. Significant DeltaQ(T) ranged from 6 to 14% for hourly, 5 to 14% for daily, and 5 to 20% for 7-day discharge in the range of 1.25 less than or equal to T less than or equal to 100 years. For a given scenario, hourly and daily DeltaQ(T) showed little variation with T, suggesting that small and large discharge events responded similarly to forest harvesting. However, this apparent trend substantially overstates DeltaQ(T) for the largest hourly and daily peak discharge events such that the relationship of DeltaQ(T) to T is inconclusive for T > 30 years. For 7-day discharge, DeltaQ(T) increases with increasing T for 1.25 less than or equal to T less than or equal to 100 years.

Storck, P., L. Bowling, P. Wetherbee, and D. Lettenmaier. 1998. Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. Hydrological Processes 12:889-904.

Spatially distributed rainfall-runoff models, made feasible by the widespread availability of land surface characteristics data (especially digital topography), and the evolution of high power desktop workstations, are particularly useful for assessment of the hydrological effects of land surface change. Three examples are provided of the use of the Distributed Hydrology-Soil-Vegetation Model (DHSVM) to assess the hydrological effects of logging in the Pacific Northwest. DHSVM provides a dynamic representation of the spatial distribution of soil moisture, snow cover, evapotranspiration and runoff production, at the scale of digital topographic data (typically 30-100 m). Among the hydrological concerns that have been raised related to forest harvest in the

Pacific Northwest are increases in flood peaks owing to enhanced rain-on-snow and spring radiation melt response, and the effects of forest roads. The first example is for two rain-on-snow floods in the North Fork Snoqualmie River during November 1990 and December 1989. Predicted maximum vegetation sensitivities (the difference between predicted peaks for all mature vegetation compared with all clear-cut) showed a 31% increase in the peak runoff for the 1989 event and a 10% increase for the larger 1990 event. The main reason for the difference in response can be traced to less antecedent low elevation snow during the 1990 event. The second example is spring snowmelt runoff for the Little Naches River, Washington, which drains the east slopes of the Washington Cascades. Analysis of spring snowmelt peak runoff during May 1993 and April 1994 showed that, for current vegetation relative to all mature vegetation, increases in peak spring stream flow of only about 3% should have occurred over the entire basin. However, much larger increases (up to 30%) would occur for a maximum possible harvest scenario, and in a small headwaters catchment, whose higher elevation leads to greater snow coverage (and, hence, sensitivity to vegetation change) during the period of maximum runoff. The third example, Hard and Ware Creeks, Washington, illustrates the effects of forest roads in two heavily logged small catchments on the western slopes of the Cascades. Use of DHSVM's road runoff algorithm shows increases in peak runoff for the five largest events in 1992 (average observed stream flow of 2•1 m3 s-1) averaging 17•4% for Hard Creek and 16•2% for Ware Creek, with a maximum percentage increase (for the largest event, in Hard Creek) of 27%.

Storck, P., and D. P. Lettenmaier. 2000. Trees, Snow and Flooding: An Investigation of Forest Canopy Effects on Snow Accumulation and Melt at the Plot and Watershed Scales in the Pacific Northwest. Water Resources Series Technical Report 161, University of Washington, Seattle.

