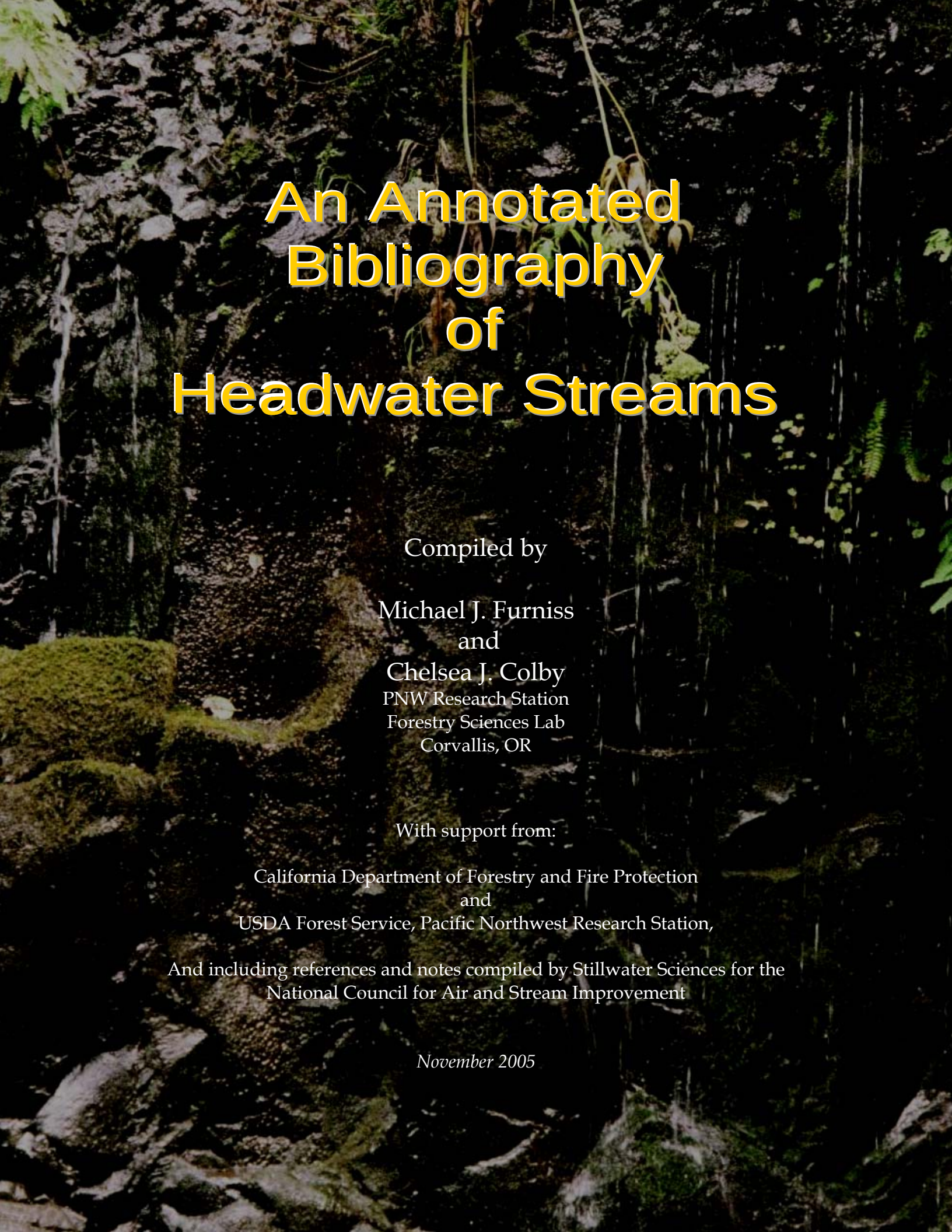

An Annotated Bibliography of Headwater Streams

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Invertebrates and Food Webs:

I. Aquatic macroinvertebrates

Ref ID: 95
Angradi, T.R. 1996. **Inter-habitat variation in benthic community structure, function and organic matter storage in a 3 Appalachian headwater streams.** Journal of the North American Benthological Society 15 (1):42-63.

Keywords : macroinvertebrates; benthic; community structure; organic matter; headwaters; riffles; pools; debris dams; K-dams; leaf pack; functional feeding groups; structure; function; streams; fish; habitat; stonefly; predators; debris

Inter-habitat variation in benthic community structure and function was investigated in 3 headwater streams in West Virginia, USA. Abundance and biomass of benthic macroinvertebrates and salamanders together with standing crop of benthic organic matter were estimated for riffles, rock faces, plunge pools, debris-dam pools, and leaf packs. In 1 stream, installation of log dams for fish habitat (K-dams) created artificial plunge pools and debris-dam pools. Standing crop of benthic organic matter was lowest in riffles and rock faces (=50 g ash-free dry mass/m^2) and was dominated by coarse (1-10 mm) and fine (0.25-1 mm) particles. Mass of benthic organic matter was highest in debris-dam pools (>2 kg ash-free dry mass/m^2), and was dominated by coarse particles and wood. Mean animal density (macroinvertebrates and salamander larvae) was highest in debris-dam pools and on rock faces (>10,000/m^2) and lowest in riffles and plunge pools (<5000/m^2). Standing biomass of animals was highest in pools (3-8 g dry mass/m^2) and lowest in riffles and on rock faces (<2 g dry mass/m^2). Chironomids and the stonefly *Leuctra* were the most abundant taxa in most habitat; co-dominant taxa differed among habitats. Ordination of macroinvertebrate taxa showed that community structure was more similar among habitats than among streams. Functional organization differed among habitats. In riffles, all functional groups were well represented. Scrapers, filterers, and gatherers predominated on rock faces. In pools, shredders and predators dominated biomass, although gatherers were the most abundant group. In plunge pools, crayfish (*Camgarus*) were relatively more abundant than in debris dam pools; the opposite was true for macroinvertebrate predators.

Overall, inter-habitat variation in taxonomic structure, animal abundance, biomass, functional organization, and benthic organic matter exceeded among-stream variation. Comparison with published data for a North Carolina headwater stream revealed common patterns of inter-habitat variation in functional organization. Installation of K-dams in a headwater stream influenced the abundance, biomass, and functional organization of the benthos by providing habitat for taxa able to exploit debris-dam pools formed upstream of K-dams, which retain abundant organic matter.

Ref ID: 96
Angradi, T.R. 1997. **Hydrologic context and macroinvertebrate community response to floods in an Appalachian headwater stream.** American Midland Naturalist 138 (1):371-386.

Keywords : macroinvertebrates; floods; headwaters; Appalachian; streams; watershed; organic matter; community structure; structure; debris; riffles; benthic; organic debris; habitat; flow; disturbance; leaf pack; debris dams

The response of aquatic macroinvertebrates to two floods was examined in a 2nd-order stream draining a 132 ha watershed on the Fernow Experimental Forest in West Virginia. Floods with recurrence intervals of 18 and 12yr occurred in February and May 1994.Benthic organic matter and macroinvertebrate abundance and community structure were affected by the floods Most of the common macroinvertebrate taxa decreased in abundance 70-95% immediately following the February flood. For most physical and biotic variables, recovery to preflood levels was complete before the May flood (42 days) based on preflood levels. Shifts in community structure following floods were small compared to seasonal variation. By August following the May flood, few differences could be detected from August of the previous year. Taxa associated with organic matter accumulations such as leaf packs and organic debris dams were affected less by the February flood than were most riffles taxa: one common leaf pack taxa, *Pteronrcys*, increased in abundance in riffles following the flood. I attribute the rapid recovery of the benthic community to abundant refugia, including organic debris dams, deep interstitial habitat, and 1st order tributaries. Analysis of the long-term flow record for the Fernow Experimental Forest suggests that a probability-based hydrologic criterion for a flow disturbance is inadequate for Appalachian headwater streams.

Ref ID: 100
Bencala, K.E. 1993. **A perspective on stream-catchment connections.** Journal of the North American Benthological Society 12 (1):44-47.

Keywords : stream-catchment connections; hyporheic zone; flow path; transient storage; solute transport; streams; Ecology

Ecological study of the hyporheic zone is leading to recognition of a need for additional hydrologic understanding. Some of this understanding can be obtained by viewing the hyporheic zone as a succession of isolated boxes adjacent to the stream. Further understanding, particularly relevant to catchment-scale ecology, may come from studies focused on the fluid mechanics of the flow-path connections between streams and their catchments.

Bottorff, R.L. and Knight, A.W. **Stonefly (*Plecoptera*) feeding modes: variation along a California river continuum.** Abell, Dana L. 235-241. 1989. Berkeley, CA, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station. General Technical Report PSW-110. 9-22-1988.

The distribution of Plecoptera along a California river was used to test several predictions of the River Continuim Concept about how functional feeding groups should change along a stream's length. Stoneflies were collected from stream orders 1-6 (123 km) of the Cosumnes River continuum in the central Sierra Nevada. The 69 stonefly

species collected were separated into three functional feeding groups-26 shredders (detritivores), 39 predators (engulfers), and 4 scraprers. Stonefly shredders and predators reached maximum species richness at middle stream orders (3-5). The relative abundance of shredders was highest in the headwaters then declined with increasing stream order. Predator relative abundance exhibited an inverse trend to shredders. Few scrapers were present, but these were most abundant at middle stream orders; they were almost entirely absent from the headwaters. These trends in diversity and relative abundance of functional feeding groups agree with predictions of the River Continuum Concept and emphasize the importance of riparian vegetation in the structure and function of Sierra Nevada streams. The type of terrestrial plant community through which the stream was flowing did not appear to affect the diversity or relative abundance of shredders.

Boulton, A.J. 1989. **Over-summering refuges of aquatic macroinvertebrates in two intermittent streams in central Victoria.** Transactions of the Royal Society of South Australia 113 (1-2):23-34.

Keywords : macroinvertebrates; refuge; habitat; Australia; insects; pools; behavioral strategies; streams; mayfly; beetles; Ontario

Eight potential refuges for macroinvertebrates were sampled in two intermittent streams in Central Victoria, Australia, during summer 1982-83 and summer 1983-84. Ninety-one aquatic taxa, mostly insects, were recorded. Receding pools harbored nearly three-quarters of these taxa; comparatively few were collected from the hyporheos or the water in crayfish burrows. Almost half the taxa were from refuges that did not hold free water. Macroinvertebrates persisted as desiccation-tolerant eggs (mayflies), larvae (Chironomids and some beetles) or adults (beetles).

There was remarkable similarity between the broad taxonomic representation in these refuges and those described for intermittent streams in Ontario, Canada.

Ref ID: 16
Boulton, A.J., Lake, P.S. 1992. **Benthic organic matter and detritivorous macroinvertebrates in two intermittent streams in south-eastern Australia.** Hydrobiologia 241 (2):107-118.

Keywords : macroinvertebrates; organic matter; detritivores; benthic; eucalypt litter; eucalypt; drought; flooding; predators; pools; riffles; habitat; feeding groups; litter; invertebrates; Australia; streams

Temporal changes in coarse (>1mm), fine (<1mm, > micrometer), and woody benthic organic matter (BOM), and densities of detritivores in pools and riffles were monitored at three sites on two intermittent streams (Werribee and Lerderderg Rivers) in Victoria, Australia during a drought year followed by a wetter year. Standing stocks of BOM peaked in both habitats during summer when discharge ceased and eucalypt leaf fall was greatest. During high winter and spring discharges, concentrations of BOM were low. Floods did not always scour BOM from the pools and riffles; after floods in October, standing stocks rose when BOM was imported from upstream or mobilized

from the riparian zone. Densities of benthic detritivores, collector-gatherers, and shredders also varied seasonally, usually peaking in summer. Correlations between detritivore feeding group densities and amounts of putative food resource were habitat-specific. There were few significant correlations in depositional habitats, even after incorporating lag-times of two and four weeks into the analysis. However, detritivore densities in riffles, especially in the Lerderderg River, were strongly positively correlated with the amounts of BOM. Possibly, physicochemical conditions in riffles are more conducive to litter conditioning and invertebrate colonization and breakdown of leaf material than are those in pools.

Ref ID: 28
Bowman, T.E., Beckett, D.C. 1978. **A redescription of the Troglobitic Isopod, Caecidotea stygia, from the environs of Cincinnati, Ohio (Crustacea: Isopoda: Asellidae).** Proceedings of the Biological Society of Washington 91 (1):294-302.

Keywords: Caecidotea stygia; Cincinnati, Ohio; isopods; invertebrates; Ohio; streams

In the second record from Ohio, *Caecidotea stygia* is reported from 3 intermittent streams near Cincinnati. The specimens collected were apparently flushed from groundwater following heavy rains. The Ohio specimens are described and illustrated in detail.

Ref ID: 2
Clifford, H.F. 1966. **The ecology of invertebrates in an intermittent stream.** Invest Indiana Lakes Streams 7

Keywords : fauna; invertebrates; Ecology; macroinvertebrates; streams; beetles; caddisfly; reproduction; growth; permanent stream; habitat; velocity

This study is concerned with the ecology and certain physiological mechanisms of macroinvertebrates in small streams of south-central Indiana that become completely dry at the surface each summer. The stream fauna is dominated by two aquatic peraearid crustaceans, *Lirceus fontinalis* and *Crangonyx forbesi*, which occur in substantial numbers throughout the year. They survive the dry season as small animals in subsurface seepage and water-saturated air spaces of moist soil. The other aquatic animals of the stream can be divided into two groups in respect to season: a late summer-autumn association, characteristic of the stream when it is dry or nearly so, and a late winter-spring association characteristic of the stream when it is flowing or nearly so. The active summer-autumn group consists mainly of adventitious species and of adult aquatic beetles, which are permanent members of the stream. The winter-spring invertebrates are mainly permanent residents, which appear each year and constitute a uniform and stable community. With the possible exception of certain caddisflies, these species are not specifically adapted to the intermittent environment but in a sense are preadapted to it by certain favorable features of their life cycles.

L. fontinalis and *C. forbesi* have an annual cycle in the intermittent stream. Both begin to breed in March and April, months that normally exhibit the maximum amount of water in the stream. In *L. fontinalis* reproduction is terminated in summer by the early

death of animals of the old generation that are still reproducing, and by an arrested growth of the new generation. Both phenomena are influenced by the onset of the dry period. In contrast, for *C. forbesi* reproduction is unvaryingly confined to the spring, with the females producing one brood and then dying prior to the drying up of the stream. Individuals of the new generations of both species grow very little during the dry summer and autumn months. Because of their small size they can survive in subsurface seepage and moist interstitial spaces. In late autumn and winter rapid growth resumes.

For *L. fontinalis* oxygen consumption declined in late spring and summer when measured at 5 degrees C but not when measured at 13 degrees C. If size is considered, however, the animals at 13 degrees C also would exhibit a lower metabolic rate in summer. When exposed to water-saturated air in the laboratory, both *L. fontinalis* and *C. forbesi* from the intermittent streams lived for a longer period of time than did related organisms from a permanent stream.

Physical features of the stream bed, especially during the dry season, are pointed out as being of prime importance in determining the permanency of an aquatic fauna in small summer-dry streams. The availability of interstitial spaces is of special importance in this respect. Besides offering a suitable habitat for aquatic animals during the dry season, they are of importance when the stream is flowing by reducing the velocity of the water, which might otherwise flush out much of the aquatic fauna. The maintenance of interstitial spaces depends on local geological and geographical features. The presence of non-angular bottom materials, the absence of a heavy silt load, and protection from daily freezing and thawing during the winter are important in this respect.

Closs, G.P. 1994. **Feeding of Galaxias olidus (Gunther) (Pisces : Galaxiidae) in an intermittent Australian stream.** Australian Journal of Marine Freshwater Research 45 (2):227-232.

Keywords : fish; invertebrates; predator-prey interactions; Galaxias olidus; Australia; flow; streams; impacts

Patterns of feeding in the mountain galaxiid *(Galaxias olidus)* were examined at dawn and dusk during low flow in April and high flow in September in an intermittent stream. During April (low flow), feeding rates were relatively low and aperiodic, whereas in September (high flow), the fish were clearly feeding diurnally at a relatively high rate. These results suggest that feeding in *G. olidus* in intermittent streams may vary on a daily and seasonal basis, possibly as a consequence of changes in light availability and stream flow. Light determines the ability of fish to find their prey, and seasonal changes in flow may determine the availability of prey (i.e. drifting invertebrates). This pattern suggests that the predatory impact of drift-feeding fish, such as *G. olidus*, is likely to be considerably less during low-flow periods when drifting invertebrates are not available than during high-flow periods when such prey may be abundant.

Cuffney, T.F., Wallace, J.B., Lugthart, J. 1990. **Experimental evidence quantifying the role of benthic invertebrates in organic matter dynamics of headwater streams.** Freshwater Biology 23 (1):281-299.

Keywords : benthic; invertebrates; organic matter; headwaters; litter; drought; community structure; Appalachian; streams; insects; fine particulate organic matter; particulate organic matter

Summary.
1. The insecticide methoxchlor was applied seasonally to one of three small headwater streams in the southern Appalachian Mountains in North Carolina, U.S.A. The initial application caused massive invertebrate drift (>1,000,000 organisms/ week) and resulted in a community with few shredders and reduced abundances of most insect taxa. 2. Bacterial densities and microbial respiration rates were not affected by treatment.
3. Disruption of the invertebrate community resulted in significant reductions in leaf litter processing rates (50-74% reduction depending on leaf species) and in the amount of leaf litter processed annually (reduction of 25-28%).
4. Reductions in leaf litter processing rates resulted in significant reductions in fine particulate organic matter (FPOM) export. Declines in both concentration and total export were detectable within 1 week if treatment. Annual FPOM export was reduced to 33% of pretreatment levels. Alteration to the invertebrate community had a much greater effect on FPOM export than a severe (50-200) drought.
5. Course particulate organic matter (CPOM) export was not significantly influenced by treatment but was influenced by hydrologic differences among years.

Ref ID: 76
Delucchi, C.M. 1989. **Movement patterns of invertebrates in temporary and permanent streams.** Oecologia 78 (1):199-207.

Keywords : invertebrates; permanent stream; upstream migration; refuge; substrate; riffles; colonization; streams; hyporheic zone; movement patterns

Although it has been shown that invertebrates recolonize reflooded temporary streams from permanent refuges, e.g., the hyporheic zone, it has not been shown that they actively move into these refuges as streams dry. Substrate filled cages and drift nets were used to monitor invertebrate movement in two temporary streams and in a permanent stream prior to and during drying to determine whether invertebrates leave drying riffles and enter flooded riffles. Invertebrate movement was essentially unidirectional in the permanent stream with downstream drift and with-in-substrate downstream movement dominating. In the temporary stream, movement vertically downward toward the hyporheic zone and upstream movement substantially contributed to a departure from a unidirectional pattern. In addition, prior to stream drying the relative colonization rate was higher and drift rate was lower in the temporary streams than in the permanent stream. During drying of the temporary stream, upstream movement continued to dominate but hyporheic movement was unimportant. Further, the upstream movement did not occur at the end of the riffle where it would lead to migration into non-drying riffles. Thus, even though movement

patterns were different in permanent and temporary streams the patterns observed during stream drying would result in the concentration and subsequent death of invertebrates in drying riffles. This observation demonstrates that movement patterns of stream invertebrates do not necessarily result in behavioral avoidance of a dry period of temporary riffles.

Ref ID: 15
Delucchi, C.M., Peckarsky, B.L. 1989. **Life history patterns of insects in an intermittent and a permanent stream.** Journal of North American Benthological Society 8 (4):308-321.

Keywords : insects; invertebrates; permanent stream; habitat; riffles; drought; adaptations; behavioral strategies; life history patterns; watershed; emergence; fauna

Samples were taken in an intermittent stream (dries only at some locations) and a permanent stream in a single watershed in Tompkins County, New York, over a 3-yr period to compare the life history patterns of specialist species (occurring primarily in intermittent streams), facultative species (occurring in both permanent habitats). We also tested the hypothesis that to avoid the dry period, populations of species grow and develop faster and emerge earlier in the intermittent than in the permanent stream. Specialist species emerged by mid-June, whereas permanent-stream species had late summer emergences. Although two of the three specialist species *(Amphinemura delosa* and *Ameletus ludens)* had drought-resistant eggs, the third *(Paracapnia opis)* had immediately hatching eggs. Nymphs of this last species survived the dry period either in the hyporheic zone or in riffles that did not dry. Only one of two facultative species and one specialist species showed greater size and/or advanced development in sites that dried compared with populations in permanent sites; however, these differences occurred only in early spring and had disappeared long before the stream dried. Thus, populations of the same species emerged at the same time from the intermittent and permanent streams. At any one time, individuals of specialist and permanent-stream species were usually larger and/or more developed in the stream or at sites where they were most abundant. Although each specialist species had life history patterns enabling it to survive drought, these patterns were not unique to the intermittent-stream fauna. In addition, species without those characteristics were also present in the stream, and species with populations in both permanent and intermittent streams did not show site-specific variation in life history patterns consistent with drought-avoidance in intermittent streams.

Ref ID: 17
Feminella, J.W. 1996. **Comparison of benthic macroinvertebrate assemblages in small streams along a gradient of flow permanence.** Journal of North American Benthological Society 15 (4):651-669.

Keywords : benthic; invertebrates; riffles; habitat; flow; insects; Alabama; permanence

Benthic invertebrates were quantified in 6 small upland streams in Alabama for 2 years to examine the degree to which variation in assemblage structure was related to the hydrologic permanence of riffle habitats. Streams differed along a gradient of flow permanence: 2 were normally intermittent (i.e., normally perennial), and 3 streams were occasionally intermittent (i.e., riffles ceased flowing during dry years). Despite large differences in flow permanence among streams, invertebrate's assemblages differed only slightly. Presence-absence data revealed that 75% of the species (171 total taxa, predominantly aquatic insects were ubiquitous across the 6 streams or displayed no pattern with respect to permanence; 7% of the total species were found exclusively in the normally intermittent streams. Although somewhat variable, many of the community richness and diversity measures were positively correlated with stream permanence. Year-to-year differences in assemblages within single streams appeared as great as differences between streams of contrasting permanence within a given year. Faunal similarity among streams was higher in 1995, a year with normal summer rainfall that followed a wet year (1994), than in 1994, a wet year that followed a dry year. Between-year differences in density and richness were lowest in the spring and winter and greatest in summer, the season when communities were directly exposed to drying of riffles in intermittent streams. Several populations of common invertebrates during summer displayed non-random distributions along the permanence gradient. These data in general support the hypothesis that 1) benthic invertebrate assemblages show predictable, albeit subtle, relationships with stream permanence, and 2) antecedent hydrologic conditions associated with riffle permanence, perhaps because of their effects on survival and recruitment of subsequent generations, can influence the structure of benthic assemblages in streams.

Ref ID: 68
Fernandez-Delgado, C., Herrera, M. 1995. **Age structure, growth and reproduction of Leuciscus pyrenaicus in an intermittent stream in the Guadalquivir River basin, southern Spain.** Journal of Fish Biology 46 (3):371-380.

Keywords : Cyprinidae; Leuciscus pyenaicus; age; growth; reproduction; fecundity; life history tatics; Spain; streams; spawning

The age, growth and reproduction of *Leuciscus pryenaicus* (Guether, 1868), an endemic cyprinid from the Iberian Peninsula, was studied from November 1987 to September 1989 in a small seasonal tributary of the Guadalquivir river basin. Maximum ages observed a 160 mm male with six scale annuli and a 171 mm female aged 7+. Maximum ages observed were 7+ in males and 8+ in females. There were no significant differences in the annual growth increments between sexes. Seasonal growth period started in March and continued for 5 to 6 months. Mean lengths of 1+ specimen onwards diminished during summer and/or autumn. Males and females matured in their third and fourth year of life respectively. The overall sex ratio (272 males : 310 females) differed significantly from equality. Spawning began in May and ended in July. *L. pyrenaicus* is a multiple spawner that releases a minimum of two batches of eggs per female each year. Eggs in each batch were similar in both size (egg diameter) and

number released. The relationship between fecundity (Fec) and fork length (mm) was represented by the formula: $Fec=1*96\ 10^{-3}L^{2*50}$.

Ref ID: 25
Fernandez-Delgado, C., Herrera, M. 1995. **Age structure, growth, and reproduction of Rutilus lemmingii in an intermittent stream of the Guadalquivir River basin, southern Spain.** Hydrobiologia 299 (3):207-213.

Keywords : age; growth; reproduction; Rutilus lemmingii; fecundity; life history tatics; Spain

The age, growth and reproduction of *Rutilus lemmingii* (Steindachner, 1866), an endemic cyprinid from the Iberian Peninsula was studied for over a period of two years in a small seasonal tributary of the Guadalquivir river basin. Approximately 65% of the total growth in length occurred in the first year of life. Males reached a maximum age of 3+ yr (Fork Length, F.L. = 114 mm). Both sexes matured during their second year of life (1+). The overall sex ratio (334 males to 389 females) differed significantly from unity. Somatic condition decreased markedly during the reproductive period of March to May. *R. lemmingii* is a multiple spawner and releases two batches of eggs per female each year. Mean egg diameter of the first batch was larger than the second one. The regression between fecundity and Fork Length (mm) was: Fec=0.014F.L.^2.858. Compared with available information, this *R. lemmingii* population, located at a lower latitude, is characterized by fast growth, early maturity, high level of reproductive effort, and a short life span. These life-history characteristics are typical of species in unstable environments, where adult mortality is high, variable or unpredictable.

Fore, L. S., J. R. Karr, and R. W. Wisseman. 1996. **Assessing invertebrate responses to human activities: evaluating alternative approaches.** Journal of the North American Benthological Society 15: 212-231.
From NCASI

Study Area

No new data were collected for this study. Macroinvertebrates had been collected from mid-order streams within the Umpqua and Rogue River drainages. Watershed area ranged from 15 km2 to 400 km2 with a median area of 54 km2.The study area was located within the Umpqua National Forest and in the Roseburg and Medford districts of the BLM in Oregon. Physically similar sites were chosen from each to form a subset for comparative purposes.

Methods

Invertebrates were collected using kick sampling and watersheds were given a land use index on a scale of 1 to 7. Seasonal effects were minimized by using data obtained in the fall of only one year. Metrics were selected from four categories: taxonomic richness and composition, tolerance and intolerance (of habitat extremes), feeding ecology, and population attributes. Candidate metrics were determined using graphical interpretations. The investigators selected metrics that varied along a gradient of human influence from the Umpqua data. Then, the successful metrics were tested

against data collected in subsequent years and from other areas to assess confidence. These were then combined to give a summary index using two methods: Benthic Index of Biological Integrity or BIBI
And Rapid Bioassessment Protocol or RBP III. A principal components analysis was conducted to test whether a statistical method would be able to adequately distinguish relatively pristine from relatively disturbed sites.

Impacts of Disturbance

High elevation sites were excluded from the analysis since it was unclear from the data whether increased taxa richness in these high elevation sites was due to the elevation or because of the infrequency of logging in these high elevation sites. In the remaining sites, taxa richness declined significantly as area logged increased. Eleven biological attributes successfully distinguished the most and least disturbed sites for two sampling years (see Table 3). Declines in total numbers of taxa, specifically decreases in Ephemeroptera, Plecoptera (*Pteronarcys* spp. particularly), and Trichoptera all responded to levels of human disturbance. For tolerance and intolerance metrics, sediment intolerant taxa decrease and percent tolerant increase with increasing human disturbance. Trophic classifications failed to distinguish between least and most disturbed sites.

To compare B-IBI with RBP III, the authors tested the hypothesis that Umpqua sites would have higher scores, reflecting higher biotic integrity, than Roseburg sites. Although the range of scores for the two sites were similar, Roseburg is on BLM and private lands, and sites there have experienced greater amounts of human disturbance (logging, urbanization, agriculture, etc.) than the Umpqua National Forest sites. RBP III failed to detect differences among sites that B-IBI did detect. Although sites identified as most disturbed or high elevation were distinguished by PCA, least disturbed sites and moderately disturbed sites were not distinct. Zeros in the data matrix most likely had a great impact on these results. The authors felt more confident using raw data to group species, rather than using statistical p-values.

Conclusions

The authors conclude that multivariate approaches are useful when little is known about the system and the goal of the study is to generate testable hypotheses. However, in terms of biological monitoring of invertebrates and the effects of human disturbance on rivers, the authors suggest that sufficient data have been collected. Thus, a method that incorporates known natural history and known ecology of an organism is a more powerful tool (metric analysis) than a method that relies on statistical algorithms (multivariate analysis).

Ref ID: 69
Grant, P.M., Stewart, K.W. 1980. **The life history of Isonychia sicca (Ephemeroptera:Oligoneuriidae) in an intermittent stream in north central Texas.** Entomological Society of America 73 (6):747-755.

Keywords : streams; Texas; co; emergence; fecundity; temperature; permanent stream

The life history of *Isonychia sicca* (Walsh) was determined from samples collected in intermittent Clear Creek, Oct. 1976-June 1978, Denton Co., TX. Fall hatching nymphs

formed a small over wintering brood, grew slowly through the winter and emerged in late Apr. A spring brood hatched in Mar. and emerged late May-early June. Adults from over wintering and spring broods supplied eggs which formed a 2nd generation that emerged late June-early July. Emergence began ca. 20 min after sunset and continued for ca 2h. The emergence period was continuous, Apr.-July 1977, with both broods and generations overlapping considerably. Average subimaginal fecundity decreased through the emergence period from 444o to 621 eggs/female, and was positively correlated with abdominal volume. A decrease in body size was noticeable for nymphs, subimagos and imagos. The sex ratio differed for each stage: 1 male : 1.6 females, nymphs; 1.4 males : 1 female, subimagos; and 1 male : 3.4 females, imagos. Nymphs filter particulate matter from water using long foreleg hairs as a seine. *Isonychia sicca* appears to diapause differentially through the fall with those breaking early producing the over wintering brood. Eggs breaking diapause in late fall and winter experience cool water temperatures which probably induce quiescence. Hatching begins again in spring. In a permanent stream, eggs continue to hatch through summer and fall until cool winter temperatures probably induce quiescence and resume hatching in spring.

Ref ID: 70
Harrel, R.C. 1966. **Stream order and community structure of benthic macroinvertebrates and fishes in an intermittent stream.** PhD Thesis. Oklahoma State University.

Keywords : benthic; macroinvertebrates; stream order; fish; community structure; drainage basin; streams; turbidity; temperature; flow; invertebrates; pools; drought; structure; Oklahoma; species diversity

The morphometry of the drainage basin, physico-chemical conditions and community structure of benthic macroinvertebrates and fishes were quantitatively related to stream order in a sixth order intermittent stream system located in North central Oklahoma. Numbers of species and individuals, species diversity indices derived from information theory and indices of heterogeneity were used in determining community structure.

Average drainage area and average lengths of streams of each order increased, and stream numbers and average gradient decreased exponentially as stream order increased. Physico-chemical fluctuations, turbidity and water temperature decreased, while flow, alkalinity and conductivity increased as stream order increased.

One hundred and twenty-one species of benthic invertebrates were collected. Numbers of species increased from 75 in third order pools to 86 in fifth order stream, as a result of reduction of micro-habitats caused by heavy siltation. Larger numbers of individuals occurred in fourth order streams throughout the year. Smaller numbers occurred in the sixth order stream during fall, winter and spring, and in third order streams during summer.

Annually, species diversity (H) increased in third, fourth and fifth order streams, and decreased in the sixth order streams. Diversity per individual (mean H) increased and redundancy (R) decreased as stream order increased. Species diversity was significantly different between and within stream orders at the 75% confidence level, diversity per individual at the 95% level and redundancy at the 90% level. During fall,

winter and spring, diversity per individual increased and redundancy decreased as stream order increased. These values were similar in all stream orders during summer. Diversity per individual was significantly different between and within stream orders at the 95% level during fall, and 90% level during winter and spring. Significance of redundancy increased from the 25% level during summer to 90% level during spring. Ranges of species diversity, diversity pre individual and redundancy decreased as stream order increased, indicating more uniform community structure in higher stream orders. Mean annual indices of heterogeneity (IH) between stations of the same order decreased as stream order increased, indicating that similarity of community structure increased progressively with stream order. A station located in a third order adventitious stream, which flowed directly into the sixth order stream and not through the hierarchy of tributaries, had a community structure more similar to higher order streams than to other third order streams. Drought and influx of oil field brines upset the stream order-community structure relationship.

Fishes were collected after eight months of continuous stream flow and again after a severe drought. Species diversity (d) values for both collections were remarkably similar. Species diversity of fishes increased as stream order increased.

Hawkins, C. P., and J. R. Sedell. 1981**. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams.** Ecology 62: 387-397.

From NCASI

Study Area

This study involved four streams in the western Cascades of Oregon, ranging from 1st to 7th order. The smallest stream, Devils club Creek, is 1st order, watershed area 0.2 km2, 40% gradient, 2.6 m bankfull width, mean Q = 0.01 m3/s (estimated), and 800 m elevation. Mack Creek is 3rd order, watershed area 6 km2, 13% gradient, 12.5 m bankfull width, mean Q = 0.3 (estimated), and 785 m elevation. The sampling site on Devils club Creek contained "massive and stable accumulations of woody debris."

Sampling/Treatment

Benthic material was vacuumed from ten 0.11 m2 quadrats of streambed at each site, except in Devils club Creek, where only 3 or 4 samples were collected. Samples were analyzed for CPOM (> 1 mm), FPOM (0.05 mm-1 mm), VFPOM (0.45µm-0.05 mm), primary production, and aquatic macroinvertebrates. Chironomids were excluded from the analysis.

Distribution of Taxa

In general, results agreed with the predictions of the River Continuum Concept (Vannote et al. 1980). Shredders dominated low-order sites and decreased in importance downstream, while collectors showed the inverse trend. Scraper importance gradually increased in a downstream direction, reaching maximum dominance in the 5th order stream, then decreased downstream. The relative importance of predators remained relatively constant between sites, except in spring, when they peaked in the 3rd order stream and were least important in the 5th order stream Seasonally, shredders were

always most important in the 1st order stream, followed by predators. In the 3rd order stream, shredder importance increased from spring to fall, during which time the relative abundance of collector and predator components decreased. Overall abundance of macroinvertebrates was lower in the 1st order stream than in the 3rd order stream, and was hypothesized to be due to the "large accumulations of silt that are retained by many large rotting logs" in the 1st order stream. Shredder density was significantly correlated with density of leaf material and small woody debris (collectively, CPOM). The results imply that "either qualitative differences in CPOM are not as important as previously thought or that high-quality CPOM is simply associated with other CPOM fractions." For collectors, food quality (proportion of chlorophyll a) appears more important than food quantity, and in fact the two may be inversely related. The authors state that "in western Cascade stream systems, diatoms and other algal derived food sources seem important in determining collector abundance." Food for scrapers that is efficiently harvested or digested easily (i.e., unicellular diatoms) "may be nearly as great or more predictable in moderately to heavily shaded streams" (lower order) than in open streams with greater production of total algal standing crop. Wood gougers accounted for 8-25% of total numbers in the 1st order stream (where woody debris was very abundant), but along with generalists, were limited in abundance and distribution elsewhere. The only generalist encountered was *Juga plicifera*, which was restricted to the 5th and 7th order streams where it was abundant only in the spring and summer. The authors speculate that this snail may be excluded by low temperatures or high gradient from many smaller Cascade range streams with large leaf inputs.

Hawkins, C. P., M. L. Murphy, and N. H. Anderson. 1982. **Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon.** Ecology 63: 1840-1856.
From NCASI

Study Area

Six streams in the western Cascades of Oregon were sampled. Two streams (Mack and Fawn Creeks) were clear-cut and had a riparian age of 8 years. NF Wycot and Couger Creek had mostly a deciduous second-growth riparian zone. Mack and Mill Creeks were surrounded by old-growth forests. Canopy was open in the two clear-cut streams and mostly shaded (mean 75%) in the other four. Stream order was unclear and not all study sites were necessarily headwater.

Methods

Three stream sections in high gradient reaches composed of boulders and cobbles and three stream sections in low gradient reaches composed of cobble, gravel, and some sand were sampled for invertebrates, detritus, and water chemistry variables that were hypothesized to vary with canopy and substrate composition. Samples were taken from both pools (3) and riffles (3) at each site over the course of three seasons, for a total of 108 benthic Surber samples. In addition, organic matter and chlorophyll standing crop on cobble was determined, and chlorophyll levels and respiration rates of interstitial organic matter were estimated. Leaf material was collected from the stream bottom to determine standing crop of detritus, and six benthic cores from each site were used to quantify substrate composition and organic storage.

Distribution of Taxa

In riffle habitats, canopy had a greater effect on distribution of taxa than gradient. Open canopy sites had higher biomass of several guilds than closed canopied sites. Only generalist species (mostly the snail *Juga plicifera*) were more abundant in shaded sites. Gradient had little impact on invertebrate abundance. For pool dwellers, both canopy and gradient had little impact on distribution. Substrate character seemed to be less important than both canopy and gradient in determining the distribution of both riffle and pool invertebrates.

Food Quality

Food quality is strongly linked to algal production in streams. Increased primary production led to increased concentrations of algae, detritus, and periphyton. The abundance of herbivores was linked closely to algal production, and was greatest in open canopied streams. Pool inhabitants were more closely linked with quantity of detritus than their riffle counterparts.

Abundance of Taxa

Generally, herbivores had greater numbers in open canopy areas than closed. Scrapers had more taxa in high gradient streams than low gradient. Although the authors expected scraper densities to be greatest in the closed canopied streams, they found that density decreased with increased periphyton. However, the mean individual biomass increased with increased levels of periphyton. The increase in biomass reflected a taxon shift rather than an increase in biomass of a single taxon. Water velocity and sheer ability to manipulate the algae (thicker, tougher layers in open areas) also may explain why larger species were able to inhabit more open reaches. Moreover, many invertebrates classified as shredders may actually be facultative in their food requirements. Shredding and piercing herbivores increased in both density and biomass with increased algal production. Predators increased in open reaches indirectly because of the greater potential prey items in these reaches.

Functional Feeding Groups

Separating invertebrates into feeding guilds may not necessarily reflect the ecology of these organisms and groups are probably not as distinct as once believed.

Impacts of Disturbance

"By manipulating stream systems we may create conditions favorable to organisms with broad tolerances rather than for different sets of specialists."

Hess, Lloyd J. 1969. **The effects of logging road construction on insect drop into a small coastal stream.** Arcata, CA: Humboldt State College; 58 p. M.S. thesis.

Because stream fisheries are so closely associated with forested watersheds, it is necessary that the streams and forests be managed jointly under a system of multiple use. This requires a knowledge of the interrelationships between these resources to yield maximum returns from both. It is the purpose of this paper to relate logging practices to fish management by ascertaining the effect of logging road construction on the drop of insects into a stream. On the South Fork of Caspar Creek the insects falling

into the stream were greatly increased after a logging road was built. A twofold increase in number and weight of insects occurred over the entire stream. In "Disturbed" areas, where the road paralleled the stream, drop insects increased three and one half times by number and one and one half times by weight over the "Insect-Control" area. In the "Highly Disturbed" areas, where the road crossed the stream, insect numbers increased by five and one half times and a threefold increase by weight over the "Insect-Control" area was noted. A more than proportionate amount of the increase occurred in those adult insects having aquatic immature stages. One such family, *Chironomidae,* had a greater occurrence after road construction than all insects combined before construction. This family showed the most significant change of the families studied.

Ref ID: 38
Malicky, H. 1981. **The phenology of dispersal of several caddisfly (Trichoptera) species in the Island of Crete.** pp.157-163**.** in Moretti, G.P. (ed.). Proceeding of the 3rd International Symposium on Trichoptera: Series Entomologica. Dr. W. Junk Publishers. The Hague. July 28 - Aug 02, 1980.

Keywords : caddisfly; Trichoptera; phenology; aestivation; adaptations; behavioral strategies

Light trap catches show regional and specific differences in the phenology of several species of *Stenophylacini* which are adapted to intermittent streams. The lack of a dispersal flight in springtime in Crete is striking; it explains the absence of the adults in caves in summer. A correlation between the specific vagility and the size of the distribution area is found in several species.

Ref ID: 147
Maslin, P.E., Ekisola, D., Nelson, K., McKinney, W.R., Moore, T. 1998. **Cyprinoid Usage of Intermittent Streams in the Sacramento River Basin.** [Unpublished report] http://www.ecst.csuchico.edu/~loggins/cyprin.html.

Keywords : Cyprinoid; streams; spawning; minnows; function; floods

We examined the intermittent section of four tributaries to the Sacramento river for the presence of cyprinoids. Intermittent streams serve as feeding and spawning grounds for many migratory minnows. Since these stream reaches serve important ecological functions, we can no longer regard them as flood control channels.

Maude, S. H., and J. Di Maio. 1999**. Benthic macroinvertebrate communities and water quality of headwater streams of the Oak Ridges Moraine, Southern Ontario.** Canadian Field-Naturalist 113(4): 585-597.
From NCASI

Study Area
This study was conducted in the Oak Ridges Moraine, a unique physiographic feature that extends into the Greater Toronto Area for the length of approximately 90 miles. Although the area is largely rural and undisturbed, increased human populations

may eventually expand into these areas. Twenty-eight sites were selected within the Moraine areas which overlapped with Greater Toronto Area that were 1st and 2nd order streams draining undisturbed lands. The streams were generally small, cold, well-oxygenated, and spring-fed.

Sampling/Methods

Chemical and benthic samples were collected once from every site. Some physiographic variables were measured from 1:50,000 topographic maps (geographic coordinates, elevation, distance from stream source to sampling point, gradient), while some were measured in the field (discharge, temperature, dissolved oxygen). Two benthic samples were collected using kicknetting into D-frame nets at each of the 28 sites. Mean benthic composition at the various sites was used to create a preliminary community model to be used as a biological reference tool when assessing ecological impacts to areas that may potentially be urbanized.

Population Indices/Metrics

Total taxon richness (total distinct taxa collected) was between 11–30, with 93 taxa collected overall. Total taxon richness was correlated with water temperature and nitrogen, and negatively correlated with dissolved inorganic carbon. Correlation with water temperature may be an artifact of seasonal variability. EPT taxon richness was between 4–14 and was directly correlated with pH and filtered reactive phosphate, and negatively correlated with dissolved organic carbon and ammonia. Non-insect taxa made up 8 percent of the samples, while major insect orders made up 92% of the benthic samples collected. Dipterans were most abundant.

Macroinvertebrate Pollution Tolerance

Hilsenhoff's Biotic Index which measures the degree of organic or nutrient pollution rated the sites between 1.33– 5.26, which corresponds with excellent to good water quality conditions. Of some macroinvertebrate groups, Plecoptera were described to be least tolerant of polluted conditions, while Coleoptera and Trichoptera were described to be somewhat tolerant, and Diptera to be rather tolerant. The abundance of these orders as well as the abundance of individuals present directly relates to the Hilsenhoff Biotic Index.

Model Application

Mean percent affinity of reference sites to the model Oak Ridges Moraine community was 67 percent for the sites sampled, with a range of 32–80 percent and a coefficient of variation of 15 percent. The authors caution a conservative application of percent affinity results. Although the assumption would be that a decrease in mean percent affinity would suggest impaired conditions at the site, similar results are obtained with macroinvertebrate community shifts from tolerant to intolerant species and/or overall low species diversity. Thus, it is crucial to understand the causes for deviation from the model before conclusions can be drawn. The effectiveness and usefulness of the model because of these shortcomings is hard to deduce. The authors suggest sampling along a gradient of disturbance as well as increasing taxonomic resolution to refine the reference model.

Mitsch, W.J., Urbikas, D.A. 1980. **Ecological comparison of intermittent streams in different land use patterns in northeastern Illinois.** pp.1-154**. in** Document No. 80/17. Illinois Institute of Natural Resources. Chicago, Illinois.

Keywords : Ecology; invertebrates; fish; models; turbidity; Illinois; flow; benthic; dissolved oxygen; stream depth; land use practices; management; watershed; monitoring

Five intermittent streams of different watershed character were studied in northeastern Illinois to determine the major considerations and measurements that must be dealt with in their management. The watersheds involved industrial, urban, agricultural, suburban, and natural land use patterns. The five-month study involved various physio-chemical and biological sampling. Benthic invertebrate measures were emphasized and statistical analyses were performed on these data to compare watersheds, sampling stations and riffles and pools. Relationships between the benthic invertebrate community and time, streamflow, velocity, stream depth, dissolved oxygen, temperature and turbidity were investigated. Preliminary stream energy models were developed from the data. Conclusions are given on the characteristics of intermittent streams, and recommendations are given for future monitoring and management of these streams.

Plotnikoff, R. W. 1996**. Aquatic invertebrates in Type 4 & 5 streams.** Pages 56-83 in Type 4 & 5 waters workshop. Timber/Fish/Wildlife Report TFW-WQ20-96-001. Washington Forest Protection Association, Olympia.
From NCASI

This "paper" consists of a brief abstract and copies of presentation slides. The physical and biological processes in headwater streams are evaluated and the potential implications of disturbance are addressed. The potential for "summer and winter communities" in headwater streams, in response to highly variable seasonal conditions, is addressed, as well as the potential for "temporal replacement of community functions" that could affect the stability of energy transfer during each season. Among the "critical" questions posed are: "Can islands of biological diversity exist in Type 4&5 streams?"; "What is the downstream influence of disturbance in Type 4&5 streams?"; "What are the implications of interruption of food chain processes in these streams?"
Impacts of Sedimentation
Responses to sediment impacts include reduction of living space and increased macroinvertebrate drift. Reduction in canopy cover can result in less allochthonous food and thus the potential for exploitation of a new food source.
Effects of altered hydrology include changes in the timing of flow increases/decreases, differing severity of physical changes during flow increases, and changes in nutrient cycling dynamics. Responses by aquatic invertebrates to degradation of headwater streams can result in: (1) life cycle adjustment, (2) increased susceptibility to high stress conditions, and (3) nutrient processing inefficiency. Response of functional groups to degradation can include: (1)

reduction of shredders, (2) increase in scrapers and filterers, (3) increase in dominant or several most dominant taxa, and (4) decrease in intolerant (EPT) taxa. Overall effects of disturbance on Type 4&5 streams include inefficient transfer of energy, the lack of a functional replacement for lost primary consumer food sources, and an overall loss of production that can translate into a loss of food for local and downstream secondary consumers (e.g., fish). Instability of these small streams results in a "punctuated transfer of energy", whereas stability maintains a uniform transfer of energy. Smaller streams are more easily disrupted, both physically and biologically, and disruption results in an oscillating energy transfer pattern that may limit downstream production. Reductions in flow can limit invertebrate habitat to the hyporheos, and may subject benthos to larger cyclical extremes. Increased sedimentation can reduce organics as a useable food source and continuous sedimentation may eliminate usable organic material altogether.

Rader, R. B., and T. A. Belish. 1999**. Influence of mild to severe flow alterations on invertebrates in three mountain streams.** Regulated Rivers: Research & Management 15: 353-363.
From NCASI

Study Area

Sampling was conducted on St. Louis Creek (3rd order) and two of its tributaries, West St. Louis and East St. Louis creeks (both 2nd order). The St. Louis Creek catchment drains 85.2 km2 and is typical of catchments in the Colorado
Rocky Mountains. Both tributaries are high gradient, narrow, confined, step-pool channels, while the main channel of St. Louis Creek is a riffle-pool channel with a substrate composed of gravel and cobbles. All three creeks were subject to periods of frequent (April–October) and infrequent (November–March) flow fluctuations as a result of water diversion management practices during the study period. St. Louis Creek was never completely diverted, i.e., some component of the natural flow remained in the channel throughout the year. Conversely, both East St. Louis and West St. Louis creeks were almost completely dewatered, and essentially all of their respective flows were diverted.

Methods

Benthic macroinvertebrates were sampled once a month at three riffles upstream and three riffles downstream along each of the three creeks using a Surber sampler. Discharge, temperature, dissolved oxygen, pH and conductivity
was also measured.