Concerns about the extent to which major Pacific Northwest floods over the last decade might have been exacerbated by logging have heightened the need for a better scientific understanding of the role of forest maturity on snow accumulation and melt. To address this need, a multi-scale field and modeling study of the effects of forest canopies on snow accumulation and melt was conducted. Over a three year period, weighing lysimeters and cut-tree experiments were used to measure the processes controlling snow interception and its fate at a site in the Umpqua National Forest, OR (elevation 1200 m). Continuous observations of below-canopy snowpack evolution were made over the same period. Over the study period, approximately 60 percent of annual snowfall was intercepted by the canopy (up to a maximum of 40 mm water equivalent). Approximately 72 percent and 28 percent of the intercepted snow was removed as meltwater drip and large snow masses, respectively. Apparent average sublimation rates from the intercepted snow were less than 1 mm per day and totaled approximately 100 mm per winter season. Observed differences in snow interception and release between trees of different species were minimal. These data, along with ancillary observations including standard micrometeorology, were used to construct, calibrate, and test an energy balance model of snow as affected by the forest canopy. Although initially implemented and tested on the Umpqua data, the model was designed for use in spatially distributed hydrology models designed to be applied at larger scales. Intercepted snow load was modeled as a function of Leaf Area Index and adjusted for the effects of air temperature. Removal of intercepted snow by sublimation, melt-water drip and mass release was explicitly modeled. A fractional canopy coverage parameter was used to scale from the plot to the stand scale. To support application in distributed hydrology models, a computationally efficient atmospheric stability correction was developed. The model was calibrated against one year of weighing lysimeter data and was tested at the plot scale against two years of weighing lysimeter data and at the stand scale against three years of snow course data taken over an area of 26 ha at the Umpqua site. The snow model was incorporated into the Distributed Hydrology Soil Vegetation Model (DHSVM) to explore the effect of forest canopy removal on floods during Rain-On-Snow (ROS) events in maritime climates like the Pacific Northwest. A sensitivity analysis of the 10 largest flood between 1988 and 1996 on the Snohomish River, which drains an area of 4000 km2 of the western slopes of the Cascade Mountains in Washington State, was conducted. Predicted peak streamflow was increased by an average of 3 percent with the current vegetation cover relative to the historic land cover. Larger increases (> 10 percent) were predicted for headwater basins (Tolt River, average increase over all ten flood events of 8.9 percent), in which forest harvest has been concentrated, and events with a large snowmelt contribution. Overall, the average predicted increase in peak streamflow for current land cover relative to historic was below the minimum that could be detected in paired catchment studies .

Available online at:
http://www.ce.washington.edu/pub/WRS/WRS161.pdf

Stover, S. C., and D. R. Montgomery. 2001. Channel change and flooding, Skokomish River, Washington. Journal of Hydrology 243:272-286.

Analysis of 35 years of cross-section data documents changes in channel width and bed elevation along the Skokomish River, Washington. The bed of the South Fork Skokomish incised over 1 m between 1940 and 1964, although both prior and subsequent to this period the mean bed elevation oscillated as much as 0.8 m with almost no cumulative change. In contrast, the mainstem Skokomish channel bed aggraded nearly 0.5 m between 1939 and 1944, oscillated at amplitudes up to 1 m with little net change from 1945 to 1964, and aggraded over 1.3 m between 1965 and 1997. In the late 1920s, prior to the onset of gaging station records, damming of the North Fork significantly reduced flow in the mainstem Skokomish. From the 1930s to the 1990s, peak discharge data for both the South Fork and the mainstem indicate no net increase in peak flows. Despite the reduced discharge from darn construction in the 1930s and no increase in peak flows during the following years, the frequency of overbank flooding in recent decades has increased on the floodplain of the mainstem. Systematic written descriptions and aerial photographs of the catchment from 1929 to 1992 document land use, including timber harvesting, road construction, and in-channel debris removal. The timing of changes in channel width and elevation imply that debris removal may have triggered periods of degradation and that near-channel and headwater land use potentially elevated the sediment supply to both reaches. Although direct land use causality is difficult to constrain, progressive reduction of channel conveyance in the mainstem as observed in USGS gage height trends does indicate that increased flooding on the mainstem Skokomish River resulted from aggradation, without an increase in peak discharges.

Swanson, F. J., S. L. Johnson, S. V. Gregory, and S. A. Acker. 1998. Flood disturbance in a forested mountain landscape. BioScience 48:681-689.

Thomas, R. B., and W. F. Megahan. 1998. Peak flow responses to clear-cutting and roads in small and large basins, western Cascades, Oregon: a second opinion. Water Resources Research 34:3393-3403.