Abundance of Taxa

In West St. Louis Creek, mean invertebrate density was 50 percent reduced in downstream riffles during infrequent flow fluctuations (nearly all of the water was being diverted). All taxonomic groups decreased downstream except for Diptera. Ephermeroptera decreased by 91 percent, and would have been even lower if not for *Ameletus* spp. which increased by 41 percent in the downstream sites. Similarly, total invertebrate density downstream would have been much lower if not for an increase in Chironomids in the downstream sites. In St. Louis Creek, mean invertebrate density was 57 percent greater downstream than in upstream furing infrequent flow fluctuations (60 percent of water was diverted). All taxonomic groups increased downstream, particularly Ephemeroptera and Plecoptera. During the period of frequent flow

fluctuations, invertebrate densities were relatively similar in both upstream and downstream reaches of all three streams.

Taxa Richness

Taxa richness was not significantly different upstream and downstream from each diversion during both infrequent and frequent flow fluctuations in all of the streams, except in West St. Louis Creek during infrequent flow fluctuations. A significant difference between the upstream and downstream average coefficient of variation was also measured for West St. Louis Creek. The authors conclude that Ephemeroptera appear to be the best indicators of the effect of diversion on stream ecology.

Impacts of Diversion

The authors conclude that there was no indication of decreased invertebrate abundance as a result of diversion in the mainstem St. Louis Creek. In fact, downstream invertebrate densities were 57 percent greater downstream than upstream reaches during infrequent flow fluctuations. Reduced wetted perimeter downstream concentrating individuals and reduced spring scouring flows disengaging individuals were dismissed as potential explanations for this result. The authors hypothesize that elevated temperatures downstream may result in increased food availability and fecundity, which may explain the greater densities downstream. In the smaller order creeks, diversion during infrequent flow fluctuations resulted in decreased invertebrate abundance in downstream reaches. Those species tolerant of low-flow conditions (namely Chironomids, Ostracods and *Ameletus* spp.) comprised 80% of the invertebrates at the downstream site on West St. Louis Creek. This decrease in invertebrate abundance could potentially affect prey resources of higher trophic levels. The authors emphasize, however, that during frequent flow fluctuations (summer), invertebrate abundance is similar both upstream and downstream in all three creeks. Although mean abundance is similar both upstream and downstream, the authors also found that the variance of mean invertebrate densities is significantly or nearly significantly greater downstream in both tributary creeks. This result indicates that the spatial distribution and temporal occurrence of invertebrates varied more among downstream than upstream communities, in addition to their already reduced numbers during infrequent flow fluctuations (maximum diversion). Depending on the frequency of free-flowing conditions and the propensity of species to reestablish in downstream reaches, the authors suggest decreased populations and/or temporary extirpations remain possible in downstream reaches of these tributaries.

Richardson, W.B. 1990. **A comparison of detritus processing between permanent and intermittent headwater streams.** Journal of Freshwater Ecology 5 (3):341-357.

Keywords : debris; permanent stream; perennial stream; decomposition; invertebrates; detritivores; litter; fauna; feeding groups; headwaters; streams

The pattern of leaf pack decomposition and density and biomass of the associated invertebrate detritivore community of an intermittent and perennially flowing headwater stream were compared in autumn and spring. Leaf packs of high *(Alnus rugosa)* and low *(Fraxinus americana)* nitrogen content were used.

Leaf litter was processed at similar rates in both streams during autumn (-k: 0.015g*d^{-1}). In spring the decomposition rates more than doubled in the permanent stream (-k>0.03) and only slightly increased in the intermittent stream (e.g. *Fraxinus*: -k: 0.017). Differences in decomposition rates between leaf species were seen only in the fall in the intermittent stream where *Fraxinus* litter decomposed slower than *Alnus*. Shredder biomass was greater than other invertebrate guilds in both streams, was reduced in the intermittent stream, and varied with season (spring > fall), particularly in the permanent stream. Shredder biomass was greater in *Alnus* leaf packs. Shredder densities were significantly lower in the intermittent stream, during both seasons, compared with the permanent stream. Greater densities of shredders occurred on *Alnus* leaf packs. Collectors outnumbered other guilds.

The intermittent stream had a depauparate shredder fauna and was numerically dominated by collectors. Lack of shredding detritivores, combined with decreased duration of submersion, resulted in reduced potential for processing of particulate carbon relative to the permanently flowing streams.

Ref ID: 85
Smith, R.E.W., Pearson, R.G. 1985. **Survival of Sclerocyphon bicolor Carter (Coleoptera: Psephenidae) in an intermittent stream in north Queensland.** Journal Aust ent Soc 24 (1):101-102.

Keywords : water penny; Sclerocyphon bicolor; Coleoptera; Psephenidae; habitat; Queensland; streams; flow; substrate

Larvae of a water penny, *Sclerocyphon bicolor,* of a range of instars were abundant in an intermittent stream in north Queensland 2 to 3 h after the commencement of stream flow. In the laboratory these larvae could survive out of water for up to 4 months, and withstand the loss of up to 79.2% of their initial body water. Field collections found larvae in substrate which had been dry for up to 6 months. The ability of these larvae to survive out of water is attributable to (i) quiescence when out of water; (ii) considerable tolerance to water loss; and (iii) seeking of cooler, more humid regions within the substrate.

Ref 64
Snellen, R.K., Stewart, K.W. 1979. **The life cycle of Perlesta placida (Plecoptera : Perlidae) in an intermittent stream in northern Texas.** Annals Entomological Society of America 72 (5):659-666.

Keywords : life cycles; Plecoptera; stonefly; growth; emergence; macroinvertebrates; Texas; streams; temperature; fecundity; stream temperature

Perlesta placida (Hagan) emerged when mean daily stream temperatures approached 20 degrees Celsius. Adults came to lights May-July, with maximum attraction at 0.5-1.0 h after sunset. Mean head capsule width decreased seasonally from 1.4 to 1.3 mm in males and 1.8 to 1.6 mm in females. Laboratory life span was ca. 8 days. Fecundity ranged 130-453 eggs/female with mean = 276$\pm$96 eggs. Eggs were smooth, brown, measured 0.44 X 0.28 mm and underwent a differential 5-6 mo or one yr and 5-6

mo diapause. Diapause was broken when mean daily stream temperatures decreased to ca. 18 degrees Celsius in Oct.-Nov. Eyespots appeared in Sept., ca. 4 wks before hatching. First instars were unpigmented, had 4 cercal and 9 antennal segments and their mean interocular distance was 0.16 mm. The life cycle was a fast type with greatest growth beginning in Mar., after emergence of *Hydroperla crosbyi* (Needham and Claassen). Female larvae were consistently larger than males. Size frequency distribution indicated ca. 12-16 instars. The 1st few instars fed primarily on detritus, whereas older carnivorous larvae preferred Chironomidae larvae; other food items included Simuliidae, *Choroterpes mexicanus* Allen and *Hydropsyche simulans* Ross.

Ref ID: 44
Sprules, W.M. 1947. **An ecological investigation of stream insects in Algonquin Park, Ontario.** University of Toronto Studies Biological Series 56 :1-81.

Keywords : insects; fauna; habitat; adaptations; Ontario; emergence; flow; riffles; pools; temperature

The effects of several ecological factors on the qualitative and quantitative distribution of stream insects in Algonquin Park, Ontario, was determined from data obtained by use of the cage-trap method of sampling the emergence of insects from unit areas in streams, at regular daily intervals.

Incidents that induced significant alterations in the physical nature of the streams were accompanied by marked reductions in the total insect population and a change in the faunal composition of the affected areas. Such incidents included a severe freshet, cessation of flow and subsequent desiccation of the stream bed, and transformation of a shallow rocky riffle into a deep sedimented pool by construction of a beaver dam.

A correlation was found between the total number of species in rocky riffle areas at different distances from the source, and the average water temperatures. The linear distribution of species was delimited by the water temperatures obtaining in different sections of the stream and this was correlated with the thermal tolerance of the immature stages.

Within the limits set by temperature the distribution of species was affected by other factors including rate of flow and nature of the bottom, two factors which are closely interrelated and fundamentally inseparable. The diversity of the fauna decreased from rubble, through gravel, and muck, to sand as the variety of utilizable microhabitats decreased. The observed distribution on different types of bottom was related to habitat preference and associated morphological adaptations in the species.

The seasonal emergence periods of different species were segregated and the species emerged in the same sequence each year. The date of first emergence and the length of the emergence period of a species differed from year to year and were determined by annual variations in water temperature.

The diurnal emergence of species showed a similar segregation in general, in that any one species emerged at the same time each day while different species emerged at different times. The maximum total emergence from a rapids during mid-summer occurred throughout the evening hours and the most important causal factor involved seemed to be a reduction in light intensity.

It has been suggested that the number of individuals present in any area depends primarily on the utilizable surface area of bottom particles exposed to the water.

Ref ID: 57
Stanley, E.H., Buschman, D.L., Boulton, A.J., Grimm, N.B., Fisher, S.G. 1994. **Invertebrate resistance and resilience to intermittency in a desert stream.** American Midland Naturalist 131 (2):288-300.

Keywords : invertebrates; adaptations; desert; colonization; beetles; snail; Pysella virgata; macroinvertebrates; flooding; Sonaran Desert; co; streams; water quality; flow; sediment; pools

Invertebrate responses to water loss were investigated during drying, dry and rewetting phases in Sycamore Creek, an intermittent Sonoran Desert stream. Some taxa were resistant to drying because they could tolerate rapidly changing water quality and/or move upstream to avoid stranding. Community shifts occurred at one site when it became isolated from up- and downstream reaches; taxa such as beetles, hemipterans, and the snail *Physella virgata* became dominant. No community changes were detected at a second site which remained connected with upstream reaches by surface flow. Mortality after water loss was severe as few individuals survived longer than 10 days. Low resistance during the dry phase was associated with raped moisture loss from sediments. Invertebrate persistence in intermittent reaches was due to recolonization after rewetting; however, density increases after floods which reestablished flow at dry sites were lower than reported values for perennial sites in Sycamore Creek. Slower rates of recovery may reflect the composition, reduced size and remoteness of macroinvertebrate colonist pools. Nonetheless, invertebrate persistence in desert streams where both flooding and drying are frequent is due largely to their ability to rapidly recolonize disturbed sites.

Stone, M. K., and J. B. Wallace. 1998. **Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic invertebrate community structure.** Freshwater Biology 39: 151-169.
From NCASI

Study Area and Treatment

This study, conducted over a period of 16 years after clearcutting, took place in two hardwood catchments in North Carolina drained by 2nd order streams. The drainage area for the reference and disturbed streams was similar (61.1 ha and 59.5 ha, respectively), as was the mean annual discharge (19 l/s and 17.7 l/s, respectively). Data were collected on macroinvertebrates, organic matter, and physical parameters 1, 5, and 16 years after clearcutting

Impacts of Timber Harvest

An increase in primary production immediately following clearcutting (to 30 times greater than in the reference stream) was accompanied by a large increase in scraper abundance and a sharp drop in shredder abundance. Allocthonous inputs increased with canopy growth over the course of this study. Consequently, scraper abundance concurrently declined and shredder abundance increased. The proportion of leaf detritus making up total standing crop increased from 9% 5 years after clearcutting

to 16% 16 years after clearcutting, and at the latter sampling period did not differ significantly from that in the reference stream.

Impacts of Disturbance

As forest succession occurs, the quality of food available to invertebrates may decrease. The authors note that leaf litter inputs to the clearcut stream consisted of a greater proportion of early successional and herbaceous litter compared to the reference. Because leaves from early successional species are conditioned and decompose more quickly than those from mature forests (Webster and Benfield 1986, Boring et al. 1988), "early successional leaves may represent a better food resource for shredders (Stout et al. 1993) and demonstrate that forest succession may affect the quality, as well as the quantity, of food resources for stream macroinvertebrates." Shredder biomass and production in the clearcut stream were 3.8 times higher than in the reference, potentially indicating that leaf litter inputs in the clearcut stream were higher quality and/or quantity. Biomass and production of all other functional groups, with the exception of filterers, were also greater in the disturbed stream 16 years after clearcutting, but not all differences were significant. The authors postulate that decreased inputs of woody debris large enough to form stable dams accompany forest succession and result in a reduction in overall "stream retentiveness." The final stages of succession, however, are characterized by increased inputs of woody debris as the forest matures. For the stream biota, a full recovery from disturbance is dependent on a return to the reference state in terms of inputs of both leaf litter and LWD. Biotic indices considered to be most effective in detecting differences between clearcut and reference streams through time include the percentage Baetis index, the shredder-scraper index, and the North Carolina Biotic Index (NCBI; uses the number of taxa, the tolerance value, the density, and the abundance). Because logging can result in substantial changes in the energy base, nutrient dynamics, insulation, and water temperature, secondary production is indicated as one of the most sensitive indicators of stream recovery. "Because production estimates energy flow through the system and takes into account differences in turnover rates among organisms (Benke et al. 1984), an index based on the scraper/shredder ratio of production through time would undoubtedly be more valuable for clearcutting than one based only on abundance." The authors point out, however, that measurements of production may not generally be feasible as indicators because of the large time and effort involved.

Ref ID: 63

Towns, D.R. 1985. **Limnological characteristics of a south Australian intermittent stream, Brown Hill Creek.** Australian Journal of Marine and Freshwater Research 36 (6):821-837.

Keywords : litter; invertebrates; insects; Trichoptera; Plecoptera; Australia; streams; flow; pools; fauna; growth; temperature

Selected physiochemical features, litter input rates and the abundance and distribution of common invertebrates were studied in Brown Hill Creek, a small intermittent stream that flows annually for about 6 months near Adelaide, South Australia. Permanent pools had very highly coloured waters and long-term low oxygen levels in summer, apparently related to seasonality of litter inputs from *Eucalyptus*

*obliqua***.** The larvae of only two species of fully aquatic insect, *Leptorussa darlingtoni* and *Lectrides varians* (Trichoptera : Leptoceridae), remained in permanent pools once flow had ceased. A more diverse fauna, dominated by *Riekoperla naso* (Plecoptera : Gripopterygidae), was present during winter when the stream was flowing. Most of the more abundant insect species had extremely unusual life histories, including terrestial egg deposition (*Leptorussa darlingtoni* and *Lectrides varians*), rapid larval growth at low temperatures *(Riekoperla naso),* and advanced *ovoviviparity (Austrocerca tasmanica).*

Vuori, K.-M., and I. Joensuu. 1996. **Impact of forest drainage on the macroinvertebrates of a small borealheadwater stream: do buffer zones protect lotic biodiversity?** Biological Conservation 77: 87-95.

Study Area

The effects of forest drainage on riffle macroinvertebrate communities were studied in a Finnish stream. Forest drainage is the process by which ditches in a watershed channel water toward the stream draining of the area. This process apparently results in considerable sedimentation in the stream, despite the use of riparian buffer strips and sedimentation ponds. While the stream is described as a headwater stream, the drainage area is 52.5 km2 and the mean discharge of the stream is 499 l/s. Stream velocity ranges from 0.3 to 1.4 m/s, and is 4-7 m wide. The dense streamside shade canopy consists of mixed conifers and deciduous trees and bushes. Stream order is not specified. The watershed is 56% peatland, 41% forest, and 3% arable land and water. The rocks along the stream channel are described as granodiorite and quartz diorite, and easily eroded.

Impacts of Sedimentation

Because forest drainage results in sedimentation, the effects are at least somewhat analogous to activities associated with timber harvest. This study showed that despite riparian buffers and sedimentation ponds, the sand and silt reaching the stream altered the relative proportion of habitat types as well as the quality of *Fontinalis* moss tufts in riffles, which are the preferred macroinvertebrate habitat. Siltation of moss tufts resulted in depletion of sensitive macroinvertebrate species, including shredders, and increased abundance of tolerant species (e.g., simuliids). This is believed to be attributable to physical disturbance, loss of suitable habitat, and elevated levels of suspended organic matter that favor filter-feeding taxa.

Wallace, J. B., and J. R. Webster. 1996**. The role of macroinvertebrates in stream ecosystem function.** Annual Review of Entomology 41: 115-139.
From NCASI

Study Area and Methods

This study was conducted in the southern Appalachian Mountains, North Carolina, at the same location as the study described in Stone and Wallace (1998) (the U.S. Forest Service Coweeta Hydrologic Laboratory). Both study streams are 1st order, with watershed areas of the treatment and control catchments of 5.5 and 7.5 ha, respectively. The average gradient of the treatment and control streams was 33% (33 cm/m) and 20% (20 cm/m), respectively, and average discharge was 1.35 l/s and 1.53

l/s, respectively. The watersheds are vegetated by mixed hardwood forests, and the streams are heavily shaded with riparian *Rhododendron*.
The entire study reach was treated with insecticide 4 times per year for 3 years. Benthic invertebrate biomass, abundance, and production in the study stream were compared before and after insecticide treatment, and compared with an untreated reference stream.

General Effects of Chemicals/Insecticides

The authors state that estimates of aquatic macroinvertebrate biomass and production better describe community dynamics during disturbance and subsequent recovery than do estimates of abundance. Although recovering invertebrate communities experienced hydrologic extremes (drought and high precipitation), cluster analysis of functional group production "showed no pattern of wet-dry years, suggesting that the effects of hydrologic fluctuations in these streams act on specific taxa rather than functional groups." Differences were noted in benthic macroinvertebrate recovery rates between mixed-substrate and bedrock habitats, with bedrock communities initially appearing to recover rapidly but then varying substantially over the 2 recovery years. Reduced shredder densities during treatment resulted in large accumulations of unprocessed leaf litter. In contrast to findings that CPOM is a limiting resource in undisturbed Coweeta streams, this study demonstrated that CPOM was not limiting during insecticide treatment. A positive correlation between shredder biomass and CPOM was gradually restored over the 2 years following treatment. Results also suggest that invertebrate predators are an important regulator of community structure in the streams studied, preying on the smaller-bodied collector-gatherer taxa that recolonized soon after treatment. "Taxa with shorter life cycles and (or) extended flight periods were capable of more rapid recolonization than those with longer life cycles and (or) shorter flight periods", a result which agrees with other recovery studies. Persistent differences in taxonomic composition and developmental stage of macroinvertebrate community members were attributed to a positive relationship between life cycle length and recovery time, suggesting possible lingering effects of the insecticide treatment on energy flow. Taxa with high vagility may be of disproportionate importance in the recovery of macroinvertebrate communities in disturbed headwater streams.

Wallace, J. B., S. L. Eggert, J. L. Meyer, and J. R. Webster. 1999. **Effects of resource limitation on a detrital-based ecosystem.** Ecological Monographs 69(4): 409-442.
From NCASI

Study Area and Methods

Two streams were sampled in the Coweeta Hydrologic Laboratory (U.S. Forest Service) in western North Carolina. The study streams were first order, headwater streams, one reference and one treatment. Because of the scale of the study, there was no replication. The substrate of both streams consisted of a heterogeneous mixture of cobbles, pebbles, gravel, sand, and silt (termed “mixed substrate”). Leaf litter was removed for three years and then small woody debris and litter was removed the fourth year in the treatment stream using elaborate canopy and fence structures, to limit both litterfall directly into the bankfull channel, as well as prevent any blow-in from the riparian zone. The reference stream was left untouched. Invertebrates and benthic organic matter samples were collected monthly for four years

on the two streams using cores in mixed substrate habitats and scraping with brushes in bedrock habitats. Invertebrates were identified at least to order, and ash free dry mass was obtained of the CPOM and FBOM samples. Annual production was calculated using the size-frequency method (Hamilton 1969) and was corrected for the cohort production interval (CPI) (Benke 1979).

Abundance of Taxa

Invertebrate abundance decreased in the litter exclusion stream (decreasing over each successive year) and increased in the reference stream (only over the course of the study, with no relationship with the number of elapsed days). Biomass in mixed substrate habitat decreased 21% in the treatment stream, while biomass of similar substrates in the reference stream exhibited little change. Biomass on moss-covered bedrock and bedrock outcrops decreased in both treatment and reference streams, exhibiting no significant difference between the treatment and reference streams. Mixed substrate and bedrock substrate habitats of the treatment stream showed a strong relationship between abundance of predators and invertebrate prey. The relationship was stronger in the treatment stream compared with the reference stream, probably because predators consume proportionally more prey per unit predator biomass in the treatment stream than those of the reference stream, the authors suggest. Additional unpublished data also suggests increased intraguild predation in treatment versus reference streams, also accounting for the stronger predator-prey relationship in the treatment stream. Combined, these data demonstrate the importance of allochthonous input in this headwater stream (i.e., strong bottom-up forces shaping the food web). Small wood removal in year 4 of the study showed an additive effect of litter removal, with a further decrease in abundance and biomass of invertebrates in mixed substrates.

Functional Feeding Groups

In a breakdown of the functional feeding groups, abundance of shredders, gatherers, predators and total primary consumers in mixed substrate habitats decreased after litter was excluded and increased in reference streams.

Salamanders (*Desmognathus* spp. and *Eurycea* sp.) also exhibited a significant treatment effect, also suggesting a strong bottom-up effect in these habitats. All groups also showed a decrease in biomass in mixed substrate habitats of the treatment stream, with the exception of scrapers. Functional feeding groups showed no significant difference between treatment and control streams in bedrock habitats.

Discussion

The authors note that when diffuse and intra-guild predation is accounted, their results actually suggest a ratio dependent positive correlation where both bottom-up and top-down forces co-limit a population. Moreover, the authors' previous conclusion that allochthonous detritus alone plays a major role in productivity of headwater streams is revised to include the importance of small woody debris in these streams. Consumption of woody debris increased in treatment streams following litter exclusion and in general, the decrease in abundance, biomass, and production of benthic invertebrates in mixed substrate habitats following the removal of small woody debris in year 4 superceded the decrease in abundance, biomass, and production of benthic invertebrates in the same habitats with only litter removal (years 1, 2, and 3).

Williams, D.D. 1998. "**The role of dormancy in the evolution and structure of temporary water invertebrate communities."** Pgs:109-124, In Evolutionary-and-

ecological-aspects-of-crustacean-diapause-Proceedings-of-the-Symposium-"Diapause-in-the-Crustacea-with-invited-contributions-on-non-crustacean-taxa"-held-in-Gent,

Keywords: Evolution / ***ephemeral*** /ponds/ Aquatic animals/ invertebrates

Temporary fresh waters support invertebrate communities that range from the complex, with many species (e.g., vernal ponds), to those that support only one or two species (e.g., ephemeral rockpools and water-filled leaf axils). For the most part, these aquatic species are well adapted to dealing with the periodic disappearance of their medium, be it through drought or freezing. Dormancy is commonly the adaptation that makes persistence possible in such habitats. This paper illustrates the role of dormancy in controlling the structure and succession of invertebrate communities in temporary fresh waters. Habitat phase selection (succession) is seen as a crucial result of dormancy and this phenomenon is examined, in detail, by reference to case studies of intermittent streams and a vernal pond in Ontario. Although dormancy is believed to typically protect an organism from habitat adversity (e.g., drought or high temperature), it is argued that it may act also to synchronize organisms with some resource opportunity, such as period of algal bloom or an influx of riparian leaf litter, or to avoid predation and/or competition. Dormancy strategies occur more frequently in temporary and unpredictable (episodic) habitats. Within a single, widely distributed species there may be differences in dormancy expression according to habitat type. in temporary fresh waters, dormancy may result from simple loss of water from an animal's tissues (producing a quiescent state; e.g., as in the larvae of the rockpool Chironomids Polypedilum vanderplanki), or from a more formal programme of arrested development involving complex external cues (true diapause; e.g., as in the eggs of many temporary pond mosquitoes). It is probably prudent to accept multiple evolutionary origins of dormancy, including those driven by the environmental features characteristic of temporary water habitats.

Williams, D. and Hynes, H.B. **The ecology of temporary streams I: the faunas of two Canadian streams.** 1976.

Keywords: ecology/ ***ephemeral streams***/ Canada

This, the first of two papers on the ecology of temporary streams, describes, in detail, the faunas of two such habitats in southeastern Canada. The adaptive mechanisms for coping with the summer drought are documented for a variety of species and faunal succession is shown to occur from the stream stage (fall-winter) through the pool stage (spring) to the terrestrial (summer).

Williams, D. and Hynes, H.B. **The ecology of temporary streams II: general remarks on temporary streams.** 1976.

Keywords: ecology/ ***ephemeral streams***/ characteristics

This, the second of two papers on the ecology of temporary streams, attempts a generalization of the unique features of these habitats. The fauna is shown to consist of three main groups: permanent stream species, facultative species and specialized species. The members of certain major taxonomic groups tend to oversummer as similar stages in their life cycles and the oversummering method used reflects the type of life cycle exhibited by a particular species. These variations in life cycle lead to faunal succession. The coexistence of closely related species is shown to be common in temporary aquatic habitats and, as far as the most abundant taxa are concerned, the species composition is very stable from year to year.

II. Mollusks of Headwater Streams

Hershler, R., and T. J. Frest. 1996. **A review of the North American freshwater snail genus *Fluminicoloa* (Hydrobiidae).** Smithsonian Contributions to Zoology 583: 1-41.

From NCASI

Distribution of Fluminicola

"Hydrobiid snails of the genus *Fluminicola* (Carpenter, 1864) (subfamily Lithoglyphinae), are among the more ubiquitous macroinvertebrates in large, lotic water bodies of northwestern North America...*Fluminicola* are usually found in clear, cold waters with high dissolved oxygen content. Large species are typically found in streams, whereas smaller species are commonly found in either spring or stream environments. Many taxa are apparently lithophiles and graze on periphyton. Often, species in this genus appear to be community dominants, comprising most of the invertebrate biomass. *Fluminicola* are fairly intolerant of impounded waters and soft substrates as well as of nutrient-enhanced or lacustrine habitats."

Holomuzki, J.R., Hemphill, N. 1996. **Snail-tadpole interactions in streamside pools.** American Midland Naturalist 136 (2):315-327.

Keywords : snails; Physella integra; tadpole; Bufo americanus; Kentucky; pools; habitat; competition; co-existence; snail; growth; reproduction; benthic

We studied competitive interactions and grazing effects of the snail *Physella integra* and the American toad *Bufo americanus* in ephemeral streamside pools in W-central Kentucky. Snails and tadpoles reared alone and combined at ambient densities in artificial pools revealed that costs of coexisting differed between taxa. Snails invested resources into growth and survival at the expense of reproduction when with anuran competitors, whereas tadpoles exhibited slowed development and decreased biomass per pool in combined-species treatments. These negative effects were likely a result of food limitation, considering that herbivory by both taxa significantly reduced algal abundance relative to ungrazed controls. Herbivory by both species also affected the assemblage of benthic algae. Diatoms, particularly *Nitzschia* spp. were the predominant algae in both single-species treatments, whereas the green algae *Eudorina* and *Oedogonium* comprised most of the community biovolume in combined-species treatment. The filamentous green algae *Cladophora* was dominant in ungrazed controls.

A survey of 16 isolated pools along three third-order streams revealed patterns of snail egg production and benthic algal assemblage similar to treatment effects in the artificial pool experiment. The survey also indicated that snails and tadpoles seldom co-occur in these pools; thus competition between them may be infrequent. Linkage between phosphate availability, predation and habitat persistence seem particularly important in mediating competitive interactions between these taxa.

III. Food Webs and other Biological Interactions of Headwater Streams

Ref ID: 61
Alkins, M.E.H. 1987. **Fish reproductive strategies in a tropical intermittent stream.** Bulletin Ecological Society of America 68 (3):252

Keywords : fish; reproductive strategies; fecundity; life history patterns; streams; flow; reproduction; flow regimes; spawning.

The reproductive strategies of six fish species were studied in an intermittent stream in Trinidad, West Indies. Species were *Gasteropelecus sternicla, Corynopoma riisei, Astyanax bimaculatus, Hemigrammus unilineatus, Corydoras aeneus and Poecilia reticulata***.** Seasonal flow regimes strongly influenced fish population sizes, life history characteristics and reproductive strategies. Peaks of reproduction five species coincided with the rainy seasons while *P. reticulata* bred continuously. Numbers of breeding seasons and their lengths varied from one short major season each year to prolonged seasons twice each year. Spawning patterns also varied from what appeared to be highly synchronized total spawning to continuous small-brood production. Maximum batch fecundities were directly proportional to species size but small species achieved relatively high fertilities by multiple spawning which also allowed variable reproductive output. Reproductive strategies were diverse and highly adaptable to unpredictable fluctuating conditions.

Ref ID: 122
Anderson, N.H. 1992. **Influence of disturbance on insect communities in Pacific Northwest streams.** Hydrobiologia 248 (1):79-92.

Keywords : disturbance; insects; Pacific Northwest; debris; detritivores; monitoring; fauna; mayfly; food webs; streams; Ecology; age; emergence; substrate; sediment; growth; riparian vegetation; vegetation

Coniferous forest of the Pacific Northwest provide a unique setting for stream ecology research because of the great age of the forests and the important role of wood debris in structuring aquatic systems. The composition and diversity of the insect community in Mack Creek, a stream in 450 yr conifer forest, was compared with that in Grasshoppper Creek where it flowed through a recent clearcut, and at Quartz Creek, which had a 40 yr deciduous canopy. Of the 256 taxa identified, Mack Creek had the highest species richness (196) and evenness. The open site had 191 taxa but high dominance of a few grazer taxa. The deciduous-canopy site had 165 taxa with abundant detritivores. Despite differences in density the biomass of emergence was similar at the three sites, ranging from 1.53 to 1.65 g m^{-2} yr^{-1}.

The importance of disturbance in structuring stream communities was demonstrated in phenomenological studies after a debris torrent at Quartz Creek, and by monitoring stream recovery following the eruption of Mt. ST. Helens in 1980. At Quartz Creek, the debris torrent eliminated the fauna from a 300 m reach, but there was rapid recovery. Emergence density in the same year was similar to that of the control site. The major shift in populations was a decrease in detritivores and moss associates and an increase in grazers, especially *Baetis* mayflies.

At Ape Creek on Mt. St. Helens, over 200 taxa were recorded by 1987 but most occurred in very low densities. This site is reset by winter freshets and by infilling with glacial fines in the summer so the fauna continues to be dominated by weedy, or early successional species. At Clearwater Creek, the presence of wood debris as stable substrate and limited inputs of fine sediments after 1980 have hastened population recovery. A decade after the eruption this site can be characterized as being in the mid-stages of succession with high insect productivity from an algal-based food web. With further growth of the riparian vegetation I predict a shift towards a detritus-based food web and fauna more similar to Mack Creek than it is at present.

Ref ID: 37
Barrett, S.C.H., Husband, B.C. 1997. **Ecology and genetics of ephemeral plant populations: Eichhornia paniculata (Pontederiaceae) in Northeast Brazil.** Journal of Heredity 88 (4):277-284.

Keywords : genetics; Ecology; Eichhornia paniculata; Pontederiaceae; habitat; pools; Brazil; flow; drought; flooding; disturbance

Organisms adapted to ephemeral habitats often display striking variation in population size owing to environmental stochasticity. Here we investigate the genetic consequences of demographic variation in *Eichhornia paniculata* (Pontederiaceae), an annual tristylous aquatic that inhabits ephemeral pools, ditches, and low-lying pastures

in the seasonally arid caatinga region of northeast Brazil. Annual censuses of populations demonstrated striking temporal variation in census number. There was no association between population size and heterozygosity at allozyme loci, but a significant positive relation was evident with the harmonic mean of population size. Both population-size measures were positively associated with style-morph diversity. Large populations were more likely to contain the three style morphs at similar frequencies than small. The amount of heterozygosity within populations was positively correlated with the local density of populations in a region, presumably reflecting greater opportunities for gene flow. Bottlenecks in population size were not severe enough to reduce genetic variation, and population persistence versus local extinction was unrelated to the amount of allozyme variation within populations. The demographic and genetic characteristics of ephemeral populations may be largely irrelevant to survival where catastrophic changes to local environments through drought, flooding, and human disturbance often occur.

Bilby, R. E., and G. E. Likens. 1980. **Importance of organic debris dams in the structure and function of stream ecosystems.** Ecology 61: 1107-1113.
From NCASI

Study Site

This study was conducted at the Hubbard Brook Experimental Forest, NH in Watershed 5, flowing into Bear Brook. The area sampled is a second-order reach, considered headwaters.

Debris Dams

"In first-order streams nearly 75% of the standing stock of organic matter is contained in organic debris dams (Table3). The proportion decreases to 58% in second-order streams and to 20% in third-order streams. The increase in the relative amount of organic matter in dams as stream size decreases is due to the higher frequency of dams in small streams (Table 3). The higher frequency of debris dams in small streams is due primarily to the smaller flows in these systems. Lower discharge makes it possible for smaller pieces of woody debris to form the framework of a debris dam and also makes it less likely that a large piece of debris will be dislodged and carried downstream. Therefore, organic debris in first- and second-order streams tends to be collected into discrete accumulations. In third-order streams a piece of debris must be large in order to maintain its position during high flows; thus debris dams are rarer.."

There is a decrease in organic debris dams as stream width increases. As the surrounding forest grows older, the presence of debris dams is more likely in higher order reaches. Although the traditional view is that CPOM is greater in headwaters because the canopy is tighter over the narrow width of the stream, it is also true that headwater streams are morphologically better equipped to retain leaf material.

Bilby, R. E. 1981**. Role of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed.** Ecology 62: 1234-1243.
From NCASI

Study Site

This study was conducted at the Hubbard Brook Experimental Forest, NH in Watershed 5, flowing into Bear Brook. The area sampled is a second-order reach, considered headwaters.

POM Export

The study was conducted to examine the relative importance of organic debris dams ("an accumulation of organic ecosystem ("debris dams trap sediments in the pool formed upstream from them and the dam structure itself collects particulate organic matter"). "An experimental approach was used in which all organic debris dams were removed from a 175-m section of second-order stream, just above a gauging weir. The material being exported from the watershed was separated into three size categories: dissolved matter (<0.5 µm), fine particulate matter (0.5 µm to 1 mm), and coarse particulate matter (>1 mm). Export of each size fraction was monitored for at least 1 yr prior to dam removal, and for 1 yr following removal....Fine particulate matter export increased dramatically at high discharges following dam removal; concentrations in some instances achieved values five times higher than any observed before dam removal. Coarse particulate matter export also was greatly increased. Calculating dissolved matter and particulate matter export from the watershed, with and without organic debris dams, showed that dam removal resulted in a 6% increase in the export of dissolved matter and a 500% increase in the export of both fine particulate and coarse particulate matter."

Effects of Logging

Although the research presented in this paper does not examine the effects of logging in the streamside forest, the authors hypothesize that removal of debris dams in effect, mimic logging on a headwater stream. Smaller organic materials (leaves and twigs) are what make the dam airtight and allow for waterfalls and effective dams to be created.

The importance of dams goes beyond simply the mechanism for retaining particulate matter, but removing dams removes waterfalls and the associated dissipation of stream energy. Consequently, streams are better able to export particulate matter, effecting both the headwater region as well as downstream reaches.

Ref ID: 149

Blaustein, A.R., Beatty, J.J., Olson, D.H., Storm, R.M. 1998. **The Biology of Amphibians and Reptiles in Old-Growth Forests in the Pacific Nothwest.** pp.1-98**. in** PNW-GTR-337. United States Department of. Pacific Northwest Research Station.

Keywords : amphibians; reptiles; fauna; Pacific Northwest; Ecology; impacts; habitat

The amphibian and reptile fauna of older forest ecosystems in the Pacific Northwest includes several endemic species, species with unique behavioral and ecological characteristics, and species whose populations have been in decline in recent years. We review the biology of these species and include information on their distinguishing characteristics, behavior, and ecology. Herpetofaunal associations with forest characteristics and the impact of habitat loss are addressed.

Ref ID: 86
Boulton, A.J., Suter, P.J. 1986. **Ecology of temporary streams- an Australian perspective.** pp.313-327.DeDecker, P. and Williams, W.W. (ed.). Limnology in Australia.Csiro/ Dr. W. Junk, Melborne and Dordrecht;

Keywords : Ecology; limnology; organic matter; nutrients; pollution; colonization; species diversity; Australia; streams; macroinvertebrates; flow; transport; particulate organic matter; structure; floods; drought

Limnologists in Australia are well positioned to make significant contributions to temporary stream ecology, a field that has received little attention worldwide. The great variation in physical and chemical conditions does not appear to depress macroinvertebrates species richness in some Australian temporary streams, and there is a considerable species overlap between permanent and temporary streams. The coincidence of zero flow with peak allochthonous organic input has important repercussions on transport of dissolved and particulate organic matter when flow resumes, and much is yet to be learnt about the biotic processing of this 'pulse' of material.

The study of intermittent streams provides a fresh approach to succession theory and to the assessment of ecosystem stability and mechanisms of community structure and recolonization because of the severity of the effects of flood and drought upon the resident species. Our ignorance of the ecology of temporary streams may limit the successful application of pollution control measures, which have been developed for streams with predictable continuous flow.

Ref ID: 65
Closs, G.P., Lake, P.S. 1994. **Spatial and temporal variation in the structure of an intermittent-stream food web.** Ecological Monographs 64 (1):1-21.

Keywords : spatial and temporal variation; food webs; food chains; predator-prey interactions; trophic interactions; Australia; streams; habitat; streamflow; flow; detritivores; predators; methodology; structure; community structure

Food webs from the Lerderderg River, an intermittent stream in Victoria, Australia, were compiled with the aim of examining changes in food web structure in a highly variable habitat. Emphasis was placed on a high degree of taxonomic precision. Spatial and temporal variation in the food webs was assessed by partitioning the study area into three sites, located approximately 1.5 km apart along the river. Sites differed in overall stream width and the length of the low streamflow period during summer. Three separate webs for each site were compiled for four different times of the year.

Relatively little spatial variation in community structure was observed. In contrast, temporal variation was considerable, with species composition and the number of species in the community changing considerably over the year. The number of species increased dramatically as the period of constant stream flow lengthened. Detritivores dominated the community, both in terms of species and individual numbers. The proportion of predators in the community increased slightly by the end of the year, suggesting that recolonization of the community by predators lags behind that of

detritivores. The increase in the number of predator species also resulted in an increase in the mean food chain length through the year.

Pattern observed in the food webs tended to fall within the range of values reported from several previous studies, suggesting that underlying constraints may structure certain aspects of food webs. However, the constancy of certain food web statistics was attributable either to methodological decisions made during compilation, or to an inherent property of the statistic itself. The potential sensitivity of several food web statistics to the methodology used to compile a food web render between-web comparisons difficult due to the confounding effects of methodology. This suggests that comparisons between food webs should be restricted to webs derived from similar habitats using a comparable methodology.

Conners, M. E., and R. J. Naiman. 1984. **Particulate allochthonous inputs: relationships with stream size in an undisturbed watershed.** Canadian Journal of Fisheries and Aquatic Sciences 41: 1473-1484.

From NCASI

Study Site

This study was conducted in First Choice Creek, Matamek River basin, Quebec. The creek is first-order/headwater.

POM Input

Terrestrial input was highly variable, in First Choice Creek, but litter traps found similar amounts and species of litter for headwater stream. The results support the general theory that "allochthonous energy per unit of stream area becomes progressively less in larger streams, shifting stream trophic structure away from the detritus based economy
of headwater streams."

Lateral Input

The study also found that the controlling factor for lateral inputs is stream width rather than bank slope as all stream sites sampled were low gradient. The headwater site is so narrow that lateral inputs made up close to 50% of total litter input.

Disturbed Watersheds

The authors conclude that geomorphic and soil characteristics are more important than riparian vegetation and stream order to make predictive statements about disturbed watersheds and understand the importance of allochthonous inputs to a given system.

Ref ID: 81

Cummins, K.W. 1974. **Structure and function of stream ecosystems.** BioScience 24 (11):631-641.

Keywords : function; structure

In summary, the basic features of stream ecosystem structure and function are now established and various functional ecological components and their interrelationships have been defined and initially dimensioned for some representative streams. The search continues for additional or alternative functional criteria to replace partially or totally the previous dependence on classical taxonomic units. Attention is now focused on two apparently generalizable conditions in nonperturbated running waters: The efficient conversion of organic matter, especially particulates, to CO2 and the maintenance of a minor role played by in-stream plant growth. Clearly the time is at hand to infuse the "new stream ecology" into management strategies directed at our precious running waters.

It has been stated often that the selection of appropriate methodological strategies for ecological investigations are highly dependent upon the question being addressed. Unfortunately this awareness has not become fully operational-questions often being formulated only after data collection. Frequently, traditional ecological studies have been taxonomic inventories of biological communities-information of limited use in answering certain function-and process-oriented questions. Such inventories seem an inappropriate fabric from which to weave important ecological generalizations. As long as the species is assumed to be the basic ecological unit, ignoring for the moment problems in defining such units, the perpetually incomplete state of our taxonomic knowledge will constitute a major constraint for the development of ecological theory.

The goal of the discussion that follows is to identify some of the process oriented questions confronting modern stream ecologists-both theoretical and practical, to examine possible methods of qualifying and quantifying functional groups involved in these processes, to speculate on the impact of process function investigations on the continual evolution of stream ecosystem theory and, finally, to examine the implications of such an approach to stream management strategies. Some interrelationships between these elements in the development of theory and management programs are conceptualized.

Ref ID: 138
Cummins, K.W., Klug, M.J. 1979. F**eeding ecology of stream invertebrates.** Annual Review of Ecology and Systematics 10 (1):147-172.

Keywords : Ecology; streams; invertebrates; model; structure; function; watershed; riparian zone; nutrients; temperature; organic matter; algae; community structure; adaptations; stream order; functional feeding groups; feeding groups; particulate organic matter

A general conceptual model of small stream ecosystem structure and function has emerged in the last decade (e.g. 34,56,77), an important cornerstone of which is the geomorphic view (e.g. 18, 40) of the stream as a subsystem of its watershed (e.g. 46). The intimate relationship between the stream and its riparian zone forms the basis for a significant (often the dominant) portion of the annual energy input. Light, and secondarily nutrients and temperature, in large measure determine changes in the balance between heterotrophy, dependent on allochthonous (terrestrial) organic matter, and autotrophy, based on autochthonous (in-stream) primary production by periphytic

algae and macrophytes (e.g. 71,113). Changes in the proportional balance between terrestrially linked heterotrophy and channel based autotrophy constitute a dominant control of broad scale differences in community structure. In-stream gross primary production approaches a balance with, or exceeds, community respiration with increasing stream size [order (89)], at least through mid-sized rivers (e.g. 36), or in other light-rich watershed settings as at higher latitudes and altitudes and in arid regions (77). Within broad temperature-defined boundaries such trophic relationships (heterotrophy/autotrophy) may be well correlated with stream invertebrate community structure (e.g. 35, 36). Because the relative dominance of invertebrate groups shifts with differences in available sources of energy, morpho-behavioral adaptations of food acquisition match well the general resource conditions in a given stream order (size).

Stream invertebrate functional feeding groups have been described according to adaptations for food acquisition rather than food eaten (e.g. 5-7, 33, 36, 66, 75, 108, 116). For example, the functional group designated scrapers (= grazers) depend primarily on autochthonous production--i.e. live plant tissue, usually epilithic algae. However, by scraping they also often ingest fine particulate organic matter (FPOM, <1mm, Table 1) and animals (e.g. 31, 33, 35). The following discussion is organized around the concept of functional feeding groups. Because other reviews cover portions of our general topic (1, 5, 33, 66, 74, 75, 109, 116), we have restricted our literature coverage to the last decade and have concentrated on various aspects of invertebrate-microbial interactions.

Ref ID: 126
Cuffney, T.F., Wallace, J.B., Webster, J.R. 1984. **Pesticide manipulation of a headwater stream: invertebrate responses and their significance for ecosystem processes.** Freshwater Invertebrate Biology 3 (1):153-171.

Keywords : headwaters; invertebrates; macroinvertebrates; organic matter; particulate organic matter; coarse particulate organic matter; transported particulate organic matter; transport; Appalachian; streams; insects; community structure; structure; predators; growth

The influence of macroinvertebrates on detrital processing was evaluated by excluding them from one of two small southern Appalachian streams. Exclusion in the treated stream was accomplished by periodic applications of 10 ppm of the insecticide methoxychlor. This caused massive invertebrate drift (>12,000 organisms/m^3 of discharge) during the initial treatment and reduced aquatic insect densities and biomass to < 10% of the levels within the adjacent untreated reference stream. Community structure in the treated stream shifted from a system dominated by small number of large shredding insects (e.g., *Peltoperla, Pycnopsyche, Tipula*) with comparatively low reproductive rates, to one dominated by large numbers of small collectors-gathers and predators (e.g. Oligochaeta, Chironomidae, Turbellaria) with high reproductive rates. Non-insect invertebrate biomass and density became significantly higher in the treated stream than in the reference stream following initial methoxychlor treatment. We interpreted this response as a consequence of increased survivorship and growth of non-insect taxa associated with both insect predator removal and a potential increase in the food quality of fine particulate organic matter (FMOP). Total invertebrate density in the treated stream increased to that of the reference stream 117 days after the initial

treatment, but total invertebrate biomass in the treated stream remained significantly lower throughout the study. Counts of fungal hyphae, respiration rates of conditioned leaf discs, and ATP content of coarse particulate organic matter (CPOM) were not affected by methoxychlor. However, ATP content of coarse particulate organic matter (TPOM). Our study indicates that insects in forested headwater streams play a major role in both the generation and subsequent transport of FPOM to downstream reaches. Biological processes in headwater streams, where there is high physical retention of CPOM, produce and entrain small particles, whereas communities in downstream areas have evolved toward exploitation of these entrained particles.

Ref ID: 82
Dennis, J. 1996. **The bird in the waterfall.** pp.106-109. The anatomy of rivers: Ephemeral and intermittent streams. Harper Collins Publisher; New York.

Keyword : Ecology

The Bird in the Waterfall is a celebration of the wonders of water and a lively foray into the natural history of rivers, lakes and oceans. With engaging text and illustrations, Jerry Dennis and Glenn Wolff explore waterfalls and seeping springs, ocean waves and tidal bores, whirligig beetles and torrent ducks, mermaids and manatees. They combine science, mythology, folklore and personal experience to address dozens of age-old aquatic mysteries: What are the sources of hot springs and geysers? of riptides and rougue waves? of the colors of water? How do migrating marine animals navigate so unerringly across thousands of miles of open ocean? And why are we so compelled by falling water and crashing surf?

Ref ID: 137
Dodd, C.K., Jr., Cade, S.C. 1998. **Movement patterns and the conservation of amphibians breeding in small, temporary wetlands.** Conservation Biology 12 (1):331-339.

Keywords : amphibians; habitat; corridor; buffer; movement patterns

Many amphibians breed in water but live most of their lives in terrestrial habitats. Little is known, however, about the spatial distribution of these habitats or of the distances and directions amphibians move to reach breeding sites. The amphibian community at a small, temporary pond in northcentral Florida was monitored for 5 years. Based on captures and recaptures of more than 2500 striped newts *(Notophthalmus perstriatus)* and 5700 eastern narrow-mouthed toads *(Gastrophryne carolinensis),* we tabulated the angles of orientation that these amphibians entered and exited the pond basin. Our results showed that movements of these species between the pond and terrestrial habitats were nonrandom in orientation, but that narrow corridors did not appear to be used. Differences between the species likely reflect differences in habitat preferences, whereas intraspecific differences among years and between the sexes likely reflects variation among individuals. For terrestrial buffer zones to be effective at conserving pond-breeding amphibian communities, they need both a distance and a directional component. The determination of a directional component may be obscured

if studies are carried out over a short time span. Conservation efforts for wetland-breeding amphibians that concentrate solely on the wetland likely will fail without consideration of the adjacent terrestrial habitat.

Feminella, J. W., M. E. Power, and V. H. Resh. 1989. **Periphyton responses to invertebrate grazing and riparian canopy in three northern California coastal streams.** Freshwater Biology 22: 445-457.
From NCASI

Study Site

This study was conducted in second-order tributaries of Mendocino Co., CA.

Methods

In each stream, 6 to 9 pools were chosen, and each pool consists of 4 plots. Each plot contained two sets of artificial substrate tiles, known to accumulate levels of periphyton and invertebrates similar to stream cobbles. To contrast between access levels of invertebrate grazers, one of the two sets of tiles was elevated 5-15 cm off the stream bottom while the other set was placed directly on the stream bottom.

Canopy Cover

Grazers had a significant impact on periphyton in heterogeneously canopied streams, but had no impact in densely shaded streams. Impacts of grazers were observed on tiles placed in streams as either controls (directly on bottom) or platforms (raised on plexiglass platform to avoid herbivory from crawling insects). In a second-order stream of heterogeneous canopy cover, Feminella et al. found that as canopy cover increased, periphyton biomass on platforms decreased. However, canopy cover had no influence on the control tiles. Apparently, the grazers controlled the standing crop of algae regardless of canopy cover. Canopy cover may not determine algal growth in heterogeneously shaded streams (probably most headwater). Grazing species themselves have greater influence on maintenance of algal biomass.

Feminella, J. W., and V. H. Resh. 1991. **Herbivorous caddisflies, macroalgae, and epilithic microalgae: dynamic interactions in a stream grazing system.** Oecologia 87: 247-256.
From NCASI

Temporal Shifts

This study examines how the competition for resources among macroinvertebrates results in shifts in algal assemblages throughout the season. The preferred food of *Gumaga nigricula* (Trichoptera) is the filamentous algae *Cladophora glomerata,* while *Helicopsyche borealis* (Trichoptera) prefers epilithic algae. However, once earlysummer grazing reduced *Cladophora* abundance the caddisflies must compete for the remaining epilithic algae later in the season. Note: *Gumaga* is infrequently found in headwaters and therefore may have little relevance to the objectives of this review.

Hansmann, E. W., and H. K. Phinney. 1973**. Effects of logging on periphyton in coastal streams of Oregon.** Ecology 54: 194-199.
From NCASI

Study Site

This study was conducted along Deer Creek, Needle Branch and Flynn Creek, all of the Drift Creek drainage in Oregon. It is unclear if samples were taken from headwaters.

Effects of Logging

Algal productivity was low in heavily shaded streams and allochthonous material provided a significant food source for riverine insects. Prior to logging, there was little filamentous algae, and diatoms were the dominant flora. Since it is unclear from the paper where along the gradient of each stream (headwaters or downstream) samples were taken, no assessment can be made for its relevance to NCASI. This is a rather general study of the effects of logging on periphyton, with data supporting preliminary conclusions that debris dams and temperatures increase in logged watersheds. Oxygen levels dipped in logged streams, but recovered within months to pre-logging and control watershed levels.

Algal Successional Response

Filamentous mats colonizing mud and silt were abundant in the logged creek. Later in the season, increased water flow removed remaining decomposed organic material.

OverHarvey, Bret C.; Nakamoto, Rodney J. 1996. **Effects of steelhead density on growth of Coho salmon in a small coastal California stream.** Transactions, American Fisheries Society 125(2): 237-243.

Weight change in age-0 coho salmon *Oncorhynchus kisutch* at about natural density was negatively related to the density of juvenile steelhead (anadromous rainbow trout *O. mykiss*) in a 6-week experiment conducted in July-August 1993 in the north and south forks of Caspar Creek, California. The experiment used 12 enclosed stream sections, each containing a pool and a portion of upstream riffle, with two replicates of three steelhead densities-zero, natural density (1X), and twice the natural density (2X)-on both the north and south forks. The natural density of coho salmon was about one-sixth the density of steelhead. Coho salmon survival was high (87% overall) and not related to treatments. In the north fork, coho salmon weight change was positive in zero density steelhead treatments, zero in 1X treatments, and negative in 2X treatments.

Coho salmon weight change in the south fork was less favorable than in the north fork but was also negatively related to the density of steelhead. These results indicate that under some conditions resource partitioning by salmonid species does not eliminate negative interspecific interactions.

Harvey, Bret C.; Nakamoto, Rodney J. 1997. **Habitat-dependent interactions between two size-classes of juvenile steelhead in a small stream**. Canadian Journal of Fisheries and Aquatic Sciences 54(1): 27-31.

The presence of small steelhead *(Oncorhynchus mykiss;* averaging 55 mm fork length) influenced the growth of larger juvenile steelhead (90 mm fork length) during a 6-week experiment conducted in North Fork Caspar Creek, California, in summer 1994. In fenced replicate deep stream sections in this small stream,

growth of the larger steelhead was greater in treatments in which small steelhead constituted half of the total biomass of fish than in treatments with an equal biomass . comprised entirely of larger fish. In shallow habitats, growth of larger fish was lower in the presence of small fish. The growth of small fish was unaffected by the presence of larger juveniles and also was independent of habitat. Survival of both size-classes was high (70-90%) and unrelated to habitat or the presence of the other size-class. The advantage of large body size in intraspecific interactions among steelhead does not exist in all types of habitat, and interactions between the two size-classes may contribute to lower abundance of large juveniles in streams where aggradation reduces water depth.

Hill, W. R., and B. C. Harvey. 1990. **Periphyton responses to higher trophic levels and light in a shaded stream.** Canadian Journal of Fisheries and Aquatic Sciences 47: 2307-2314.
From NCASI

Study Site

This study was conducted along Ish Creek within the Oak Ridge National Environmental Research Park, TN. The creek is second-order and considered headwaters.

Effect of Grazers

"The effects of higher trophic levels on benthic primary producers were examined in the context of light limitation in a shaded headwater stream." Because the experimental treatment examined the influence of fish on headwater streams, the specific details of the study are not relevant to this project. However, the authors do conclude that fish and snail effects (herbivory) on total primary production seemed negligible when compared with the effects of light in this forest system.

Holopainen, A.-L., and P. Huttunen. 1992**. Effects of forest clear-cutting and soil disturbance on biology of small forest brooks**. Hydrobiologia 243/244: 457-464**.**
From NCASI

Study Site

This study was conducted in a first order stream in eastern Finland.

Effects of Logging

Species richness decreased directly following clearcutting (due to turbidity), but increased during the following years. Certain algal groups were more affected than others. Dominant groups of alga changed (possibly in some sort of successional sequence). Specifics on algal groups are not applicable to Pacific Northwest streams. Water quality effects remained evident for at least 3 years and soil disturbance effects for at least 4 after logging.

Lowe, R. L., S. W. Golladay, and J. R. Webster. 1986. **Periphyton response to nutrient manipulation in streams draining clearcut and forested watersheds.** Journal of the North American Benthological Society 5: 221-229**.**
From NCASI

Study Site

This study was conducted at the Coweeta Hydrologic Laboratory in Macon Co., NC, along the headwaters of Big Hurricane Branch and Hugh White Creek, both of which are second order.

Canopy Cover – Algal Biovolume

This study examined the response of periphyton assemblages to nutrient additions under different light availability scenarios (e.g., harvested and forested streamside vegetation). "Algal periphyton in the clearcut stream accumulated more chlorophyll and biovolume than in the forested stream across all nutrient treatments. Light appears to limit algal accumulation in the forested stream and there is evidence that some populations in the clearcut stream may be nutrient limited."

Canopy Cover – Algal Community Structure

"Algal community structure was significantly different between streams but not between nutrient treatments." The authors discuss the importance of recognizing algal assemblages as highly diverse communities (this study included 47 taxa from three different algal divisions) which would be expected to (and did) have differential responses to the addition of a single limiting resource.

Canopy Cover – Physiognomy

"Algal physiognomies were also significantly different between streams, with filamentous green algae dominating the clearcut stream and erect diatoms dominating the forested stream. Adequate light also resulted in a more architecturally diverse community." Most of the algae in the forested stream was of the erect form, allowing for the most light to reach diatom cells from all angles. The next most abundant was the *Eunotia* type (prostate to the rock), explained by the fact that sheer stress in high gradient streams may favor this form. Filamentous forms would probably be most efficient at light gathering, but are growth-limited by the lack of light in forested streams. On the other hand, filamentous alga are the most abundant form found in clearcut streams. Without light limitation, the algae is able to take on more complex forms in these open canopied streams.

Ref ID: 75

Mahnken, R., Wilhm, J. 1998. **Diel variation in species composition and diversity, density, and chlorophyll, content of phytoplankton in an intermittent stream in Oklahoma.** The Southwestern Naturalist 27 (1):79-86.

Keywords : phytoplankton; diatoms; algae; pollution; species composition; Oklahoma; species diversity

Physicochemical measurements and phytoplankton were collected every 3 h during four, 24-h sampling periods in summer, 1976 and 1977, from Otter Creek, Oklahoma. Chlorophyll concentration and phytoplankton density were correlated with highest values occurring in late morning or afternoon. Ninety-four taxa of phytoplankton were collected; most were planktonic diatoms, green algae, or euglenophytes. Diel variations in species diversity and equitability was small and generally reflected changes in one or two dominant species. The algal pollution index

exhibited considerable diel variation, indicating the importance of considering time of day when using the index.

Martinez, B., Velasco, J., Suarez, M.L., and Vidal Abarca, M.R. **"Benthic organic matter dynamics in an intermittent stream in South-East Spain."** *Arch.Hydrobiol.* 141, no. 3 (1998): 303-320.

Keywords: population density/ Ecosystems/ Benthic environment/ Streams / Spain / Benthos / Organic Matter/ Sampling / Detritus / ***Intermittent Streams***/ Population Dynamics / Particulate Matter/ Spatial Distribution/ Temporal Distribution/ Particle Size/ Aquatic Habitats/ Streambeds

This study investigates (1) the standing stocks of benthic particulate organic matter (BPOM) and its fractions; (2) their temporal and spatial variability; (3) the environmental variables that explain their dynamics; and (4) the relationship between the standing stocks of the different fractions and total BPOM on the one hand and functional feeding group densities on the other. The study was conducted at four sties (two pools and two runs) located along a perennial middle section (354 m length) of Chicamo stream, a 4th-order saline and intermittent tributary of the Segura river basin in southeast Spain. Three benthic organic matter samples were collected monthly by corers in a stratified pattern in each site during 1994. Coarse (CPOM, >1 mm), fine (FPOM, 56 mu m-1 mm) and ultrafine (UPOM, 0.7-56 mu m) size fractions were determined. Benthic POM at all sites was dominated by FPOM, followed by UPOM and CPOM fractions. There were no significant differences in the overall amount of BPOM or its fractions between dates. In contrast, spatial variation was considerable between sites, in accordance with the high spatial heterogeneity of the stream. Habitat-specific variables (type and size of habitat, substrate, current, depth and type of primary producers) determined the production, retention and storage of the different BPOM fractions in the streambed. Shredders were absent from the stream due to the scarcity of their food (CPOM). No significant correlations were found between the densities of the detritivorous feeding groups and their presumed food resources. This lack of correlation may reflect an over-abundance of detritus in the stream.

Mayer, M. S., and G. E. Likens. 1987**. The importance of algae in a shaded headwater stream as food for an abundant caddisfly (Trichoptera).** Journal of the North American Benthological Society 6: 262-269.
From NCASI

Study Site

This study was conducted in the intermittent headwaters of Bear Brook , at the Hubbard Brook Experimental Forest, NH.

Assimilation

Gut contents of *Neophylax aniqua* were collected bi-weekly during summer months and slide mounted. Percent area of slides were designated as algae, detritus, or animal matter to determine source of nutrition. An assimilation efficiency ratio of 3:1 (algal:detritus) was used. Algae made up 50% of gut contents and is estimated to account for 75% of larval growth.

Substrate Type

Because different techniques were used to measure algal accumulation on gravel (-1 to –4 on phi scale; gravel and pebble on Cummins scale) and rock (-5 to –8 on the phi scale; cobble and boulder class on Cummins scale), the authors were not able to compare the two for algal growth.

Leaf litter

Previous studies have shown that allochthonous inputs account for 99% of the total energy in the creek. The authors claim to have underestimated the amount of algae found on submerged leaves. This part of the study is not as convincing, as it remains unclear how they subsampled from the leaf packs or how they determined algal density within the leaf packs.

Mihuc, T. B., and G. W. Minshall. 1995. **Trophic generalists vs. trophic specialists: implications for food web dynamics in post-fire streams.** Ecology 76: 2361-2372**.**
From NCASI

Study Site

This study was conducted in streams of Yellowstone National Park and within the laboratory.

Leaf Litter

This study concludes that burned organic material is a poor food source for most organisms examined. Only *Paraleptophlebia heteronea* (Ephemeroptera; detritivore) exhibited positive growth on burned FPM and CPM. Low protein and lipid content, in addition to high ash content makes it a lower quality food choice. *P. heteronea* prefers gravel/sediment substrate and has a history of eating poorer quality foods.

Effects of Fire

Many lotic invertebrates are trophic generalists. Thus, when resource availability changes, benthic invertebrates may switch consumption to more readily available food items. Generalist resource use is probably favored in postdisturbance streams.

Minshall, G. W., K. W. Cummins, T. L. Bott, J. R. Sedell, C. E. Cushing, and R. L. Vannote. 1983. **Interbiome comparison of stream ecosystem dynamics.** Ecological Monographs 53: 1-25.
From NCASI

Methods

Studies were conducted in four distinct geographic areas to examine benthic and transported organic matter, primary community production and respiration, stream retention, and macroinvertebrates in light of the River Continuum Concept. Studies were conducted in Oregon, Idaho, Michigan and Pennsylvania. Only relevant data regarding Devil's Club Creek in Oregon are reported here. General comments below refer to general conclusions reached by the authors regarding all four study sites unless otherwise specified. Each of the four river systems was divided into four stations. The headwater station is most applicable to NCASI, and that is where the comments below are focused. If it seemed important, information regarding downstream reaches was also included.

Benthic Organic Matter

Oregon's headwater stream stored large quantities of organic matter (AFDM annual mean 1420 g/m2) compared with the other 3 downstream sites. This pattern was not seen elsewhere in the U.S. Local geomorphic features that determine sediment deposition were more important in determining the variance of detritus standing crop than the season or the size of the stream. The Oregon stream followed what is expected from the River Continuum Concept. The headwaters receive allochthonous input, where it is retained and processed. At the other sites, it may be that dense vegetation retains fine particulates in much lower gradient streams, so as not to follow the pattern observed in Oregon.

Among Oregon sites, mean chlorophyll a concentration was lowest at the headwater site and greatest at the downstream site. The prediction is that the ratio of fine to coarse materials should increase from headwaters to downstream reaches. This was not the case in the OR system. The authors explain that it may be due to local riparian inputs all the way down the stream, rather than a pulse in the headwaters.

Primary Productivity

Productivity generally increased from headwaters to downstream reaches in all streams.

Functional Groups

Shredders were most abundant in headwaters and decreased in numbers downstream. There was a general tendency for greater numbers of collectors as you progressed downstream. Grazers were most abundant in downstream reaches. Predators seemed scattered throughout the watershed with no distinct pattern to their abundance.

Collectors tended to be the most predominant functional group across all sites.

Retention

Headwater streams tended to be more retentive than downstream reaches. In the Oregon stream, the sheer mass of woody debris loading within the stream accounted for much of the CPOM retention. Further downstream, as the channel widened, the size and bulk of the material became less important. Thus, a combination of geomorphic characters in addition to watershed area, discharge, depth, width and channel roughness contribute to the retentiveness of a stream channel.

Murphy, M. L., and J. D. Hall. 1981. **Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon.** Canadian Journal of Fisheries and Aquatic Sciences 38: 137-145.
From NCASI

Study Site

This study was conducted in first- and second-order streams within H.J. Andrews Experimental Forest, OR.

Invertebrate Predators

Insect diversity and biomass were greater in clearcut than in old-growth forest sites (28% and 88% respectively).Fewest predatory insect taxa were found in the densely shaded, second-growth forested areas. In general, steeper gradient stream pools had greater increases of insect density than in lower gradient reaches post-logging. No pattern between riffle gradient and abundance was detected in the study. However,

riffle-inhabitants were more abundant than pool-inhabitants in streams surrounded by clear cuts.

Vertebrate Predators

The effects of logging on salamander predators depended on stream gradient. In steep gradient reaches, salamander biomass was greater in clearcut rather than old-growth forests. However, in low gradient (less than 9%) reaches, amphibian biomass was greater in the old-growth sections. "Because salamanders inhabit substrate crevices they should also be directly affected by shifts in sediment composition. The cutthroat trout, however, feeds on drifting organisms (Brocksen et al. 1968) and its production should be sensitive to changes in productivity of riffles. These relations may explain why pool insects and salamanders showed variable effects of logging depending on stream gradient, whereas riffle insects and trout showed increased abundance regardless of stream gradient." Thus, these shifts may lead to greater productivity in high gradient headwater reaches but depress productivity, insect abundance, etc. in low gradient downstream reaches

Algal Succession and Response

Clearcutting opened up the canopy and increased periphyton growth. The greatest volume of organic debris was found in first-order streams, with debris randomly distributed.

Substrate Type

The amount of sand/gravel was also correlated with gradient. In high gradient streams, old growth sites had greater sediment deposits than clearcut. However, in low gradient reaches, logged sites had finer sediments than unlogged sites.

Effects of Logging

Authors conclude that canopy opening and sedimentation are probably the most important effects of logging. Opening of the canopy happens naturally upstream to downstream; hence, canopy removal has a smaller effect on periphyton production downstream. Similarly, gradient decreases naturally downstream; hence, lower gradient (and further downstream) reaches will be most affected by sediment retention. Thus, small, high-gradient streams should have large increases in primary production leading to a response from predators. This prediction is supported by the results of this study.

Current velocity

Both primary production and sedimentation are related to current velocity. Riffles exhibit little alteration in primary production due to logging. Higher water velocity in riffles also carries away sediment and deposits it in slower moving water. Thus, after clearcutting, predators in riffles should gain more energy from ambient levels of primary production in riffles than predators in pools, where sedimentation will most likely decrease rates of primary production after logging.

Nakamoto, Rodney. 1998. **Effects of timber harvest on aquatic vertebrates and habitat in the North Fork Caspar Creek.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 87-95.

I examined the relationships between timber harvest, creek habitat, and vertebrate populations in the North and South forks of Caspar Creek. Habitat inventories suggested pool availability increased after the onset of timber harvest activities. Increased large woody debris in the channel was associated with an increase in the frequency of blowdown in the riparian buffer zone. This increase in large woody debris volume increased the availability of pools. No dramatic changes in the abundance of young-of-the-year steelhead, yearling steelhead, coho, or Pacific giant salamanders were directly related to logging. High interannual variation in the abundance of aquatic vertebrates made it difficult to contrast changes in abundance between pre-logging and post-logging periods. Changes in channel morphology associated with increased volume of large woody debris in the channel suggest that yearling steelhead, coho, and Pacific giant salamanders may benefit from logging in the short-term because of increased living space. However, over a longer time scale these conditions will probably not persist (Lisle and Napolitano, these proceedings

Richardson, J. S. 1992. **Coarse particulate detritus dynamics in small, mountain streams of southwestern British Columbia.** Canadian Journal of Fisheries and Aquatic Sciences 49: 337-346.
From NCASI

Study Site

This study was conducted along Mayfly, Spring, and Blaney Creeks, Coast Range, British Columbia, all of which are second-order. *Allochthonous Input* Input of deciduous leaves was similar among the three creeks sampled. Input of conifer needles was greater in streams draining old-growth forest than streams draining second-growth forests. More deciduous leaf fall was observed in autumn, from September to November, with very little fall in winter/spring and only moderate fall in the summer.
Decomposition

The more retentive streams had lower rates of leaf litter decomposition. Decomposition rates increased with increasing water temperature. Models predicting the expected mass of leaf material from estimates of leaf litter input and temperature-dependent decomposition rates indicated that over 70% of leaf material was unaccounted for. This material was most likely lost due to export or burial, two technologically difficult hypotheses to test. CPOM is decomposed fastest when it is least abundant (in summer) due to higher temperatures, so there always appears to be a shortage of food for detritivores. Rates of decomposition were similar in pools and riffles, although densities of macroinvertebrates were greater on riffle leaf packs. The rates may be similar because microbes compensate for the lack of macroinvertebrate activity in the slower flowing water by decomposing anaerobically. Retention of CPOM depends on slope, substrate type, geomorphology, and discharge and may explain some of the loss downstream.

Rosemond, A. D. 1993. **Interactions among irradiance, nutrients, and herbivores constrain a stream algal community.** Oecologia 94: 585-594.
From NCASI

Study Site

This study was conducted on the headwaters of Walker Branch, at the Oak Ridge Reservation, TN.

Effect of Grazers

Stream-side flow through channels were used to determine effects of light, nutrients, and grazers on an algal community. Regardless of nutrient and light levels, grazers maintained a low algal biomass. Ungrazed communities were comprised of mostly diatoms. Single-factor analysis yielded some different results from multifactor analysis, indicating the importance of co-varying factors. At ambient snail density and nutrient concentration, light had negative effects on periphyton growth. However, if grazers were removed and nutrients were added, then light had strong positive effects on periphyton growth. Interaction between these three important ecological factors may dictate algal assemblage in this stream. The effect of nutrients, light, and grazing had the most significant impact together, compared with single factors. Multifactor experiments are necessary to test multi-variable effects.

Rosemond, A. D. 1994**. Multiple factors limit seasonal variation in periphyton in a forest stream.** Journal of the North American Benthological Society 13: 333-344.
From NCASI

Study Site

This study was conducted on the headwaters of Walker Branch, at the Oak Ridge Reservation, TN.

Effect of Grazers

No seasonal variation was found in grazer density (snails = 1000 animals/m2). High and constant density of snails seemed to maintain a low standing crop of grazer-resistant algae (*Stigeoclonium* sp. basal cells), demonstrating little variation seasonally of periphyton biomass and productivity. Seasonal variation in periphyton biomass was only weakly correlated with light, nutrients, and temperature. Seasonal variation in primary productivity was small, and was slightly correlated with inorganic nitrogen concentration, which was highest in the summer. In streams where herbivore density was high, periphyton biomass and productivity remained virtually constant, even with the addition of potentially limiting chemical and physical factors. It is also possible that asynchrony in certain growth factors may contribute to the constant level of periphyton abundance. For example, nutrient concentrations were highest in the summer when radiance was at a minimum. Both discharge and water temperature may also have had an effect on productivity. These results suggest that herbivores dictate the lack of seasonal variation in periphyton biomass. Often, the streams where seasonal variability is observed are those streams with scouring winter/spring discharge, NCASI which dislodge herbivores, and allow for greater algal recruitment. Headwater streams usually do not experience such scouring flows, thus maintain a steady herbivore population, whose effects outweigh those of physical and chemical variables determining periphyton seasonality.

Rosenfeld, J. S. 1997. **The effect of large macroinvertebrate herbivores on sessile epibenthos in a mountain stream.** Hydrobiologia 344: 75-79.
From NCASI

Study Site

This study was conducted along the perennial headwater Mayfly Creek, in British Columbia. The substrate composed of mostly gravel and cobble. The stream bed has a gradient of 1% and the channel has a discharge from 1-30 m3/s.

Effect of Grazers

The ability of large invertebrate grazers to displace smaller invertebrates (namely Chironomids) was explored. Mayflies (*Ameletus* sp.) and *Ascaphus* tadpoles reduced algal biomass and Chironomid abundance in controlled trough experiments. The authors suggest that larger invertebrates have a more significant effect than smaller ones. The exact competitive mechanism is unknown but may be direct resource competition (between Chironomids and mayflies for algae) or consumption (predation).

Schofield, K., C. R. Townsend, and A. G. Hildrew. 1988**. Predation and the prey community of a headwater stream**. Freshwater Biology 20: 85-95.
From NCASI

Study Site

This study was conducted on Broadstone Stream, Ashdown Forest, in southern England. The stream is first order and small, acidic, and iron-rich.

Predator

Discusses predator-prey dynamics in which a top predator (fish) is able to replace a mid-level consumer (caddisfly) with no release of caddisfly prey. Specific species not relevant to Pacific Northwest, and thus not this project.

Smock, L. A. 1990. **Spatial and temporal variation in organic matter storage in low-gradient, headwater streams.** Archiv fur Hydrobiologie 118: 169-184.
From NCASI

Study Site

This study was conducted on Buzzards Branch (perennial) and Colliers Creek (intermittent), both first-order headwater streams in Surry Co., Virginia

Methods

CPOM storage/processing was studied in low-gradient streams with sand to clay substrates, with particular attention paid to the entire stream system: channel surface, channel subsurface, and floodplain.

Retention

Buzzards Branch, with mostly sand sediment, exhibited low leaf retention during high flow. Debris dams provided hot spots for invertebrate shredder activity, and little FPOM was retained so far upstream.

Floodplain Importance

"Floodplains seemingly are the functional headwaters of many low-gradient streams and rivers, processing much of the autumnal leaf fall into the system and then exporting detritus to main channels. This input of detritus supports microbial and macroinvertebrate communities in the channel. In-channel storage patterns in turn

further affect spatial and temporal patterns of stream structure, functioning and productivity."

Williams, D.D., Hynes, H.B.N. 1977. **The ecology of temporary streams; II. General remarks on temporary streams.** Internationale Revue der Gesamten Hydrobiologie 62 :53-61.

Keywords : habitat; fauna; permanent stream; facultative stream; specialized stream; life cycles; life history patterns

This, the second of two papers on the ecology of temporary streams attempts a generalization of the unique features of these habitats. The fauna is shown to consist of three main groups: permanent stream species, facultative species and specialized species. The members of certain major taxonomic groups tend to oversummer as similar stages in their life cycles and the oversummering method used reflect the type of life cycle exhibited by a particular species. These variations in life cycle lead to faunal succession. The coexistence of closely related species is shown to be common in temporary aquatic habitats and as far as the most abundant taxa are concerned, the species composition is very stable from year to year.

Ecological Processes and Conditions:

I. Large Woody Debris (LWD)Recruitment and wood-associated Habits of Headwater Stream

Andrus, C. W., B. A. Long, and H. A. Froehlich. 1988**. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging.** Canadian Journal of Fisheries and Aquatic Sciences 45: 2080-2086.
From NCASI

"Large quantities of woody debris persisted 50 yr after logging and fire in stream channels of a small coastal Oregon watershed. Debris from the current stand represented only 14% of total debris volume and 8% of debris volume responsible for creating pools. The greatest number of pools were located in downstream sections of the watershed where gradient was reduced, discharge was increased, and streambed material was finer. Seventy percent of pools with a volume greater than 1.0 m were associated with woody debris in the channel...Study results indicate that riparian trees 3 must be left longer than 50 yr to ensure that an adequate, long-term supply of woody debris is available to stream channels. Debris from previous stands plays a crucial role in the interim and should not be removed from stream channels."

Greatest number of pools were located in downstream sections of a small coastal Oregon watershed where gradient was reduced, discharge was increased, and streambed material was finer. Large quantities of LWD persisted 50 yr after logging and fire in the watershed. Short harvest rotations and high wood utilization can reduce supplies of LWD.

Aumen, N.G., Hawkins, C.P., Gregory, S.V. 1990. **Influence of woody debris on nutrient retention in catastrophically disturbed streams.** Hydrobiologia 190 (1):183-192.

Keywords : woody debris; debris; nutrients; nutrient cycling; algae; substrate; disturbance; streams; Pacific Northwest; fine particulate organic matter; particulate organic matter; organic matter; colonization

The role of woody debris in nutrient cycling was investigated in two catastrophically disturbed streams in the Pacific Northwest that had been subjected to large inputs of wood. One study site in each catchment had all woody removed (take section), while the debris in the other study site was left intact (leave section). Nitrate, phosphate and chloride (a conservative tracer) were released in each section and nutrient retention was monitored at downstream stations. Phosphate was removed from solution more than nitrate, probably due to the high N : P ratio in the stream water. However, there were no major differences in nutrient retention between the take and leave sections. In contrast, experiments in recirculating chambers showed that woody debris and cobbles exhibited higher nitrate and phosphate uptake per unit surface area than sand/gravel or fine particulate organic matter. The high uptake rates of woody debris and cobbles may be related to their suitability for colonization by heterotrophic microorganisms and algae. Wood may not influence nutrient retention significantly at the reach level because of its low surface area relative to other substrates. However, wood may be very important at small spatial scales because of its high uptake activity.

Beechie, T. J., and T. H. Sibley. 1997**. Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams.** Transactions of the American Fisheries Society 126: 217-229.
From NCASI

"Pool spacing decreased as the number of woody debris increased in both moderate slope (0.02 < slope < 0.05) and low slope (0.001 < slope < 0.02) channels, but the relationship was stronger in moderate slope channels." "...the influence of LWD on pool formation chances with channel slope. Analysis of pool-forming mechanisms indicated that low-slope channels are less sensitive to LWD abundance because pools are formed by mechanisms other than LWD when LWD abundance is low. Size of LWD that formed pools increased with increasing channel width, but was not related to channel slope."

Ref ID: 101
Benda, L. 1990. **The influence of debris flows on channels and valley floors in the Oregon Coast Range, U.S.A.** Earth Surface Process and Landforms 15 (1):457-466.

Keywords : debris flows; morphology; sediment; headwaters; Oregon Coast Range; Oregon; debris; flow; organic debris; channel bed; landscape

Debris flows are one of the most important processes which influence the morphology of channels and valley floors in the Oregon Coast Range. Debris flows that initiate in bedrock hollows at heads of first-order basins erode the long-accumulated sediment and organic debris from the floors of headwater, first- and second-order channels. This material is deposited on valley floors in the form of fans, levees, and terraces. In channels, deposits of debris flows control the distribution of boulders. The stochastic nature of sediment supply to alluvial channels by debris flows promotes cycling between channel aggradation which results in a gravel-bed morphology, and channel degradation which results in a mixed bedrock- and boulder-bed morphology. Temporal and spatial variability of channel-bed morphology is expected in other landscapes where debris flows are an important process.

Ref ID: 130
Benda, L., Dunne, T. 1997. **Stochastic forcing of sediment supply to channel networks by land sliding and debris flow.** Water Resources Research 33 (1):2849-2864.

Keywords : sediment; channel networks; debris flows; disturbance; transport; drainage basin; mass wasting; landslides; landscape; debris; flow

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 network.

Beschta, R.L., Platts, W.S. 1986. **Morphological features of small streams: Significance and function.** Water Resources Bulletin 22 (3):369-379.

Keywords : habitat; pools; riffles; bed material; streambanks; flow; bedload; transport; morphology; fish; management; hydraulic

Throughout the United States, land managers are becoming increasingly aware of the importance of small streams for a wide range of resource benefits. Where channel morphology is modified or structural features are added, stream dynamics and energy dissipation need to be considered. Unit stream power, defined here as the time-rate loss of potential energy per unit mass of water, can be reduced by adding stream obstructions, increasing channel sinuosity, or increasing flow resistance with large roughness elements such as woody root systems, logs, boulders, or bedrock. Notable morphological features of small streams are pools, riffles, bed material and channel banks. Pools, which vary in size, shape, and causative factors, are important rearing habitat for fish. Riffles represent storage locations for bed material and are generally utilized for spawning. The particle sizes and distributions of bed material influence channel characteristics, bedload transport, food supplies for fish, spawning conditions, cover and rearing habitat. Riparian vegetation helps stabilize channel banks and contributes in various ways to fish productivity. Understanding each stream feature individually and in relation to all others is essential for proper stream management. Although engineered structures for modifying habitat may alter stream characteristics, channel morphology must ultimately be matched to the hydraulic, geologic, and (especially) vegetative constraints of a particular location.

Bilby, R. E. 1984. **Removal of woody debris may affect stream channel stability.** Journal of Forestry 82:609-613**.**
From NCASI

Effects of reduced LWD

Cited in Murphy et al. (1986): "Apparently, pools are lost from clear-cut reaches as natural debris is removed when logs are salvaged, logging slash is cleared from the stream channel, or destabilized debris washes downstream or floats onto the stream banks (Toews and Moore 1982b, Bryant 1983, Bilby 1984b)."

Study area and methods

Stream studied was a fourth-order tributary to Chehalis River in Coast Range of Washington, draining a watershed of about 900 ha. Some of the headwater areas harvested about 25 yr ago; lower watershed unlogged prior to 1980. Section studied had average bankfull channel width of 11.5 m and average gradient of 1.5%.

Retention/longevity in stream channels

"In defining what constitutes stable debris, this study indicates that size and degree of anchoring are the most important. The propensity of a piece to move during high flow was closely related to its length (fig. 3A). Pieces less than 2.5 m long moved readily while those longer than 10.0 m rarely moved. The long pieces were usually stabilized at several points along their length by stream banks or channel obstructions. Diameter of a piece also influenced the probability of its moving (fig. 3B). Pieces more than 50 cm in diameter moved much less frequently than smaller pieces, since deeper water was needed to float them." "Length of debris was inversely related to the distance traveled by those pieces which moved."

"The relative degree of anchoring or burial also influences the stability of debris (fig 4). Pieces not anchored in the bed or banks were apt to move during high flows. Anchoring one end or the face of the log greatly reduced the probability of movement. Pieces having both ends and their upstream face buried in the stream banks and bed did not move."

Bilby, R. E. 1985. **Influence of stream size on the function and characteristics of large organic debris.** Pages 1-14 *in* Proceedings of the west coast meeting of the National Council for Air and Stream Improvement. Technical Bulletin No. 466. National Council of the Paper Industry for Air and Stream Improvement, Portland, Oregon.
From NCASI

The author summarizes the role of LWD in streams (>2.5 m bankfull width) and presents general summary of management guidelines regarding debris retention and recruitment. The article focuses on influences to channel morphology, sediment transport, wood transport, organic material retention, and benefits to aquatic habitat.

Functions and influences on stream channels

"Channel form is affected by debris in a number of ways. Debris in smaller channels has been shown to widen and shallow the channel due to sediment retention behind and around wood (Zimmerman et al. 1967). Debris also forms pools by directing flow in such a way that the bed or bank is scoured or by a damming of water upstream of the obstruction (Lisle and Kelsey 1982)."

Retention/longevity in stream channels

The author found that both length and diameter contribute to debris stability in the channel. "...only the largest pieces of debris were stable in the largest streams and smaller pieces were able to maintain position in smaller channels. Thus, more debris was found in smaller channels."

Bilby, R. E. 1988. **Interactions between aquatic and terrestrial systems.** ***Streamside management: riparian wildlife and forestry interactions.*** College of Forest Resources, University of Washington. Pages 13-29 *in* K. J. Raedeke, editor.
From NCASI

"Debris torrents are another catastrophic event influencing riparian structure. The torrents follow streams downslope and typically occur only in very high gradient channels; hence, they tend to be restricted to small stream systems (Swanson and Swanston 1977). Torrents typically remove all vegetation from a zone immediately adjacent to the channel. Depending upon site characteristics and the severity of the torrent, the resulting riparian substrate might be bare mineral soil or predominantly bedrock. The resulting soil conditions determine the rate of re-establishment and the characteristics of the post-torrent streamside vegetation (Swanson et al. 1982)."

Functions and influences on stream channels

"Creation of sediment terraces behind pieces of woody debris may also serve to increase the size of the riparian area by forming wide, flat areas adjacent to the channel. In stream systems bordered by steep terrain, these debris-formed terraces may compose a significant proportion of the area displaying riparian characteristics. This process is notable in that it entails the terrestrial system impacting the aquatic in terms of input of the woody debris and then, as a result of the debris input, the aquatic system influences the terrestrial through the formation of an area with soil and water availability characteristics distinct from upland sites."

Effects of stream size on riparian zone characteristics

"Stream size, along with topography of the site, is one of the primary determinants of the size of the riparian zone (Leopold et al. 1964). Many small streams in the Pacific Northwest, especially those in forested areas, drain steep watersheds, limiting the potential for the development of riparian areas...However, even in areas of low relief, small streams will produce smaller riparian zones than will larger systems simply because the smaller systems carry much less water and, as a result, do not influence as broad an area as can a system containing a much higher volume of water..."

Bilby, R. E., and J. W. Ward. 1989. **Changes in characteristics and function of woody debris with increasing size of streams in western Washington.** Transactions of the American Fisheries Society 118: 368-378.

From NCASI

"In second- to fifth-order streams that drain old-growth timber in western Washington, characteristics and function of woody debris changed in relation to stream size. Average diameter, length, and volume of pieces of wood increased as stream size increased, whereas the frequency of occurrence of woody debris decreased. In streams with channel widths less than 7 m, 40% of the pieces of debris were oriented perpendicularly to the axis of flow; in streams with channel widths over 7 m, more than 40% of the pieces were oriented downstream. The types of pools most commonly associated with pieces of wood changed from plunge pools in small streams (42%) to debris scour pools in larger systems (62%).

Pool area was correlated with the volume of the piece of wood forming the pool in streams of all sizes. However, this relationship was most evident in larger channels. Nearly 40% of the pieces of wood in channels less than 7 m wide were associated with sediment accumulations. Less than 30% of the pieces retained sediment in channels from 7 to 10 m wide, and less than 20% retained sediment in channels greater than 10 m wide. Surface area of sediment accumulations and the volume of the piece of wood forming the accumulation were related in all streams, but the relationship was clearest in the

larger channels. Accumulations of particulate organic matter associated with woody debris were more frequent in small streams but were larger in large streams. No relationship was observed between the volume of fine particulate matter accumulated by a piece of wood and the piece of wood's volume."

Bilby, R. E., and J. W. Ward. 1991. **Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington.** Canadian Journal of Fisheries and Aquatic Sciences 48: 2499-2508**.**
From NCASI

"Amount of large woody debris (LWD) surveyed in 70 stream reaches flowing through old-growth, clear-cut, and second-growth forests decreased with increasing stream size for all stand types but was greatest at old-growth sites. Average piece volume was larger at old-growth sites than at other stand types in streams > 10 m wide, but no differences were seen in smaller streams. Scour pools accounted for 90% of the wood-associated pools at second-growth and clearcut sites but only 50% at old-growth sites, which contained more pools than other stand types, particularly for larger streams. Pool size was similar for all stand types in smaller streams, but averaged 10 m in streams >10 m wide at old- 2 growth sites and 4 m for other stand types. Sediment and fine organic matter retained by woody debris decreased with 2 increasing stream size for all stand types, but old-growth sites contained greater amounts of both materials than other stand types. The frequency of pool formation, the type of pool formed, and sediment accumulation were influenced by the amount of fine debris associated with LWD. Changes in LWD amount, characteristics, and function occurred very rapidly following removal of streamside vegetation."

"Channel size affects both wood amount and the relative influence of LWD on channel features (Swanson et al. 1976; Bilby 1979; Long 1987; Bilby and Ward 1989)...Morphology of the bed may also influence LWD amount (Bilby and Wasserman 1989). Susceptibility of riparian trees to windthrow can play a major role in determining quantities of LWD in streams (Lienkaemper and Swanson 1987; Robison and Beschta 1990a)..."

"Comparisons of the amount of LWD in streams flowing through old-growth and previously logged forests in several areas in the Pacific Northwest have verified the decrease in wood after removal of the streamside vegetation (Grette 1985; Long 1987). Some information is also available on the influence of stream size and channel characteristics on the rate of change in LWD amount after removal of streamside vegetation (Long 1987; Murphy and Koski 1989)...The purpose of this study was to compare LWD abundance, characteristics, and function in streams bordered by forests of differing ages: old-growth forest, recently clear-cut areas, and 40- to 60-year-old second-growth forest. Comparison of the three stand age-classes provides an indication of the rate at which changes in LWD occur following timber removal from the riparian area."

Bilby, B. 1996. **Large woody debris in Type 4 and 5 streams: abundance, distribution, function and relationship to forest management.** Pages 27-52 *in* Type 4 & 5 waters workshop. Timber/Fish/Wildlife Report TFW-WQ20-96-001. Washington Forest Protection Association, Olympia.

From NCASI

Document primarily consists of graphs and tables which were used as overheads in the presentation. Some information included in tables: (1) percent elevation drop in small streams due to LWD, (2) stand age vs. channel width, (3) comparison of export of dissolved material and fine and coarse sediment with and without LWD, (4) sediment transport and LWD, (5) LWD and organic matter loading and transport, (6) LWD influence on nutrient transformations, (7) LWD and temperature influence, (8) LWD input and elimination from Type 4 & 5 streams, (9) management options for Type 4 & 5 streams.

Bisson, P. A., R. E. Bilby, M. D. Bryant, C. A. Dolloff, G. B. Grette, R. A. House, M. L. Murphy, K. V. Koski, and J. R. Sedell. 1987**. Large woody debris in forested streams in the Pacific Northwest: past, present, and future.** Pages 143-190 *in* E. O. Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. College of Forest Resources, University of Washington, Seattle. Contribution No. 57.
From NCASI

Cited in Robison and Beschta (1990a): "The occurrence of CWD along the larger second-order and smaller third-order stream in this study was relatively continuous, a finding similar to that of other studies (Bisson et al. 1987). The fourth order stream also was typified by continuous debris along most of the channel, even though high flows were obviously instrumental in floating and rearranging debris into jams at various points."

Functions and influences on stream channels

"Some species, notably Coho salmon, avoid riffle habitats almost entirely when competitors are present (Hartman 1965, Bisson et al. 1982, Dolloff 1983) and rely instead on pools with ample cover provided by large woody debris (although exceptions are known: see Stein et al. 1972, Bisson et al. 1985)...It is primarily because pools possess lower current velocities that most stream fish inhabit them. In addition to the slower movement of water, pools are usually deeper than riffles. The greater depth affords fish a better chance of escaping from terrestrial predators."

"In small streams (up to about third-order) single pieces of large woody debris or accumulations of smaller pieces anchored by a large piece often create a stepped longitudinal profile (Figure 2) consisting of an upstream sediment deposit, the debris structure, and a downstream plunge pool (Heede 1972a). Lisle and Kelsey (1982) suggested that numerous debris accumulations can increase pool frequency, and Grette (1985) noted a significant correlation between the number of pools and debris pieces in low gradient western Washington streams..."

"The size and location of pools are also strongly influenced by debris position. The size of a single log or accumulation of logs spanning the channel can affect the size of the associated pool... Beschta (1983) simulated logs of different diameter and found that larger structures created longer and deeper pools, provided they were suspended above the streambed. Bilby (1985 and unpublished data) showed that pool area was positively correlated with the volume of the debris that anchored the pool, and that the correlation improved with increasing channel width in streams up to

approximately 20 m wide (Figure 3). Many pools, however, are not created by scouring action of flow along the channel thalweg, but rather by eddies behind debris and other structures located at the channel margin (Figure 4). These pools, often called backwater or eddy pools, are common features of both small and large streams and are used extensively by salmonids for rearing in the spring (Stein et al. 1972), summer [many citations], autumn (Sedell et al. 1982a, Murphy et al. 1984), and winter (Bustard and Narver 1975a, 1975b, Tschaplinski and Hartman 1983)."

"Logs extending partly across the channel deflect the current laterally, causing it to diverge and widen the streambed (Zimmerman et al. 1967)...Even where the stream becomes too large to permit logs to span the main channel, debris accumulations along the banks cause meander cutoffs and create well-developed secondary channel systems (Keller and Swanson 1979, Swanson and Lienkaemper 1982). In addition to increasing the spatial diversity of stream habitats, debris also influences variation in channel depth by producing scour pools downstream from flow obstructions (Keller and Tally 1979, Hogan 1985). Debris therefore maintains a diversity of physical habitat by (1) anchoring the position of pools along the thalweg, (2) creating backwaters along the stream margin, (3) causing lateral migration of the channel and the formation of secondary channel systems in alluvial valley floors, and (4) increasing depth variability."

"Fine organic material stored by woody debris is considered to be a more important energy source for benthic invertebrates in streams than the wood itself...Without the extensive storage capacity provided by large debris, much of the organic input from terrestrial vegetation in forested watersheds would be rapidly transported downstream without first being reduced to detritus-size particles (Reice 1980, Bilby and Likens 1980, Triska et al. 1982)...As in steep headwater streams, the storage of detritus by stable debris is the mechanism whereby terrestrial organic material is retained long enough to be processed by invertebrates along river margins and in secondary channels..."

Bragg, D. C., and J. L. Kershner. 1997**. Evaluating the long-term consequences of forest management and stream cleaning on coarse woody debris in small riparian systems of the central Rocky Mountains.** Fish Habitat Relationships Technical Bulletin, FHR Currents No. 21. USDA Forest Service, Six Rivers National Forest, Eureka, California.
From NCASI

The authors present a LWD recruitment model specific to the central Rockies and simulate six different management scenarios as they relate to LWD recruitment and loading. "We present the integration of a growth and yield model with a mechanistic recruitment model to simulate long-term effects of harvesting and CWD removal from streams in northwestern Wyoming."

Bryant, M. D. 1983. **The role and management of woody debris in west coast salmonid nursery streams.** North American Journal of Fisheries Management 3: 322-330.
From NCASI

Recruitment mechanisms

"Keller and Swanson (1979) listed biological agents (tree mortality caused by disease or insects) and physical agents (blowdown, streambank cutting, and debris

avalanches) as the primary natural causes of large organic debris inputs to streams. The rates of entry and type of material within those categories differ. In the case of tree mortality, inputs are sporadic and relatively sparse along the course of the stream. Trees entering the stream as a result of bank cutting may be sound, and usually the root wad goes with the tree into the stream. Again, this type of material is usually sparsely distributed along the stream. Inputs resulting from bank cutting may increase as a result of wind or may induce additional blow down by opening the forest canopy. In either event, wind throw may consist of one or several trees.

Under natural conditions, a dozen or more trees may be crisscrossed over the channel. Many of the trees may be above the channel, dropping down into the stream over a number of years. Large trees may be anchored in or along the bank by root wads which, along southeast Alaska streams, may be as much as 2-3 m in diameter. Usually, this material enters during storms that tend to flush out fine particulate matter rapidly and reorient unstable material into a relatively stable alignment within the stream. Therefore, readjustment of stream morphology is fairly rapid following the natural input of large organic material."

"Because trees entering the stream as a result of mortality from insects or disease may be partially decomposed, their residence time will be shorter than sound green trees entering as a result of bank cutting or blow down. The partially decomposed tree will be more apt to shatter on impact and will be more easily processed into the carbon cycle of the stream system. The net result will be a more rapid assimilation into the biological cycle and potentially less effect on channel morphology."

Ref ID: 141
Bugosh, N., Custer, S.G. 1989. **The effect of a log-jam burst on bedload transport and channel characteristics in a headwater stream.** pp.203-211**. in** Woessner, W.W. and Potts, D.F. (ed.). Proceedings of the symposium on headwater hydrology. American Water Resources Association. Bethesda, Maryland.

Keywords: bedload; log jam; transport; headwaters; hydrology; hydraulic; sediment; morphology; geomorphology; streams; function; runoff

Hydraulic factors are commonly assumed to exercise primary control on sediment transport in high-gradient headwaters streams. Research in 1983 and 1984 on Squaw Creek, a tributary to the Gallatin River in Montana, has shown that other hydrologic and geomorphic factors are also important. One of these factors is log-jams. A log-jam functions as a sediment storage area and as a local base level. The catastrophic dispersal of an old log-jam in the study reach was observed and recorded during 1983. The log-jam broke when discharge was 6.4 m^3/s. A pulse of sediment was released from storage. One side of the channel was filled and channel morphology was altered. As the stream adjusted to the new morphology, average bedload transport was as high as 0.4 kg/m^{-s}. This rate is at least two times the bedload transport rate measured at similar and higher discharges during runoff in 1983 and 1984. Thirty percent of the measured bedload in 1983 moved in a three day period and is directly attributable to the burst of the log-jam. The dispersal of this log-jam and the resulting instantaneous changes in bedload transport parameters had greater effect on bedload in Squaw Creek than any

other parameter studied. Log-jam breakage affects bedload availability, bedload transport and channel characteristics in headwater streams.