In this paper, we conduct a reanalysis of methods and data used by Jones and Grant [1996]. Data from three small watersheds (60–101 ha) and three pairs of large basins (60–600 km^2) in Oregon’s western Cascades were used to evaluate effects of timber harvest and road construction on peak flows. We could not detect any effect of cutting on peak flows in one of the large basin pairs, and results were inconclusive in the other two large basin pairs. One small watershed was 100% clear-cut, a second was 31% patch-cut with 6% of the area affected by road construction, and a third was held as a long-term control. Peak flows were increased up to 90% for the smallest peak events on the clear-cut watershed and up to 40% for the smallest peak flows on the patch-cut and roaded watershed. Percentage treatment effects decreased as flow event size increased and were not detectable for flows with 2-year return intervals or greater on either treated watershed. Treatment effects decreased over time but were still found after 20 years on the clear-cut watershed but for only 10 years on the patch-cut and roaded watershed.

Thyer, M., J. Beckers, D. Spittlehouse, Y. Alila, and R. Winkler. 2004. Diagnosing a distributed hydrologic model for two high-elevation forested catchments based on detailed stand- and basin-scale data. Water Resources Research 40:W01103, doi:01110.01029/02003WR002414.

This study evaluates the performance and internal structure of the distributed hydrology soil vegetation model (DHSVM) using 1998 - 2001 data collected at Upper Penticton Creek, British Columbia, Canada. It is shown that clear-cut snowmelt rates calculated using data-derived snow albedo curves are in agreement with observed lysimeter outflow. Measurements in a forest stand with 50% air crown closure suggest that the fraction of shortwave radiation transmitted through the canopy is 0.18 - 0.28 while the hemispherical canopy view factor controlling longwave radiation fluxes to the forest snowpack is estimated at 0.81 +/- 0.07. DHSVM overestimates shortwave transmittance (0.50) and underestimates the view factor (0.50). An alternative forest radiation balance is formulated that is consistent with the measurements. This new formulation improves model efficiency in simulating streamflow from 0.84 to 0.91 due to greater early season melt that results from the enhanced importance of longwave radiation below the canopy. The model captures differences in canopy rainfall interception between small and large storms, tree transpiration measured over a 6-day summer period, and differences in soil moisture between a dry and a wet summer. While the model was calibrated to 1999 snow water equivalent (SWE) and hydrograph data for the untreated control basin, it successfully simulates forest and clear-cut SWE and streamflow for the 3 other years and 4 years of preharvesting and postharvesting streamflow for the second basin. Comparison of model states with the large array of observations suggests that the modified model provides a reliable tool for assessing forest management impacts in the region.

Wemple, B., and J. Jones. 2003. Runoff production on forest roads in a steep, mountain catchment. Water Resources Research 39:1220, doi:1210.1029/2002WR001744.

This study investigated how roads interact with hillslope flow in a steep, forested landscape dominated by subsurface flow and how road interactions with hillslope flow paths influence hydrologic response during storms in a second-order catchment. Runoff was measured continuously from 12 subcatchments draining to road segments and covering 14% of a 101-ha, second-order catchment (WS3) in the Andrews Forest, Oregon. Observed runoff over the 1996 water year was compared to predictions for runoff timing and interception of a hillslope water table based on a simple model of kinematic subsurface storm flow. Observed runoff behavior was consistent with model estimates, a finding that underscores the utility of this simple approach for predicting and explaining runoff dynamics on forest roads constructed on steep hillslopes. Road segments in the study area interacted in at least four distinct ways with complex landforms, potentially producing very different effects depending on landform characteristics. Hillslope length, soil depth, and cutbank depth explained much of the variation in road runoff production among subcatchments and among storm events. Especially during large storm events, a majority of instrumented road segments intercepted subsurface flow and routed it to ditches and thence directly to streams with a timing that contributed to the rising limb of the catchment-wide hydrograph. The approach used in this study may be useful for model development and for targeting road segments for removal or restoration.