Carlson, J. Y., C. W. Andrus, and H. A. Froehlich. 1990. **Woody debris, channel features, and macroinvertebrates of streams with logged and undisturbed riparian timber in northeastern Oregon, U. S. A**. Canadian Journal of Fisheries and Aquatic Sciences 47: 1103-1111.
From NCASI

Woody debris was defined as pieces greater than 10 cm diameter and 1 m in length.
Functions and influences on stream channels
"Pool volume was inversely related to stream gradient and directly related to the amount of woody debris in the stream"
"Neither the number of pools per 11 m of stream, the mean pool volume, nor the percent area in pools differed significantly between paired logged and undisturbed stream segments. No correlation was found between percent area in pools and woody debris or boulder abundance. However, when pool volume was examined, woody debris abundance did help explain variation between sites as shown by the equation. The equation indicates pool volume is greater at lover stream gradients and where there is more woody debris. The equation also indicates that sites with the greatest difference between spring and summer flows have the highest proportion of area in pools. Streams with a high spring flow to summer flow ratio are more likely to have deep pools scoured into their channels. Andrus et al. (1988) found similar results for a coastal Oregon stream where differences in pool volumes throughout a watershed were determined by channel size and gradient as well as woody debris abundance."

Elswick, D., Lydgage, W. 1994. **Information concerning intermittent streams and their study in the Pacific Northwest: a compilation of current literature and observations.** [Unpublished report] Humboldt Interagency Watershed Analysis Center.

Keywords : riparian reserves; Pilot Creek; watershed

This paper is meant to be a guideline to help researchers and land use managers start focusing on the most pertinent questions that need to be addressed regarding impact effects on intermittent streams. Written in the style of a literature review, I have attempted to summarize existing information concerning the study of intermittent streams and ecosystems in general. Many sentences have been "lifted" directly from their respective sources and the reader is encouraged to references these valuable papers. Also included are thoughts and observations from intermittent stream studies conducted during the summer of 1994 for the Humboldt Interagency Watershed Analysis Center.

Fausch, K. D., and T. G. Northcote. 1992**. Large woody debris and salmonid habitat in a small coastal British Columbia stream.** Canadian Journal of Fisheries and Aquatic Sciences 49: 682-693.
From NCASI

Sections of small British Columbia stream previously cleaned of LWD compared with sections with most debris remaining and with other sections where debris had been relatively undisturbed for at least 40 years. "Three sections where debris had been removed had simple habitat that was less sinuous, wider, and shallower and had less pool volume and overhead cover than four sections with more complex habitat where debris was retained. Habitat in four relatively undisturbed sections was generally similar to complex sections. Most pools in all sections were scour or plunge pools formed by LWD or large roots oriented perpendicular to the flow or angled downstream. Standing crop...and individual weights of age 1+ and older Coho...and cutthroat...were significantly greater...in complex than in simple sections. Biomass of age 1+ and older salmonids was closely related to section pool volume...Projections based on this model and average habitat conditions suggest that during 1990 a total of 8.0 kg of salmonid biomass, 5 times the current standing crop, was forgone in the 332-m simple reach due to prior debris removal."

Gregory, K. J., A. M. Gurnell, and C. T. Hill. 1985. **The permanence of debris dams related to river channel processes.** Hydrological Sciences 30: 371-381.
From NCASI

Frequency and volume estimates

"Vegetation debris dams occur on average every 27 m of channel in a drainage basin in the New Forest, Hampshire, England, and within less than 12 months 36% changed position or were destroyed and 36% changed character. Such dams significantly affect the timing of flood peaks as they are routed through the channel network..."

The drainage basin that was studied was 11.4 km in area; other details about the basin are probably located in Gurnell and Gregory 21984). Authors noted that dam spacing was "markedly different from the 395 m of channel per dam noted in the central Oregon Coast Range (Marston 1982), but closely resembles the range of log step spacing, usually between 3.1 and 26 m, in Arizona and Colorado (Heede 1981) and the 2.5–5.0 m average spacing in New England streams (Likens and Bilby 1982)."

Gregory, K. J., and R. J. Davis. 1992. **Coarse woody debris in stream channels in relation to river channel management in woodland areas.** Regulated Rivers: Research and Management 7: 117-136.
From NCASI

Cited in Hughes (1997): "There is a considerable literature on the role of large woody debris in determining channel morphology particularly in headwater streams, and it has been well reviewed elsewhere (e.g., Gregory and Gurnell 1988, Gregory 1990, Gregory and Davis 1992, Keller and MacDonald 1995)." This document reviews a great deal of other research and includes some good diagrams and drawings of LWD.

"A number of specific management recommendations are included which reference the above points [regarding management implications]. These include the recommendations that large debris should be moved into the channel when distances of 5 to 10 channel widths have no large debris, that bridges and culverts should be

designed to allow the passage of large organic debris, and that in some cases it may be necessary to install logs, deflectors, or small dams to improve habitats."

Gregory, K. J., R. J. Davis, and S. Tooth. 1993**. Spatial distribution of coarse woody debris dams in the Lymington Basin, Hampshire, UK.** Geomorphology 6: 207-224.
From NCASI

Frequency and volume estimates

"There are significant variations in biomass according to forest type and catchment area. The highest values are associated for channel reaches in redwood forests; Douglas fir forests also give high values, while western hemlock and other mixed conifer forests exhibited lower values."

"...the greatest density of debris dam frequency in the Lymington basin occur at approximately 2.5 km downstream from the headwaters succeeded by a more rapid decrease in density downstream."

"...partial dams are most numerous more than 5 km downstream from the headwaters with the number of partial dams exceeding the other types between the distances of 4 and 12 km. An explanation for this pattern is that in the headwater areas the narrow channels allows even small pieces of CWD to cross the channel to form complete or active dams. Further downstream, as the channel increases to widths greater than 3m the number of partial dams continues to increase as the number of active and complete dams decreases owing to their inability to form across a wider channel."

"No clear patterns were found to exist between the magnitude and frequency of debris accumulations and stand age for predominantly coniferous or deciduous reaches."

In the Lymington basin, U.K. (drainage area 110.4 km) the average density of debris dams is 1.15 per 100 m, the 2 volume of material averages 1.38 and 2.53 kg per m for net and gross loading respectively. These values are less than 2 average values obtained from other forest areas (Tables 1 and 2)."

"Zimmerman et al. (1967) identified two thresholds on Sleepers River, Vermont: one at a drainage area of 1.5 km and 2 the other at a drainage area of 12.9 km which separated three levels of influence of vegetation on stream channel 2 morphology."

Grette, G. B. 1985. **The role of large organic debris in juvenile salmonid rearing habitat in small streams.** Master's thesis. University of Washington, Seattle.
From NCASI

Recruitment mechanisms

Cited in Andrus et al. (1988): "Healthy young stands typically produce less woody debris than do the older stands they replace (Grette 1985)."

Cited in Bisson et al. (1987): "In an examination of small, low gradient coastal streams in western Washington, Grette (1985) found that the primary entry mechanism of debris in second-growth forests was by bank undercutting of living trees, while in old-growth forested streams of similar size, mortality of senescent trees was believed to be more important...Grette (1985) found that the majority of trees that entered the channels of second-growth forested sites were red alder, which possessed shallow root

systems and had a low resistance to undercutting. The rate of input of second growth conifer debris in Grette's study was very slow and did not begin to increase until approximately sixty years after timber harvest (Figure 9)."

Study area and methods

Study streams were located in the western Olympic Peninsula of Washington and ranged in gradient from 0.5 to 2.0 percent. Watershed drainage areas ranged from 3.4 to 12.4 km . Electrofishing was conducted in late summer and in 2 winter. Population estimates were calculated for Coho, steelhead (1+), and cutthroat (1+ and older) for individual habitats and the entire site. Densities of salmonids in individual pools were correlated with habitat characteristics specific to each pool. "Numbers and density of salmonids in individual habitats at summer low-flow were correlated with habitat parameters specific to that habitat entity. Analysis was exclusively of pool habitats (only pools connected to the stream were used) as this is where nearly all the Coho, steelhead (1+), and cutthroat (1+) were found...The intent of the correlations were to identify habitat characteristics (particularly cover) that influence the quality of salmonid habitat. Habitat quality could be reflected in terms of densities of individuals (number/m) or densities of biomass (g/m). 2 2 Habitat quality in this case, is defined in terms of density of individual fish present in a particular habitat during the summer low-flow period...Numbers of salmonids present during the winter were correlated with the habitat characteristics measured during the summer low-flow period." All sites did not appear to be fully seeded for Coho, but results still illustrate trends in use of habitats.

Frequency and volume estimates

"For the size and gradient of streams sampled in this study, the maximum debris load (volume) is about 100 m per 100 3 lineal meters of channel length...unlogged sites had considerable more debris [than unlogged] (average 78.1 m) and less 3 variability (range 41.7 to 101.5 m)..." 3

Retention/longevity in stream channels

"The net rate of loss of debris due to these natural processes [rot, breakage, and displacement during floods] is about 0.5 pieces of debris per year per 100 meters of stream channel." The rate of decline probably increases as the general state of decay of the debris load increases. Assuming a "piece" of debris to equal 1.6 m (the average piece size in the 3 unlogged stream).

Harmon, M. E., J. F. Franklin, F. J. Swanson, P. Sollins, S. V. Gregory, J. D. Lattin, N. H. Anderson, S. P. Cline, N. G. Aumen, J. R. Sedell, G. W. Lienkaemper, K. Cromack Jr., and K. W. Cummins. 1986. **Ecology of coarse woody debris in temperate ecosystems.** Advances in Ecological Research 15: 133-302.

From NCASI

Effects of stream size on LWD

"Amounts of CWD are generally highest in the smallest streams and decrease with increasing stream size, given a particular physiographic and forest setting (Table 6). *[Note: Table 6 "Volume and biomass of coarse woody debris in streams flowing through natural (unmanaged) temperate forests" consists of 3 pages of data listing streams, stand age, drainage area, mean channel width, reach length sampled, and the volume and biomass of coarse woody debris associated with each stream.]* The general downstream decrease in CWD results from several factors. Larger streams have a greater ability to transport CWD downstream and

out of channels onto floodplains. Larger channels also have a more limited source of CWD because forests do not grow in the most active channels, while very small streams can flow through forests without influencing overall stocking amounts. Furthermore, woody vegetation adjacent to rivers may be maintained in an immature stage by frequent disturbance, and the resultant lower biomass of these streamside forests thus limits availability of CWD for channels. However, when large channels migrate laterally and entrain mature forests, a large amount of CWD can be added. Along large floodplain rivers, CWD moves both into and out of the channel during floods, but it is not known whether the floodplain is a net source or sink for CWD."

Characteristics of LWD in streams

"In riparian and stream environments, the arrangement of CWD and architecture of accumulations are influenced by both the mechanisms adding CWD and the geomorphic processes within streams. Several types of spatial arrangements are common in small (i.e., first- and second-order) channels, but randomly distributed CWD appears to be the most widespread. Small streams cannot move CWD, and the spatial pattern of CWD in these streams reflects the spatial pattern of input."

"In small- and intermediate-sized streams, CWD forms large accumulations with a very open structure when windthrow and earthflows are the major agents adding CWD to channels. Addition of CWD to channels by rapid soil mass movements and snow avalanches results in formation of large accumulations with a tight, interlocking fabric. Similarly, rapid mass movements of colluvium, alluvium, and CWD down channels result in tightly meshed accumulations...As channel gradient decreases, the debris flow eventually stops, leaving a wedge of sediment up to 10 m thick...trapped behind a CWD accumulation that has been impregnated with sediment..."

"CWD has a moderately clumped distribution in intermediate-sized streams where few pieces are large enough to be stable during floods...Pieces wider than the active channel can remain in place for up to several centuries...and often trap smaller pieces of CWD as they float downstream..."

"In large channels, a high proportion of CWD pieces can be moved during floods. CWD accumulates at sites such as heads of islands, mouths of secondary channels, heads of point bars, and outside of meander bends...This leads to a highly clumped distribution of CWD in large channels..."

Harris, C. D. 1988. **A summary of the effects of streamside logging treatments on organic debris in Carnation Creek.** Pages 26-30 *in* T. W. Chamberlin, editor. Proceedings of the workshop: applying 15 years of Carnation Creek results. Pacific Biological Station, Nanaimo, British Columbia.

From NCASI

Study area and methods

"Debris dynamics have been studied for sixteen years in the Carnation Creek watershed. Four reports (Schultz 1981, Toews and Moore 1982a, 1982b, and Harris 1986) have documented the changes in debris piece size, stability, and volumes throughout the study period."

Effects of reduced LWD

"In all reaches studied, loss or movement of debris resulted in changes in bank stability, gravel bars, and pool complexes...Removal of large woody debris from the stream can result in reduction of important debris structures for channel stability."

"Harris (1986) indicates that the number of debris jams have increased, especially in the careful logging treatment. In addition, after logging, there is an increase in the mean number of pieces in both the leave strip and intense treatments (Table 1) coupled with an overall decrease in mean volumes in five of the seven study reaches (Table 2). This suggests that either the larger pieces are being broken down or that a large amount of small debris from logging entered the stream channel, resulting in an overall decrease in mean piece volume...In Carnation Creek, all study areas (except 2, 3, and 9) showed decreasing mean length values. Bilby also reports that diameter of debris influences the probability of the piece moving."

Hartman, G. F., J. C. Scrivener, L. B. Holtby, and L. Powell. 1987. **Some effects of different streamside treatments on physical conditions and fish population processes in Carnation Creek, a coastal rain forest stream in British Columbia.** Pages 330-372 *in* E. O. Salo and T. W. Cundy, editor. Streamside management: forestry and fishery interactions. College of Forest Resources, University of Washington.
From NCASI

Deals primarily with fish-bearing streams and effects of management on salmonid habitat.

Effects of reduced LWD

"In coastal rain-forest streams such as Carnation Creek that are subject to frequent and severe freshets, large, stable woody debris within the channel acts to dissipate much of the hydraulic energy (Toews and Moore 1982b, Sedell and Swanson 1984). In the intensive treatment [which consisted of logging on both sides of the creek, removal of merchantable timber from creek, herbicide treatment of riparian alder, etc.], loss of woody debris resulted in much of the energy being directed against streambanks. As a result of debris loss, and bank soil layers being weakened by loss of root strength (Burroughs and Thomas 1977), the banks eroded most rapidly in the intensive treatment area."

Heede, B. H. 1981. **Dynamics of selected mountain streams in the western United States of America.** Zeitschrift fur Geomorphologie 25: 17-32.
From NCASI

Study area and methods

Study streams are located in the southern Rocky mountains of Colorado and Arizona. Gradient of the study streams ranged between 4% and 22% for individual reaches. All stream reaches have drainage area < 3 km . 2 "The great potential flow energies indicated by these gradients imply drastic erosion rates especially in young landscapes. Although those erosion rates would normally produce deeply incised channels and oversteepened valley side slopes, this was not the case in our study watersheds."

Functions and influences on stream channels

"Submerged gravel bars and log steps cause increases in bedform and roughness until they are filled by sediment. The overflow from unsubmerged gravel bars and log steps dissipates energy below them, and the stilling effect of the tailwater reduces energy behind them. After filling, the sediment deposits form a gentler channel gradient than existed before. In the study streams, the deposit gradients averaged 75% of the original gradients."

"The flow progresses from shooting flows to nearly still conditions behind completely filled dams. The dissipation of energy caused by a waterfall over a dam is followed (in a downstream direction) by an acceleration of flow, climaxing in shooting flow conditions. Thus the cycle is repeated many times as the flow progresses down channel."

"Availability of forest debris influences log step formation." "The abundance of standing dead and/or dying trees contributes to log-step progression. Some debris will fall parallel to the channel while others will only partially traverse the channel. Consequently, not all fallen trees or logs will form channel flow barriers or steps."

"The ratio of the cumulative height of the gravel bars and log steps to the total fall of the stream is one indicator of potential energy reduction. The ratio ranged from 0.40 to 0.99 for the study streams." On average, 39 to 66 percent of the steps were log formed, with the exception of Tony Bear Creek with only 17% of steps formed by logs. Average logstep spacing ranged from 3.1 to 26.0 with the exception of lower Tony Bear Creek that exhibited average log-step spacing of 331.1.

In West Willow Creek, "step length decreases with increasing upstream channel gradient."

"In many small mountain streams, slope adjustment by meandering and braiding processes is prohibited by narrow valley bottoms. Here the role of transverse gravel bars and log steps is of special importance, because channel degradation would become the dominant adjustment process, i.e., without the stepped profile, the equilibrium sediment transport rate would be greater than the actual rate, and adjustment between both would be required (Vanoni et al. 1961). Degradation leads to lower channel gradients that support flows with less transport requirements (smaller equilibrium rate)."

"Preventing fall of logs and trees into small mountain streams...will result in the formation of more gravel bars to take place of rotted log steps. these gravel bars will be formed by an increase in bed material movement."

Heede, B. H. 1985a. **Interactions between streamside vegetation and stream dynamics. Pages 54-58 in Proceedings of the symposium on riparian ecosystems and their management: reconciling conflicting uses.** USDA Forest Service, Region 3, Albuquerque, New Mexico.
From NCASI

Cited in Smith et al. (1993a): "Removal of LWD from a first-order stream in the White Mountains of Arizona eliminated local base levels [of sediment] imposed by log steps and caused increased sediment delivery by bank erosion (Heede 1985). Formation of new gravel bars at the sites of removed steps replaced lost debris-related resistance (Heede 1985)."

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. **Responses of salmonids to habitat changes.** Pages 483-518 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19, Bethesda, Maryland.
From NCASI

Effects of forest management on LWD

"Among the most important long-term effects of forest management on fish habitat in western North America have been changes in the distribution and abundance of large woody debris in streams. These changes have extended from small headwater streams to the estuaries of major rivers (Sedell and Luchessa 1982, Maser et al. 1988). Overall trends have included reduction in the frequency of pieces of large, stable debris in streams of all sizes; concentration of debris in large but infrequent accumulations; and loss of important sources of new woody material for stream channels (Bisson et al. 1987)...these trends have been accelerated by stream channelization and by debris removal for navigation (Sedell and Luchessa 1982), for upstream fish migration (Narver 1971), and for reduction of property damage during floods..."

Functions and influences on stream channels

"Large woody debris plays an important role in controlling stream channel morphology [citations], in regulating the storage and routing of sediment and particulate organic matter [citations], and in creating and maintaining fish habitat (Bryant 1983, Lisle 1986a [*included in this reference list*], Murphy et al. 1986, Bisson et al. 1987). The abundance of salmonids is often closely linked to the abundance of woody debris (Figure 14.2), particularly during winter (Bustard and Narver 1975b, Tschaplinski and Hartman 1983, Murphy et al. 1986, Hartman and Brown 1987). Large woody debris creates a diversity of hydraulic gradients that increases microhabitat complexity (Forward 1984), which in turn supports the coexistence of multispecies salmonid communities (Figure 14.3)." "Protection from the high velocities of winter peak flows is the main role of woody debris in areas with winter floods (Chamberlin et al. 1991)."

Effects of reduced LWD

"Almost without exception, removal of large woody debris has resulted in loss of important habitat features and a decline in salmonid population abundance (Bryant 1980, Toews and Moore 1982b, Lestelle and Cederholm 1984, Dolloff 1986, Elliott 1986). Debris removal caused a decline in channel stability and a corresponding reduction in the quality and quantity of pools and cover. Bisson and Sedell (1984) observed enlarged riffles and a reduction in the number of pools in cleaned stream channels in Washington. The increased frequency of riffles favored under yearling steelhead and cutthroat trout, which preferred riffle habitat, but caused a decrease in the relative proportions of Coho salmon and older age classes of steelhead and cutthroat trout, which preferred pools."

"A decrease in the supply of large woody debris is another change in habitat that may not occur for many years. Recent studies in Oregon have indicated that many existing stable pieces of large woody debris entered streams years ago. Heimann (1988) found that in watersheds logged without a buffer strip, preharvest debris continued to be the predominant wood in streams 140 years after timber harvest, but the total amounts of debris were only about 30% of preharvest levels....there may be a lag time of many years before the shortfall is apparent."

Effects of forest management on LWD

"Removal of nearly all large trees from riparian zones during logging has also caused a long-term reduction in the recruitment of new large woody debris to stream channels, leading to a reduction in the quality of fish habitat. There may be a short-term increase in the debris load caused by entry of slash during harvesting and yarding, but this small debris is often floated downstream within a few years, to be trapped in a few widely spaced debris jams (Bryant 1980). If the debris load of a channel is not replenished by large-scale inputs such as extensive blow downs or debris avalanches, the second-growth riparian zone becomes the principal source of new woody debris. In young forest stands, inputs of debris large enough to be stable in streams with channel widths greater than about 15 m remain low for at least the first 60 years of riparian forest regrowth (Grette 1985, Long 1987). Many streams in second-growth forests have become progressively debris-impoverished following logging to the edge of the channel. Young riparian stands do not produce sufficient debris of the proper size and quality to replace material lost when channels are cleaned and the large preharvest debris gradually decays (Sedell et al. 1984, Andrus et al. 1988). The effect on fish habitat has been a decrease in channel complexity, in number and volume of pools, in quality of cover, and in capacity of streams to store and process organic matter."

Hogan, D. 1985. **The influence of large organic debris on channel morphology in Queen Charlotte Island streams.** Proceedings of the Western Association of Fish and Wildlife Agencies 64: 263-273.
From NACSI

Study area and methods

Study reaches were in higher-order streams in southeast Alaska and are not directly applicable to smaller, headwater streams.

Characteristics of LWD in streams

"Another feature of large organic debris arrangement is the tendency for material to accumulate into large clusters. To investigate this clustering, the study reaches were partitioned into zones with length equal to one bankfull width. The volume of material within each zone was calculated and the differences between these values and the mean volume for the entire reach were plotted...Although the study reaches are relatively short it is possible to consider the implications of the orientation and clustering studies...Large woody debris appears to accumulate into clusters which range between 3 and 4 widths apart in unlogged channels. Pool and riffle spacing appear to be slightly less than the cluster spacing. These patterns could be duplicated in attempts to rehabilitate disturbed stream channels."

Functions and influences on stream channels

"Large organic debris influences several channel features; its effect on channel gradient, depth and width will be considered here...in both [logged and unlogged] stream types large organic debris exerts considerable control over the long profile. In unlogged streams, slope is adjusted to a combination of log jams and discrete debris steps while in logged channels, slope is influenced primarily by log jams. The stability of the unlogged channel is increased because sediment is stored more evenly along the channel and the many log steps and minor jams buffer the effects of large flood flows and failure of individual barriers. Large floods in logged channels may displace infrequent debris obstructions resulting in major redistribution of sediment."

"This study indicates that although there is no difference in the number of large organic debris pieces between logged and unlogged basins, there is a shift towards smaller material in the former type. In third and fourth order streams, woody material has a tendency to be oriented diagonally across the stream with their large ends located against the downstream banks. Material tends to cluster at intervals of approximately 3 to 4 widths and the clusters tend not to exceed 2 widths in length. It has been shown that woody material influences channel gradient and stability, increases depth variability and causes local channel widening."

Hogan, D. L. 1986. **Channel morphology of unlogged, logged, and debris torrented streams in the Queen Charlotte Islands.** Land Management Report No. 49. Ministry of Forests and Lands, Vancouver, British Columbia**.**
From NCASI

Study area and methods

Study of ten stream channel reaches on Queen Charlotte Island in southeast Alaska. All channels had cobble or gravel beds and gradients less than 0.0500. Stream order ranged from third- to fifth-order (Strahler 1957). Mean bankfull width of study reaches ranged from 18.8 to 45.4 m. Reach lengths varied from approximately 200 to 460 m. LWD length and diameter (at both ends) was measured, volumes estimated, and pieces mapped. Decay (time in channel) was estimated using indicators such as bark, branches, and moss remaining on LWD pieces and the age of trees growing on in-channel pieces. The influence of LWD on channel morphology was documented. Additional measurements were taken related to longitudinal profiles, in-channel topography and bed configuration, and sediment characteristics. Detailed morphological studies were conducted in eight reaches: four unlogged, three logged, and one logged and debris-torrented. Study reaches were not headwater in nature, therefore this study is more relevant to higher-order, fishbearing streams.

House, R., V. Crispin, and J. M. Suther. 1991**. Habitat and channel changes after rehabilitation of two coastal streams in Oregon.** American Fisheries Society Symposium 10: 150-159.
From NCASI

Frequency and volume estimates

"Prior to treatment, three pieces of LWD per 100 m were located in the upper Nestucca River channel. Of those, only 0.4 piece per 100 m of stream was large enough to directly influence the channel. After treatment, the installation of structures increased the number of interventions that dammed or directly influenced the channel to 2.5 pieces per 100 m of stream. This is still only half the number of pieces influencing streams in undisturbed old-growth coniferous riparian zones (Sedell et al. 1982a)."

Keller, E. A., and F. J. Swanson. 1979. **Effects of large organic material on channel form and fluvial processes.** Earth Surface Processes 4: 361-380.
From NCASI

Effects of stream size on LWD

"Debris concentrations are highest in small headwater streams and generally decrease downstream, due to increased stream area per unit length and greater ability of wider streams and rivers to carry large debris to floodplains and downstream reaches."

"In small streams large debris will be located randomly where it initially fell, because even at peak flow these streams are too small to redistribute the relatively large pieces of debris. In western Oregon these conditions prevail in first- and second-order channels (Figure 3). Intermediate-sized channels are large enough to redistribute debris, frequently forming distinct accumulations that may directly affect the entire channel width (Figure 4). Large rivers (>fifth-order in western Oregon) generally have scattered large debris in the high water zone on banks (Figure 5) and large accumulations of debris set up on obstructions in the channel and on the outside of river bends. In these situations organic debris has little influence on a channel except at high flow conditions....These examples are taken from western Oregon, an area typified by large trees and high gradient streams that carry high annual runoff and flood flows."

Functions and influences on stream channels

"...in steep mountain streams the effects of debris jams are often considerably different [than those in meandering streams]. In many steep streams with little or no valley-flat, sediment storage behind obstructions to flow becomes significant; as does development of plunge pools immediately downstream from organic debris dams."

"Large organic debris is also important in steep mountain streams although its role differs somewhat from that played in low gradient streams. Morphology of steep mountain streams is commonly controlled by bedrock, boulders and large organic debris, whereas hydraulic factors that cause channels to meander are dominant in shaping low-gradient streams incised in easily eroded substrates..." Example of steep mountain stream is Watershed 2 Creek in Western Cascades of Oregon. Typical small steep stream of Pacific Northwest. Steep-walled valley with slopes averaging about 40 degrees. Channel gradient approximately 15 degrees "...and where not influenced by organic debris, bedrock is exposed in the streambed." Surrounded by oldgrowth Douglas-fir, western red cedar and western hemlock. Large debris may reside in the channel for over a century.

"Large debris in the channel has formed plunge pools downstream from logs and has trapped sediment upstream from obstructions...This is the opposite of conditions in the examples of low gradient meandering streams where the scour was in a similar location but stored sediment was primarily in midchannel bars downstream of the obstruction. Large debris in Watershed 2 Creek produces a stepped stream profile similar to that discussed by Heede (1972a). The water surface is relatively flat upstream of obstructions and steep going over them (Figure 12). Commonly in such small western Oregon streams 30 to 80 percent of the drop of the stream is influenced by debris and 20 to 35 percent of the stream area is occupied by woody debris. A stepped stream profile may result in dissipation of much of the stream's energy at debris-created falls and cascades which occupy a relatively small percentage of stream length."

"...debris-created stepped channel profile (organic stepping) with plunge pools and areas of sediment storage. The water-surface profile of the stream at low stage is somewhat analogous to that of a pool-riffle sequence. However, debris created stepping is probably more analogous to the stepped-bed morphology of channels in arid regions (Wertz 1966 and Bowman 1977). The average spacing of debris accumulations that deflect flow in five third-order Oregon streams have spacings of one to two channel

widths. This is similar to the spacing of Bowman's stepped-bed morphology, but is considerably less than the spacing of pools and riffles, which tend to average 5 to 7 times the channel width (Keller and Melhorn 1973)."

"The relative importance of large organic debris in affecting sediment storage and energy dissipation in streams decreases with channel slope. In low-gradient streams much in-channel storage occurs in point bars, riffles and floodplains. In steep streams these storage sites are often not present, and thus the large organic debris may account for a much larger portion of total sediment storage."

Keller, E. A., and A. MacDonald. 1983. **Large organic debris and anadromous fish habitat in the coastal redwood environment: the hydrologic system.** Technical Completion Report. Prepared by Department of Geological Sciences, University of California, Santa Barbara for California Water Resources Center, University of California, Davis.
From NCASI

Study area and methods

"Watersheds of Little Lost Man, Hayes, and Prairie Creeks support extensive old-growth redwood forest (*Sequoia sempervirens*) with minimal recent disturbance. In contrast, the Lost Man Creek basin above the USGS gaging station was 97% logged between World War II and the creation of Redwood National Park in 1968 (Iwatsubo et al. 1976)."

Retention/longevity in stream channels

"Residence time of redwood debris in stream channels can exceed 200 years (Keller and Tally 1979), and accumulations of Douglas fir are known to remain in channels for more than 100 years (Swanson et al. 1976)".

Effects of stream size on LWD

"The dominant process by which large organic debris may enter a stream channel depends upon local geologic and geomorphic conditions...In general, there is an inverse relationship between the stream size (measured in terms of upstream drainage basin area) and debris loading. This results because small streams tend to have narrow valleys, steep valley slopes, and a relatively high frequency of landslides, all of which tend to increase the debris loading. Marston (1982) reports a peak in the frequency of log steps (not total debris loading) in third order streams, resulting from the fact that the headward portions of streams often have narrow, V-shaped valleys in which there is little likelihood of trees actually falling in and blocking the thalweg...Tally (1980) indicates a good correlation...between debris loading and frequency of large trees within 50 m on either side of the channel."

"In larger streams, such as the lower portions of Redwood Creek, flood discharges are sufficient to float even the largest debris, and the residence time is therefore shorter."

Keller, E. A., and A. MacDonald. 1995. **River channel change: the role of large woody debris.** Pages 217-235 *in* A. Gurnell and G. Petts, editors. Changing river channels. John Wiley & Sons, Chichester, England.
From NCASI

Functions and influences on stream channels

Cited in Hughes (1997): "There is a considerable literature on the role of large woody debris in determining channel morphology particularly in headwater streams, and it has been well reviewed elsewhere (e.g., Gregory and Gurnell 1988, Gregory 1990, Gregory and Davis 1992, Keller and MacDonald 1995)."

The authors present a summary of the role of LWD regarding the influence to channel form and process, explain the findings of a LWD removal study conducted in the Prairie Creek basin (CA), and present an example of specific influence of log steps within one of the study reaches.

Lienkaemper, G. W., and F. J. Swanson. 1987**. Dynamics of large woody debris in streams in old-growth Douglas-fir forests.** Canadian Journal of Forest Research 17: 150-156.
From NCASI

"Transfer of large woody debris (> 10 cm diameter) from old-growth Douglas-fir...forests into five first- to fifth-order stream reaches (drainage areas of 0.1 to 60.5 km) has ranged from 2.0 to 8.8 Mg/ha/year in 7- to 9-year study periods. 2 Amounts of large debris in these streams range from 230 to 750 Mg/ha, with generally lower values in larger channels. The addition of woody debris is widely scattered in time and space and comes mainly from single trees rooted away from the streambank. We infer that wind is a major agent for entry of wood into these streams. Downstream movement of debris is strongly related to length of individual pieces; most pieces that moved were shorter than bankfull width."

"The highest reported quantities of woody debris (660 Mg/ha) are found in streams draining basins of less than 1000 ha and flowing through old-growth coastal redwood...stands in north coastal California (Keller et al. 1986 [*see Keller et al. 1995 in this list*]). Streams of similar size flowing through other types of old-growth coniferous forests in northwestern North America contain 100 to 300 Mg/ha (Harmon et al. 1986)."

Lisle, T. E. 1986. **Effects of woody debris on anadromous salmonid habitat, Prince of Wales Island, southeast Alaska.** North American Journal of Fisheries Management 6: 538-550.
From NCASI

"The effects of woody debris on anadromous salmonid habitat in eight streams on Prince of Wales Island, southeast Alaska, were investigated by comparing low-gradient (1-9%) first- or second-order streams flowing through either spruce-hemlock forests or 6-10-year-old clear-cuts, and by observing changes after debris was selectively removed from clear-cut reaches. Woody debris decreased the rate of shallowing as discharge decreased, thus helping to preserve living space for fish during critical low-flow periods. Debris dams were more frequent in clear-cut streams (14.9/100m), which contained more debris, than in forested streams (4.2/100m). As a result, total residual pool length (length when pools are filled with water but there is no flow) and length of channel with residual depth greater than 14 cm--the depth range occupied by 84% of Coho salmon--were greater in clear-cut streams than in forested streams. Greater volumes of woody debris in clear-cut streams produced greater storage of fine sediment

(<4 mm diameter) unless the stream gradient was sufficiently high to flush sediment from storage. One-half of the debris dams broke up or were newly formed over a 3-year period, which suggests that they usually released sediment and woody debris before the pools they formed were filled with sediment. Woody debris removal decreased debris-covered area, debris dam frequency, and hydraulic friction in some cases, but in others, these variables were unaffected or recovered within 2 years after erosion and adjustment of the streambed. No consistent differences in pool dimensions were found between treated and untreated clear-cut reaches. Comparisons of habitat in forested and clear-cut streams suggested that removing debris from clear-cut streams reduced salmonid carrying capacity. Retention and natural reformation of debris dams in cleared reaches prevented the expected deterioration of habitat. However, the removal and destabilization of existing woody debris may cause depletion of debris before riparian trees can regrow and furnish new material to the clear-cut streams."

Lorensen, T., C. Andrus, and J. Runyon. 1994**. The Oregon Forest Practices Act--water protection rules: scientific and policy considerations.** Oregon Department of Forestry, Forest Practices Policy Unit.
From NCASI

Functions and influences on stream channels

"Another key relationship is how the 'function' of large woody debris relates to stream size. Research (Bilby 1985) has found that length and diameter of stable woody debris in a stream is in part a function of channel width (Figure 6). Consistent with this, other research has found that large woody debris functions differently depending upon stream size and gradient. For example, most pools in small, low-gradient streams are step pools formed by individual pieces of wood; in larger streams, debris jams are common, and they form larger, scour-type pools."

MacDonald, L. H., A. W. Smart, and R. C. Wissmar. 1991. **Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. Report No. 910/9-91-001.** U. S. Environmental Protection Agency, Region 10, Seattle, Washington and Center for Streamside Studies, University of Washington, Seattle.
From NCASI

Recruitment mechanisms

"The length of time needed for riparian areas to produce LWD after harvest depends upon the size of the stream. Measurable contributions of wood from second-growth riparian areas did not occur until 60 years after harvest for third order channels on the Olympic Peninsula (Grette 1985). Bilby and Wasserman (1989) indicate that it takes longer than 70 years for streamside vegetation to provide stable material to streams wider than 15 m in southwestern Washington."

"Relatively little is known about the importance of upstream source areas for maintaining LWD in larger rivers. If upstream areas are an important source of LWD in downstream areas, any reduction in LWD in these smaller upstream channels could have important off-site impacts. However, the capacity of a system to transport wood

increases in a downstream direction. This suggests that on-site recruitment from the riparian area is the most likely source of stable LWD in larger rivers."

LWD standards

"Standards for LWD in streams have not been established for any state, although an attempt was made in the development of Washington's forest practice regulations to maintain wood levels at those seen in old-growth stands (Bilby and Wasserman 1989). However, LWD amounts and characteristics vary as a function of stream size, vegetation type, and other factors, thus inhibiting the establishment of strict numerical standards."

Best Management Practices for LWD

"Most Pacific Northwest states have established Best Management Practices (BMPs) to control the adverse effects of forest management on stream channels and riparian areas. The most recent revisions of these BMPs have incorporated provisions for retaining LWD in streams and ensuring a continuing supply from the riparian area. Approaches currently in use or being considered include defining strips along the stream in which no harvest is permitted (e.g., Alaska), establishing specific numbers of trees to be left along the stream (e.g., Washington), or establishing a minimum basal area which must be retained along the stream (e.g., Oregon)."

Marston, R. A. 1982. **The geomorphic significance of log steps in forest streams.** Annals of the Association of American Geographers 72: 99-108.
From NCASI

Functions and influences on stream channels

Marston found that log steps dissipated 6% of the stream's potential energy for streams along the central Oregon coast.

"Instream large woody debris that does not span the entire active channel and create a vertical drop of water surface elevation does not dissipate potential energy...Potential energy dissipation by log steps of 6 percent does not approach figures reported in the literature for other forest regions. In forest streams of the Colorado Rocky Mountains and White Mts. of Arizona, Heede (1972a, 1975, 1976) reports 50 to 100% dissipation of stream energy by log steps and gravel bars. Keller and Tally (1979) cite a range from 18 to 60% dissipation by log steps in Redwood Creek, CA. Bilby (1979) finds 10 to 52% dissipation in the White Mts. of New Hampshire. Energy dissipation of 30 to 80% and 32 to 52% are reported by Keller and Swanson (1979) and by Swanson et al. (1976), respectively, for the western Cascades of Oregon. A single previous study in the central Oregon Coast Range found only 4% dissipation of potential energy by log steps (Dietrich 1975)...the discrepancy ...may be attributed to the failure of past studies to distinguish dissipation of potential energy by log steps from dissipation of kinetic energy by instream LWD as it deflects streamflow and increases channel roughness."

Effects of stream size on LWD

"The highest concentration of log steps occurs in third-order streams at 3.97 per kilometer. Log steps created by natural treefall are most frequent in third-order streams. Though actual treefall may occur most often in first- and second-order streams, log steps do not fully develop because the typical 'V-notch' topography of steep stream-adjacent slopes prevents positioning of logs across the narrow channels. In fourth- and fifth-order streams, competent storm flows tend to remove instream large woody debris left from treefall before log steps can fully develop...The frequency of log steps created by debris

torrents decreases as stream order increases. Debris torrents originating in first-order streams leave log steps that remain stable in second- and third-order streams but are often breached by storm flows in fourth- and fifthorder streams."

McDade, M. H., F. J. Swanson, W. A. McKee, J. F. Franklin, and J. Van Sickle. 1990. **Source distances for coarse woody debris entering small streams in western Oregon and Washington.** Canadian Journal of Forest Research 20: 326-330.
From NCASI

"Coarse woody debris from streamside forests plays important biological and physical roles in stream ecosystems. The distance from stream bank to rooting site was determined for at least 30 fallen trees at each study site on 39 streams in the Cascades and Coast ranges of Oregon and Washington. The study sites varied in channel size (first- through thirdorder), side-slope steepness (3 to 40E), and age of surrounding forest (mature or old-growth stands). The distribution of distance from rooting sites to bank was similar among streams, with 11% of the total number of debris pieces originating from within 1 m of the channel and over 70% from within 20 m. Stands with taller trees (old-growth conifers) contributed coarse woody debris from greater distances than did stands with shorter (mature) trees."

Minore, D., and H. G. Weatherly. 1993. **Riparian trees, shrubs, and forest regeneration in the coastal mountains of Oregon.** New Forests 8: 249-263.
From NCASI

Cited in Morgan and Smith (1997): conifer basal area increased with elevation, gradient, time since disturbance, and distance from stream; decreased with stream width. Study was in Coast Range of Oregon, 22 study streams with gradients of from 2 to 40 percent.

Morgan, A., and D. Smith. 1997**. Trends in disturbance and recovery of selected salmonid habitat attributes related to forest practices.** TFW-AM9-97-002. Prepared by Northwest Indian Fisheries Commission for Timber Fish Wildlife Ambient Monitoring Program.
From NCASI

Recruitment mechanisms

Includes a good table summarizing recruitment ("delivery") processes and relative recruitment rates.

"Natural disturbances of in-channel LWD that move large amounts of LWD out of the channel are generally of two types; peak flows and debris flows. Large flow events can completely change the channel of a stream by relocating wood, large amounts of sediment, and even sometimes the channel itself. Large flows also increase recruitment of large woody debris from the riparian forest, the net effect being extremely variable and dependent on the characteristics of the peak flow event or cumulative effect of several events. For example, high flows that rise suddenly and drop equally quickly, often move some LWD to the channel margins, flush some out and recruit some resulting in small net changes to the total in-channel LWD volume.

Extended periods of high flow, however, often result in a decrease in volumes of in-channel LWD."

Munn, J. 1997. **Caspar Creek large organic debris. Unpublished report**. California Department of Forestry and Fire Protection, Sacramento.
From NCASI

Study area and methods

Report summarizes information on the accumulation of LWD from second-growth redwood and Douglas-fir stands in North Fork Caspar Creek watershed. This drainage has an area of 508-ha (1225 acres). Drainage area for the study site was 384 ha (926 acres). Old-growth forest was logged in late 1800s. Second-growth forest was logged in 1989 and completed in 1991, during which approximately 48% of the watershed within the study area was clearcut under rules generally the same as current California Forest Practice Rules for watercourse protection. LWD in a 1,850-m reach was measured in 1986 prior to logging (O'Connor and Ziemer 1989), in 1994 following logging (Surfleet and Ziemer 1996), and again in 1996 following a major windstorm (Keppeler 1996). LWD was defined as pieces > 10 cm diameter.

Recruitment rates

Assumption was made that all original in-channel LWD was removed during logging of original old-growth forest. "As a result, the 437 m /ha of effective and potential LOD measured in 1986 represents about 95 years of accumulation from 3 the second-growth stand. This gives an overall, average accumulation rate of approximately 4.6 m /ha per year, 3 assuming uniform, annual inputs. O'Connor and Ziemer (1989) assumed that the first 30 years of regrowth after oldgrowth logging contributed little LOD, resulting in an average accumulation rate of 5.3 m /ha. However, measuring 3 LOD that has accumulated over a 60-year, or longer, period is likely to underestimate the short-term input rate because the amount of new LOD is countered by some decay (loss) of older LOD. In addition, the recruitment of LOD perhaps follows a sigmoid curve with virtually no input during the first few years after channel and streamside zone clearing, then a steep increase in annual input for a number of years, followed by a flat (stable) rate as the stand matures. However, input of LOD is probably episodic in response to windstorms, fire, and disease."

"The effective and potential [effective LWD = within the active channel, up to 0.5 m above water surface or channel bed; potential = suspended 0.5 m or more above the channel, extending laterally 1 m beyond the vertical channel bank] LOD accumulation rate...for the 8 years between 1986 and 1994 was 9.6 m /ha per year, including any effects of the 3 1990 and 1991 logging operations. Because the rate of natural debris accumulation is likely to have been changing with stand age, as described above, this increase from the pre-logging rate cannot be attributed to the effects of harvesting

alone. And adding the additional 8 year LOD accumulation to the long-term average gives a rate of only 5.0 m /ha per 3 year for the longer 103 year period, which does not indicate a notable change in overall LOD recruitment."

"Between 1994 and 1996, debris entered the stream at the rate of 42 m /ha per year, which is more than 4 times the rate 3 observed during the previous 8 years. This substantial increase was probably caused by the severe windstorms of 1995,

and may have been promoted by openings created along the margins of WLPZs adjacent to the harvest units. Unfortunately, the interactions of this major climatic event with potential management impacts prevents using the available data summaries to estimate the effects of timber harvesting on the long-term LOD accumulation rate."

"The total North Fork LOD accumulations of 437 m /ha for the pre-logging period and 598 m /ha in 1996 compare 3 3 favorably with the values of 434 and 980 m /ha reported for old-growth stands with similar drainage areas in Prairie 3 Creek (570 ha) and Little Lost Man Creek (409 ha), respectively (Keller and Tally 1979). This comparison may not be exact, however, because it is not clear what portion of the channel was used for measuring LOD in this earlier study. And it is more likely that more of the LOD volume in old-growth stands is from larger diameter pieces."
"The North Fork LOD studies indicate that 100-year old, second-growth stands can accumulate total amounts of LOD that are similar to LOD volumes found in the channels of streams in old-growth forests with similar drainage area. However, it is likely that a higher proportion of LOD in the North Fork is composed of smaller diameter material."

"The current, natural LOD accumulation rate in the North Fork lies somewhere between 4.6 and 9.6 m /ha per year. 3 This brackets the rates for the 1986, pre-logging average and the 1986 to 1994 period that includes both natural recruitment from the now mature stands and the impacts of the 1990 through 1991 harvesting...Because of likely changes in accumulation rates during the development of the second-growth stand and potential interactions between harvesting impacts and the 1995 windstorm, the effect of logging operations on LOD accumulation cannot be distinguished from any of the current data summaries."

Murphy, M. L., and K. V. Koski. 1989**. Input and depletion of woody debris in Alaska streams and implications for streamside management.** North American Journal of Fisheries Management 9: 427-436.
From NCASI

"Debris was inventoried in a variety of stream types in undisturbed old-growth forest...A model of changes in LWD after timber harvest (which accounted for depletion of LWD and input from second-growth forest) indicated that 90 years after clear-cut logging without a stream-side buffer strip large LWD would be reduced by 70% and recovery to prelogging levels would take more than 250 years. Because nearly all LWD is derived from within 30 m of the stream, the use of a 30-m wide, unlogged buffer strip along both sides of the stream during timber harvest should maintain LWD."

Nakamura, F., and F. J. Swanson. 1993**. Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon.** Earth Surface Processes and Landforms 18: 43-61.
From NCASI

Study area and methods

Watershed areas ranged from 0.96 to 10.7 in 4 of the study streams (these four were second- and third-order streams). Average channel width for these 4 streams ranged 7.6 to 18.1 m. Gradients ranged from 7 to 21 percent.

Effects of stream size on LWD

"Most fallen trees appear to suffer breakage prior to interacting with low-order stream channels. We hypothesize that breakage of key-CWD decreases with increase in stream order, because steep sideslopes bordering low-order channels and streambanks and steps between terrace levels commonly cause breakage upon impact."

Recruitment mechanisms

"...CWD is delivered primarily by windthrow and landslides in steep, narrow, low-order streams...The historical record in the Lookout Creek basin indicates that, in general, debris flows initiate in channel heads and steep, narrow streambeds, entrain CWD and sediment, flush materials downstream, and deposit piles of CWD along low-gradient channels and on alluvial fans formed at junctions with mainstem channels."

"Key-CWD in medium- and high-order streams is primarily supplied by tree-fall, but occasionally key-CWD pieces are supplied from upstream areas when CWD leaves a relatively wide, unconstrained reach and becomes trapped in a narrower, constrained reach. Alternatively, most CWD pieces that move from a constrained to a wider, unconstrained reach are left scattered over gravel bars and floodplains..."

O'Connor, M. D., and R. R. Ziemer. 1989. **Coarse woody debris ecology in a second-growth *Sequoia sempervirens* forest stream.** General Technical Report PSW-110. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Arcata, California.

From NCASI

Recruitment mechanisms

"In the effective zone and its pool-associated component, windthrow and logging contributed approximately equal proportions of CWD. Bank erosion contributed about as many pieces of CWD as windthrow and logging combined."

"...most CWD volume in the potential zone (60 percent) was windthrown fir. Many fallen trees uprooted from the lower slopes of the inner gorge criss-crossed the valley floor and were suspended above the stream channel."

"We attribute [LWD distribution within the valley and channel] in large part to the dimensions of the stream channel and the mechanics of tree fall. Because the channel lies within the vertical streambanks 1 to 2 m high, many trees fall across the channel and remain suspended above it. Trees falling from greater horizontal distances are less likely to be suspended above the channel because their upper trunks shatter or are not supported by the opposite bank. Tree trunks broken into lengths less than or equal to the width of the channel (4 to 5 m) are more likely to enter the effective zone.
Trees falling parallel to the channel have a better chance of entering the effective zone because they do not have support points on both banks. Trees succumbing to bank erosion are likely to enter the effective zone."

Debris jams

"Debris jams, which develop after CWD input, are of equal or greater importance than direct input processes (windthrow and bank erosion) as pool-associated debris. Debris jams accounted for 27 percent of the volume and 56% of the pieces of pool-associated CWD."

Characteristics of pool-forming pieces

"Diameter and length affected the likelihood of CWD being associated with pools and being transported by the stream. Mean length, mean diameter, and mean volume of CWD was significantly greater, at the 95% level of confidence, when associated with pools than when it was not. The mean volume of CWD associated with pools was 0.17 m compared 3 with 0.07 m for CWD not associated with pools." 3 "CWD entering the effective zone tends to become pool-associated in these situations: when the piece is massive and is situated such that a pool is formed by scour, if the piece becomes lodged in a debris jam which in turns causes bed-scour and pool formation, or if the piece happens to fall directly into an existing pool. Circumstances in which CWD is associated with pools are limited due to the precise placement required to form pools."

Retention/longevity in stream channels

"Mobile CWD had significantly smaller mean values of length, diameter, and volume than non-mobile CWD. The mean volume of mobile CWD was 0.06 m , compared with 0.16 m for non-mobile CWD."

Frequency and volume estimates

"The mean density of CWD in Caspar Creek, 339 m /ha (combined potential and effective zones), is less than that for 3 many streams in old-growth redwood forest. Mean CWD for 12 sample reaches in Redwood National Park were reported by Keller and others (in press) to be 1590 m /ha. The densities ranged from 240 m /ha to 4500 m /ha. The CWD density we measured in Caspar Creek is comparable to that for *P. menziesii* old-growth forest streams in the Klamath Mountains--mean of 282 m /ha and range from 10 m /ha to 1200 m /ha for 11 sample reaches (Harmon and others 1986)."

Percent of LWD associated with pools

"The distribution of CWD can be visualized as follows: of each 10 m of CWD within the limits of the valley floor, 3 about 2.5 m are in the potential zone, 1.2 m are in the effective zone, and 6.3 m are lying on that portion of the valley floor outside of these two zones. Within the effective zone, 0.7 m of CWD are associated with pools."

O'Connor, M. 1996**. Sediment production, transport and routing.** Pages 22-26 *in* Type 4 & 5 waters workshop. Timber/Fish/Wildlife Report TFW-WQ20-96-001. Washington Forest Protection Association, Olympia.

From NCASI

Most of this presentation dealt with large woody debris in terms of its sediment storage functions.

Debris torrents

"Another important function of Type 4 & 5 channels may be accumulation of wood (and sediment) for eventual delivery to fish-bearing streams by debris flow. Where debris flows are an important process, debris flow is a major mechanism delivering wood to fish-bearing channels."

Recruitment rates

O'Connor lists two major information gaps in his presentation: (1) wood recruitment and wood dam dynamics, and (2) Type 4 & 5 processes in eastern Washington. Regarding (1), O'Connor states "Rates of recruitment of wood, dam frequency, and processes of formation and failure of dams are not well-quantified. These data are critical to simulation models for sediment routing. There is also little sediment

transport or streamflow data for these types of streams. The spatial and temporal variation of wood dams has been quantified in few areas."

Peterson, N. P., A. Hendry, and T. P. Quinn. 1992**. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions.**
Timber/Fish/Wildlife Report No. TFW-F3-92-001. Prepared by Center for Streamside Studies, University of Washington, Seattle for the Washington Department of Natural Resources and Cooperative Monitoring Evaluation and Research Committee, Olympia.
From NCASI

This is a very good source of information since it reviews lots of recent articles and reports: Bilby and Ward 1989, 1991; Bilby and Wasserman 1989; Robison and Beschta 1990a; Murphy and Koski 1989; Fox 1992; Ralph et al. 1994; Triska and Cromack 1980; Bisson et al. 1987...

Effects of forest management on LWD

"Reductions in LWD frequency and volume have been directly attributed to forest practices (Grette 1985; Heifetz et al. 1986; Lisle 1986; Murphy and Koski 1989; Bilby and Ward 1991). Logging can also change channel orientation and distribution of LWD in streams (Hogan 1986; Tripp and Poulin 1986a), often resulting in the accumulation of large, infrequently spaced debris jams (Bryant 1980; Bisson et al. 1987; Potts and Anderson 1990)..."

"In some instances, LWD frequency is reduced in streams draining managed forests (Bilby and Ward 1991; Figure 6) and in others the difference is not detectable (Ralph et al. (in prep.); Figure 7). However, due to recruitment from mature coniferous riparian stands, unmanaged forests have larger average debris sizes (Andrus et al. 1988; Ralph et al.(in prep.); Figure 8). These larger pieces tend to be more stable (Lienkaemper and Swanson 1987) and do not decay as fast (Anderson et al. 1978). For these reasons debris volume may be an important indicator of the energy buffering capacity of streams and the effect of logging on this capacity. To detect the multiple impacts of forest practices on LWD loading, we use LWD frequency in pieces per channel width and debris volume index as units for the establishment of target conditions."

Effects of stream size on LWD

"Some research has indicated that LWD frequency decreases with increasing channel width (Figure 6) while other studies show the opposite trend (Figure 7) (Tables 2a and 2b). Gradient and channel width tend to vary simultaneously and it is difficult to see a clear effect of gradient on LWD loading (Tables 3a and 3b). The average diameter, length and volume of individual pieces of wood increases with stream size (Bilby and Ward 1987, 1989, 1991; Robison and Beschta 1990a). As channel width increases, debris jams become larger, less frequent and more closely associated with the stream margins (Triska and Cromack 1980, Bisson et al. 1987)."

Frequency and volume estimates

"Large woody debris frequency in streams draining unmanaged watersheds is highly variable (Tables 2a and 2b; Figure 7). One of the most complete data sets for unmanaged Washington streams is that of Bilby and Ward (1989) and target conditions have been set using their channel width dependent regression. A conversion of these

data to pieces per channel width was performed to plainly display LWD loading for streams of different size. This conversion indicates that LWD frequency ranges from 2.44 pieces per channel width to 2.03 pieces per channel width as bank full width increases from 4 m to 19 m (Table 2a-column 1). Use of Bilby and Ward's (1989) regression equation to predict LWD loadings for streams of other sizes is not appropriate. Bilby and Wasserman (1989) indicate that LWD frequencies are similar in unmanaged sites in eastern Washington and other authors document similar or higher values in channels wider than 5 m (Table 2a). The higher values of Robison and Beschta (1990a) and Murphy and Koski (1989) may, in part, be due to the use of a smaller minimum length criterion in these studies (1.5 m and 1 m, respectively)."

Effects of stream size on LWD

"One notable inconsistency in the existing literature for unmanaged stream systems is the effect of channel width on LWD frequency (Tables 2a and 2b). Data from western Washington suggest a decrease in LWD frequency with increasing channel width (Bilby and Ward 1989, 1991; Figure 6), however, most other research in unmanaged systems demonstrates an opposite trend (Murphy and Koski 1989; Robison and Beschta 1990a; Fox 1992; Ralph et al. (in prep.); Fig 7). While LWD size criteria differ between these studies (Table 4), both smaller and larger size criteria than those of Bilby and Ward (1989, 1991) were used. Bilby and Ward's (1989) and Ralph et al.'s (in prep.) streams had a wide range of gradients (1-18%) while those examined in Alaska did not have gradients >3% (Murphy and Koski 1989; Robison and Beschta 1990a). Streams examined in Mt Rainier National Forest also had a wide range of gradients (2- 14%) (Fox 1992). Thus, the apparent inconsistency in LWD frequency trends by channel width cannot easily be explained and has yet to be thoroughly examined."

Potts, D.F., Anderson, B.K.M. 1990. **Organic debris and the management of small stream channels.** Western Journal of Applied Forestry 5 (1):25-28.

Keywords : organic debris; management; debris; sediment; perennial stream; organic matter; timber harvest; woody debris

Longitudinal profiles, riparian and in-channel debris loads, and sediment storage were measured in eight reaches of first to third order, snowmelt-dominated, intermittent, and perennial streams in western Montana. Low-order channels tended to concentrate debris. Organic matter provided over 60% of total sediment storage in all study reaches. We suggest that Streamside Management Zones (SMZs) be extended to include intermittent channels and possibly the lowest portion of ephemeral channels in anticipation of their activation. Predisturbance appraisal of downed woody fuels in these SMZs is recommended to provide a target debris loading during site preparation thus ensuring a steady-state supply of organic materials to maintain channel stability following timber harvest.

Rainville, R. P., S. C. Rainville, and E. L. Lider. 1986. **Riparian silviculture strategies for fish habitat emphasis.** Pages 23-33 in Silviculture for wildlife and fish: a time for leadership. Proceedings of the 1985 Technical Section of the Wildlife and Fish Ecology Working Group. SAF86-07. Society of American Foresters, Bethesda, Maryland.

From NCASI

Cited in Van Sickle and Gregory (1990): "Rainville et al. (1986) produced probabilistic estimates of the number of trees per decade falling into stream channels for three western coniferous habitat types. When coupled with a dynamic model of stand growth and management, their model provides long-term projections of LWD loading into streams."

Ralph, S. C., G. C. Poole, L. L. Conquest, and R. J. Naiman. 1994. **Stream channel morphology and woody debris in logged and unlogged basins of western Washington.** Canadian Journal of Fisheries and Aquatic Sciences 51: 37-51.
From NCASI

"Channel morphology and habitat characteristics of stream segments draining unharvested old-growth forests were compared with those from streams within intensively and moderately logged basins. Sites covered a broad geographic range in western Washington State and were stratified by basin area and channel gradient. Although the number of pieces of LWD within stream channels was unaffected by timber harvest, there was a clear reduction in LWD size in harvested basins. Timber harvest also resulted in a shift in location of LWD towards the channel margins, outside the low-flow wetted width of the channel. Intensive harvest simplified channel habitat by increasing riffle area and reducing pool area and depth, although the commonly used index of pool-to-riffle ratio appears inadequate to document these changes. Given the natural variation from stream to stream, we conclude that simple counts of instream LWD and channel units (habitat types) are not useful as management objectives. Instead, these attributes should be used collectively as indicators of the complexity and stability of in-stream habitat with respect to the specific channel and valley geomorphology."

Reid, L.M. and Ziemer, R.R. **Evaluating the biological significance of intermittent streams.** 5-4-1994.

Keywords: ***intermittent streams***/ ecosystems/ evaluation/ management/ riparian habitat

Intermittent streams are those with discernible channels which show evidence of annual deposition or scour, but which do not carry flow year-round. Intermittent streams were not consistently protected from land-use disturbances in the past. Tractors occasionally used them as skid roads, and trees were commonly yarded across them. These sites frequently accumulated large volumes of logging debris and so were likely to support intense fires when units were burned.

Reid, L.M., Hilton, S. 1998. **Buffering the buffer.** p.15 **in** Conference on Coastal Watersheds: The Caspar Creek Story. California Department of Forestry and Fire Protection, USDA Forest Service, and University of California Cooperative Extension. Ukiah, California. 1998 May 06.

Keywords : buffer; core buffer; fringe buffer; riparian zone; tree fall; blow down; riparian zones; woody debris; watershed; streams; stream temperature; temperature; sediment; transport; floods; debris

Riparian buffer strips are widely accepted tool for helping to sustain aquatic ecosystems and to protect downstream resources and values in forested areas, but controversy persists over how wide a buffer strip is necessary. Riparian zones are important to adjacent in-stream ecosystems because they strongly influence the availability of food, distribution of stream temperatures, and form of channels, and they are important to downstream channels because they regulate sediment input and transport, moderate flood peaks, and provide organic material. Of these roles, that of maintaining appropriate channel form is particularly important. Woody debris is a critical physical component of forest-land channels, and the primary source of in-channel wood is forest stands adjacent to channels. To the extent that it is affected by woody debris, the physical integrity of stream channels is expected to be sustained if tree-fall rates and characteristics along buffered reaches are similar to those in undisturbed forests.

A study carried out along the North Fork of Caspar Creek addresses the width of riparian buffer needed to protect the physical integrity of the channel by determining (1) how far from a stream tree-fall can influence a channel, and (2) the distance over which a clearcut edge affects tree-fall rates. All downed trees and an equal number of randomly selected standing trees were measured and described in 10 buffer-strip plots and 4 plots located in un-reentered second-growth. All standing and recently downed trees were then mapped in 12 of these and in three additional plots. A major windstorm occurred shortly after mapping was completed, and all newly downed trees that influenced the channel were inventoried along 4 km of North Fork Caspar Creek.

Results show that all tree-fall related sediment inputs and most woody debris inputs to Caspar Creek are generated by tree-fall within a tree's height of the channel. However, about 30% of those tree-falls are triggered by trees falling from further upslope, suggesting that the core zone over which natural rates of tree-fall would need to be sustained is wider than previously assumed. A no-cut buffer of 1.1 tree heights' width would be needed to maintain 96% of the potential input frequency of wood to the stream in a steady-state condition. Most trees fell downhill, a pattern which enhances the relative importance of sources farther from the creek.

An additional width of "fringe" buffer is necessary to protect the core buffer from accelerated rates of tree-fall caused by the presence of the clearcut edge, and this width depends on the rate at which tree-fall rates decline with distance from a forest edge. Analysis of the distribution of tree-falls in buffer strips and un-reentered stream-side forests along the North Fork of Caspar Creek suggests that rates of tree-fall are abnormally high for a distance of at least 200 m from the edge. The appropriate width of fringe buffer needed to protect the core zone will need to b determined from analysis of the long-term effects and significance of accelerated tree-fall rates immediately following logging.

Richmond, A. D., and K. D. Fausch. 1995. **Characteristics and function of large woody debris in subalpine Rocky Mountain streams in northern Colorado.** Canadian Journal of Fisheries and Aquatic Sciences 52: 1789-1802.

From NCASI

Majority of pools (76%) were plunge and dammed pools formed by LWD, most of which spanned the channels perpendicular to stream flow. Smaller streams have greater proportion of such perpendicular pool-forming pieces than larger streams. Pieces in larger undisturbed streams were more often located at stream margins, oriented diagonally, or distributed in clumps than in smaller streams. Pools made up 11-22% of wetted area in all but one low-gradient stream.

Robison, E. G., and R. L. Beschta. 1990a. **Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA.** Canadian Journal of Fisheries and Aquatic Sciences 47: 1684-1693.
From NCASI

"Coarse woody debris (>0.2 m in diameter and 1.5 m long) was measured along five undisturbed low-gradient stream reaches; volume, decay class, and horizontal orientation in relation to channel flow of first-, second, third-, and fourthorder coastal streams were determined. Debris was also classified into four influence zones based on stream hydraulics and fish habitat. Average debris length, diameter, and volume per piece increased with stream size. Eighty percent of debris volume of the first-order and the smaller second-order streams was suspended above or lying outside the bankfull channel, while less than 40% was similarly positioned in the fourth-order stream. Approximately one-third of all debris was oriented perpendicular to stream flow, regardless of stream size. First-, second-, and third-order streams had a higher proportion of recent debris in the channel than the fourth-order stream (>19 vs. 8%) ...Tree blowdown had a major influence on debris distribution along the smaller stream reaches. Debris jams and accumulations in the largest stream were formed from floated debris..."

Robison, E. G., and R. L. Beschta. 1990b. **Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, U. S. A.** Earth Surface Processes and Landforms 15: 149-156.
From NCASI

"Coarse woody debris and channel morphology were evaluated for five low-gradient streams that ranged from first to fourth order (0.7 to 55 km watershed area). Debris volumes were directly related to variations in bankfull width. 2 Woody debris was associated with 65 to 75 per cent of all pools and the relative proportion of types of pools (i.e. plunge, lateral scour, etc.) varied with stream size. High variability in channel depths and widths was common. The results provide benchmark values of woody debris loadings and channel morphology for undisturbed coastal Alaska systems."
"Coarse woody debris loadings generally increased with stream size (Table 1). The number of debris pieces per 100 m averaged 25 for the two smaller streams and 39 for the three larger streams. The volumes of debris in Zone 1 and 2 per 100 m of channel surface area at bankfull flow ranged from 1.5 m for the two smaller streams to 2.3 m for the largest 2 3 3 stream. These volumes index the amount of wood that is impeding and altering current patterns during bankfull flow."

"Our results indicate that the interaction between woody debris and stream morphology changes with stream size. For example, there are relatively few deflector pools on the smallest and largest streams but in the medium sized streams approximately one quarter of all channel units are deflector pools related to debris. Thus, stream structures that are installed for enhancing fish production should be designed not just to create pools, but to create the types of pools that would occur naturally in that size of stream."

Robison, E. G., and R. L. Beschta. 1990c**. Identifying trees in riparian areas that can provide coarse woody debris to streams.** Forest Science 36: 790-801.
From NCASI

Recruitment rates

"The purpose of this paper: (1) to present a method for determining probability that a tree, upon falling, will provide coarse woody debris to a stream and (2) to relate this probability to the basal area factor (BAF) obtained by a wedge device or prism so that specific leave trees can be easily and consistently selected in the field."

"Analysis of downed timber on 17–70% hillslopes in the Oregon Cascades (R. L. Beshta, unpubl. data) indicate that the probability of a tree falling downslope is greater than 75%. If a similar condition exists for trees in riparian areas, the probabilities presented later in this paper would underestimate actual values for streams with sideslopes."

"In this study, we assumed that a tree bole must be > 8 inches in top diameter *and* > 5 ft long for it to be considered as coarse woody debris."
For this methodology, the probability that a tree will be recruited into the stream channel is based on the tree species, height, and the distance from the active channel to the tree. Equal probability is given to a tree falling in any particular direction. Thus, the greatest probability that a tree will be recruited to a channel, upon falling, is 50% (i.e., when the tree is zero distance from the streambank). A species-specific tapering equation is used to determine tree height and the minimum length necessary for a tree to be recruited into the stream channel. Effective tree height is defined as that portion of a tree that qualifies as coarse woody debris (i.e., large enough to modify channel characteristics). An example of this methodology is explained for Douglas-fir.

Schuett-Hames, D., J. Ward, M. Fox, A. Pleus, and J. Light, editor. 1994. **Large woody debris survey module. *In* Ambient monitoring program manual. Timber/Fish/Wildlife Report No. TFW-AM9-94-001.** Prepared by Northwest Indian Fisheries Commission for Washington Department of Natural Resources, Olympia.
From NCASI

Methods

Three types of LWD are identified: logs, rootwads, and large debris jams. Logs (based on definition of Bilby and Ward (1989, 1991): (1) must be dead or imminently dying), (2) have root system wholly or partially detached, no longer capable of supporting the log's weight, (3) have diameter of at least 10 cm for at least 2 m of its length, (4) intrude into the bankfull channel.

Rootwads: (1) must be less than 2 m long (except for old-growth stumps) and have root system attached, (2) must be at least 20 cm diameter at base of stem where it meets the roots, (3) must have roots that are detached from their original
position on the floodplain or terrace; and/or the rootwad has the ability to fall over, (4) must intrude into the bankfull channel.

Large Debris Jams: Defined as accumulations of 10 or more qualifying logs or rootwads that are in contact with one another. Each qualifying piece must meet the minimum size criteria and must intrude into Zone 1, 2, or 3. While smaller accumulations may sometimes function as debris jams, they are not counted as "large debris jams".

Channel location: System (based on Robison and Beschta 1991) consists of four location zones or categories: *Zone 1* = the wetted low flow channel, defined as the area under water at the time of the survey. *Zone 2* = the area within the influence of the bankfull flow. This zone is within the perimeter of the bankfull channel and below the elevation of the water at bankfull flow (excluding areas defined as Zone 1). Zone 2 includes areas such as gravel bars that are exposed at low flow. *Zone 3* = the area directly above (vertically) the bankfull channel--from the bankfull flow waterline upwards indefinitely.

This zone includes pieces that extend out over the channel but are suspended above the elevation of the water at bankfull flow. *Zone 4* = the area outside the bankfull channel perimeter. This zone includes the upper banks and riparian areas not directly influenced by bankfull flows.

"Collecting information on LWD pieces in Zone 1 and 2 is important because they interact with the stream during bankfull (channel-forming) flows. These pieces can play an important role in formation of pool habitat and creation of habitat diversity during these events. They also play an important role in regulating sediment transport, routing and storage and can control the abundance and distribution of spawning gravels in some stream segments. Pieces or portion of pieces in Zone 1 also provide critical cover for salmonids during summer low flows. Pieces (especially accumulations) in both Zone 1 and 2 provide critical winter refuge habitat for juvenile Coho salmon during freshets...Collecting information on portions of LWD pieces in Zone 3, although they do not affect a stream hydraulically, can provide information on cover quality, LWD recruitment resources to the channel, and identify key pieces which are causing debris accumulations or jams. Collecting information on portions of LWD pieces in Zone 4 is important because their size or placement often act as anchors for the portions within the bankfull channel as well as provide potential recruitment into the channel."
Information on measuring lengths by channel location is given on page 11-12.

Retention/longevity in stream channels

"A root system is defined as having increased stability at bankfull flow due to the presence of roots or a rootball. Buried is defined as having increased stability at bankfull flow due to complete burial of either end or lateral burial of 50% or more of the piece. Pinned is defined as having increased stability at bankfull flows due to having another qualifying LWD piece on top of it, or due to being pegged between other logs, standing trees, or bedrock...If none of the above stability factors are present, then the piece is considered unstable."

Sedell, J. R. 1984. **Habitats and salmonid distribution in pristine, sediment-rich river valley systems: S. Fork Hoh and Queets River, Olympic National Park. Pages 33-46 in W. R. Meehan, T. R. Merrell Jr. and T. A. Hanley, editors. Fish and wildlife relationships in old-growth forests**. American Institute of Fishery Research Biologists, Juneau, Alaska.
From NCASI

Cited in House et al. (1991): "In undisturbed valley-wall channels of the South Fork [Hoh] River, Washington, Sedell et al. (1982, 1984) found that five (1982) and four (1984) pieces of LWD per 100 m of stream, respectively, either dammed the channel or directly influenced it by creating pool habitat." This represents the number of pieces influencing streams in undisturbed old-growth coniferous riparian zones.

Sedell, J. R., and F. J. Swanson. 1984**. Ecological characteristics of streams in old-growth forests of the Pacific Northwest. Pages 9-16 *in* W. R. Meehan, T. R. Merrell Jr and T. A. Hanley, editors. Fish and wildlife relationships in old-growth forests.** American Institute of Fishery Research Biologists, Juneau, Alaska.
From NCASI

This is a more general review with little specific information on headwater streams. Discusses role of fire in old-growth forest systems and effects on in-channel LWD: "Even where fires burn across valley floors and riparian zones, the structural influence of the forest is retained because most of these fires consume little of the large wood pieces. Old burns usually contain numerous snags. Swanson and Lienkaemper (1978) examined organic debris loading in streams flowing through stands that are in different stages of recovery following major wildfire. They observed that large organic debris in small- and intermediate-sized streams may persist for long periods, enen through the period of stand reestablishment following wildfire (Fig. 2). The large wood component continues to influence and shape stream channels until the post-fire stand begins to produce large woody debris."

Sedell, J. R., and R. L. Beschta. 1991. **Bringing back the "bio" in engineering.** American Fisheries Society Symposium 10: 160-175.
From NCASI

Functions and influences on stream channels

"Woody debris and snags in streams act to (1) create and maintain pools, (2) cause local reductions in stream velocities that serve as foraging sites for fish feeding on drifting food items, (3) form eddies where food organisms are concentrated, (4) supply protection from predators, (5) provide shelter during winter high flows, (6) trap and store organic inputs from streamside forests, enabling them to be biologically processed (a key link in the food chain of salmonids of the Pacific Northwest and Alaska)."

Habitat restoration

"In many instances, structures may only represent stopgap measures until suitable vegetation diversity and size return...Yet management prescriptions designed to make streamside vegetation ecologically and biologically diverse are generally lacking.

Ecological diversity can provide the structural diversity of dead wood, different canopy heights, and a varied vegetative community. However, maintaining biological diversity and habitat for fish species in managed watersheds may involve much more than setting aside strips of riparian vegetation. For example, additional research and administrative studies are needed to understand how various tree species, root systems, debris sizes, etc., function through time with channels of different widths, gradients, and valley form. Such information is necessary to aid decisions regarding where, what kind, and how many trees (or shrubs) are to be selectively planted or maintained in riparian areas to optimize fish habitat requirements over the long term. This is obviously a major challenge...For a wide variety of resource values, including fisheries, reestablishing the functional attributes of streamside vegetation is crucial to improving the bank characteristics and riparian conditions for streams and rivers..."

Smith, R. D., R. C. Sidle, P. E. Porter, and J. R. Noel. 1993a. **Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream.** Journal of Hydrology 152: 153-178.
From NCASI

"Experimental removal of woody debris from a small, gravel-bed stream in a forested basin resulted in dramatic redistribution of bed sediment and changes in bed topography. Removal of debris changed the primary flow path, thereby altering the size and location of bars and pools and causing local bank erosion and channel widening. Marked bed adjustments occurred almost immediately following experimental treatment in May 1987 and continued through to the end of the study period in 1991. Increased bed material mobility was attributable to destabilization of sediment storage sites by removal of debris buttresses, elimination of low-energy, backwater environments related to debris, and an inferred increase in boundary shear stress resulting from the removal of debris related flow resistance. In contrast to these changes, which favored sediment mobilization, deposition was favored by the elimination of debris-related scouring turbulence and by increased flow resistance from a developing sequence of alternate bars. A more regularly spaced sequence of alternate bars replaced the pretreatment bar sequence, whose location, size, and shape had been strongly influenced by large woody debris as well as by bank projections and channel curvature. Following initial readjustment of the stream bed during the first posttreatment year, loss of scouring turbulence and increased flow resistance from alternate bars resulted in deposition of approximately 44 m of sediment within the 96 m 3 study reach. The loss of 5.2 m to bank erosion left a net increase in sediment storage of 39 m . Mean spacing of 3 3 thalweg cross-overs and pools did not change measurably following debris removal, although variability of spacing between thalweg cross-overs tended to decrease with time as the location of bars stabilized. No consistent pattern of change in mean residual depth of pools or in distribution of depths occurred within the first 4 years following debris removal."

Smith, R. D., R. C. Sidle, and P. E. Porter. 1993b. **Effects on bedload transport of experimental removal of woody debris from a forest gravel-bed stream.** Earth Surface Processes and Landforms 18: 455-468.
From NCASI

"Experimental removal of woody debris from a small, gravel-bed stream in a forested area resulted in a four-fold increase in bedload transport at bankfull discharge. This was caused by increased transportability of sediment previously stored upslope of debris buttresses or in low-energy hydraulic environments related to debris. Bank erosion delivered additional sediment to the channel, and transport energy was increased by an inferred increase in the component of total boundary shear stress affecting grains on the bed. Increased transport following debris removal in May 1987 continued throughout the entire autumn storm season through late November 1987, indicating persistent adjustment of the stream bed and banks despite marked response to earlier flows as large as bankfull. Stream bed adjustments included development of a semi-regular sequence of alternate bars and pools, many of which were spaced independently of former pool locations."

"Increased transport and redistribution of sediment formerly in storage sites stabilized by woody debris, resulted in stream bed adjustments along the entire debris-removal reach. These included development of a semi-regular sequence of alternate bars. Similar sequences are common in streams without the dominant influence of large, in-channel obstructions such as woody debris (Leopold et al. 1964, p. 203; Church and Jones 1982; Ikeda 1984). Some pools were dramatically altered by debris removal. In an extreme example, nearly 0.7 m of aggradation, which is more than the mean bankfull depth, occurred by May 1991 at what had been the deepest point in one pool."

"Results of this study indicated that major reductions in woody debris loading in forest streams can, at least temporarily, result in increased bedload transport and, by inference, increased deposition in downstream storage sites...Increased deposition at downstream sites can damage incubating salmonid eggs if infiltration of fines reduces oxygen availability below optimum levels or if escapement of fry is physically impeded (Everest et al. 1987). In addition to scour, increased grain shear stress may cause coarsening of the channel bed and banks, potentially altering habitat or the ability of fish to excavate the bed."

Sollins, P. 1982. **Input and decay of coarse woody debris in coniferous stands in western Oregon and Washington.** Canadian Journal of Forest Research 12: 18-28. **From NCASI**

Study area and methods

Measured biomass of standing and fallen coarse wood in old-growth forest plots (terrestrial habitats). May be of use in developing recruitment models for in-channel and riparian LWD or comparing biomass of downed wood between managed and unmanaged stands. Has good description of decay classification and stages on p. 26 for terrestrial downed wood.

Spence, B. C., G. A. Lomnicky, R. M. Hughes, and R. P. Novitzki. 1996. **An ecosystem approach to salmonid conservation. Part II: Planning elements and monitoring strategies**. Draft Report No. TR-501-96-6057. Management Technology.
From NCASI

Important physical, chemical, and biological processes affecting salmonids and their habitats include the following: [physical-chemical] morphological development of stream channels, sediment transport, hydrology, heat transfer in streams, nutrient cycling, and various functions provided by standing or downed riparian vegetation (e.g., bank stabilization, sediment control, shading, coarse and fine organic inputs, microclimate, physical structure, etc.); [biological] physiological and biological requirements of individual fish (e.g., food, space, migration routes), population level processes (e.g., local adaptation, life-history patterns and diversity), and community-level interactions (e.g. predator-prey, competitor, and disease-host relationships).

"Our review of the literature...revealed six specific functions of riparian zones that are essential to the development and maintenance of aquatic habitats favorable to salmonids. Riparian vegetation provides shade to stream channels, contributes large woody debris to streams, adds small organic matter to streams, stabilizes streambanks, controls sediment inputs from surface erosion, and regulates nutrient and pollutant inputs to streams. In addition to these functions that directly influence aquatic habitats, riparian areas are critical habitats for a variety of terrestrial and semiaquatic organisms and serve as migration or dispersion corridors for wildlife species (FEMAT 1993). Many of these benefits derive from the availability of water and unique microclimates in these zones."

"In constrained reaches, the active stream channel remains relatively stable through time and riparian zones of influence may be defined based on site-potential tree heights and distance from the active channel.

Stack, W. R., and R. L. Beschta. 1989. **Factors influencing pool morphology in Oregon coastal streams. Pages 401-411 *in* W. W. Woessner and D. F. Potts, editors. Proceedings of the symposium on headwaters hydrology**. American Water Resources Association, Bethesda, Maryland.
From NCASI

"Pool morphology and related stream characteristics were surveyed along 14 stream sections [the length of each section was approximately 70 bankfull channel widths] in the central Oregon Coast Range; six of the upstream watersheds were undisturbed and the remaining eight had a low degree of timber harvesting (i.e., < 20 % of the area). Watershed areas and channel gradients ranged from 1.3 to 17.3 km and from 0.5 to 5.6%, respectively. Residual pool volumes and the 2 number of residual pools were significantly ($p < 0.10$) correlated to drainage area...Processes associated with pool formation (e.g., plunge, deflection) were significantly correlated with the channel gradient; the direction of these correlations varied with the type of process. Certain elements associated with pool formation (i.e., woody debris and boulders) were significantly correlated with an index of total stream power; the percentage of wood-formed pools decreased as total stream power increased, whereas boulder-formed pools increased..." Because of their major effect on calculated pool volumes, beaver-influenced streams were initially separated from the data set to address the importance of other independent variables on pool size.

Sullivan, K., T. E. Lisle, C. A. Dolloff, G. E. Grant, and L. M. Reed. 1987. **Stream channels: the link between forests and fishes. Pages 39-96 *in* E. O. Salo and T. W.**

Cundy, editors. Streamside management: forestry and fishery interactions. College of Forest Resources, University of Washington, Seattle. Contribution No. 57.
From NCASI

Functions and influences on stream channels

"Large obstructions such as woody debris, boulders, and bedrock outcrops alter channel width, increasing the variation in velocity and depth in the vicinity of the obstruction and anchoring the position of pools."

"Woody debris forms abundant storage sites for sediment in forest streams as large as fourth order (20 to 50 km), where 2 storage is otherwise limited by steep gradients and confinement of channels between valley walls. Annual sediment yields from small forested watersheds are commonly less than 10% of the sediment stored in channels (Megahan and Nowlin 1976, Swanson and Lienkaemper 1978). In Redwood Creek, California, Pitlick (1981) found that woody debris in redwood-dominated tributaries stored 74% of the sediment in the channel and 56% of the sediment produced by recent landslides; debris in Douglas-fir dominated basins stored 37% of in-channel sediment and 8% of recent landslide material. Redwood-produced debris accounted for greater sediment storage, because it decomposes more slowly than logs from species found in Douglas-fir forests and thus was longer lasting and more abundant. Pearce and Watson (1983) found that a volume of sediment equivalent to 50 to 220 times the average annual input remained stored behind debris jams in a New Zealand stream five years after its introduction by a massive landsliding episode."

"Channel obstructions, ranging from single logs lying along a streambank to major bedrock bends, greatly diversify channel morphology and hydraulic conditions and add to channel stability (Keller and Swanson 1979). By influencing hydraulic conditions, these structural features store and sort sediment, enhance scour and deposition of the bed material, diversify velocity and depth, and fix the position of bars and pools (Lisle 1986). Consequently, structural elements are vitally important in managing forest watersheds to preserve fish habitat."

Surfleet, C. G., and R. R. Ziemer. 1996**. Effects of forest harvesting on large organic debris in coastal streams.Pages 134-136 *in* J. LeBlanc, editor. Proceedings of the conference on coast redwood forest ecology and management.** University of California, Cooperative Extension, Forestry.
From NCASI

Study area and methods

LWD was inventoried in two coastal streams of 90-year-old second-growth: one that had been 60% clearcut with riparian buffer strips 4 years previous, and another that had 60% selective harvest and stream cleaned of LWD 25 years previous. These were compared to a control stream in old-growth forest.

Effects of forest management on LWD

LWD increased after logging because residual trees were left adjacent to stream or in buffer strips. Windthrow of fir provided largest input of LWD to the second-growth streams. LWD is predicted to continue to decline in second-growth areas where

residual pieces play a major role. Streams cleaned of LWD are predicted to have continued low levels of LWD for more than 25 years.

Swanson, F. J., M. D. Bryant, G. W. Lienkaemper, and J. R. Sedell. 1984. **Organic debris in small streams, Prince of Wales Island, southeast Alaska. General Technical Report PNW-166**. U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon**.**
From NCASI

This study examines the role of LWD in small, low-gradient, fish-bearing streams.

Frequency and volume estimates

"The four streams sampled in old-growth forested areas contained an average of 9.4 kg/m of course debris and 0.9 2 kg/m of fine debris. These concentrations of coarse debris are similar to streams sampled in Engelmann spruce- 2 lodgepole pine (*Pices engelmannii-Pinus contorta*) stands in Idaho and spruce/true-fir stands (*Picea* spp./*Abies* spp.) in New Hampshire and Tennessee (Anderson and Sedell 1979). But values of coarse and fine debris loadings in the study streams of southeast Alaska are 24 and 30 percent, respectfully, of values reported for small streams flowing through old-growth Douglas-fir/western hemlock/western red cedar (*Thuja plicata*) stands in western Oregon. Concentrations of large debris in streams flowing through coast redwood (*Sequoia sempervirens*) stands are still higher (Keller and Tally 1979; F. J. Swanson, unpublished data). Contrasts in conditions of stream debris in different forest types reflect differences in quantity and size distribution of woody biomass in adjacent forests, rate of wood decay, and successional dynamics of the forest ecosystems supplying large debris to streams." Cited in Robison and Beschta (1990a): "The Zone 1 and 2 CWD in this study is similar in definition to the 'effective inchannel debris' of Swanson et al. (1984), who found an average loading of 10.1 kg/m for several study streams in 2 southeast Alaska. If a density of 0.5 g/cm is assumed, CWD loadings for Zone 1 and 2 range from 7 kg/m ...to 12.5 3 2 kg/m ..., which indicates that inchannel debris loadings of streams in both study areas were generally equivalent."

Toews, D. A. A., and M. K. Moore. 1982b**. The effects of three streamside logging treatments on organic debris and channel morphology of Carnation Creek. Pages 129-153 in G. F. Hartman, editor.** Proceedings of the Carnation Creek workshop: a ten-year review. Pacific Biological Station, Nanaimo, British Columbia**.**
From NCASI

Effects of forest management on LWD

Cited in Murphy et al. (1986): "Apparently, pools are lost from clear-cut reaches as natural debris is removed when logs are salvaged, logging slash is cleared from the stream channel, or destabilized debris washes downstream or floats onto the stream banks (Toews and Moore 1982b, Bryant 1983, Bilby 1984a)." Cited in Harris (1988):

"Toews and Moore (1982a) observed the impact of one intense logging treatment on the stability and distribution of large organic debris, and this report was updated to evaluate the impacts of the three streamside logging treatments on Carnation Creek (Toews and Moore 1982b)."

The following is a review of the findings of this report as found in Harris (1988): "(1) there was a significant reduction in stability (post logging) in the careful and intense treatment. The leave strip showed an increase in the mean stability index after logging. (2) The change in the number of pieces was generally a large increase immediately following logging (due to the introduction of tops, branches, broken pieces, etc.) which quickly flushed through the reaches and a return to prelogging levels. (3) The intense treatment showed a large increase in small organic debris (SOD) piles. These piles were very mobile. (4) Changes in debris dynamics were noticed immediately, whereas changes in channel features took time because they were related to storm events, sediment movement and bank erosion in addition to the influences of large organic debris. (5) The careful and intense treatments had similar results of reduced stability of LOD and introduction of SOD piles, which contributed to changes in channel form and streambank erosion. In these treatments, debris was smaller in size and volume."...

"Toews and Moore (1982b) suggested that in the intense and careful treatments, a possible long term change in debris following logging is the erosion of debris jams and the gradual breakdown and removal of small debris piles. Also, existing channel debris will gradually decay and new material (which is smaller) would be added towards the end of successive rotations."

Triska, F. J., and K. Cromack Jr. 1980. **The role of wood debris in forests and streams. Pages 171-190 *in* R. H. Waring, editor. Forests: fresh perspectives from ecosystem analysis**. Proceedings of the 40th Annual Biology Colloquium. Oregon State University Press, Corvallis.

From NCASI

Effects of stream size on LWD

Cited in Bilby and Ward (1989): "Our study indicates that the distribution and size of accumulations of particulate organic matter associated with woody debris changes from frequent, small aggregations in smaller streams to less frequent, larger accumulations in larger systems. A similar pattern of increased debris clumping with increased stream size has been observed in Oregon (Triska and Cromack 1980)."

Recruitment mechanisms

"debris accumulations must be considered over a period of about 500 years...accumulations of debris are greater in the Pacific Northwest than elsewhere because of the larger biomass of the region's tree boles (Grier and Logan 1977). In most cases, natural catastrophes would result in greater accumulations than depicted here (Franklin and Waring 1980), but those that would result from clear-cutting followed by yarding and burning are adequately portrayed."

"By far the largest amount of wood debris occurs in streams draining old-growth redwoods and Douglas-fir/western hemlock."

"Toward the end of succession, even a single tree can introduce a large amount of organic matter. For example, the biomass of a tree 100 cm in diameter equals 10 metric tons."

"...woody debris in young stands is finely divided and highly susceptible to microbial attack, whereas an equal amount of large woody debris with its low surface-to-volume ratio may have a decomposition period of hundreds of years. Furthermore,

the wood component in litterfall is less than 10 percent in young stands but 70 percent in old-growth forests (Grier and Logan 1977)."

Triska, F. J., J. R. Sedell, and S. V. Gregory. 1982. **Coniferous forest streams. Pages 292-332 *in* R. L. Edmonds, editor. Analysis of coniferous forest ecosystems in the western United States. Hutchinson Ross, Stroudsburg, Pennsylvania.**
From NCASI

Recruitment mechanisms

"Old-growth western Cascades forests (>400 years) have trees that are large (>50 cm diam) and often infected with heartrot, which increases susceptibility for windthrow into streams. The result is episodic input of large wood debris."

Effects of stream size on LWD

Accumulation of debris in dams is less likely to occur in large channels than in small streams, regardless of gradient. Instead, larger streams deposit bole wood on bends and flood terraces inundated only briefly during the year. Debris in these larger streams functions as food or habitat to only a limited extent. In smaller streams, large boles are not moved by water except during debris torrents. Debris clumped into dams, trap small organic debris and sediments as well as help shape and stabilize the channel. Because of forest age, large tree size, and resistance to decomposition and export, bole wood overwhelms the amount of small wood in Cascade streams (Table 10.6)...Neither the fifth-order section of Lookout Creek nor of McKenzie River has significant accumulations of large woody debris, because of the transport capacity of these larger streams."

"...capacity for retention and time for biological processing within a reach decreases in a downstream direction as the capacity for transport increases in large stream orders."

Functions and influences on stream channels

"The transport ratio indicates that first-order streams supply downstream reaches primarily through input of FPOM to collector invertebrates rather than input of intact leaf litter to shredders...Large wood in small streams dissipates the energy of flow and retains coarse organic particulates, while in larger streams channel morphology dissipates energy but permits transport of larger organic particles."

"For streams in the northwest, wood greatly influences channel morphology. In terms of routing of water and sediment, wood (boles) is every bit as important to streams as the timing and quantity of sediment and water...In the natural stream, loading with large wood debris occurs more or less evenly through time. With short-rotation timber harvesting this important morphological component may be permanently removed. Furthermore, as the last old-growth timber lands are cut, wood may diminish as a significant organic input. Eighty-year rotations, in conjunction with precommercial thinning, could gradually eliminate debris dams as a morphological feature of streams. The highest gradient streams may then erode to bedrock and become functionally depauperate in a biological sense. Sediments could be routed more rapidly and sediment load formerly retained as habitat may impact downstream fisheries. Removal of debris dams, which formerly dissipated energy of water in high gradient streams, may in the future allow high water to erode banks, promote siltation, and speed discharge to lower gradient streams with resultant flooding...If the stream does not

retain organic material and maintain a diversity of physical habitats then, biologically, it may be unable to process organic matter from the adjacent forest and large, functional and structural components in the stream ecosystem could disappear."

Van Sickle, J., and S. V. Gregory. 1990. **Modeling inputs of large woody debris to streams from falling trees.** Canadian Journal of Forestry Research 20: 1593-1601.
From NCASI

"A probabilistic model predicts means and variances of the total number and volume of large woody debris pieces falling into a stream reach per unit time. The estimates of debris input are based on the density (trees/area), tree size distribution, and tree-fall probability of the riparian stand adjacent to the reach. Distributions of volume, length, and orientation of delivered debris pieces are also predicted. The model is applied to an old-growth coniferous stand in Oregon's Cascade Mountains. Observed debris inputs from the riparian stand exceeded the inputs predicted from tree mortality rates typical of similar nonriparian stands. Debris pieces observed in the stream were generally shorter, with less volume per piece, than those predicted by the model, probably because of bole breakage during tree fall. As a second application, predicted debris inputs from riparian management zones of various widths are compared with the input expected from an unharvested stand."

Wood-Smith, R. D., and F. J. Swanson. 1997. **The influence of large woody debris on forest stream geomorphology.** Pages 133-138 *in* S. S. Y. Wang, E. J. Langendoen and J. F. D. Shields, editors. Proceedings of the conference on management of landscapes disturbed by channel incision. University of Mississippi, University.
From NCASI

This article provides a summary of the influence of LWD on stream channel morphology based on findings to-date reported in the scientific literature.
Reference conditions for pools

"Pool spacing in LWD-affected streams is commonly less than the expected 5–7 channel widths for bar-pool type channels (Leopold et al. 1964), owing to the pool forming function of LWD. Robison and Beschta (1990b) employ time series analysis to determine that spacing of pools in the forested stream of southeast Alaska varies in an irregular way, as a function of the random spacing of LWD rather than a predictable function of channel size or discharge. Published values for pool spacing in forest, bar-pool streams fall within a fairly consistent range despite inconsistencies in how pools are defined. These values include 1.8 to 6.6 channel widths for northwestern California streams (Keller et al. 1981 [*1982 in this list*]), 1.7 to 3.5 widths in the Queen Charlotte Islands, British Columbia (Hogan 1986), 1.0 to 1.6 widths (derived from a regression equation) for undisturbed streams in southwestern Washington (Bilby and Ward 1991), 4 widths in western Cascades Mountains of Oregon (Nakamura and Swanson 1993), 0.2 to 3.7 widths in southeastern Alaska and western Washington (Montgomery et al 1995), and 0.3 to 3.3 widths in southeastern Alaska (Wood-Smith and Buffington 1996). Montgomery et al. (1995) find that in addition to LWD distribution, pool spacing depends on channel type, slope, and width."

Young, M. K. 1994. **Movement and characteristics of stream-borne coarse woody debris in adjacent burned and undisturbed watersheds in Wyoming.** Canadian Journal of Forest Research 24: 1933-1938.
From NCASI

Appears that increased flows and decreased bank stability following fire increased transport of LWD in burned watershed. Notes that much less is known about debris movement than about input ("but see Grette 1985, Lienkaemper and Swanson 1987, and Benke and Wallace 1990").

"There were differences between stable and mobile pieces of tagged debris in each stream. In Jones Creek, stable debris was significantly greater in volume and less likely to be in contact with the stream surface than was mobile debris...Similarly, stable debris in Crow Creek was significantly longer and greater in volume, but also more likely to have some portion buried."

Zimmerman, R. C., J. C. Goodlet, and H. C. Comer. 1967. **The influence of vegetation on channel form of small streams.** Pages 255-275 *in* Symposium on river morphology. International Association of Scientific Hydrology.
From NCASI

Cited in Gregory et al. 1993. "Zimmerman et al. (1967) identified two thresholds on Sleepers River, Vermont: one at a drainage area of 1.5 km and the other at a drainage area of 12.9 km which separated three levels of influence of 2 2 vegetation on stream channel morphology."

Cited in Gregory et al. 1985. "A major research paper by Zimmerman et al. (1967) demonstrated the influence that vegetation has upon small streams. They showed how variations in channel width were dependent upon the effect exerted on the channel by riparian vegetation and this influence persisted downstream until the second of two thresholds at a drainage area of about 5 miles (12.9 km), was exceeded." 2 2

Functions and influences on stream channels

The most common relationships between forest processes and channel morphology are "a widening of the channel upstream from dams of organic debris, widening of the channel where a tree is thrown in a direction away from the stream, narrowing of the channel where roots or living plants are in or along the channel, and meandering wherever a fallen tree does not span the entire channel or spans the channel but channel shifting cannot occur because of other obstructions...Other common adjustments of the stream to forest processes are tunneling or channel-shifting where blowdown mounds or large amounts of organic debris have completely blocked the channel."

Authors described two "thresholds" for their Vermont study streams. "These thresholds may serve to separate tentatively small streams, with their distinctive relationships between process and form, from rivers that largely 'construct their own geometries' (Langbein 1964, p. 301). Small streams differ from rivers by having discharges that correspond, at most recurrence intervals, to volumes of flow that are small in relation to the activity of vegetation. These discharges create channels that are, again, small in relation to the geomorphic effect of plants. Thus, simply because of scale,

channels of small streams are subject to processes that in rivers either do not occur, are almost completely counteracted by discharge, or have a negligible effect on channels hundreds or thousands of feet wide. Two processes peculiar to small streams are the extension of roots and the formation of dams of organic debris across the entire channel...In small streams, because of absolute volumes of flow, these changes brought about by non-fluvial processes are not quickly 'healed' by fluvial erosion and sedimentation. This is clearly shown by those localities where a local widening of the channel can be traced to a fallen tree whose stage of decay suggests a tree-throw 10 or more years earlier

II. Geomorphic Characteristics and processes

Ref ID: 79
Abrahams, A.D. 1984. **Channel networks: A geomorphological perspective.** Water Resources Research 20 (2):161-168.