Whitaker, A., Y. Alila, J. Beckers, and D. Toews. 2002. Evaluating peak flow sensitivity to clear-cutting in different elevation bands of a snowmelt-dominated mountainous catchment. Water Resources Research 38:1172, doi:1110.1029/2001WR000514.

A hydrologic model of the mountainous snowmelt-dominated Redfish Creek catchment (British Columbia) is used to evaluate Interior Watershed Assessment Procedure (IWAP) guidelines regarding peak flow sensitivity to logging in different elevation bands of a basin. Simulation results suggest that peak flow increases are caused by greater snow accumulation and melt in clear-cut areas while similar evapotranspiration rates are predicted under forested and clear-cut conditions during spring high flow. Snow accumulation and melt are clearly related to elevation, but the relationship between logging elevation and peak flow change is more complex than perceived in the IWAP. Logging in the bottom 20% of the catchment causes little or no change in peak flow because of the small low-elevation snowpack and the timing of snowmelt, while clear-cut area alone appears to be a good indicator of peak flow increases due to logging at higher elevation. Temporal variability in peak flow changes due to clear-cutting is substantial and may depend more on temperatures during snowmelt than on the size of the snowpack. Long-term simulations are needed to improve quantitative estimates of peak flow change while the importance of watershed topographic characteristics for snowmelt and peak flow generation must be further examined.

Ziemer, R. R. 1998. Proceedings of the conference on coastal watersheds: the Caspar Creek story. 6 May 1998; Ukiah, California. General Technical Report PSW GTR-168, Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, California.

These proceedings report on 36 years of research at the Caspar Creek Experimental Watershed, Jackson Demonstration State Forest in northwestern California. The 16 papers include discussions of streamflow, sediment production and routing, stream channel condition, soil moisture and subsurface water, nutrient cycling, aquatic and riparian habitat, streamside buffers, cumulative effects, monitoring. A detailed annotated bibliography of 107 papers from Caspar Creek is included."

Available online at:
http://www.treesearch.fs.fed.us/pubs/viewpub.jsp?index=8703

Ziemer, R. R., J. Lewis, R. M. Rice, and T. E. Lisle. 1991. Modeling the cumulative watershed effects of forest management strategies. Journal of Environmental Quality 20:36-42.

There is increasing concern over the possibility of adverse cumulative watershed effects from intensive forest management. It is impractical to address many aspects of the problem experimentally because to do so would require studying large watersheds for 100 yr or more. One such aspect is the long-term effect of forest management strategies on erosion and sedimentation and the resultant damage to fish habitat. Is dispersing activities in time and space an effective way to minimize cumulative sedimentation

effects? To address this problem, Monte Carlo simulations were conducted on four hypothetical 10 000-ha fifth-order forested watersheds: one watershed was left undisturbed, one was completely clearcut and roaded in 10 yr, with cutting starting at the head of the watershed and progressing toward the mouth, another was cut at the rate of 1% each year beginning at the watershed's mouth and progressing upstream, and another was cut at a rate of 1% each year, with individual cut areas being widely dispersed throughout the watershed. These cutting patterns were repeated in succeeding centuries, rebuilding one-third of the road network every 100 yr. The parameters governing the simulations were based on recent data from coastal Oregon and northwestern California, Mass wasting, the most important source of sediment in that environment, was the only hillslope process modeled. The simulation results suggest that (i) the greatest differences between management strategies appeared in the first 100 yr and were related primarily to the rate of treatment. By the second 100 yr, when all watersheds had been treated, the principal difference between logging strategies was the timing of impacts. (ii) Dispersing harvest units did not significantly reduce cumulative effects. (iii) The frequency of bed elevation changes between 1 and 4 cm is dramatically increased by logging.

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