Keywords : models; channel networks; random topology model; model; geomorphic process; streams; monitoring; drainage basin; morphology

The study of channel networks, has been dominated since 1966 by the random model. However, recent work has shown (1) that although the topological properties of small networks conform to the random model more closely than those of large ones, even small networks exhibit systematic deviations from topological randomness and (2) that the topological and length properties of channel networks are controlled to a large degree by the spatial requirements of subbasins and the need for these subbasins to fit together in space, by the size, sinuosity, and migration rate of valley bends, and by the length and steepness of valley sides. The factors that control the density properties of channel networks vary with the scale of the investigation and the geomorphic processes governing channel initiation. Although progress has been made toward a satisfactory stream junction angle model, further work is needed. The evolution of channel networks has been investigated by a variety of methods, including the development of conceptual and simulation models, the monitoring of small-scale badland and experimental drainage basins, and the substitution of space for time. The morphology of most channel networks is largely inherited from the past or strongly influenced by inherited forms. In as much as there is no way of ever knowing the origin or complex history of such networks, the use of stochastic models in their study seems unavoidable.

Ref ID: 117
Adams, J. 1979. **Wear of unsound pebbles in river headwaters.** Science 203 (1):171-172.

Keywords : pebbles; headwaters; transport; Sternberg law; model; New Zealand

Pebbles that are initially weathered, in homogeneous, angular, or fractured ("unsound") become sound with transport. The Sternberg law describes well the wear of sound pebbles found in large rivers, but describes poorly that of unsound pebbles in river headwaters. For unsound pebbles the Sternberg coefficient (which is assumed to be a constant) decreases appreciably downstream. An alternative to the Sternberg law is derived in which the coefficient is proportional to the reciprocal of the downstream distance traveled. The laws are compared by using data from the Clutha basin in New Zealand.

Ref ID: 99
Beaty, K.G. 1994. **Sediment in a small stream following two successive forest fires.** Canadian Journal of Fisheries and Aquatic Sciences 51 (1):2723-2733.

Keywords : sediment; fire; disturbance; transport; streams; bedload; Ontario; organic debris; debris

The transport of stream bedload sediment was monitored continuously in a small stream from 1975 to 1982 following forest fires in 1974 and 1980. The stream is located in the east subcatchment (170 ha) of Lake 239 in the Experimental Lake Area,

northwestern Ontario. Precipitation, stream discharge, bedload transport, and concentration of suspended materials were measured quantitatively and organic debris was observed and collected. Bedload transport increased 20 fold following the first fire and threefold after the second. Particle sizes tended to increase during the period of study. Bedload data suggest a recovery period of 5-6 yr following the first fire and a shorter one following the second. A mass budget of material load transported in a single year following recovery indicated a dominance of dissolved load (87%), followed by suspended load (10%), and bedload (3%).

Ref ID: 129
Benda, L., Dunne, T. 1997. **Stochastic forcing of sediment routing and storage in channel networks.** Water Resouces Research 33 (12):2865-2880.

Keywords : sediment; channel networks; bed material; transport; morphology; Oregon; Oregon Coast Range; drainage basin; fire; erosion; model

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 topography, 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 concentration 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 km^2 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.

Beschta, R. L. 1981. **Patterns of sediment and organic-matter transport in Oregon Coast Range streams.** Pages 179-187 *in* T. R. H. Davies and T. Dunne, editors. Erosion and sediment transport in Pacific Rim steeplands. IAHS Publication No. 132. Christchurch, New Zealand.
From NCASI

This paper summarizes 1977–1979 results of sediment transport studies being conducted at Flynn Creek, a 3rd-order stream draining an undisturbed forested basin in the Oregon Coast Range.

Billi, P., V. D'Agostino, M. A. Lenzi, and L. Marchi. 1995. **Bed and suspended load measurements, slope and channel processes in a high altitude alpine torrent.** Third international workshop on gravel-bed rivers. Held 21–26 August 1995, Gold Bar, Washington.
From NCASI

This paper contains information on step-pool channels in Dolomites, Italy.

Bovis, M. J., and B. R. Dagg. 1987. **Mechanism of debris supply to steep channels along Howe Sound, southwest British Columbia.** Pages 191-200 *in* R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation of the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.
From NCASI

This study expands the use of a hydro-climatic approach to debris flow prediction by considering lithologic characteristics, and differences between areas with debris flows,

Buchanan, P., and K. W. Savigny. 1990. **Factors controlling debris avalanche initiation.** Canadian Geotechnical Journal 27: 659-675**.**
From NCASI

This paper contains information about hillslope stability in low-order basins in the Washington Cascades.

Bradley, J.B., Whiting, P.J. 1992. **A process-based stream classification system for small streams in Washington.** pp.1-70**. in** Timber, Fish and Wildlife Project. No. TFW-SH11-91-001. WEST Consultants, Inc. Seattle, Washington.

Keywords : stream classification; classification; Washington; landscape; forest practices; hillslope; streams; drainage basin; fish; water quality; sediment; mass wasting; monitoring; channel size; geomorphology; management; roads; timber harvest; silvicultural practices; riparian zones; riparian zone; debris; debris flows; flow; erosion; channel bed; headwaters; woody debris; organic debris; disturbance; floods; channel networks; impacts

A fundamental prerequisite for the application of landuse regulations to the natural domain is the identification of those parts of a landscape that are environmentally sensitive and warrant various degrees of protection. This is particularly true in the evaluation of forest practices, which depending on the geometry of a hillslope, the character of the stream channel and the history of the drainage basin, have notably different consequences upon fish, wildlife and water quality. This report, commissioned by the Sediment and Mass Wasting Committee (SHAMW) of the Cooperative Monitoring, Evaluation and Research Committee (CMER), outlines a geomorphically process-based stream classification system for small forest streams which provides the framework for building rational landuse regulations.

The stream typing system presently used in the State Washington is based on an assortment of factors including channel size, water use and fisheries. Type 4 and 5 waters are defined as those not containing anadromous fisheries (WAC 222-16-030) whereas Types 1-3 do contain anadromous or resident fisheries. Channel size generally decreases from Type 1 through Type 5. The present system does not consider stream process or geomorphology except as size is associated with stream type. Best management practices (BMPs) mandated for environmental protection vary significantly between Types 1-3, and Type 4 and 5 streams. BMPs for forests in Washington govern activities conducted on or directly pertaining to forested lands and related to growing, harvest, or processing of timber. Specific issues of concern include roads, timber harvest, silvicultural practices and riparian zones. Of particular significance is that riparian zone practices vary dramatically between Type 3, 4, and 5 streams. Consequently, downstream effects on beneficial uses (fisheries, water quality, ect.) are not well understood in terms of physical process. A 1989 review (MacDonald and Ritland) for the SHAMW revealed a definite need for improvement of descriptive techniques for small streams. It may be that an improved physically based channel identifier will result in more accurate appraisals of channel sensitivity, and at the same time yield more general support from a regulatory viewpoint. At present the local forester and even the scientific expert has trouble with such delineations because they are poorly correlated to environmental sensitivity. The reason for this is that the present system is based upon stream size, fisheries, and water use rather than upon an understanding of physical processes that determine environmental sensitivity.

To date, only limited research information on stream processes, forest practices, and related effects on downstream beneficial uses is available for Type 4 and 5 waters within the state of Washington. Debris flows and debris avalanches are thought to be the dominant physical processes in such streams in the western Cascades, the northwest coast and, on a less frequent basis, in the eastern Cascades, Blue Mountains and southwestern Washington. Bank erosion, channel bed erosion and streamside rotational slides are important sediment sources throughout Washington. Sediment storage in headwater streams is strongly tied to channel obstructions, and the amount of woody debris including large organic debris (LOD). On the west side of the Cascades channel recovery following a debris flow, avalanche, or undifferentiated debris torrent, is generally thought to be rapid with significant reduction in sediment supply within a decade following a disturbance. The time frame for recovery is longer east of the Cascade divide but the occurrences are less frequent. The direct effects of debris flows re usually limited to headwater reaches or where steep tributary channels enter mainstem valleys. On occasion debris flows or dam break floods may "runout" along lengthy portions of the channel generating disturbances and sedimentation problems well down the channel network. Increased fluxes of fine sediment are often noted well downstream of debris flows.

The first section of this report is a timely overview of previously proposed stream classifications. The next section develops a process-based, geomorphic classification system for small streams that takes into account the drainage's propensity for mass wasting and the channel's capacity for transporting material. Downstream impacts as related to stream class are then presented. In conclusion, we present an appraisal of the classification scheme based upon our own field study and the comments of solicited

Experts.

Bull, W.B. "**Discontinuous ephemeral streams.**" *Geomorphology* 19, no. 3-4 (1997): 227-276.

Keywords: arroyos / ***ephemeral streams***/ geomorphology / semiarid lands/ climatic data/ degradation / aggradation / stream erosion/ alluvium / topographic mapping/ erosion / sediment transport/ basins/ North America/ geomorphology / river valleys/ temperature/topography

Many ephemeral streams in western North America flowed over smooth valley floors before transformation from shallow discontinuous channels into deep arroyos. These inherently unstable streams of semiarid regions are sensitive to short-term climatic changes, and to human impacts, because hillslopes supply abundant sediment to infrequent large streamflow events. Discontinuous ephemeral streams appear to be constantly changing as they alternate between two primary modes of operation; either aggradation or degradation may become dominant. Attainment of equilibrium conditions is brief. Disequilibrium is promoted by channel entrenchment that causes the fall of local base level, and by deposition of channel fans that causes the rise of local base level. These opposing base-level processes in adjacent reaches are maintained by self-enhancing feedback mechanisms. The threshold between erosion and deposition is crossed when aggradational or degradational reaches shift upstream or downstream. Extension of entrenched reaches into channel fans tends to create continuous arroyos. Upvalley migration of fan apexes tends to create depositional valley floors with few stream channels. Less than 100 years is required for arroyo cutting, but more than 500 years is required for complete aggradation of entrenched stream channels and valley floors. Discontinuous ephemeral streams have a repetitive sequence of streamflow characteristics that is as distinctive as sequences of meander bends or braided gravel bars in perennial rivers. The sequence changes from degradation to aggradation - headcuts concentrate sheetflow, a single trunk channel conveys flow to the apex of a channel fan, braided distributary channels end in an area of diverging sheetflow, and converging sheetflow drains to headcuts. The sequence is repeated at intervals ranging from 15 m for small streams to more than 10 km for large streams. Lithologic controls on the response of discontinuous ephemeral streams include: (1) amount and size of sediment yielded from hillslopes: (2) infiltration capacity of valley-floor alluvium that influences both the unit stream power available for upstream headcut migration, and the attenuation of flashy streamflow events by riparian vegetation in sheetflow reaches; and (3) cohesiveness of alluvium, which affects headcut and streambank morphology, and rates of arroyo extension, downcutting, and widening. Initiation of arroyo cutting may be too complex to be attributed to a single cause such as change in mean annual precipitation or grazing by livestock, but is most likely associated with a decrease in density of protective plant cover on hillsides and along valley floors. Relatively larger unit stream power makes downstream reaches more susceptible to initial entrenchment during floods than headwaters reaches, and favors persistent arroyos. Entrenchment continues until an equilibrium longitudinal profile is briefly attained. Then, channel widening occurs: streambanks are undercut and aggradation begins.

Cafferata, Peter H.; Spittler, Thomas E. 1998. **Logging impacts of the 1970's vs. the 1990's in the Caspar Creek watershed.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 103-115.

Key Words: PSW4351, Caspar Creek, watershed, stream, geology, geomorphology, logging impacts

The Caspar Creek watershed study provides resource professionals with information regarding the impacts of timber operations conducted under varying forest practices on sensitive aquatic habitats. In the South Fork watershed, roads were constructed near watercourse channels in the 1960's, and the watershed was selectively logged using tractors during the early 1970's. Subwatersheds in the North Fork were clearcut from 1985 to 1991 using predominantly cable yarding and roads located high on ridges. Numerous landslides were documented after road construction and logging in the South Fork owing to inadequate road, skid trail, and landing design, placement, and construction. In contrast, the size and number of landslides after timber operations in the North Fork to date have been similar in logged and unlogged units. Considerably more hillslope erosion and sediment yield have also been documented after logging operations in the South Fork when compared to the North Fork.

Ref ID: 134
Chartrand, S.M. 1997. **A geometric analysis of step-pool architecture in alluvial headwater streams of Idaho.** Master's thesis. Case Western Reserve University.

Keywords : headwaters; geomorphology; step-pool; Idaho; slope; streams; pools; riffles; sediment; flow; function

Alluvial mountain streams exhibit a range of channel forms: among these are bar-pool, plane-bed, step-pool, and cascades. Bar -pools are characterized by a sinuous or meandering channel form which contains pools, riffles, and point-bars. Plane-beds are characterized by long stretches of relatively uniform cross-stream topography which lack well-defined bedforms. Step-pools are characterized by alternating steep and gentle channel segments. The steep segments are accumulations of cobble and boulder size material organized into discrete channel spanning risers. The gentle segments consist of pools containing water and finer sediment and are located between successive risers. Cascades are characterized by rough, nearly continuous whitewater flow across the entire channel width.

Field investigations demonstrate that channel slope plays an important role in the occurrence of these channel forms. Previous work suggests that these forms exist

within discrete slope classes. Measurements conducted on streams in west-central and central Idaho demonstrate that there is substantial overlap in the slopes associated with these channel forms. Bar-pool topography was found at slopes between 0.0010 and 0.015; plane-beds between 0.0010 and 0.35; step-pools between 0.015 and 0.14; and cascades between 0.050 and 0.12. The data further demonstrate that slope progressively steepens as one moves from bar-pool, to plane-bed, to step-pool, and finally to cascades. Median slope for bar-pool topography is 0.0060, for plane-beds is 0.012, for step-pools is 0.042, and for cascades is 0.067.

Despite the widespread occurrence of step-pool channels, they have historically received little research attention. Field measurements conducted in this study sought to characterize the fundamental geometric relationships of step-pool channels. From statistical analysis, riser spacing (wavelength) was found to be primarily a function of the median riser particle size (D_{50}) and the channel width. This result is much different from past studies which have reported channel slope to be the dominant control on step wavelength. Step height was found to be primarily a function of the median particle size found on the riser. The result has previously not been reported in step-pool literature but has in literature dealing with the occurrence of transverse ribs found in proglacial mountain streams.

Two theories which describe the development of step-pools were examined in this study: the antidune theory and the theory of maximum resistance to flow. A fundamental criteria of the antidune theory suggests that the wavelength of step-pools must be greater than the minimum expected wavelength of antidunes as wavelength varies with D_{50}. Our data satisfy this criteria. Our data do not, however, reproduce a flume derived relationship used to build the theory of maximum resistance to flow. Therefore, this study suggests that the development of step-pools is described more appropriately by the antidune theory than the theory of maximum resistance to flow.

Chartrand, S. M., and P. J. Whiting. 2000**. Alluvial architecture in headwater streams with special emphasis on step-pool topography.** Earth Surface Processes and Landforms 25: 583-600.
From NCASI

This study examines frequency distributions of various bedforms within previously proposed discrete channel slope classes (Montgomery and Buffington 1993, 1997, and 1998). The authors examined channels in central and westcentral Idaho, in the North Fork Payette River, Salmon River, Big Wood River and Weiser River drainages. The analysis examined 100 channel reaches that exhibited pool-riffle, plane-bed, step-pool and cascade morphologies.

The authors concluded that there is a substantial overlap in the channel slopes associated with all major channel forms, perhaps even greater than the overlap proposed by Montgomery and Buffington (1997). Step-pools were found at slopes between 0.015 and 0.134, and cascades between 0.05 and 0.12. The significant overlap in channel slopes for each given major bedform is attributed to confinement, riparian vegetation, LWD and debris flows, in addition to channel gradient.

Although not specific to 1st and 2nd order channels, the article discusses step-pool geometry and formation mechanisms in step-pool channels ranging in width from 1.9 to 10.9 meters. The article includes a review of previous studies on step-pool streams.

Chin, A. 1989. **Step pools in stream channels.** Progress in Physical Geography, 13 (3): 391-407

From NCASI

The author synthesizes the literature on step pools, with particular reference to theory construction and explanatory models.

Danehy, R. J., N. H. Ringler, and R. J. Ruby. 1999. **Hydraulic and geomorphic influence on macroinvertebrate distribution in the headwaters of a small watershed.** Journal of Freshwater Ecology 14: 79-92.

From NCASI

"Spatial variability of aquatic macroinvertebrates was examined in riffles of 2nd to 4th order streams in central New York. Aquatic macroinvertebrates were distributed primarily by a headwater-to-valley gradient as defined by mean width and water surface slope. Secondary and tertiary gradients were based on hydraulic character. Direct gradient analysis using canonical correspondence analysis (CCA) examined the common and rare macroinvertebrate assemblage among sites. The variables used in this analysis were mean wetted width, water surface slope, mean Froude number and Froude number variance. The first CCA axis explained 43.1% of the variability. Froude number variance and Froude number affected the second and third CCA axes most strongly. The gradients revealed by the second and third CCA axes did not influence lower gradient valley sites, but did separate the headweater sites based on hydraulic character. Taxa were also distributed by functional feeding groups (i.e. collector-gatherer). The headwater-to-valley gradient did separate taxa slightly by functional feeding groups; however, the hydraulic gradient clearly separated scrapers and shredders from collector filterers."

Four geomorphic and hydraulic variables explained much of the distribution of aquatic insect taxa across a narrow range of habitat conditions (e.g., location in the drainage, instream flow characteristics). The Froude number includes both morphometric (hydraulic depth or cross-sectional area) and hydrologic (velocity or discharge) components, thereby integrating various habitat features. Moreover, the Froude number may be more applicable because it includes biologically relevant variables.

"Heede and Rinner (1990) recognized that hydraulic determinants of habitat have rarely been employed in habitat analyses and comparisons. They encouraged the inclusion of morphological and hydrological factors in habitat assessments and urged the use of hydrodynamic parameters such as Froude and Reynolds numbers to quantify objectively the type of flow for improved mathematical and statistical analyses of habitat relationships. Jowett (1993) assigned Froude numbers to pool, riffle, and run habitats. In his system, cross-sections with Froude number of less than 0.18 are pools and those greater than 0.41 are riffles. Using this framework, comparisons can be made between locations in addition to the correlating aquatic communities with stream hydraulics."

"At each…cross-section per site the following measurements were made: mean wet width, 11 equally spaced depth measurements, percent substrate composition, and bank angles. Water surface and bed grades were measured,...discharge was

measured,...[and] velocity was measured at 0.6 m of depth from the surface at 20–25 evenly spaced locations across a relatively uniform cross-section."
"Twenty-one abiotic variables were selected based on survey data and site maps. To reduce collinearity, correlations among all variables were examined and the following rules used to reduce the number of environmental variables: 1) if two variables had a correlation coefficient greater than 0.9, only one was selected for this analysis; and 2) if a variable had a correlation coefficient greater than 0.7 with two or more other variables, it was deleted from the analysis. This reduced the data set to seven variables: mean wet width, mean pebble size, mean Froude number, Froude number variance, pebble sorting, streambank stability, and water surface slope. The seven variables were further reduced to fur (mean wet width, mean pebble size, Froude number and Froude number variance and water surface slope)...."

"...Sites were classified into three categories: valley, transition, and headwater.… The mean reach channel width ranged from 3.1 to 6.5 m, and slope 0.7 to 5.2%."

"The aquatic insect data set was subdivided into four levels of density: abundant (>5% of total), common (0.5-5%), rate (0.001-5%) and very rare (<0.001%). The abundant taxa *Baetis* cf. *tricaudatus*, *Ceratopsyche* cf. *glossonae*, *Stenelmis* sp. and *Optioservus* sp. were not included in this analysis. The ubiquitous abundant taxa were excluded because they weaken the identification of environmental gradients due to their ability to inhabit a variety of habitats. Very rare insect taxa with five or fewer individuals collected or found only at a single site were also excluded from the analysis...."

Dieterich, M. and N.H. Anderson. 1998. **Dynamics of abiotic parameters, solute removal and sediment retention in summer-dry headwater streams of western Oregon.** Hydrobiologia 379: 1-15.
From NCASI

Sediment Supply and Load

"Headwater streams represent the maximum interface with the terrestrial environment (Vannote et al. 1980). In relative terms, the exchange surface and the biologically active boundary layer between sediment and water column are large. At the same time the density of retention devices in small streams is high (Bilby and Likens 1980) while stream power is low (Naiman and Sedell 1979). Large exchange surface and long particle residence time result in short nutrient turnover lengths in headwaters (Minshall et al 1983, Naiman et al 1987, Stream Solute Workshop 1990)...During their period of flow, summer-dry headwaters become an integral part of a catchment's drainage system often exceeding permanently wet channels in total length. The biological and physical processes in these small channels then affect the habitat and water quality in permanent downstream reaches, in lentic systems into which many streams discharge, and in groundwater to which they are connected.....In many respects water quality in summer-dry headwaters therefore mirrors groundwater qualities and thus geological conditions and soil properties in small drainage areas."

"Ephemeral streams effectively retain sediment....The filtration efficiency of ephemeral headwater streams results from the shallowness of the water column, combined with the large number of retentive structures-both organic debris and living plants (grass, mosses) and, more importantly, from the pattern of lateral and longitudinal expansion and contraction in response to precipitation."

Dietrich, W. E., and T. Dunne. 1978. **Sediment budget for a small catchment in mountainous terrain.** Zeitschrift fuer Geomorphologie N. F. 29: 191-206.
From NCASI

This paper describes processes controlling sediment budget in 4th-order drainage in the Oregon Coast Range; sediment delivery from hillslopes to low-order channels, and sediment routing through low-order channels, including particle attrition, are quantified in detail. Dietrich and Dunne constructed a sediment budget model and estimated some of the components, including sediment residence times and importance of breakdown of weathered sediment particles, for Rock Creek watershed (16 km2) in the Oregon Coast Range.

Sediment Supply and Load

The authors investigated effects of the 1974 debris flow that scoured one of the first-order channels in the Rock Creek basin. The debris flow was triggered by two small debris slides that traveled 2-4 meters/sec and scoured 1000 meters of the channel bed and caused 6 small hillslope failures along the channel. It was estimated that about 4000 m3 of poorly sorted gravel, sand, silt and clay were deposited in a debris fan at the mouth of the tributary, and 1700 m3 along the main 3rd- and 4th-order channel. Approximately 35% of the sediment transported originated from the tributary channel bed, 3% originated in the tributary from streamside slides, and the remainder originated from the terrace deposits along the valley walls.

"Soil that is discharged into channels may experience immediate sorting when fine material is washed away as suspended or wash load, or it may be carried to a debris fan by a debris torrent and be deposited essentially unsorted....Despite continued transport to the mouth of Rock Creek, channel sediment shows no further textural change because attrition during weathering and transport are approximately balanced by the influx of coarse particles along the stream....In soils, gravel-size rock fragments are angular, measuring 1.0-1.5 on the Powers (1953) scale. In tributaries, rounding increases from angular to subangular to subrounded (1.5-2.0)...."

"...about 50% of the detritus which is discharged into the stream from soils is quickly removed as suspended load. Thus, on a first or second order tributary, 50% of the sediment is carried as fluvial bedload or debris flow..."

Dietrich, W. E., T. Dunne, N. F. Humphrey, and L. M. Reid. 1982. **Construction of sediment budgets for drainage basins.** Pages 5-23 *in* F. J. Swanson, R. J. Janda, T. Dunne and D. N. Swanston, editors. Workshop on sediment budgets and routing in forested drainage basins: proceedings. General Technical Report PNW-141. U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describe processes controlling sediment budget in 2nd-order drainage in Marin County, CA. The authors quantified both sediment delivery from hillslopes to low-order channels and sediment routing through low-order channels. The paper provides a detailed description of various hillslope processes and their process rates. The authors propose a process/form linkage-based methodology for proper understanding of dynamics of sediment transport processes and storage sites in a drainage basin. This paper describes in detail major hillslope processes and

their process rates, and also quantifies sediment transit and residence times.

Sediment Supply and Load

"...in drainage basins free of extensive valley-floor deposits, the particle-size distribution of alluvium is controlled by soil formation processes and by attrition and sorting during fluvial transport. In low-order channels stream transport has little opportunity to sort or comminute sediment supplied by slope processes. Residence time of sediment is small, steep tributaries in many areas is probably 100 years or less (Dietrich and Dunne 1978), so chemical weathering probably has little effect on particle hardness. In the long term, the relative proportions of bedload-size and suspended size particles discharged from these channels must largely reflect the texture of the soil, with the coarsest fraction being transported by debris flows in some regions....The rate of breakdown is greatly influenced by the degree of weathering of debris in the parent soil."

Ferrier, K.L, J.W. Kirchner, and R.C. Finkel. 2004. Erosion rates over millennial and decadal timescales at Caspar Creek and Redwood Creek, Northern California Coast Ranges. In review, Earth Surface Processes and Landforms. 37 p. http://www.seismo.berkeley.edu/~kirchner/reprints/200x_Ferrier_coast_range_erosion.pdf

Comparing millennial-scale denudation rates from cosmogenic nuclides with decadal-scale sediment yields can shed light on erosional processes and on the effects of land use on sediment delivery to streams. Detailed measurements of sediment fluxes in the Northern California Coast Ranges at Caspar Creek and Redwood Creek have provided estimates of physical erosion rates since 1963 and 1971, respectively. We used cosmogenic ^{10}Be to measure millennial-scale denudation rates averaged over 1,400-8,900 years at six catchments in Caspar Creek and four catchments in Redwood Creek. Our ^{10}Be measurements at Caspar Creek imply denudation rates that are nearly spatially uniform across the entire catchment and average 0.09 ± 0.02 mm yr^{-1}. These millennial-scale rates implied by cosmogenic ^{10}Be are faster than physical erosion rates of 0.005 ± 0.001 mm yr^{-1} to 0.046 ± 0.007 mm yr^{-1} inferred from sediment flux measurements over the past few decades in the same catchments. At Redwood Creek, our cosmogenic ^{10}Be measurements imply millennial-scale denudation rates that vary across the catchment from 0.14 ± 0.03 mm yr^{-1} to 0.43 ± 0.08 mm yr^{-1}, in contrast to physical erosion rates ranging from 0.038 ± 0.011 mm yr^{-1} to 0.48 ± 0.09 mm yr^{-1} derived from sediment flux measurements made over the past few decades at the same catchments. The decadal-scale and millennial-scale measurements tend to differ most at the smallest tributaries, but differ by less than a factor of 3 for the Caspar Creek and Redwood Creek catchments as a whole. These measurements suggest that denudation rates at Caspar Creek are slower than rock uplift rates of 0.3-0.4 mm yr^{-1} (Kennedy et al., 1982; Merritts and Bull, 1989), implying that Caspar Creek is not in topographic steady state.

Ref ID: 48

Gregory, S.V., Swanson, F.J., McKee, W.A., Cummins, K.W. 1991; **An ecosystem perspective of riparian zones, focus on links between land and water.** BioScience 41 (8):540-551.

Keywords : riparian zones; landscape; riparian vegetation; geomorphology

Riparian zones are the interfaces between terrestrial and aquatic ecosystems. As ecotones, they encompass sharp gradients of environmental factors, ecological processes, and plant communities. Riparian zones are not easily delineated but are comprised of mosaics of landforms, communities, and environments within the larger landscape. We propose a conceptual model of riparian zones that integrates the physical processes that shape valley-floor landscapes, the succession of terrestrial plant communities on these geomorphic surfaces, the formation of habitat, and the production of nutritional resources for aquatic ecosystems.

Jackson, W. L., and R. L. Beschta. 1982. **A model of two-phase bedload transport in an Oregon Coast Range stream.** Earth Surface Processes and Landforms 7: 517-527.
From NCASI

The authors present a descriptive model for bed material routing in a third-order Flynn Creek in the Oregon Coast Range in terms of fractional, grain-size based mobilization.

Keller, E. A., A. MacDonald, T. Tally, and N. J. Merrit. 1995. **Effects of large organic debris on channel morphology and sediment storage in selected tributaries of Redwood Creek, northwestern California**. Pages P1-P29 *in* K. M. Nolan, H. M. Kelsey and D. C. Marron, editor. Geomorphic processes and aquatic habitat in the Redwood Creek basin, northwestern California. U. S. Geological Survey Professional Paper 1454. Washington, D. C.
From NCASI

Large Woody Debris (LWD)

This paper examines the effects of LWD on channel morphology and sediment storage in second-through fourth-order basins in Northwestern California. The streams are located in both managed and unmanaged redwood forests.

"On steep sections of Little Lost Man Creek, for example, where the stream flows over resistant conglomerates and massive sandstone, the valley sides tend to be steep, and landslides commonly deliver large organic debris to the channel."
The authors state that, all factors being equal, debris loading would be expected to decrease downstream. This is because "(1) tree density is partially related to topography (greater areal density on steeper slopes), (2) area of active channel increases downstream, and (3) flow in the upper reaches may not be sufficient to float large

organic debris, whereas farther downstream there is sufficient stream power and water depth to move and sort debris into distinct debris accumulations or jams."

"59 percent of the decrease in elevation along the channel is associated with organic steps or debris dams" for the upper reach of Little Lost Man Creek, a second-order stream. And for some of these steps there is "extensive ponded or stored sediment upstream from the debris. However, in Little Lost Man Creek, it was also observed that debris dams on some of the steeper sections, where the channel is in conglomerate, have less effect on the thalweg profile than do dams on the less resistant shale and sandstone. This situation occurs because bed material in the steeper reaches of Little Lost Man Creek often consists of very large boulders, and the large organic debris rest on these boulders, above the stream channel. " Keller et al. State that "nearly all the pools in the upper reaches of Prairie Creek are either produced directly by large organic debris of are influenced by it...."

Kelsey, H. M. 1982. **Hillslope evolution and sediment movement in a forested headwater basin, Van Duzen River, north coastal California**. Pages 86-96 *in* F. J. Swanson, R. J. Janda, T. Dunne and D. N. Swanston, editors. Workshop on sediment budgets and routing in forested drainage basins: proceedings. General Technical Report PNW-141. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

This paper describes the movement of debris avalanche-derived sediment down stream channels.

Lehre, A. K. 1981. **Sediment budget of a small California Coast Range drainage basin near San Francisco.** T. R. H. Davies and T. Dunne, editors. Erosion and sediment transport in Pacific Rim steeplands. IAHS Publication No. 132. Christchurch, New Zealand.
From NCASI

The author examines the nature and rates of hilllslope processes and their episodic sediment delivery to low-order channels.

Lehre, A. K. 1982. **Sediment budget of a small Coast Range drainage basin in north-central California.** Pages 67-77 *in* F. J. Swanson, R. J. Janda, T. Dunne and D. N. Swanston, editors. Workshop on sediment budgets and routing in forested drainage basins: proceedings. General Technical Report PNW-141. U. S. Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon**.**
From NCASI

This is essentially a brief version of Lehre (1981).

Lenzi, M. A., P. Billi, and V. D'Agostino. 1997. **Effects of an extremely large flood on the bed of a steep mountain stream.** Pages 1061-1066 *in* S. S. Y. Wang, E. J. Langendoen and J. F. D. Shields, editors. Proceedings of the conference on management of landscapes disturbed by channel incision. University of Mississippi, University.

This paper describes high sediment supply effects on a step-pool channel in the Dolomites, Italy.

Lewis, Jack. 1998. **Evaluating the impacts of logging activities on erosion and sediment transport in the Caspar Creek watersheds.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 55-69.

Key Words: PSW4351, Caspar Creek, logging impacts, sediment, erosion, soils

Suspended sediment has been sampled at both the North and South Fork weirs of Caspar Creek in northwestern California since 1963, and at 13 tributary locations in the North Fork since 1986. The North Fork gaging station (NFC) was used as a control to evaluate the effects of logging in the South Fork, in the 1970Õs, on annual sediment loads. In the most conservative treatment of the data, suspended loads increased by 212 percent over the total predicted for a 6-yr period commencing with the onset of logging. When the roles of the watersheds were reversed and the same analysis repeated to evaluate harvesting in the North Fork under California Forest Practice Rules in the 1990Õs, no significant increase was found at NFC in either annual suspended or bed load.

Lewis, Jack; Mori, Sylvia R.; Keppeler, Elizabeth T.; Ziemer, Robert R. 2001. **Impacts of logging on storm peak flows, flow volumes and suspended sediment loads in Caspar Creek, California.** *In:* Mark S. Wigmosta and Steven J. Burges (eds.) Land Use and Watersheds: Human Influence on Hydrology and Geomorphology in Urban and Forest Areas. Water Science and Application Volume 2, American Geophysical Union, Washington, D.C.; 85-125.

Key Words: PSW4351, Caspar Creek, watershed, clearcut, suspended sediment, storm runoff, logging, streamflow, road building, geomorphology, hydrology

Models are fit to 11 years of storm peak flows, flow volumes, and suspended sediment loads on a network of 14 stream gaging stations in the North Fork Caspar Creek, a 473-ha coastal watershed bearing a second-growth forest of redwood and Douglas-fir. For the first 4 years of monitoring, the watershed was in a relatively undisturbed state, having last been logged prior to 1904, with only a county road traversing the ridgetops. Nearly half the watershed was clear-cut over a period of 3 years, and yarded primarily using uphill skyline cable systems to spur roads constructed high on the slopes. Three tributaries were maintained as controls and left undisturbed. Four years of data were collected after logging was completed. Exploratory analysis and model fitting permit characterization and quantification of the effects of watershed disturbances, watershed area, antecedent wetness, and time since disturbance on storm runoff and suspended sediment. Model interpretations provide insight into the nature of certain types of cumulative watershed effects.

Lisle, T.E. 1989. **Sediment transport and resulting deposition in spawning gravels, north coastal California.** Water Resources Research 25(6): 1303-1319.

Incubating salmonid eggs in streambeds are often threatened by deposition of fine sediment within the gravel. To relate sedimentation of spawning gravel beds to sediment transport, infiltration of fine sediment (<2 mm in diameter) into clean gravel beds, bed material size distributions, scour-fill depths, and sediment transport during 10 storm flow events were measured in three streams of north coastal California. Although suspended sediment comprised most (75-94%) of the clastic load during storm flows, bed load material (0.25-2 mm) accounted for most (70-78%) of the fine sediment accumulated in experimental gravel implanted in the streambeds. Sand trapped in the interstices of the top several centimeters formed a seal that impeded deeper deposition of very fine sand and finer material. The seal was responsible at least in part for a decrease in the rate of fine-sediment accumulation with increasing cumulative bed load transport. Areas of the streambeds commonly scoured or filled 0.1 m or more during storm flows, and thus scour and fill commonly created a sandy layer at least as thick as the seal formed by sediment infiltration. Scour could erode eggs laid in the bed and expose deeper levels of the bed to infiltration by fine sediment, but at the same time could allow fine sediment to be winnowed away. Great temporal and spatial variation in sedimentation in these streams suggests that individual storms of moderate size pose a threat to eggs in many but not all areas selected by fish for spawning.

Lisle, T. E. 1987. **Overview: Channel morphology and sediment transport in steepland streams.** Pages 287-297 *in* R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.
From NCASI

The author describes channel morphology and its link to debris flows in channel with slopes ranging from 0.01 - 0.10 in the Pacific Northwest It follows from the article that "steep" channels are defined as having gradient from 1 to 10%. This article, therefore, should be used for assessment of downstream effects of hillslope-channel processes in headwater streams.

Sediment Supply and Load

"Steep channel gradients ...affect bedload transport by causing local supercritical flow and hydraulic jumps. Although widespread supercritical flow in natural channels is rare, it can be frequent in the vicinity of large bed particles in steep, coarse-bedded channels (Peterson and Mohanty 1960). Hydraulic jumps associated with local supercritical flow can affect forces acting on particles and greatly increase flow friction. At steeper slopes, hydraulic jumps occur behind smaller particles, and thus friction is greater for a given relative submergence…."

"...The wide range in particle sizes in steep channels further complicates bedload transport. The high exposure of large particles and the hiding of small particles may cause heterogeneous sizes to have nearly equal mobility (Parker and Klingeman 1982, Andrews 1983)....Sand, however, can increase gravel transport by creating locally smooth areas over which gravel is rapidly transported (Iseya and Ikeda 1987)...."

"...Debris flows and torrents have such large and long-lasting effects on channels that fluvial processes during intervening periods may play only a secondary role in

shaping channel features...In the Pacific Northwest, outside of areas around active volcanoes, widened channels and clast-supported deposits signifying single events of voluminous bedload transport are much more common than deep, narrow channels and matrix-supported deposits signifying debris flows...."

"...High-magnitude, infrequent floods can be especially effective in shaping steepland channels...Steep hillslopes and channels and locally constricted valley bottom can generate extreme unit stream power…."

"...the study of sediment routing is important to understanding channel behavior because it forces us to explore linkages between sediment transport and channel morphology at a drainage-basin scale. At this scale, it is impractical to trace the transport of sediment particles over a long period, and short-term observations will document the operation of the system in only one of many possible permutations. Probability and continuity models may offer the best theoretical approach."

Ref ID: 30
Lowham, H.W., Smith, M.E. 1993. **Characteristics of fluvial systems in the plains and deserts of Wyoming.** pp.1-57**. in** Water-Resource Investigations. 91-4153. U.S. Department of the Interior, U.S. Geological Survey. Denver, Colorado.

Keywords : desert; plains; geomorphic process; fluvial; Wyoming; landscape; drainage basin; sediment; flow

This report describes results of an investigation of geomorphic processes affecting fluvial systems in the energy-resource areas of Wyoming. The purpose of the investigation was to provide information needed for land-use planning and for design of drainage systems that are disturbed by energy-related developments, particularly from surface mining.

Energy-resource development in Wyoming mainly occurs in the plains and desert areas. Flowing water is the major natural force affecting disturbed and reclaimed areas. Streams originating in the plains and deserts are mainly ephemeral, flowing in response to rainstorms and snowmelt. Erosion of basin surfaces and stream channels is predominant during floodflows, which occur only periodically.

Currently, engineering and geomorphic approaches are used in design of reconstructed landscape. This investigation applies geomorphic principles. Statistical summaries and equations based on measured geomorphic features are presented for design of drainage basins and stream channels for areas that have been disturbed and are in need of reclamation. A qualitative description of natural drainage characteristics was derived from a sample of 124 drainage basins, for which as many as 27 characteristics were measured for each basin. On the basis of these data, statistical summaries and regression relations were developed that can be applied for design of disturbed land areas.

Review of field and laboratory studies of drainage development and sediment yield indicate that reclamation will be relatively more successful if the disturbed area is reconstructed to simulate the landform of an immature basin, rather than a fully developed drainage network. Greater revegetation success, and smaller sediment loads transported from the reconstructed basin, will occur if first-order streams are not reconstructed, but rather are left to develop naturally.

Statistical summaries and equations, based on measured geomorphic features for design of streams channels that are in need of reconstruction, were derived from an analysis of channel measurements for 68 sites on natural streams in the plains and desert areas. Bankfull flow, which occurs on the average once every 2 years, is considered to be dominant in channel formation and is used as the basis for design of stream channels. After determining bankfull discharge from gaged information or appropriate estimating equations, the cross-section and pattern properties of the stream channel can be determined.

Reclamation of large land areas in the arid and semiarid West has only been done for a few years; there is much to learn concerning methods that are most successful in designing and reconstruction drainage basins. There is need to establish a data-measurement base for a network of reclaimed basins, especially in view of the great importance and large expense of reclamation. Additional studies of channel pattern and hydraulic-geometry relations for stream channels also are needed.

Ref ID: 11
Marcus, A. 1980; **First-order drainage basin morphology definition and distribution.** Earth Surface Processes 5 :389-398.

Keywords : drainage basin; morphology; drainage development; multivariate analysis; headwaters; streams; slope; flow

First-order drainage basin morphology consists of two complementary regions: a headwater region, the valley head; and a stream region, the channelway. Each subbasin's morphology is represented by a set of principal components factors that include the properties of area, length, slope, relief, elongation and plan curvature. The channel way region is a highly-integrated morphological unit that is dominated by a size-shape factor, indicative of an organized flow system and the presence of a permanent channel. The valley head-channelway definitions utilized to classify first-order basins into three morphological groups or types. Basin type is related to basin location within the larger drainage network, and this relation helps to explain variations in subbasin morphology. The channelway's morphologic properties are influenced by the location of the first-order basin's bifurcation or junction within the higher-ordered network; and valley head morphology is related to the location of the basin's divide position within the drainage net.

Marcus, W. A., K. Roberts, L. Harvey, and G. Tackman. 1992**. An evaluation of methods for estimating Manning's n in small mountain streams.** Mountain Research and Development 12: 227-239**.**
From NCASI

This paper evaluates 11 techniques for estimating Manning's n in small steep stream with hydraulic radius less than 0.25 meters, in Alaska.

Montgomery, D.R., Buffington, J.M. 1993; **Channel classification, prediction of channel response, and assessment of channel condition.** pp.1-84**. in** TFW-SH10-93-002.

Department of Geological Sciences and Quaternary Research Center, University of Washington. Seattle, Washington.

Keywords : classification; assessing; landscape; geomorphology; watershed; morphology; drainage basin; transport; sediment; fluvial; debris; flow; woody debris; slope; disturbance; hillslope; impacts

A process-based landscape and channel classification is proposed as a framework for assessing watershed response to natural and anthropogenic environmental change. Our proposed classification is based on a hierarchy of process-regimes at several spatial scales: i) geomorphic province, ii) watershed, iii) valley segment, iv) channel reach, and v) channel unit. The geomorphic province level identifies watersheds developed in similar materials, topography, and climates, reflecting comparable hydrologic, erosional, and tectonic processes. The watershed level distinguishes hillslopes from valleys, defining fundamental differences in transport processes within a contiguous drainage basin. Valley segment morphologies further distinguish transport processes and general relations between transport capacity and sediment supply of both channeled and unchanneled valleys. At the reach level, distinct morphologies may be identified based on sediment transport characteristics, channel roughness configurations. Channel reaches, in turn, are composed of finer-scale channel units.

Within this framework, our discussion focuses mainly on the valley segments and channel reach levels. Valley morphology and sediment transport characteristics define colluvial, alluvial, and bedrock valley segments. Unchanneled valleys (hollows)are characterized by a lack of fluvial processes, resulting in a transport-limited accumulation of colluvium that is periodically excavated by mass wasting processes. Channeled colluvial valleys are those in which fluvial sediment transport maintains a channel, but in which the transport capacity is insufficient to mobilize all of the colluvium delivered from the surrounding hillslopes. In mountain drainage basins, colluvial valleys are dominantly carved by mass wasting processes. Alluvial valleys contain predominantly alluvial fills and are characterized by fluvial transport of sediment over a variety of alluvial bed morphologies. Alluvial valley segments may be either confined or unconfined, reflecting general relations between transport capacity and sediment supply. Bedrock valley segments lack a continuous alluvial cover due to high transport capacities. Valley morphology generally reflects the relation between sediment supply and transport capacity.

At the channel reach-level of the classification, bed morphology is coupled with both the potential for debris flow impacts and the role of large woody debris loading to characterize channel processes and provide a framework within which to examine potential channel response. Colluvial and bedrock channels occupy corresponding valley segments, but we recognize six alluvial channel types: regime, braided, pool-riffle, plane bed, step-pool, and cascade. We hypothesize that observed systematic and local downstream changes in alluvial channel morphology and channel roughness correlate with changes in channel slope, sediment supply (size and amount of material available for transport) and transport capacity (a function of the available shear stress). These differences provide the basis for interpreting the potential response of different areas of the channel network to perturbation. In general, steep alluvial channels (step-

pool and cascade) tend to maintain their morphology while transmitting increased sediment loads. In contrast, low-gradient channels (regime and pool-riffle) typically respond to increased sediment loads through morphologic adjustment. In essence, steep channels effectively act as sediment delivery conduits connecting zones of sediment production on hillslopes to downslope low-gradient channels. Such distinctions allow recognition of source, transport, and response reaches. Channel morphology thus reflects the local and watershed-integrated processes influencing sediment supply and transport capacity. Evaluation of channel response potential within the context of morphologically-characteristic processes allows distinction of different response potential for different portions of a channel network.

While the proposed channel classification provides insight into potential channel response that can guide impact assessment, changes in sediment supply and transport capacity may result in either similar or opposing effects. This highlights the reality that changes in discharge and sediment supply cannot be examined in isolation; both need to be considered when assessing either watershed conditions or the potential for future impacts. In particular, it is necessary to focus on aspects of channel morphology and dynamics that are sensitive indicators of perturbation and to consider the specific channel type and position in the channel network. A number of quantitative and qualitative approaches provide insight into evaluating watershed impacts and predicting potential responses to continuing or anticipated watershed disturbance.

Montgomery, D. R., and J. M. Buffington. 1997. **Channel reach morphology in mountain drainage basins.** Geological Society of America Bulletin 109: 596-611.
From NCASI

Although stream channels possess a continuum of characteristics identifiable at spatial scales that range from individual channel units to entire drainage basins (Frissell et al. 1986, in Montgomery and Buffington 1997), in this paper, the authors propose to classify channels on a reach scale, defined as 10 to 20 channel widths long. According to Rice (1994), the degree of hillslope-channel coupling changes downstream, resulting in changes in both the characteristics and delivery mechanisms of sediment to the channel. Montgomery and Buffington expand this notion by suggesting that downstream progression of channel morphologies causes an association of hillslope coupling and channel type. They suggest that transient morphologic changes often result from debris-flow scour to bedrock, and that such scoured channels may slowly revert to their pre-disturbance morphologies.

Colluvial channels

Colluvial channels, generally first-order channels, "are small headwater channels at the tips of a channel network that flow over a colluvial valley fill and exhibit weak or ephemeral fluvial transport....Shallow and ephemeral flow in colluvial channels appears insufficient to mobilize all the colluvial sediment introduced to the channels, resulting in significant storage of this material (Dietrich and Dunne 1978, Dietrich et al. 1982, Benda 1990)....Large clasts, woody debris, bedrock steps, and in-channel vegetation further reduce the energy available for sediment transport in colluvial channels....Intermittent flow may rework some portion of the surface of the accumulated material, but it does not govern deposition, sorting, or transport of the valley fill...colluvial channels are strongly coupled to adjacent hillslopes, and net sediment transport from these weakly

fluvial reaches is affected by the frequency of upslope debris flows and mass movements...in source segments, sediment-storage sites are subject to intermittent debris flows scour..."

"Colluvial channels are confined and are characterized by variable bed material and bedform pattern, ...have drainage areas ranging from 0.07 to 0.3 km2, and reach-scale gradients steeper than 0.2, are transport-limited and are considered to be source reaches (as indicated by colluvial accumulations on valley bottoms). Grains are dominant roughness elements, and the bed is the main sediment storage element."
The authors note that episodic transport by debris flows may account for most of the sediment transport in steep headwater channels, citing Lehre's (1982) sediment budget for Lone Tree basin, CA, where debris flows accounted for more than half of the long-term sediment yield. Swanson et al. (1982) estimated that about 20% of the total sediment flux out of a first-order channels in the Oregon Cascade Range was achieved by fluvial transport only, supporting the notion that the long-term sediment flux from low-order channels is dominated by episodic debris flow processes.

Residence time of sediment in the colluvial channels has been estimated to be on the order of hundreds of years (Dietrich and Dunne 1978) and 300-500 years (Kelsey 1980).

"Benda (1990) proposed a conceptual model for the evolution of channel morphology in steep headwater channels that involves cyclical alterations of bed morphology from gravel to boulder to bedrock in response to episodic sediment inputs. The accumulation of colluvial valley fills during periods between catastrophic scouring events indicates that transport capacity, rather than sediment supply, limits fluvial transport in colluvial channels."

According to the authors, a channel's transport capacity relative to it's sediment supply and channel morphology influence channel response to perturbations in sediment supply and discharge. Due to transport-limited conditions and low fluvial transport capacities of low-order channels, the authors conclude that the response of colluvial channels to changes in the sediment supply is manifested mainly by changes in sediment storage.

Cascade Channels

Cascade channels, generally second-order channels "are characterized by pervasive tumbling and jet-and-wake turbulent flow over and around individual large clasts (along with hydraulic jumps causing dissipation of much of the mechanical energy)....are confined and are characterized by random bedform pattern of longitudinally and laterally disorganized boulder-sized bed material (with channel-spanning pools less than one channel width apart)....have high bankfull shear stress and are considered to be transport reaches. Grains and banks are dominant roughness elements. Channels with cascade alluvial morphology have drainage areas ranging from 0.3 to 10 km2, and reach-scale gradients ranging from 0.065 to 0.3...."

"Most of the channel bed comprises large, effectively immobile particles. Such particles become mobile under low frequency (with 50-100 yr recurrence, Grant et al. 1990, Kondolf et al. 1991, Whittaker 1987) hydrologic events, and their mobilization is accompanied by high sediment transport due to the release of gravel trapped under the boulders (Sawada et al. 1983, Warburton 1992). During higher frequency flows (about 5-15 yrs, based on Kondolf et al. 1991), gravel stored in depositional areas (velocity

shadows such as lee and stoss sides of flow obstructions) is mobilized and rapidly and efficiently transported over more stable bed-forming clasts as bedload (Griffiths 1980, Schmidt and Ergenzinger 1992)."

"Therefore, two thresholds for sediment transport occur in cascade channels: moderate recurrence-interval flows characterized by rapid scour of depositional sites and supply limited transport conditions, and low recurrence flows during which bed-forming clasts are mobilized. In contrast to colluvial channels, alluvial cascade channels are resilient to most discharge or sediment-supply perturbations because of high transport capacities and generally supply-limited conditions. Lateral confinement and large, immobile bed-forming clasts make channel incision or bank cutting unlikely responses to changes in sediment supply or discharge."

Montgomery, D. R., and J. M. Buffington. 1998**. Channel processes, classification, and response**. Pages 13-42 *in* River ecology and management, R. J. Naiman and R. E. Bilby, editor. Springer-Verlag, New York.
From NCASI

"This paper discusses physical processes, classification, and response potential of channels in mountain drainage basins of the Pacific coastal ecoregion….Different portions of mountain channel networks are dominated by different geomorphic processes and relationships between transport capacity (a function of discharge and boundary shear stress) and sediment supply (size an amount of material available for transport)…."

Channel Morphology

"Colluvial reaches typically occupy headwater portions of a channel network and occur where drainage areas are large enough to sustain a channel for the ground slope (Montgomery and Dietrich 1988). Soil creep, tree throw, burrowing by animals, and small-scale slope instability introduce sediment into colluvial reaches. Intermittent flow reworks some portion of the accumulated material, but does not govern deposition, sorting, or transport of most valley fill because of low shear stresses (Benda 1990). Large grains, woody debris, bedrock steps, and in-channel vegetation reduce the energy available for sediment transport. Ephemeral, low discharges in colluvial reaches result in a poorly sorted bed with finer grain sizes than in downstream alluvial reaches. Episodic transport by debris flows account for most of the sediment transport in steep headwater channels (Swanson et al. 1982)."

"Bedrock reaches exhibit little, if any, alluvial bed material or valley fill, and are generally confined by valley walls and lack floodplains…Steep headwater channels in mountain drainage basins may alternate through time between bedrock and colluvial morphologies in response to periodic scour by debris flows (Benda 1990)."

"Cascade reaches occur on steep slopes with high rates of energy dissipation and are characterized by longitudinally and laterally disorganized bed material, typically consisting of cobbles and boulders confined by valley walls. Flow in cascade reaches follows a tortuous convergent and divergent path over and around individual large clasts; tumbling flow over these grains and turbulence associated with jet-and-wake flow around grains dissipates much of the mechanical energy of the flow (Peterson and Mohanty 1960, Grant et al. 1990). Large particle size relative to flow depth make the

largest bed-forming material of cascade reaches mobile only during infrequent events (i.e., >25 yr, Grant et al. 1990). In contrast, rapid transport of the smaller bedload material over the more stable bed-forming clasts occurs during flows of moderate recurrence interval. Bedload transport studies demonstrate that steep, alluvial, mountain streams are typically supply limited, receiving seasonal or stochastic sediment inputs from local mass wasting events (Griffiths 1980, Whittaker 1987)."

"Step-pool reaches consist of large clasts organized into discrete channel-spanning accumulations that form a series of steps separating pools containing finer material. The stepped morphology of the bed results in alternating turbulent flow over steps and tranquil flow in pools. Channel-spanning steps provide much of the elevation drop and roughness in step-pool reaches (Whittaker and Jaeggi 1982). Step-forming clasts may be viewed as a congested zone of large grains that cause increased local flow resistance and further accumulation of large particles (Church and Jones 1982), or as macroscale antidunes (Whittaker and Jaeggi 1982). Step-pool morphologies develop during infrequent flood events and are associated with supply-limited conditions, steep gradients, coarse bed materials, and confined channels (Chin 1989).

Like cascade reaches, bed-forming material mobilizes infrequently (Grant et al. 1990), while finer pool-filling material is transported annually as bedload (Schmidt and Ergenzinger 1992). Step-pool reaches often receive episodic slugs of sediment input that travel downstream as bedload waves (Whittaker 1987)." The authors define channel types based upon confinement and gradient. Core gradients for major reach-scale morphologies are: 4-8% for step-pool, 8-20% for cascade, and >20% for colluvial. However, due to varying confinement in the Pacific Northwest, LWD loading, and legacy of disturbance regimes, slope ranges for each morphology type significantly overlap. The frequency distributions of reach average slopes for steppool channels (51 reaches surveyed): 2-4 (35%), 4-8 (55%), 8-20 (10%); and cascade channels (78 reaches surveyed): 2-4 (5%), 4-8 (25%), 8-20 (70%).

Sediment Supply and Load

"Changes in sediment storage dominate the response of colluvial reaches to altered sediment supply because of transport-limited conditions and low fluvial transport capacities; depending on valley fill, increased discharge can significantly change reach morphology. In contrast, bedrock, cascade, and step-pool reaches are resilient to most discharge or sediment supply perturbations because of high transport capacities and generally supply-limited conditions. Lateral confinement and large, relatively immobile, bed-forming clasts make channel incision or bank cutting unlikely responses to changes in sediment supply or discharge in most cascade and step-pool reaches."

Large Woody Debris (LWD)

"External flow obstructions, such as LWD and bedrock outcrops, force local flow convergence, divergence, and sediment impoundment that respectively form pools, bars, and steps….In small channels, LWD is generally stable over years to decades, and individual logs can dominate channel morphology by anchoring pool and bar forms….Flow obstructions can force specific channel morphologies on steeper slopes than is typical of analogous free-formed alluvial morphologies. In particular, LWD may force pool-riffle formation in otherwise plane-bed or bedrock reaches (Montgomery et al. 1995, 1996)…LWD may also force step-pool morphologies in otherwise cascade or bedrock reaches. It is important to recognize forced morphologies as distinct reach types

because the interpretation of whether such obstructions govern bed morphology is crucial for understanding channel response."

Debris Flows

"Debris flows are primary agents of channel disturbance in mountain drainage basins….The morphology of mountain channels prone to debris flows…reflects the time since debris flow scour, as well as position within the fluvial system."

Naiman, R. J., T. J. Beechie, L. E. Benda, D. R. Berg, P. A. Bisson, L. H. MacDonald, M. D. O'Connor, P.L. Olson, and E. A. Steel. 1992. **Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion.** Pages 127-188 *in* R. J. Naiman, editor. Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York.

From NCASI

This paper contains a good description of basin geomorphology and runoff processes in low-order channels.

Channel Morphology

"Bedforms in steep first- and second-order channels are generally limited to plunge pools in coarse-textured substrate, migrating gravel sheets originating from streamside landslides, and local accumulations of finer sediment upstream from woody debris and boulder obstructions."

Sediment Supply and Load

"In the Pacific Northwest, low-order (e.g. first- and second-order) stream segments represent >70% of the cumulative channel length in typical mountain watersheds (Benda et. al 1992).....Hence low-order channels are the primary conduits for water, sediment, and vegetative material routed from hillslopes to higher-order rivers."

".....first- and second-order channels in steep bedrock of mountain basins do not transport significant quantities of sediment by water flow, hence these channels have limited amounts of stored alluvium."

"...Swanson et al. (1982) estimated that fluvial transport accounted for approximately 20% of the total sediment yield from a first-order basin in the central Oregon Cascades. In the Oregon Coast Range, Benda and Dunne (1987), using a sediment budget approach that included specifying sediment routing by debris flow, estimated that fluvial processes accounted for 10-20% of the total sediment yield."

Large Woody Debris (LWD)

"LWD is the principal factor determining the characteristics of aquatic habitats in low- and mid-order forested streams."

"Woody debris jams store sediment and contribute to discontinuous sediment transport during storms (Heede 1972, Mosley 1981)...and can account for the majority of energy loss of flowing water in steep, low-order channels (Beschta and Platts 1986), implying the less energy is available for sediment transport."

Effects of Natural Disturbance Mechanisms on Fluvial Processes

"A disturbance is any significant fluctuation in the supply or routing of water, sediment, or woody debris which causes a measurable change in channel morphology and leads to a change in a biological community (Pickett and White 1985).....Changes in the supply or the routing of sediment and organic debris are usually the result of local mass wasting or large floods....Floods not associated with mass wasting have less of an

influence on low-order to mid-order rivers (Grant 1986)....During floods, sediment transport resulting from bank erosion in low-order channels reaches its maximum."

"Disturbances related to erosion and sedimentation in low- to mid-order basins are thought to be characterized by high magnitude and low frequency because of the large number of mass wasting events and the potential for wildfires to range over these basins (Swanson et al. 1982, Benda 1994)."

Hydrology

"In the heavily forested Pacific coastal ecoregion, overland flow is usually not an important process because infiltration capacities greatly exceed precipitation intensity (Harr 1976). Lateral subsurface flow is the dominant runoff process (Dunne 1978, Burt and Arkell 1986, Beschta et al. 1987, Troendle 1987)."

"Water storage is limited by steep hillslopes and shallow soils adjacent to the channel. Exceptions occur in zones of small floodplains and wet meadows where local subsurface water may contribute to streamflow....Subsurface areas may act as a storage compartment in winter and as a source for organic and inorganic nutrients (Triska et al. 1989)."

"Hyporheic processes are limited to small floodplains, meadows, and stretches of stream where coarse sediment is deposited over bedrock. System continuity is further interrupted by mass wasting and debris dam breaks which gouge channels....Local hyporheic systems are fed by subsurface flow from hillsides."

Nakamura, F., and F. J. Swanson. 1993. **Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon.** Earth Surface Processes and Landforms 18: 43-61.

From NCAI

This paper describes interactions between LWD and first- and second-order, and larger, channels in the Lookout Creek drainage basin. Both low-order drainages have a drainage area of about 1 km2.

Large Woody Debris (LWD)

"Fallen trees in low-order (first-second) streams tend to be suspended over the channel or are pointing downslope and sticking into the valley floor, which limits interactions between CWD and streams, especially where bedrock constrains lateral movement of the stream channel...Most fallen trees appear to suffer breakage prior to interacting with low-order stream channels,...because steep sideslopes bordering low-order channels and streambanks and steps between terrace levels commonly cause breakage upon impact...." and "...relatively wide channels developed where key-LWD accumulated."

"Sediment storage...in first- and second-order channels in the Lookout Creek Basin: ...In Watershed 1, sediment produced by landslides and other processes" (e.g. windthrow) "was once stored on the streambed, particularly behind CWD during prelogging, logging (1962-1966) and slash-burning (1967) periods. Increased sediment discharge developed thereafter and bedload discharge has continued at a rate five times greater than in Watershed 3" which was not logged, "whereas suspended load remains approximately the same. Thus bedload discharge is controlled in part by catch and release of sediment associated with CWD movement and decay. These processes were first reported by Swanson and Fredriksen (1982); however, the trend continues 10 years

later, indicating that effects of CWD on sediment storage processes can last for decades following disturbance."

"Channels with key-CWD are about 1.5 times wider than channels without key-CWD...Much of the CWD causing channel widening consists of decomposed, fragmented pieces, because large, solid pieces of CWD tend to be suspended by valley walls. However, the abundance and range of decay classes of CWD are influenced primarily by the history of watershed disturbances, such as windthrow, landslides, debris flows and logging. The step-forming and channel-widening effects of CWD are most pronounced in sediment-rich streams, but are limited in channels with narrow valley floors and steep gradients. Long-distance CWD transport in small streams is accomplished mainly by debris flows, because these streams are too small to redistribute most of their CWD by stream flow, even during peak flows. Variation in channel width associated with CWD shows no periodic spatial pattern."

"A certain rate of sediment delivery and retention is needed for CWD to affect stream width and gradient...in mid-order reaches....Landslide-delivered sediment typically contains large boulders that are moved only rarely by fluvial processes. These structures create rough channel reaches that may impede sediment transport and facilitate entrapment of CWD pieces."

Napolitano, Michael Brent. 1996. **Sediment transport and storage in North Fork Caspar Creek, Mendocino County, California: water years 1980-1988.** Arcata, CA: Humboldt State University; 148 p. M.S. thesis.

The old-growth redwood forest of North Fork Caspar Creek was clear-cut. between 1864 and 1904. Previous research on logging-related changes in suspended sediment and streamflow would suggest that North Fork Caspar Creek has recovered from historical logging (Rice et al., 1979; Ziemer, 1981); research on the influence of large woody debris (LWD) on channel form and function would suggest it has not (Sedell and Luchessa, 1982; Keller and Tally, 1979).

I developed a sediment budget for mainstem North Fork Caspar Creek for water years (WY) 1980-1988 to evaluate controls on sediment storage changes. Sediment budget findings, Caspar Creek logging history, and research on LWD were reviewed together to evaluate persistence of historical logging impacts. During the study period, at least 70 percent of changes in sediment storage occurred at LWD jams, recent slidescars, and tributary junctions. Elsewhere, the streambed is well- armoured and net changes in sediment storage were slight. As of 1987, debris jams were near or at maximum storage capacity affording little prospect for attenuation of large-volume, sediment inputs. Over the study period, debris jam filling and LWD- related bank erosion were roughly equivalent, and hence, the effect of LWD on the sediment budget was fairly neutral.

Average annual sediment yield for North Fork Caspar Creek during WY 1980-1988 was 69 tonnes/km2, 9 tonnes per km2 of which was bedload. This is comparable to estimates for other basins underlain by competent Franciscan terrane (Janda, 1972; Kelsey, 1980; Madej et al., 1986).

North Fork Caspar Creek may not have recovered from nineteenth-century logging.

Comparison of LWD loading on North Fork Caspar Creek (24 kg/m2) to similar streams in old-growth redwood basins (49 to 268 kg/m2) and review of historical descriptions of log drives and channel preparation for drives, suggests that LWD loading and stability were greatly diminished by channel preparation for drives, the log drives themselves, and change to second-growth cover. These changes are significant, as LWD creates diverse habitat and provides long-term, large-volume sediment storage sites in old-growth streams (Keller et al., 1981). Extent and significance of impacts is unclear, however, because sufficiently detailed information describing historical channel conditions and fisheries is not available.

Napolitano, Michael. 1998. **Persistence of historical logging impacts on channel form in mainstem North Fork Caspar Creek.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 97-101.

The old-growth redwood forest of North Fork Caspar Creek was clear-cut logged between 1860 and 1904. Transportation of logs involved construction of a splash dam in the headwaters of North Fork Caspar Creek. Water stored behind the dam was released during large storms to enable log drives. Before log drives could be conducted, the stream channel had to be prepared by removing all obstructions, including large woody debris jams, from the channel.

Comparison of present-day woody debris loading on North Fork Caspar Creek (24 kg m-2) to physically similar streams in old-growth redwood basins (49 to 268 kg m-2) suggests that wood-loading and stability were greatly diminished by historical logging activities and change to second-growth cover. These changes are important, as woody debris creates large-volume, long-term sediment storage sites and diverse aquatic habitat conditions. Although historical logging appears to have caused lasting channel changes, including channel incision, simplification of form, and reduction in sediment storage capability, the significance of habitat-related changes remains unclear.

O'Connor, M., and R. D. Harr. 1994**. Bedload transport and large organic debris in steep mountain streams in forested watersheds on the Olympic Peninsula, Washington.** Final Report No. TFW-SH7-94-001. Prepared by College of Forest Resources, University of Washington, Seattle and USDA Forest Service, Pacific Northwest Research Station for Sediment, Hydrology and Mass Wasting Steering Committee of the Timber/Fish/Wildlife Agreement, Washington Department of Natural Resources, Olympia**.**
From NCASI

This paper focuses on sediment transport in low-order channels in the Olympic Mountains, Washington, and provides an overview of MacDonald and Ritland's conceptual model of sediment transport processes in low-order channels. In addition, the authors present results of a stochastic model, and discuss the management implications of the model results.

In this rather comprehensive report the authors present results of two stochastic models: bedload transport capacity as a function of flow intensity, and routing of sediment through a 1 km-long network of second- and third-order channels (the second-order channel model utilizes results from the frequency distribution of annual bedload transport rates produced by the bedload transport model). The routing model was used to assess the sensitivity of bedload flux to changes in the abundance of LWD on the channel bed. Over a 60-year period; the Monte Carlo simulation model predicted increases of approximately 40 to 130 percent in the bedload yield from low-order watersheds resulting from the gradual decline in recruitment of LWD to channels. The study also modeled mean scour depth and bedload velocity (particle travel distance) as a function of grain-size and excess unit stream power.

The model suggested that fluvial sediment transport processes in low-order channels are significant and that LOD exerts a significant control on bedload storage and transport. In the introduction the authors state that "...although mass wasting in headwater areas is likely to be the dominant source and routing mechanism of sediment found in high-order channels, fluvial sediment transport is a determinant of sediment storage and, consequently, sediment routing by debris flows (Benda 1994). In addition, fluvial sediment transport from low-order channels determines the sediment supply to high-order, fish-bearing streams in the absence of episodic delivery of sediment by debris flow. Hence, fluvial sediment transport in low-order streams is one of the major processes determining the sediment characteristics in spawning and rearing habitats of salmonids...."

Sediment Supply and Load

The conceptual model of bedload routing was originally provided by McDonald and Ritland (1989). In addition, O'Connor and Harr offer a model for the interactions between sediment supply, sediment storage, and streamflow that control sediment transport in stepped-bed channels. Fundamentally, the model consists of the following components: a) sediment entry to channel either by creep or erosion (which is due to discharge greater than critical discharge, at which point fluvial sediment transport occurs as well), and b) deposition of entrained sediment in areas of low transport capacity (usually pools upstream of obstructions which fill as long as transportable sediment and competent streamflow are available). Mcdonald and Ritland's model asserts that sediment transport rates in channels are low as long as storage sites are not filled to capacity. Once storage sites are filled, sediment transport increases rapidly downstream.

O'Connor and Harr, while acknowledging that MacDonald and Ritland's model captures many essential elements of sediment routing model, argue that the model lacks validation and a detailed description of the interaction between sediment storage reservoirs and fluvial sediment transport processes. They argue that MacDonald and Ritland's model is static because it does not take into account re-entrainment of sediment from storage sites. O'Connor and Harr provide a dynamic model that does not assume that in-channel sediment flux equals sediment input to channels when channel storage sites are filled, thereby taking re-entrainment of sediment from storage sites in account. "Sediment yield is coupled to the net change in density of LOD dams. Sediment export occurs during the periods of declining density of LOD dams. During the period of increasing density of LOD dams, sediment export is zero, reflecting the increasing sediment storage capacity of LOD dams. When density of LOD dams reaches its

maximum value, sediment export becomes possible because no new storage capacity is available, and new sediment entering the system can be routed downstream."
"Annual bedload transport rates have rarely been measured in low-order stream channels (Sidle 1988, Grant and Wolfe 1991, cited in this report)."

"O'Connor (1993) found that for sediment grains greater than minimum size , ranging form about 180 mm to 340 mm depending on stream size, individual sediment grains were likely to be either immobile or weakly-mobile....Cobble and boulder obstructions are less effective sediment storage sites...than LOD....Sand, gravels and cobbles between about 1 and 180 mm are transported as bedload and comprise the mass contained in the detention reservoirs".

For modeling sediment inputs by soil creep, the authors used detailed creep rate data in undisturbed headwater streams
on the western Olympic Peninsula collected by Reid (1981). In that study, the mean estimate of creep was 7.5 m3/channel km/yr where 70% of inputs were assumed to be coarser than 1 mm and thus enter the sediment reservoirs of the channel bed.

Results of Modeling

"The quantity of excess bedload transport capacity, at least three times bedload yield in the upper second-order channels, suggests that *first-order channels may also be supply-limited* [our italics]. If first-order channels were also supply-limited, they would be expected to transport quantities of bedload that are significant in the context of the routing model. The routing model implicitly assumes that bedload transport in first-order channels is negligible. No field data for bedload transport were collected in first-order channels...."

The authors estimated bedload transport rates in first-order channels from an empirical relationship between modeled bedload yield and transport capacity in second- and third-order channels as a function of drainage area. They then extrapolated this relationship to drainage areas of 0.1 km2 for a first-order channels. They found that bedload yield and transport capacity are approximately equal, suggesting that first-order channels may be transport-limited. Mean annual bedload yield was estimated to be approximately 0.2 m3, which is approximately 25% of that routed in second-order channels. Considering that there are 8 first-order links in the modeled channel network, the sum of 1.6 m3/yr represents about 20-50% of the total bedload yield from third-order channels.

"In the modeled channel network, transport of sediment by fluvial processes is likely to be at least as great as the longterm creep rate of sediment into channels, LOD notwithstanding."

Large Woody Debris (LWD)

"Erosion and deposition patterns in stepped-bed channels are governed by obstructions (LOD dams) that act as local base levels. Upstream of the obstruction, channel slope and therefore stream power is reduced and downstream, turbulence dissipates energy in a plunge pool and maintains the suspension of relatively coarse particles. Significant storage of sediment upstream of LOD and other obstructions has been observed in field surveys. Where sediment yield has been monitored in conjunction with channel storage in undisturbed watersheds, annual sediment yield ranges from 3 to 30 percent of in-channel storage."

Bedload yield for second and third-order channels was modeled for several LOD density scenarios, with steady-state as the best estimate of the sediment routing process

in natural channels. The greatest change in bedload yield occurred with an initially high dam density that decreases over time. Residence time of sediment in second-order channels sediment ranged from about 30 to 115 years, and from 18 to 68 years for third-order channel.

The routing model assumes that the LOD reservoirs are filled to capacity when the density of LOD dams is in a steadystate condition, when sediments inputs from creep (2.3 m3/channel km/yr) are routed downstream. "In a 3 m-wide channel, a 0.7-m high LOD dam could store about 4 m3 of bedload sediment."

Effects of Management Practices on Fluvial Processes

"Alteration of LOD inputs to channels (reduction of natural tree recruitment over long time due to clear-cut logging or increase due to logging slash deposition) substantially effects formation of LOD dams, and thus alters sediment routing and yield. In the former case the yield is higher due to removal of storage from behind LOD dams, and in the latter the sediment export is nearly zero due to increasing sediment storage capacity of new LOD dams."

"Logging may significantly affect input rates of LOD to stream channels, in some cases doubling the density of LOD (e.g., Froehlich 1973).....A period of 60 years of forest regrowth is required prior to resumption of significant inputs of coniferous LOD to stream channels (e.g. Andrus et al. 1988)...The turnover time (i.e., standing crop divided by input rate) for LOD in two stream channels less than 1 km2 in the Oregon Cascades averaged 59.5 years (Lienkaemper and Swanson 1987)."

"Analysis of residence times [of bed material] could help forest and aquatic ecosystems managers to assess the effects of alternate land management plans on sediment delivery to stream channels of interest, such as those containing spawning and rearing habitat for sensitive fish species."

"...based on the results of the routing model, this approach suggests that in stream channels draining watersheds of 0.3 km2 or smaller (for example, Type 4 streams in Washington), inputs of LOD should be maintained at levels equivalent to those found in unlogged forests...The primary functions of this LOD is the creation of quasi-stable reservoirs for sediment storage. Failure to maintain a steady, long-term supply of LOD to such channels would allow the quantity of stable storage reservoirs to diminish,...release sediment from storage,...resulting in a net loss of storage and an increase in sediment export...downstream over a period ranging from a few to several years."

"In streams where sediment yield is limited by transport capacity, LOD dams would be expected to be less significant. In supply-limited streams, the presence of LOD dams is highly influential because sediment stored by these features would otherwise be transported downstream."

"Owing to the fact that LOD enters headwater streams gradually over time from the stream banks, the most effective means to preserve LOD function for sediment storage is to maintain a riparian forest stand sufficient to provide a steady supply of LOD to the channel."

"If forests are harvested in a manner that prevents recruitment of LOD to these streams, and the channels do in fact lose most of the sediment storage capacity associated with LOD, then a significant change in channel morphology and bedload routing could be expected. These channels would be expected to be dominated by bedrock and cobbleboulder beds. Local channel slopes would tend to be nearly equal

to the average valley slope....bedload residence times would be short, and sediment eroded from hillslopes...would quickly be routed to low-gradient, fish-bearing channels immediately downstream."

"Another likely, but unproved, consequence of logging old growth forests adjacent to low-order channels is that the average diameter of LOD recruited to channels in the future would decrease....having a significant effect on potential sediment storage because the volume of the retention reservoirs are proportional to the square of dam height."

O'Connor, M. D. 1994**. Sediment transport in steep tributary streams and the influence of large organic debris.** Doctoral dissertation. University of Washington, Seattle.

This dissertation describes quantitative field investigation of fluvial sediment transport processes in low-order channels in the Olympic Mountains, Washington, and presents a stochastic simulation model -and its results- of bedload yield over a 60-yr period.

Channel Morphology

"The complex morphology of steep, low-order channels results in streamflow patterns that may often be unsteady and non-uniform in many locations. Channel morphology is least complex in wedge and cascade segments. To the extent that approximately steady and uniform flow conditions are found in such channels, it would be in wedge and cascade segments..." (p. 39).

"The depth of scour in small gravel-bed streams has rarely been measured." As a result, the author performed scour monitoring on three locations using monitor design developed by Frissel. The authors observed an average of 8 scour events per site (such events are a function of excess unit stream power), with maximum and average mean scours of 0.35 m and about 0.1 m, respectively, and ratios of mean scour to mean flow depth ranging from 0.11 to 0.78 m. The scour depths are direct measures of the thickness of the active bed. The width of the active channel bed was nearly equal to, but somewhat less than, the bankfull width. Drainage for a first-order channel is estimated as 0.1 km2 and annual bedload yield -described as functionally related to the drainage area- approximately 0.2 m3.

Sediment Supply and Load

"Where sediment yield has been monitored in conjunction with in-channel storage in undisturbed low-order watersheds, annual sediment yields from individual watersheds ranged from 3 to 30 percent of in-channel storage (Megahan 1982)" (pp. 9-10).

"Tally (1980) found that coarse surface sediment upstream of LOD obstructions was more mobile than riffle gravel" (p. 10).

"...In the Oregon study (Grant and Wolff 1991), bedload transport was monitored over a 30-year period in three loworder streams with channel gradients ranging from 0.27 to 0.36 and with drainage areas ranging from 0.6 km2 to 1.01 km2. Mean annual bedload transport rates prior to logging ranged from 3 t/km2 to 14 t/km2. Annual bedload transport rates after logging ranged from 230 t/km2 to 820 t/km2..." (p.14).

"Sediment yield is coupled to the net change in density of LOD dams...Sediment export occurs during the period of declining density of dams..." (p.19).

"Suspended sediment is transported through channels rapidly and is expected to comprise a small fraction of the bed material. Consequently, bedload sediment is the primary constituent of the channel bed. Bedload moves downstream at relatively low velocity, residing in storage in the channel bed over periods of decades as it is routed through low-order channels" (p. 22).

"Fluvial sediment transport occurs as a consequence of the tractive forces exerted by moving water on the channel bed.....In steep, low-order channels characterized by stepped-bed morphology, the longitudinal variation of channel slope is extreme, ranging over an order of magnitude. It is hypothesized that local channel slope is the dominant determinant of variation of the total boundary shear stress in steep, low-order channels....Local channel slope is expected to have a strong influence on local sediment transport potential. The distribution of sediment grain sizes on the channel bed is widely considered to reflect local tractive forces (e.g. Dietrich et al 1989)....Form roughness is another determinant of the tractive force of the flow on sediment grains...In steep, low-order streams, complex bed morphology should create high form roughness. Form roughness reduces the grain roughness. As channel morphology becomes increasingly complex, the proportion of the total boundary shear stress exerted on sediment grains on the channel bed diminishes. This reduces potential entrainment and transport of bed material" (pp. 32-35).

For the transport and routing simulation model the author used the following quantities and relationships: 1) the threshold of entrainment of bed sediment in terms of stream discharge and unit stream power, 2) sediment grain sizes transported in suspension, 3) mean bedload velocity for transport events as a function of peak unit stream power in excess of threshold unit stream power, 4) mean depth of bed scour for transport events as a function of excess unit stream power, 5) mean width of the active channel, 6) peak stream discharge as a function of 24-hour precipitation, and 7) mean annual probability of failure and formation of LOD dams (p. 131). "In nine bulk samples of bed material..., sediment finer than 1 mm represented an average of 11.1 percent of the bed material" (p. 165).

"Typical grain size distributions of soils in the field (Soil Conservation Service 1987) indicates that roughly 30 percent of the sediment entering stream channels -via creep- processes is finer 1 mm, ... roughly 70 percent of hillslope sediments were coarser than 1 mm....Hillslope sediment was assumed to have a density of 1 tonne/m3....Accounting for sorting and changes in bulk density, 1 m3 of creep inputs generated 0.33 m3 of bed material" (p. 167).

The author provided a comparison of observed sediment yields from low-order stream in the Pacific Northwest (H.J. Andrews, Flynn Creek, Coyote Creek) on p. 221. Yield ranged from 3 to 14 t/km2/yr, 14 to 98 t/km2yr for bedload and suspended load, respectively. The ratio of bedload to suspended load ranged from 0.07 to 0.36.

Large Woody Debris (LWD)

The author reports observed densities of LOD dams in steep, narrow headwater streams with drainage areas less than 2 km2 in the western Olympic peninsula and in northern California. Frequencies of debris dams in undisturbed channels ranged between 3.4 and 13.9 dams/100 m, while frequencies of key debris dams in the same reaches ranged between 1.4 and 7.5 dams/100 m. In disturbed reaches (debris flows, logging, or fire), the frequency ranged from 1.2 to 17.5, and 1.2 to 9.0 dams/100 m for debris dams and key debris dams, respectively.

Effects of Management Practices on Fluvial Processes

"Protecting the character of, and processes in , low-order streams is arguably necessary to maintain fish habitat downstream owing to the fact that water, sediment, and biota tend to be transported downstream. Significant inputs of organic material to fish-bearing streams from headwater streams has been documented (Vannote et al. 1980, Swanson
et al. 1982). Sediment budgets and landslide inventories have shown that large quantities of sediment originated in headwater areas..." (p. 4).

"In general, timber harvest increases sediment yield (McDonald and Ritland 1989) and diminishes the supply of LOD to channels for at least 50 to 60 years (Andrus et al. 1988). Hedin et al (1988) and O'Connor (1986) presented evidence that LOD dams diminish in some instances following timber harvest. In the former study, it was` hypothesized that the release of sediment stored when LOD disintegrates could account for much of the observed increases in sediment yield from watersheds following timber harvest...Based on these observations it is inferred that changes in sediment routing in headwater streams can occur as a result of timber harvest..." (pp. 4-5).

"The simulation model suggests that forest managers should carefully consider the effects of logging on low-order channels in areas where the streams are supply-limited. These channels are likely to route downstream within a few years any additional sediment supplied to them. In addition, these channels are sensitive to persistent decreases in recruitment of LOD from riparian forest stands....it is likely that downstream effects caused by changes in fluvial sediment routing in low-order channels can be avoided by maintaining a diverse riparian forest stand with functional characteristics similar to "old-growth" stands and by preventing sediment generated by management activities from reaching low-order channels" (p. 241).

Perkins, S. J. 1989. **Landslide deposits in low-order streams --their erosion rates and effects on channel morphology.** Pages 173-182 *in* W. W. Woessner and D. F. Potts, editors. Proceedings of the symposium on headwaters hydrology. American Water Resources Association, Bethesda, Maryland**.**
From NCASI

A method is presented for prediction of rates of erosion of landslide deposits by low-order streams and the effects of landslide-supplied sediment of downstream channel morphology in the Chehalis watershed, WA.

Pitlick, J. 1982. **Organic debris in tributary streams of the Redwood Creek basin.** Pages 177-190 *in* R. N. Coats, editor. Proceedings of a symposium: watershed rehabilitation in Redwood National Park and other Pacific coastal areas. Center for Natural Resource Studies, John Muir Institute, Inc., Napa, California.
From NCASI

This paper deals primarily with storage of sediment by organic debris.
Most tributaries in this study area were "characteristically low order, high gradient streams draining small watersheds (Figure 3). Their channels are in general deeply incised and have narrow, discontinuous floodplains." Table 1 gives tributary names, drainage areas (1.55 to 44.03 km2), predominant rock type, and predominant forest type.

Cited in Sullivan et al. (1987): "In Redwood Creek, California, Pitlick (1982) found that woody debris in redwood dominated tributaries stored 74% of the sediment in the channel and 56% of the sediment produced by recent landslides; debris in Douglas-fir dominated basins stored 37% of in-channel sediment and 8% of recent landslide material. Redwood-produced debris accounted for greater sediment storage, because it decomposes more slowly than logs from species found in Douglas-fir forests and thus was longer lasting and more abundant."

Rice, S., and M. Church. 1996. **Bed material texture in low order streams on the Queen Charlotte Islands, British Columbia.** Earth Surface Processes and Landforms 21: 1-18. **From NCASI**

This paper examines the nature and causes of variations in the bed material texture of two small streams.

Rice, Raymond M. 1996. **Sediment delivery in the North Fork of Caspar Creek.** Unpubl. Final Report prepared for the California Department of Forestry and Fire Protection, Agreement No. 8CA94077. 28 October 1996. 11 p.

Sediment delivery was estimated for 13 tributary watersheds and the North Fork of Caspar Creek. The ratio of sediment to erosion averaged 16.4%, ranging from 1.0% to 89.7%.
Because the data were so highly skewed their median is a better indicator of central tendency
than their mean. The median delivery ratio was 6.3%. The ratios were accurately (R2 = 91.5%)
estimated by a 2-variable linear equation. However, the coefficients of the variables in the
equation have signs contrary to their physical effects on delivery of eroded material to a stream.
The analyses suggest that more research is needed into estimating sheet erosion and stream
channels as sediment sources. Compared to the earlier study in the South Fork of Caspar Creek
(Rice et al. 1979) logging of the North Fork resulted in erosion that was about half as large and a
sediment delivery ratio that was also about half of the 1979 estimate.

Rice, Raymond M.; Tilley, Forest B.; Datzman, Patricia A. 1979. **A watershed's response to logging and roads: South Fork of Caspar Creek, California, 1967-1976.** Res. Paper PSW-146. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 12 p.

A long-term study of the effects of logging and

roadbuilding on streamflow and sedimentation is underway at Caspar Creek, near Fort Bragg, California. Two experimental watersheds are being studied: North Fork and South Fork of the Creek. The study is a joint effort by the Pacific Southwest Forest and Range Experiment Station and the California Department of Forestry. Results of the first 14 years of the study are reported here.

The forest in the South Fork, the logged watershed, was about 85 years old in 1962, when the study was begun. It consisted mainly of redwood, Douglas-fir, Grand fir, and hemlock. In summer 1967, 4.2 miles (6.8 km) of logging roads were built. The effects of that activity were measured for 4 years and then, during 1971-73, about 65 percent of the stand volume was removed. On-site erosion, annual suspended sediment loads, and debris basin accumulations were estimated in order to evaluate the effects of road construction and the timber harvest.

Erosion associated with logging was measured on seven plots totaling 94 acres (38 ha). They were distributed throughout the watershed so as to be representative of site variability and the three seasons of cutting. Suspended sediment load was estimated each year by multiplying the volume of flow in each of 19 discharge classes by the mean suspended sediment concentration in each class and summing. Annual debris basin accumulations were estimated by comparing annual surveys of the basins. Two regression equations were computed in order to predict the effects of roadbuilding and logging. They estimated the suspended sediment load or debris basin accumulation in the South Fork based on streamflow and suspended sediment load or debris basin accumulation in the North Fork.

During logging, an additional 0.7 mile (1.1 km) of spur road was constructed. Of the total 4.9 miles (7.9 km) of roads, 2.4 miles (3.9 km) of the main haul road, and 1.3 miles (2.1 km) of spur roads were within 200 feet (61 m) of the stream. During the 4 years of measurement before logging began, we estimated that 1304 cu yd/sq mi (385 m3/km2) excess sedimentation occurred, or about 80 percent above the amount that would be predicted for the South Fork in an undisturbed condition.

The South Fork watershed produced a total of 4787 cu yd/sq mi (1413 m3/km2) excess sediment during the 5 years after logging was started. This sediment represents nearly a threefold increase over that which would have been expected had the watershed remained undisturbed. Analysis of the sediment/stream power relationship of Caspar Creek strongly suggests that the reason for the increase in sedimentation is that logging and roadbuilding had made additional sediment available for transport. In the undisturbed condition, the Caspar Creek watersheds showed relatively modest

increases in sediment load as stream power increased. After disturbance, the South Fork showed substantial increases in sediment transport as stream power increased. The undisturbed regime was highly dependent on supply; the disturbed regime became more dependent on stream power.
The erosion and sedimentation data collected as part of this study were used to estimate the long-term impacts of repeating such disturbances at 50-year intervals. If the estimated erosion rate reflected losses of soil from the site, the soil would be completely eroded in about 7900 years. If, on the other hand, excess sedimentation rates were a better measure of soil loss, exhaustion would occur in about 34,000 years. Either

of these estimates is so far beyond current planning horizons that they have little relevance to current management until they are more accurately estimated.
Activities in the South Fork of Caspar Creek may have resulted in turbidities in excess of those permitted by local water quality regulations. Turbidity was not measured as part of this study but because of the nature of the suspended sediment load of Caspar Creek, turbidity increases would probably parallel closely the observed suspended sediment increases. If that is true, then the average turbidity of the South Fork exceeded background by more than 20 percent (the limit set by regulation) in 8 of the 9 years after road construction was started.

Rice, Raymond M.; Ziemer, Robert R.; Lewis, Jack. 2004. **Evaluating forest management effects on erosion, sediment, and runoff: Caspar Creek and northwestern California.** Pp. 223-238 in: George G. Ice and John D. Stednick (eds.), A Century of Forest and Wildland Watershed Lessons. Bethesda, Maryland: Society of American Foresters.

KEY WORDS: automatic sampling, California Forest Practices Act of 1973, clearcut, discriminant analysis, erosion, erosion hazard rating (EHR), evapotranspiration, fish, floods, interception lag time, landslides, peak flows, roads, sedimentation, selective harvest, slope stability, stage-based sampling, storm volume, streamflow, suspended sediment, turbidity- based sampling, transient snowpack, water yield

The effects of multiple logging disturbances on peak flows and suspended sediment loads from second-growth redwood watersheds were approximately additive. Downstream increases were no greater than would be expected from the proportion of the area disturbed.

Annual sediment load increases of from 123 to 269% were measured in tributary watersheds but were not detected at the main channel gages, implying that sediment was being temporarily stored in the intervening channels.

Rice, Raymond M.; Ziemer, Robert R.; Lewis, Jack. 2001. **Forest management effects on erosion, sediment, and runoff: Lessons from Caspar Creek and northwestern**

California. Pages 69-75 in: Proceedings, Society of American Foresters 2000 National Convention, November 16-20, 2000. Washington, DC: Society of American Foresters.

KEY WORDS. Streamflow, runoff, sediment, erosion, logging, roads, monitoring, Caspar Creek

The effects of multiple logging disturbances on peak flows and suspended sediment loads from second-growth redwood watersheds were approximately additive. Downstream increases were no greater than would be expected from the proportion of the area disturbed. Annual sediment load increases of from 123 to 269% were measured in tributary watersheds but were not detected at the main channel gages, implying that sediment was being temporarily stored in the intervening channels. The failure of previous studies to detect increases in large peak flows following timber harvests may be due to variability in measurements rather than absence of an effect. A few sites are responsible for a large proportion of the erosion resulting from management-related disturbances.

Sidle, R. C. 1987. **A dynamic model of slope stability in zero-order basins. Pages 101-110 *in* R. L. Beschta,** T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.
From NCASI

This study offers a conceptual model, based on infinite-slope analyses, of evaluation of mass wasting probability on hillslopes in a zero-order basin in the Pacific Northwest over time.

Swanson, F. J., R. L. Fredriksen, and F. M. McCorison. 1982. Material transfer in a western Oregon forested watershed. Pages 233-266 *in* R. L. Edmonds, editor. Analysis of coniferous forest ecosystems in the western United States. Hutchinson Ross Publishing, Stroudsburg, Pennsylvania.

This paper discusses primarily hillslope processes and provides a general description of material transfer in channels. In this chapter, the authors examine important roles of material transfers in the functioning of forest-stream ecosystems, especially focusing on a small 0.1 km2 Watershed 10 in H. J. Andrews Experimental Forest, OR.

Channel Morphology

Channel morphology is not specifically discussed, but important notions pertaining to long-term morphology are mentioned "...If input generally exceeds output, the streambed should experience aggradation. The stream in Watershed 10 "is at the bottom of a steep-sided, V-notch valley, indicating a long history of downcutting. Short-term watershed budget studies and examination of sediment routing function and history of large woody debris in streams (Swanson et al. 1976) suggest, however, that channel systems may be sites of net increase in storage for long periods of time interrupted by infrequent, major flushing events. Consequently, such forested streams may be aggrading on the time scale of years and decades, while experiencing degradation on a broader time scale."

Sediment Supply and Load

The authors found that the principal hillslope processes that delivering dissolved, suspended and bed loads to stream channels are solution transport (material from hillslopes carries dissolved constituents leached from vegetation, soil, and weathering bedrock), litterfall (the final transfer in a chain of processes involving nutrient uptake by roots, translocation to biomass in the above ground portion of vegetation, and the fall of litter to the forest floor), surface erosion (organic and inorganic particulate matter occurs throughout the year), debris avalanches, creep, root throw, slump and earthflow.

Debris avalanches and torrents appear to be dominant processes and solution transfer (one of the most continuous processes) is the second most important sediment transfer mechanism. Creep, surface erosion, and root throw have secondary importance, while litterfall, slump, and earthflow processes are presently insignificant in terms of transporting inorganic matter. Much less variation in the relative importance of most processes is reported for organic transport.

"These processes are highly interactive. Some events may directly trigger other processes, as in the case of root throw, which may instantaneously initiate a debris avalanche. One process may also set the stage for the occurrence or acceleration of another process, such as baring of mineral soil by root throw and debris avalanche, which leads to a period of increased surface erosion. Processes also supply material for transport by other processes, so that transfer of a particular particle of soil through a watershed occurs as a series of steps in a variety of modes of transport."

"Vegetation increases the rates of some transfer processes while decreasing others. Rooting strength, the mass of vegetation on a hillslope, and hydrologic effects of vegetation regulate rates of debris avalanche, creep, slump, and earthflow activity. Root throw occurs because standing trees serve as a medium for transfer of wind stress to the soil mantle. Nutrient uptake by plants and other processes regulate export of dissolved material. Litterfall results in a net downslope transfer of particulate organic matter as a result of nutrient uptake, incorporating into biomass, and subsequent abscission or pruning by wind or other means…."

"Overland flow is observed only rarely and very locally in the study area (of the Watershed 10). No evidence of rill formation exists in most forested watersheds in western Oregon except on some debris avalanche scars, road cuts, and other disturbed sites."

"In stands of large, old-growth forests on steep slopes erosion by root throw is accentuated by massive root wads and their tendency to slide downslope. Such events are episodic, occurring in wind storms that have a return period of several years to decades. Deep-seated earth movement by slump, earthflow, and creep processes can lead to tipping and even splitting of trees, thereby increasing their susceptibility to blowdown."

"Particulate organic matter export from small watersheds may...be regulated by retentiveness or roughness of the channel system. Boulders and living and dead vegetation in and adjacent to the channel slow downstream routing of particulate matter, providing more opportunity for biological processing and export from the system by respiration and leaching...."

Effects of Natural Disturbance Mechanisms on Fluvial Processes

"As a result of numerous interactions between vegetation and material transfer processes in forests, severe disturbances of vegetation affect transfer processes throughout forested watershed ecosystems. This fact has been amply demonstrated in terms of sediment yield from paired watersheds in areas of diverse climate, vegetation, and geomorphic setting (for example, Fredriksen 1970, Brown and Krygier 1971, Bormann et al. 1974, Fredriksen et al. 1975)…."

"To fully assess effects of ecosystem disturbance on material transfer, a broad historical perspective is needed...material transfer history under both managed and natural conditions is composed of periods with transfer rates characteristic of established forest conditions interspersed with periods of accelerated transfer spanning up to several decades following severe disturbance of the ecosystem...."

"In many Pacific Northwest *Pseudotsuga menziesii* forests, natural premanagement disturbances during the past 1000 years have been predominantly major crown fires with a return period of several centuries. Erosional consequences of this type of disturbance are doubtless great, but unknown in steep landscapes...."

Effects of Management Practices on Fluvial Processes

"Initial observations in Watershed 10 and other experimental watersheds suggest that postclearcut watershed export comes from three sources, each associated with specific time frame: 1) material input to the channel during falling and yarding operations, consisting mainly of fine, green organic matter and some mineral soil; 2) material that had entered the channel by natural processes and was in temporary storage behind debris obstructions before logging, but is released from storage when large pieces of organic debris are removed from the channel during logging; and 3) material input to the channel by hillslope erosion processes following logging. A general phasing of watershed export of materials from these three sources may occur with material from source 1 mainly leaving the watershed in the first one to three years following cutting, source 2 gaining importance in the latter part of this period, and the postlogging hillslope erosion (source 3) becoming a dominant source several years after cutting...."

"...The timing of change in debris avalanche potential is partly a response to the timing of decay of root systems in the postcutting stand. The net effect of this and possibly other factors in areas of the H.J. Andrews Experimental Forest similar to Watershed 10 has been a 2.8 times increase in debris avalanche erosion over about a twelve-year period following clearcutting (Swanson and Dyrness 1975). Surface erosion involves a pulse of material transfer during and soon after the logging operation followed by a period of recovery. Timing of recovery is controlled by the rate of reestablishment of ground cover or development of a residual armor layer of coarse soil particles....recovery of vegetation reduces annual water yield to predeforestation levels over a period of a decade or more. Root throw within the deforested watershed is eliminated as a significant process for several decades until regeneration trees are large enough to be subject to blowdown…."

Tsukamoto, Y., and H. Minematsu. 1987. **Hydrogeomorphological characteristics of a zero-order basin.** Pages 61-70 *in* R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.

This paper discusses relationships between slope types, soil properties, mass-wasting, storm runoff processes and the occurrence of saturated overland flow, and liquefaction of colluvial deposits.

Ref ID: 83
Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., Cushing, C.E. 1980. **The river continuum concept.** Canadian Journal of Fisheries and Aquatic Sciences 37 (1):130-137.

Keywords : river continuum; geomorphology; community structure; community succession; function; structure; headwaters; transport; fluvial; streams; substrate; River Continuum Concept

From headwaters to mouth, the physical variables within a river system present a continuous gradient of physical conditions. This gradient should elicit a series of responses within the constituent populations resulting in a continuum of biotic adjustments and consistent patterns of loading, transport, utilization, and storage of organic matter along the length of a river. Based on the energy equilibrium theory of fluvial geomorphology, we hypothesize that the structural and functional characteristics of stream communities are adapted to conform to the most probable position or mean state of the physical system. We reason that producer and consumer communities characteristic of a given reach become established in harmony with the dynamic physical conditions of the channel. In natural stream systems, biological communities can be characterized as forming a temporal continuum of synchronized species replacements. This continuous replacement functions to distribute the utilization of energy inputs over time. Thus, the biological system moves towards a balance between a tendency for efficient use of energy inputs through resource partitioning (food, substrate, ect.) and an opposing tendency for a uniform rate of energy processing throughout the year. We theorize that biological communities developed in natural streams assume processing strategies involving minimum energy loss. Downstream communities are fashioned to capitalize on upstream processing inefficiencies. Both the upstream inefficiency (leakage) and the downstream adjustments seem predictable. We propose that this River Continuum Concept provides a framework for integrating predictable and observable biological features of lotic systems. Implications of the concept in the areas of structure, function, and stability of riverine ecosystems are discussed 'construct their own geometries' (Langbein 1964, p. 301). Small streams differ from rivers by having discharges that correspond, at most recurrence intervals, to volumes of flow that are small in relation to the activity of vegetation. These discharges create channels that are, again, small in relation to the geomorphic effect of plants. Thus, simply because of scale, channels of small streams are subject to processes that in rivers either do not occur, are almost completely counteracted by discharge, or have a negligible effect on channels hundreds or thousands of feet wide. Two processes peculiar to small streams are the extension of roots and the formation of dams of organic debris across the entire channel...In small streams, because of absolute volumes of flow, these changes brought about by non-fluvial processes are not quickly 'healed' by fluvial erosion and sedimentation. This is clearly shown by those localities where a local

widening of the channel can be traced to a fallen tree whose stage of decay suggests a tree-throw 10 or more years earlier.

Whiting, P.J., "**A Process-Based Classification System for Headwater Streams,**" in *Earth Surface Processes and Landforms* : John Wiley & Sons, Ltd., (1993), 603-12.

Keywords: watershed management/ channels/ ***headwater***/ streams

In this paper we developed a classification systems for small headwater streams predicated upon an understanding of the dominant physical processes acting in the channel and its basin, and the conditions under which these processes operate. The variables used to build the classification are hillslope gradient, valley width as compared to channel width, channel gradient, channel depth and sediment size. Using physical laws and morphologic relationships, we recognize domains in which various processes dominate. Channels within the same process domain can be expected to behave in a similar manner in transporting sediment and water and responding to and recovering from basin disturbance, therefore we use the domains to recognize distinct channel types. This classification system provides the foundation for building an approach to identifying basins and streams that are comparably sensitive to land use.

Whiting, P.J., Bradley, J.B. 1993. **A process-based classification system for headwater streams.** Earth Surface Processes and Landforms 18 :603-612.

Keywords : classification; sediment; disturbance; management; landform analysis; headwaters; streams

In this paper we develop a classification system for small headwater streams predicated upon an understanding of the dominant physical processes acting in the channel and it basin, and the conditions under which these processes operate. The variables used to build the classification are hillslope gradient, valley width as compared to channel width, channel gradient, channel depth and sediment size. Using physical laws and morphologic relationships, we recognize domains in which various processes dominate. Channels within the same process domain can be expected to behave in a similar manner in transporting sediment and water and responding to and recovering from basin disturbance, therefore we use the domains to recognize distinct channel types. This classification system provides the foundation for building an approach for identifying basins and streams that are comparably sensitive to landuse.

Whiting, P. J., J. F. Stamm, D. B. Moog, and R. L. Orndorff. 1999. **Sediment-transporting flows in headwater streams.** Geological Society of America Bulletin 111: 450-466.
From NCASI

"This study describes the bed load transport regime as it is linked to hydrology and geomorphology in 23 headwater gravel-bed streams in snowmelt-dominated parts of central and northern Idaho..... The bedload is much finer than the surface and subsurface material, suggesting selective transport of the finer sizes. Nonetheless, the

majority of the load is sand at all flow discharges..... Flows above bankfull discharge move 37% of the bed load, whereas flows between mean annual discharge and bankfull move 57% of the bed load. The bed-load effective discharge has a recurrence interval that averages 1.4 yr. and the magnitude of effective discharge averages 80% of bankfull discharge. The recurrence interval of bankfull discharges averages 2 yr. The ratio of effective to bankfull discharge is independent of basin size, grain size, and gradient, although the ratio increases with the relative magnitude of large infrequent events."

Sediment Supply and Load

The sediment sizes most relevant to the creation or maintenance of the channel geometry are those of the material making up the bed and banks. In upland channels, the coarse nature of the load means that much of the material moves along the channel as bedload. The bed and banks are composed of this coarse material, hence the channel geometry is related to the magnitude and frequency of flows transporting bed load.

Whittaker, J. G. 1987a. **Modelling bed-load transport in steep mountain streams.** Pages 319-331 *in* R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon**.**
From NCASI

The author develops equations for water scour model and sediment transport processes for channels with step-pool morphology. This study is not specific to the Pacific Northwest.

Whittaker, J. G. 1987b. **Sediment transport in step-pool streams.** Pages 545-579 *in* C. R. Thorne, J. C. Bathurst and R. D. Hey, editors. Sediment transport in gravel-bed rivers. John Wiley and Sons, New York.
From NCASI

The author uses physical and empirical models to investigate scour and sediment transport in step-pool streams.

Wiberg, P. L., and J. D. Smith. 1987**. Initial motion of coarse sediment in streams of high gradient.** Pages 299-308 *in* R. L. Beschta, T. Blinn, G. E. Grant, F. J. Swanson and G. G. Ice, editors. Erosion and sedimentation in the Pacific Rim. IAHS Publication No. 165. International Association of Hydrological Scientists, Corvallis, Oregon.
From NCASI

This paper presents a method for calculating the boundary shear stress necessary to set clasts of various sizes in noncohesive bed in motion in steep mountain streams, a situation in which the Shields technique breaks down.

III. Stream Channel Stability and Vegetation Influences on Stability

Ref ID: 120
Andrews, E.D. 1994. **Marginal bed load transport in gravel bed stream, Sagehen Creek, California.** Water Resources Research 30 (7):2241-2250.

Keywords : transport; streams; hydraulic; function; bed material; gravel

Marginal bed load transport describes the condition when relatively few bed particles are moving at any time. Bed particles resting in the shallowest bed pockets will move when the dimensionless shear stress exceeds a value of about 0.020. As shear stress increases, the number of bed particles moving increases. Significant motion of bed particles, i.e., when a substantial fraction of the bed particle are moving, occurs when shear stress exceeds a value of about 0.060. Thus marginal bed load transport occurs over the domain 0.020 < shear stress < 0.060. Marginal bed load transport rates and

associated hydraulic characteristics of Sagehen Creek, a small mountain gravel bed stream, were measured on 55 days at discharges ranging from slightly less than one half of the bank -full discharge to more than 4 times the bank-full discharge. Dimensions shear stress varied from 0.032 to 0.042, and bed particles as large as the 80th percentile of the bed surface were transported. The relation between reference dimensionless shear stress and relative particle protrusion for Sagehen Creek was determined by varying shear $stress_{ri}$ to obtain the best fit of the Parker bed load function to measured transport rates. During the period of record (water years 1954-1991), the mean annual quantity of bed load transported past the Sagehen Creek gage was 24.7 tons. Forty-seven percent of all bed load transported during the 38 years of record occurred in just 6 years. During 10 of the 38 years if record, essentially no bed load was transported. The median diameter of bed load was 26mm, compared to58 mm in the surface bed material.

Barrow, J.R.**Use of floodwater to disperse grass and shrub seeds on native arid lands**. Clary, Warren P., McArthur, E. Durant, Bedunah, Don, and Wambolt, Carl L. 167-169. 1992. Ogden, UT, Intermountain Research Station. General Technical Report INT-289. 5-29-1991.

Keywords: range management/ ***intermittent streams***/ arid lands/ riparian vegetation/ floods/ revegetation

Dry stream channels of arid rangelands are typically more fertile and mesic than adjacent slopes. The productivity of these channels is evident by their relatively abundant plant biomass. Substantial down channel establishment of seeded and native species from root plowed and seeded strips was observed on the Jornada Experimental Range. There appears to be good potential for using flood water as a low input method of seed dispersal for subsequent revegetation of natural waterways

Ref ID: 89
Barton, D.R., Taylor, W.D., Biette, R.M. 1985; **Dimensions of riparian buffer strips required to maintain trout habitat in southern Ontario streams.** North American Journal of Fisheries Management 5 (1):364-378.

Keywords : buffer; riparian vegetation; trout; habitat; temperature; fish; Ontario; streams; model

The relationships between riparian land use and environmental parameters that define the suitability of southern Ontario streams for trout were examined for 40 sites on 38 streams. Weekly observations of maximum and minimum temperature, coarse and fine suspended matter, and discharge were made during June, July, and August 1980. Land use was determined from aerial photographs of each stream. Fish were surveyed at each site during August by electro fishing and seining.

The only environmental variable which clearly distinguished between trout and nontrout streams was weekly maximum water temperature: streams with trimean

weekly maxima less than 22 C had trout; warmer streams had, at best, only marginal trout populations. Trout streams tended to have low concentrations of fine suspended solids and a more stable discharge, but so did many of the other streams. Water temperature, concentration of fine particulate matter, and variability of discharge were inversely related to the fraction of the upstream banks covered by forest. Fifty-six percent of the observed variation in weekly maximum water temperature could be explained by the fraction of bank forested within 2.5 km upstream of a site. Other land uses were not clearly related to stream variables, except that high concentrations of fine suspended solids were most often observed in reaches used as pasture.

Analysis of data from sites located within buffer strips yielded a regression relating maximum weekly temperatures to buffer strip length and width. The regression accounted for 90% of the observed variation in water temperature for these sites. The model was verified further by comparisons with observed temperatures at a second set of sites located downstream from buffer strips.

Baattrup Pedersen, A., Riis, T., Hansen, H.O., and Friberg, N. **"Restoration of a Danish headwater stream: short-term changes in plant species abundance and composition."** *Aquatic-Conservation-Marine-and-Freshwater-Ecosystems* 10, no. 1 (2000): 13-23.

Keywords: Environmental restoration/ Streams / Plants / Abundance/ Species composition/ Denmark / Denmark/ Gudenae River/ ***Headwaters*** / Plant Populations/ Valleys / Rehabilitation / Soil Water/ Plant Growth/ Submerged Plants/ Riparian Vegetation/ River banks/ Short term changes/ Community composition/ Aquatic plants/ Species diversity/ Restoration / Rivers / Plantae / Denmark/ Gudenae River

This paper describes the short-term effects (2 years) of stream restoration on vascular plant communities in a 1.4 km upper reach of the River Gudenae, Denmark. The effects of restoration were assessed in terms of the abundance and composition of plant species in the stream, on the banks and in the stream valley. 2. Total species richness was similar before and after restoration, and comprised approximately 150 species representing 12% of the entire Danish vascular plant flora. 3. In the stream, total plant cover had not recovered to pre-restoration levels 2 years after restoration. Cover by submerged, amphibious and terrestrial species growing submerged decreased, as did the number of amphibious and terrestrial species growing submerged. 4. On the banks, total plant cover almost attained pre-restoration levels the second year after restoration.

The plant communities changed from dominance by non-riparian species to more diverse communities with a greater number and increased cover of riparian gramineous species requiring higher soil moisture content. 5. In the valley, the plant communities only changed slightly after restoration, although growth of riparian species was enhanced on the southern side of the stream.

Belmonte, A.M.C. Beltran, F.S.2001. **Flood events in Mediterranean ephemeral streams (ramblas) in Valencia region, Spain.** Catena, vol 45, 3: 229-249.

Keywords: Spain/ Valencia/ Mediterranean region/ Catchment Areas/ Regional Analysis/ Flash Floods/ ***Ephemeral Streams***/ Rainfall runoff Relationships/ Hydrologic

Data/ Hydrographs / Infiltration / Floods / Flooding / stream discharge/ storm runoff/ Rainfall / Spain/ Valencia

This article deals with flood events in Mediterranean ephemeral streams typical of the Valencia region. The combination of the basin physical characteristics (steep slopes, sparse vegetation, thin soils and permeable rock) and intense, heavy and irregularly distributed rain generates flash floods. Runoff generation is sudden, giving rise to flash floods with sharp, narrow hydrographs with short time lags. The high amount of runoff is, nevertheless, only a small fraction of the total rainfall, since the characteristics of the river basins are such that infiltration of large amounts of water occurs. Using daily hydrological data from the Rambla de la Viuda basin and 5-min data from both the Barranc del Carraixet and the Rambla de Poyo basins, the rainfall-runoff processes have been analyzed during flood events in these ephemeral streams.

Ref ID: 133
Belt, G.H., O'Laughlin, J., Merrill, T. 1992. **Design of forest riparian buffer strips for the protection of water quality: Analysis of scientific literature.** Report No.8. Idaho Forest, Wildlife and Range Experiment Station, University of Idaho. Moscow, Idaho.

Keywords : buffer; riparian reserves; riparian vegetation; water quality; timber harvest; forest practices; habitat; stream temperature; woody debris; fish; impacts; streams; temperature; vegetation; debris; sediment; models; literature review; function; roads; nutrients; forestry; Pacific Northwest; model; Washington; riparian zone

The primary purpose of this report is to identify, evaluate, and synthesize research-based information relating riparian buffer strips to forest practices, water quality, and fish habitat. (Definitions of technical terms such as buffer strips, riparian, forest practices and water quality are provided in a Glossary at the of this report.

Scientific literature documenting the role and importance of buffer strips in reducing the impacts of forest practices is extensive. More than300 scientific papers were located and reviewed; nearly 100 papers and documents were found to be relevant and are cited in this report. Information was extensive on some topics and surprisingly limited on others. A substantial amount of information was found regarding stream temperature changes resulting from the removal of riparian vegetation. Much recent research has focused on the importance of large organic debris (LOD) and how it can be affected by timber harvest. In contrast, little information was found on slash burning and sediment production within buffer strips. Research on some topics was in a case study format, making generalization difficult.

Objectives for this report are stated as five focus questions around which the report is organized: [1] What is a buffer strip? [2] How do forest practices within buffer strips affect water quality and fish habitat? [3] How effective are buffer strips in reducing impacts of forest practices? [4] What are the issues in buffer strip design? [5] What models are available for use in buffer strip design? A summary of replies to these focus questions is provided in a short section immediately following this executive summary.

This literature review suggests that scientists are at different stages in their understanding of the several important functions provided by buffer strips, which

include temperature moderation, sediment filtration and LOD recruitment. The importance of buffer strips in moderating the impacts of forest practices on water quality and fish habitat is generally understood, even though quantitative relationships are difficult to establish. Research on the effects of canopy removal on stream temperature has resulted in a practical understanding of the problem and some useful predictive models. In two other areas that have received recent emphasis--the impacts of forest practices on LOD recruitment and the aquatic food chain--knowledge is more descriptive. Some predictive models have been developed, but their utility is limited.

Information on the sediment filtering function of riparian buffer strips is limited. Much of what is known is inferred from the special case of buffer strips between a road and a stream. The importance problem of cumulative effects within buffer strips has not yet been satisfactorily addressed. Existing studies, including those on slash burning, point out the potential for the accumulation of nutrients and chemicals along with sediment form both agricultural and forestry operations in riparian areas and the possible impacts on water quality and fisheries.

Studies describing different approaches to establishing buffer strip widths are limited. Despite literature describing the utility of variable width buffer strip models and their use in other states in the Pacific Northwest, no studies were found documenting the advantages of variable width buffer strips, as compared to minimum fixed width buffer strips.

Based on this literature review, two ideas seem to stand out as having some potential to enhance the effectiveness of buffer strips: (1) the use of a simplified field procedure (such as the TFW model in the State of Washington) for determining the impact of canopy removal on stream temperature, and (2) the use of variable width buffer strip model to address site-specific biological or physical requirements of the stream or riparian zone.

Bloss, D.A. and Brotherson, J.D.; **"Vegetation response to a moisture gradient on an ephemeral stream in central Arizona."** *Great Basin Naturalist* 39, no. 2 (1979): 161-176.

Keywords: plant populations/ water stress/ deserts/ ***ephemeral streams***/ moisture gradient/ flood plains/ ecology/ species diversity

Ecological aspects of desert vegetation in relation to a moisture gradient along an ephemeral stream in central Arizona were investigated. The stream channel, flood plain, and north-, west-, south-, east-facing slopes represent a moisture gradient going from mesic to xeric conditions. Vegetation in some areas of the stream channel intergraded into flood plain vegetation, which in turn intergraded into slope vegetation types. In other areas there were sharp delineations between stream channel and flood plain and between flood plain and slope. Trees and legume species preferred mid-moisture habitats, but forbs, shrubs, and succulents preferred dryer areas. Family groups like the Asteraceae and the Poaceae were found to be distributed ubiquitously. Niche widths were broadest for flood plain species. Diversity was highest on the slopes. Negative correlations existed between stand diversity and the Synthetic Stand Moisture Index (i.e., as moisture increased diversity increased). It is believed that disturbance as well as moisture influenced diversity.

Bottorff, Richard L.; Knight, Allen W. 1996. **The effects of clearcut logging on stream biology of the North Fork of Caspar Creek, Jackson Demonstration State Forest, Fort Bragg, CA -- 1986 to 1994.** Unpubl. Final Rept. prepared for the California Department of Forestry and Fire Protection, Contract No. 8CA63802. May 1996. Sacramento, CA. p.177

Key Words: PSW4351, Caspar Creek, Jackson State Forest, CDF, logging, stream, cumulative effects, fish

The dense coniferous forests of the North Coast Range of California have been harvested for valuable redwood (Sequoia sempervirens), Douglas fir (Pseudotsuga menziesii), and other tree species for more than 100 years. Initially, the primary focus of logging activities was to efficiently fall the trees and transport them to the mill site without much concern for the sustained productivity of the renewable forest resource and other environmental components within the drainage basin. However, for some time now, it has been recognized that logging activities can have significant impacts, both short- and long-term, within the drainage basin (Salo & Cundy 1987, Meehan 1991, Naiman 1992). These impacts are not localized just to the specific areas of tree cutting, but extend downstream into the network of streams draining the logged sites. Understanding how to minimize these downstream impacts is especially vital because many North Coast streams serve as habitat for valuable salmonid fishes. There is also interest in whether cumulative effects of logging are impacting stream biological communities.

Ref ID: 20
Boulton, A.J. 1991; **Eucalypt leaf decomposition in an intermittent stream in south-eastern Australia.** Hydrobiologia 211 (2):123-136.

Keywords : eucalypt; litter; decomposition; Australia; microbial use; feeding groups; pools

Eucalypt leaf packs were placed at two sites in an intermittent stream during summer to examine the hypothesis that terrestrially-exposed leaf litter accumulates a richer microbial flora than submerged leaves - a phenomenon observed in Canadian vernal pools. This did not occur; during the experiment, microbial biomass (as ATP) rose steadily on submerged leaves but remained low on terrestrially-exposed leaves. Densities of most functional feeding groups on the submerged leaves increased with time. Scrapers appeared to be more important than shredders in eucalypt leaf breakdown at both sites.

Ref ID: 112
Budd, W.W., Cohen, P.L., Sanders, P.R., Steiner, F.R. 1987. **Stream corridor management in the Pacific Northwest: I. Determination of stream-corridor widths.** Environmental Management 11 (1):587-597.

Keywords : stream corridor; corridor; buffer width; management; Washington

King County, Washington is part of the rapidly growing Pacific Northwest region. This growth has placed pressure on stream corridors. Past studies about regional stream corridors provide a rich source of information for environmental planners and managers. This article draws on existing literature and case studies to provide guidelines for determining optimal stream corridor widths in watershed located in King County, Washington.

Clary, W.P., Abt, S.R., and Thornton, C.I. 1993. **Sediment entrapment by stream channel vegetation.** 335-342. American Society of Civil Engineers, Irrigation and Drainage Division. 7-21-1993.

Keywords: stoneflies/ stream order/ species composition/ ***headwaters***/ food habits/ insect behavior/ species diversity/ prediction/ field tests/ riparian vegetation/ structure/ mountains

Degraded headwater streams are common in the mountainous West. They have experienced a variety of stresses from public and private uses and will require specific management consideration to recover during continued use. It is generally recognized that deposited sediments are required for natural rebuilding of stream banks. This study evaluated the effects of vegetation lengths and other attributes in entrapping and retaining sediments on a simulated stream reach in the Hydraulics Laboratory at Colorado State University. Loading and flushing of sediments was a function of vegetation characteristics and stream discharge. A simulated stream reach was used in the laboratory to evaluate sediment deposition and entrapment by herbaceous vegetation in a riparian system. A flattened hydrograph was routed through the channel. Sediments were injected for the first 6 hours, but not during the subsequent 6-hour period of flushing. Vegetation significantly enhanced deposition and retention of sediment in the channel. The amount of sediment entrapped during the deposition phase and retained during the flushing phase was a function of vegetation length and flow velocity. For Kentucky bluegrass, sediment deposition was greater with the shorter suitable heights. However, the longest leaves were just as effective in retaining sediments during the simulated hydrograph tail-off or flushing phase. The vegetation retained up to 70 percent of the sediments at the highest flows. The effect of leaf length during the flushing phase was somewhat different than the effect during the loading phase. The short, stiff leaf blades did not protect sediments from flushing more than long leaf blades. An unanticipated result was the substantial loss of sediments from the sod with 7.62-cm leaf blades during the low-velocity flushing flows. These medium-length leaves appeared to undulate more in the current than either the longest or shortest leaf blades. This undulation dislodged sediment particles. As flow increased, the sediment retention improved for all leaf lengths. Sod with leaves 1.27 cm long had

the most total retained sediments at the lowest flows, but at the highest flows total retained sediments were similar for sod with leaves 1.27 and 7.62 cm long. A wider, less rigid leaf structure, represented by field corn seedlings, was comparatively ineffective in entrapping sediment because it flattened in the current, creating a relatively smooth surface.

Ref ID: 88
Clifton, C. 1989. **Effects of vegetation and land use on channel morphology.** pp.121-129**. in** Gresswell, Barton, and Kershner (ed.). Practical Approaches to Riparian Resource Management an Educational Workshop. Billings, Montana. May 8-11, 1989.

Keywords : vegetation; morphology; management; streams; structure; organic debris; debris; stream depth; Oregon

Spatial and temporal morphologic variability in mountain streams may be attributed to local prevailing conditions. Morphologically distinct reaches of Wickiup Creek in the Blue Mountains of central Oregon, result from differences in the composition and structure of streamside vegetation, physiography, and land use. Comparisons of grazed and ungrazed meadow reaches and a forested reach loaded with large organic debris reveal specific differences related to the local environmental setting. Overall, width, depth, and cross section area do not increase systematically downstream. The greatest widths are found in the forested reach. Stream depths are at a maximum through the ungrazed meadow reach. Spatial variability results from prevailing vegetation conditions. Temporal variability in the ungrazed exclosure results from the exclusion of livestock and subsequent revegetation of the meadow. Over a 50-year period without grazing, a 94% reduction in channel cross section area occurred.

Ref ID: 121
Coho, C., Burges, S.J. 1994. **Dam-break floods on low order mountain channels of the Pacific Northwest.** pp.1-70**. in** Prepared by Department of Civil Engineering, University of Washington, Seattle for Washington Department of Natural Resources, Olympia. TFW-SH9-93-001. Department of Natural Resources Timber/Fish and Wildlife. Seattle, Washington.

Keywords : floods; disturbance; dam-break floods; Pacific Northwest; Washington; organic debris; debris; streams; riparian vegetation; vegetation; fish; habitat

Flood waves produced from dam breaks attenuate with distance traveled downstream (Costa1985). Flood waves produced from dam breaks in low order mountain channels, however, mobilize significant amounts of organic debris within the stream valley and may cause the formation of a moving dam composed almost exclusively of organic material. This dam is propelled downstream in a manner often destructive to riparian vegetation, fish habitat, and downstream dwellings, until riparian

conditions, channel geometry, or supply of organic debris are altered causing the movement to cease. Initiation mechanisms, movement, and ultimate deposition locations of debris from dam-break floods are described for twenty locations in the Pacific Northwest. Four low order mountain channels that experienced destructive dam-break floods are described in greater detail. A strategy for evaluating the potential for destructive dam-break floods in low order channels is provided.

Ref ID: 127
Corn, P.S., Bury, R.B. 1989. **Logging in western Oregon: Responses of headwater habitats and stream amphibians.** Forest Ecology and Management 29 (1):39-57.

Keywords : headwaters; habitat; streams; amphibians; disturbance; logging practices; Oregon; substrata

We compared occurrence and abundance of four species of aquatic amphibians in 23 streams flowing through uncut forests to 20 streams flowing through forests logged between 14 and 40 years prior to the study. Species richness was highest in streams uncut forests. Eleven streams in uncut forests contained all four species, and only two of these streams had fewer than three species present. Eleven streams in logged stands had one or no species present, and only one contained all four species. Density and biomass of all four species were significantly greater (2 - 7 X) in streams in uncut forests. Physical comparisons between types of streams were similar, except that streams in logged stands had generally smaller substrata, resulting from increased sedimentation. Densities of Pacific giant salamanders *(Dicamptodon ensatus)* and Olympic salamanders *(Rhyacotriton olympicus)* were positively correlated with stream gradient in logged stands, but not in uncut forests, suggesting that the disruptive effects of increased sedimentation are greatest in low-gradient streams. Tailed frog *(Ascaphus truei)* and Dunn's salamander *(Plethodon dunni)* occurred more often in streams in logged stands when uncut timber was present upstream, but neither density nor biomass of any species were related to either presence of uncut timber upstream or years since logging. Logging upstream from uncut forests also had no effect on the presence density or biomass of any species. Tailed frogs and Olympic salamanders may be extirpated from headwaters traversing clear cuts; these streams should be afforded some protection in plans for managed forests.

Ebisemiju, F.S. **"The sinuosity of alluvial river channels in the seasonally wet tropical environment: Case study of river Elemi, southwestern Nigeria."** *Catena* 21, no. 1 (1994): 13-25.

Keywords: rivers/ channels/ meanders / river mechanics/ geomorphology/ erosion/ riparian vegetation/ ***intermittent streams***/ Watershed management/ case studies/ Nigeria/Elemi River/ river meanders/ fluvial sediments/ river beds/ tropical regions/ sinuos flow

Investigations carried out in the Elemi river basin, southwestern Nigeria suggest that small intermittent streams in the seasonally wet humid tropics have a tendency to develop very sinuous channels characterized by compound and highly convoluted

loops. Analysis of arc symmetry and the repetition of symmetry indicate that the 153 bends alone the 39.3 km long river are not true meanders as objectively defined by Brice in 1964. The dominant factor controlling the degree of sinuosity is channel bank resistance to lateral erosion as influenced primarily by the nature of riparian vegetation and secondarily by the percentage silt/clay in channel bank sediment. The influence of bank vegetation is particularly pronounced in view of the preponderance of low flow discharges, high proportion of suspended sediment and gentle bed slope. The high density of riparian trees account for the relatively short length of the straight reaches and the high frequency of bends, compound and convoluted loops. The implications for river management of the inherent instability of small channels in seasonally wet humid tropical environments, and of the considerable channel bank erosion which occurs at the numerous bends are briefly highlighted

Ref ID: 33
Harrison, A.D. 1958. **Hydrobiological studies on the Great Berg River, Western Cape Province. Part 2. Quantitative studies on sandy bottoms, notes on tributaries and further information on the fauna, arranged systematically.** Transactions of the Royal Society of South Africa 35 :227-276.

Keywords : fauna; benthic; channel bed; substrate

This part consists of three sections. The first deals with quantitative studies of the fauna of sandy bottoms sampled at two points on the river; a Birge-Ekman grab was used and samples were sifted through No. 3 grit gauze. The second section deals with the bottom fauna of three tributaries and discusses possible reasons for differences between these faunas and that of the main river. The third section comprises biological notes on most of the species encountered during the survey; these are arranged systematically.

Ref ID: 107
Hynes, H.G.N. 1970. **The ecology of running waters.** pp.1-555.University Toronto Press; Ontario:

Keywords : Ecology; macroinvertebrates

Noel Hynes compiled a comprehensive, critical review of the literature pertaining to stream limnology. Included are physical and chemical characteristics of flowing waters, plant life, the benthos, fish and finally, man's effects on watercourses.

Keppeler, Elizabeth T., Jack Lewis, Thomas E. Lisle. 2003. Effects of forest management on streamflow, sediment yield, and erosion, Caspar Creek Experimental Watersheds. In: Renard, Kenneth G.; McElroy, Stephen A.; Gburek, William J.; Canfield, H. Evan; Scott, Russell L., eds. First Interagency Conference on Research in the Watersheds, October 27-30, 2003. U.S. Department of Agriculture, Agricultural Research Service; 77-82.

Caspar Creek Experimental Watersheds were established in 1962 to research the effects

of forest management on streamflow, sedimentation, and erosion in the rainfall-dominated, forested watersheds of north coastal California. Currently, 21 stream sites are gaged in the North Fork (473 ha) and South Fork (424 ha) of Caspar Creek. From 1971 to 1973, 65% of the timber volume in the South Fork was selectively cut and tractor yarded, and from 1985 to 1991, 50% of the North Fork basin was harvested, mostly as cable- yarded clearcuts. Three unlogged tributaries serve as controls.

Ref ID: 62
Lampkin, A.J.I., Sommerfeld, M.R. 1982. **Algal distribution in a small, intermittent stream receiving acid mine-drainage.** Journal of Phycology 18 (2):196-199.

Keywords : algae; algal distribution; acid mine-drainage; Arizona

Lynx Creek, a small intermittent creek in the Bradshaw Mountains of Arizona, is subjected to drainage from an abandoned copper mine. The mine-drainage decreases the pH of the Creek about three units and greatly increases sulfate and heavy metal concentrations. Chemical recovery of the Creek occurs downstream through precipitation of metal hydroxides and dilution by tributaries. Changes in Creek chemistry are accompanied by changes in alga flora. Above the mine and downstream after substantial recovery the flora is dominated by *Tribonema affine, Achnanthes spp*. and *Synedra ulna* and several zygnematacean species. In the mine seep entering the Creek and in the Creek just below the seep the flora is reduced in species richness and dominated in abundance by *Microthamnion kuetzingianum* and *Eunotia tenella***.**

Liquori, M.K. 2002. Observations on the morphology of headwater streams. Symposium on small stream channels and their riparian zone: their form, function and ecological importance in a watershed context. Feb 19-20, 2002, Vancouver, B.C.

As stream protection strategies shift higher into channel networks, it becomes important that we better understand how ecosystem processes influence channel behavior in headwater streams. While some patterns in headwater streams are similar to those found in higher-order channels, many significant differences exist that may shed light on the dependency on riparian communities and other ecosystem processes to create and maintain important habitats. I've examined data collected on 980+ stream segments, representing over 150 miles of headwater streams in the western cascades near Mt. Rainier. Trends include upstream fining and downstream increases in reach-average shear stress, which are opposite observations from fully alluvial (e.g. higher-order) channels. There are marked disequilibria in local gradient for some stepped headwater channels that may be linked to limited stream power, high sediment supply, or limits in step-forming structures. LWD load has little influence on channel type (at least between stepped and cascade channels). There is also no relationship between LWD size and residual pool depth. Small woody debris, either in jams or as single pieces, often provides step features, as can large clasts (cobbles/boulders), bedrock, or hydraulic scour. LWD frequency is also significantly lower than found in higher-order channels, likely due to fewer active LWD recruitment processes. These results suggest that greater focus on headwater channels may elucidate management objectives in headwater channels that may be significantly different than higher-order channels.

Lisle, Thomas E.; Napolitano, Michael. 1998. **Effects of recent logging on the main channel of North Fork Caspar Creek.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 81-85.

The response of the mainstem channel of North Fork Caspar Creek to recent logging is examined by time trends in bed load yield, scour and fill at resurveyed cross sections, and the volume and fine-sediment content of pools. Companion papers report that recent logging has increased streamflow during the summer and moderate winter rainfall events, and blowdowns from buffer strips have contributed more large woody debris. Changes in bed load yield were not detected despite a strong correlation between total scour and fill and annual effective discharge, perhaps because changes in stormflows were modest. The strongest responses are an increase in sediment storage and pool volume, particularly in the downstream portion of the channel along a buffer zone, where large woody debris (LWD) inputs are high. The association of high sediment storage and pool volume with large inputs of LWD is consistent with previous experiments in other watersheds. This suggests that improved habitat conditions after recent blowdowns will be followed in future decades by less favorable conditions as present LWD decays and input rates from depleted riparian sources in adjacent clearcuts and buffer zones decline.

Ref ID: 78
Miller, A.J. 1990. **Fluvial response to debris associated with mass wasting during extreme floods.** Geology 18 (1):599-602.

Keywords : mass wasting; debris flows; fluvial; floods; erosion; hydraulic; Appalachian; debris; streams; sediment; flow

Evolution of channels and bottomlands in mountain valleys of the central Appalachians is strongly influenced by debris supplied to stream channels from mass wasting during extreme storms. The type of change observed varies with basin scale and storm characteristics. Along channels receiving coarse sediment from debris avalanches or debris flows during Hurricane Camille in 1969, pure scour occurred in drainage areas less than 1 km^2 and gradients steeper than 0.1; in Hurricane Camille and in the June1949 storm, mixed erosion and deposition with continuous reworking of the valley floor was observed along streams with drainage areas up to 65 km^2. In basins larger than 100 km^2, valley-floor reworking associated with influx of debris during both storms was localized and discontinuous.

In the South Branch Potomac River basin in West Virginia, intense precipitation within a small contributing area generated scores of debris slides and avalanches in June 1949; debris transported by tributaries to main valleys exceeded the competence of the larger channels and formed new bottomland. Long-duration moderate-intensity

precipitation in November 1985 generated fewer debris avalanches. Flood peaks associated with a larger contributing area along the main valleys were 80% to 190% larger than in 1949 and caused extensive channel and flood-plain erosion, including truncation and removal of 1949 deposits. At some locations relict debris deposits may have influenced hydraulic conditions and affected patterns of erosion and deposition during the 1985 storm. Sequential occurrence of extreme storms with different hydrologic characteristics creates a bottomland mosaic of surfaces with varying elevations and textures.

Ref ID: 51
Montgomery, D.R., Dietrich, W.E. 1988. **Where do channels begin?** Nature 336 :232-234.

Keywords : headwaters; slope; landscape; watershed; growth; models; runoff; flow

The closer channels begin to drainage divides, the greater will be the number of channels that occupy a unit area, and consequently the more finely dissected will be the landscape. Hence, a key component of channel network growth and landscape evolution theories, as well as models for topographically controlled catchment runoff, should be the prediction of where channels begin. Little field data exist, however, either on channel head locations or on what processes act to initiate and maintain a channel. Here we report observations from several soil-mantled regions of Oregon and California, which show that the source area above the channel head decreases with increasing local valley gradient for slopes ranging from 5 to 45 degrees. Our results support a predicted relationship between source area and slope for steep humid landscapes where channel initiation is by landsliding, but they contradict theoretical predictions for channel initiation by overland flow in gentle valleys. Our data also suggest that, for the same gradient, drier regions tend to have larger source areas.

Ref ID: 51
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Nouh, M., "**Methods of Estimating Bed Load Transport Rates Applied to Ephemeral Streams.,"** in *Sediment Budgets.*: International Association of Hydrologic Science, 1988), 107-15.

Keywords: sediment/methods/ bed load/ ***ephemeral streams***

Bed load transport rates were calculated with different methods and measured in 37 straight ephemeral channels varying in width, slope, surface roughness, and flood flow characteristics. The methods of Diplas (1987), Samage et al. (1986). Misri et al. (1984), and Profitt & Sutherland (1983) are considered. None of the methods were satisfactory although the first methods proved relatively the best for the investigated channels. To improve the applicability of these methods in ephemeral channels, a modification which considers the effect of unsteady flow during flash floods is introduced. The modified methods produced satisfactory results in most of the investigated channels.

Ref ID: 5
Reid, L.M., Ziemer, R.R. 1994; **Evaluating the biological significance of intermittent streams.** Chapter 2 **in** Federal approach to watershed analysis. Review Draft Report. USDA Forest Service. Arcata, California.

Keywords : biological values; watershed; policy; landscape; slope; fauna; sediment; habitat; management

Intermittent streams comprise a large proportion of the drainage network in many parts of the Pacific Northwest, and recent policy changes brought about by the Northwest Forest Plan now afford them an unprecedented level of protection. If, during watershed analysis, these sites are found to be relatively unimportant in maintaining the overall ecosystem, their level of protection is likely to be decreased. An important function of watershed analysis on Federal lands of the Pacific Northwest is thus to evaluate the roles that these landscape features play in maintaining ecosystems on adjacent slopes, in riparian areas, and in downstream aquatic environments. Intermittent streams which are large enough to support distinctive riparian vegetation influence fauna both on-site and downstream, while smaller channels are important primarily because of their influence on the supply of sediment, water, and organic materials to downstream habitats. Neither the physical nor the biological role of intermittent streams can be evaluated without consideration of the streams' interactions with hill slope ecosystems and physical processes. Watershed analysis can provide information in different parts of a watershed about the extent of the intermittent stream network, the types of interactions important for ecosystems at those sites and downstream, how management activities influence those interactions, and the types of information that will be useful to gather before or during project-level assessments. Watershed analysis cannot define Riparian Reserve boundaries, and collection of new inventory information is not intended as a part of watershed analysis.

Ref ID: 110
Stanley, E.H., Fisher, S.G. 1992. **Intermittency, disturbance and stability in stream ecosystems.** pp.271-280**. in** Robarts, R.D. and Bothwell, M.L. (ed.). Aquatic ecosystems in semi-arid regions; implications for resource management. National Hydrology Research Institute. Saskatoon, Saskatchewan. Aug 27-30, 1990.

Keywords : disturbance; intermittency; management; streams; structure; flow; biota

Intermittent streams are common particularly in arid and semi-arid regions of the world, yet are seldom studied and poorly understood. We argue that more attention needs to be focused on drying as it is often a major determinant of ecosystem structure and functioning and that drying should be viewed as a natural disturbance. Intermittency is characterized by three hydrologic phases: 1) drying, marked by the development of discontinuous longitudinal flow 2) dryness, when surface water is absent, and 3) rewetting, which can be either gradual or rapid. Each phase poses distinct challenges to the biota, and consequently studies should be designed according to these phases. Changes in state variables can then be interpreted with respect to ecosystem stability. Resistance to this disturbance is partitioned into resistance to drying (resistance I), resistance to dryness (resistance II), and resistance to rewetting (resistance III). Resilience is the rate of recovery following rewetting. By studying drying as a disturbance and measuring changes in state variables with respect to resistance and resilience, variability caused by different antecedent conditions or different drying regimes can be quantified and compared. Thus, hypothesis explaining differential effects of drying on the stream ecosystem can be generated and tested.

IV. Hydrology and Hydrologic Regimes

Albright, J. S. 1991;**Storm hydrograph comparisons of subsurface pipe and stream channel discharge in a small, forested watershed in northern California.** Master's thesis. Humboldt State University, Arcata, California.
From NCASI

Subsurface Erosion Processes

Albright examines piping, a term he says describes "subsurface erosion processes and concentrated subsurface water discharge." Piping typically occurs due to "effects of mechanical (e.g., corrosion), chemical (e.g., soil dispersion), or biotic (e.g. animal burrowing) forces normally occurring in subsurface environments." Piping is thought to be geomorphically and hydrologically important, although understanding of the magnitude of its importance and of the general applicability of findings about piping is limited. Albright's study involved measurement of pipe discharge, stream discharge, and rainfall for 3 winter storm seasons in the uppermost portion of the North Fork Caspar Creek basin, California. This study indicated that "pipes respond dynamically to rainfall inputs (iii)", particularly during high-intensity precipitation events or during events with high antecedent soil moisture. Albright also found that peaks of pipe discharge occurred later than stream discharge peaks, were lower on a unit-area basis, and were not as flashy. Following cessation of rainfall, discharge response in pipes

declined more rapidly than in surface channels, and runoff events in surface channels therefore had greater duration. Pipe discharge measured at 3 swales averaged 50-68% of discharge measured in a surface channel, although Albright suggests his results do not provide a statistically sound means of evaluating the importance of pipeflow contributions to storm runoff from his study swales. Albright suggests that the magnitude and timing characteristics of pipeflow response are intermediate between the responses of surface channels and matrix throughflow. Antecedent soil moisture and rainfall intensity appear to be the most important factors in determining the similarity of the hydrologic (timing) response of pipes and surface channels to precipitation.

Albright indicates that the larger peak flows observed in the surface channel are suggestive of saturation overland flow (SOF), a process that does not contribute to pipe runoff, although SOF was not observed during the study. He also suggests that the contributing area for pipe discharge may be smaller than the surface area of swales, suggesting that unit-area estimates of pipe runoff may underestimate the efficiency of pipes in routing precipitation (p. 71). Albright suggests that the concentration of pipes in swales and their contribution to runoff is likely higher than in the larger watershed.

Anderson, S. P., W. E. Dietrich, R. Torres, D. R. Montgomery, and K. M. Loague. 1997a. **Concentration discharge relationships in runoff from a steep, unchanneled catchment.** Water Resources Research 33: 211- 225**.**
From NCASI

This research was conducted in the source area for a first-order ephemeral stream in the Oregon Coast Range.

Runoff Water Chemistry

This article discusses hydrologic controls on runoff chemistry related to the role of “o runoff. The authors base their findings on sprinkling experiments in an 860-m2 catchment in the Oregon Coast Range near Coos Bay. Sprinkling experiments using both high- and low-ionic strength precipitation resulted in similar concentration-discharge relationships; soils buffered rainwater chemistry, resulting in release of low-solute water as runoff. Runoff is also diluted by stored water. “Nearly all runoff from the [study] catchment passes through underlying weathered bedrock rather than perching and discharging only through soil (p. 211).” They also found that “new rainwater contributes to runoff in proportions that increase with continuing rainfall (p. 224).” They conclude that in their study site, “the widely observed inverse relationship between runoff and solute concentration results from consistent differences between soil water and bedrock water chemistry and from variations in water contact time within the bedrock. The bedrock flow path control on runoff chemistry may be fairly common, as bedrock in unglaciated terrain is seldom hydrologically tight (p. 224).”

Flow Paths and Runoff Water Chemistry

The authors observation that "old" water dominates storm runoff suggests that “release of low-solute water from soils rather than rainwater must cause storm runoff dilution."

"...conclusion that the low-concentration component [of the discharge] is water that has flowed rapidly through the catchment. Because Horton overland flow, an obvious source of rapidly delivered water, does not operate over most vegetated, humid catchments, much hydrologic modeling has focused on other fast processes such as

saturation overland flow and macropore flow (Dunne and Black 1970, de Vries and Chow 1978, Mosley 1979, Smettem et al. 1991). These flow mechanisms are characterized by high flow velocities and short residence times and are therefore expected to transmit rainwater through the catchment with only slight chemical modification..."

"The soil in the catchment is so conductive (Ksat of order 10-3 m/s) (Montgomery et al. 1997) that neither is Horton overland flow produced nor is the soil saturated to the surface during rain storms. Rainwater infiltrates everywhere and percolates vertically through the soil (R. Torres et al. 1996)..."

"From a chemical perspective we therefore consider two water types: soil water, or water that traverses the soil in either unsaturated or saturated zones, and bedrock water..."

"Solute concentrations in runoff depend on the proportions of runoff from the soil and from the rock and from small and large pores, both of which as a function of discharge. Rainwater chemistry is buffered, probably within the soil, so that runoff chemistry cannot be characterized as a simple mixture of rain and prevent water. Water in the bedrock varies in composition through storms as the mean residence time of water in the rock changes. At low flow water exfiltration from the rock has had a longer, more intimate contact with the bedrock on average and therefore has high solute concentrations. At high flow, water has shorter contact times with the rock on average and therefore runoff reflects the lower solute concentrations resulting from reactions in the overlying soil. Rain appears to enhance exchange of water and solutes between rain events to be swept out during rain events".

Nutrients

"Nitrate concentrations in runoff have shown wide variation on annual, seasonal, and sprinkling experiment timescales. Measured nitrate concentrations were highest during January 1990 and were successively lower in each of the two following winters. Presumably, the concentrations during the winter of 1990 are from the effects of logging in 1987 and herbicide treatment in 1988. These types of disturbances are known to increase the export of nitrogen in the form of nitrate from the forest soil (Vitousek et al 1982). The decline in nitrate over subsequent winters suggests the recovery to a balance between nitrate production and uptake by plants and microorganisms. Concentrations also rose and fell on a seasonal scale: winter runoff concentrations were higher than those measured in our late springtime sprinkling experiments in 1990 and 1992. The difference between the 17.5 ppm nitrate at 1 mm/h discharge in January 1990 and the 3.5 ppm nitrate at the same discharge 5 months later, in May 1990, can probably be attributed to uptake by plants and microorganisms..."

"Nitrate concentrations followed a distinctive pattern during the sprinkling experiments. Concentrations rose sharply to a maximum within one and a half days after the sprinklers were turned on in experiment 1 and then declined steadily through the rest of the sprinkling experiment. Experiment 2 lacked the initial rise in concentrations but again showed steady decline through the experiment...These temporal patterns during the course of the sprinkling experiments may reflect the dynamics of the biota. The initial sharp rise in concentrations may show the increased efficiency of nitrogen mineralization (nitrate production) with the onset of rain, and the subsequent decline in concentration reflects either increased uptake by growing plants and microbes or exhaustion of the mineralization source. Because these biodynamics are

not coupled to the flow paths in the catchment, nitrate does not show the same variations with discharge that inorganic species do".

Anderson, S. P., W. E. Dietrich, D. R. Montgomery, R. Torres, M. E. Conrad, and K. Loague. 1997b. **Subsurface flow paths in a steep unchanneled catchment.** Water Resources Research 33: 2637-2653.
From NCASI

Runoff Water Chemistry

This research was conducted in the source area for a first-order ephemeral stream in the Oregon Coast Range.

The authors use tracer studies during sprinkler experiments in a small, steep Oregon Coast Range catchment to describe subsurface flow paths. They found that near-surface fractures in bedrock are an important route for movement of saturated flow (at the base of the colluvium). During low-intensity sprinkling and natural storms, the authors did not observe preferential flow of new water. "In response to rainfall, waters from the deeper bedrock pathway, which have traveled through the catchment, exfiltrate into the colluvium mantle and mix with relatively young vadose zone water, derived locally, creating an area of surbsurface saturation near the channel head. This effectively becomes a subsurface variable source area, which, depending on its size and the delivery of water from the vadose zone, dictates the apportioning of old and new water in the runoff and, correspondingly, the runoff chemistry. The slow movement of water through the vadose zone allows for chemical modification and limits the amount of new water in the runoff. Moreover, it suggests that travel time of new rain water does not control the timing of runoff generation (p. 2637)." The authors suggest that "this type of subsurface variable source area is likely to be important in runoff generation and stream chemistry of other steep lands with shallow soils overlying fractured bedrock." (p. 2651). The authors note that, in general, subsurface flow paths are poorly understood but are important in determining runoff chemistry and runoff generation. Prior to the use of tracers in recognizing the role of old water, "the variable source area conceptual model identified dynamic regions near streams where rapid saturation overland flow paths (both return flow and direct precipitation onto saturated areas) could be established quickly during storms or to produce the runoff response" (p. 2638). As understanding of the role of old water in dominating storm runoff in basins with high infiltration capacity has developed, researchers have focused on identifying subsurface flow paths (rather than on the variable source model), in particular the mechanisms by which old water is displaced by subsurface storm flow.

Flow Paths and Runoff Water Chemistry

"Subsurface flow is the sole source of storm discharge in the CB1 catchment, as is common in humid, soil-mantled, vegetated, headwater regions (Dunne et al 1975, Freeze 1974, Cheng 1988, Turton et al. 1992, Bonell 1993, Mulholland 1993, Allan and Roulet 1994, Eshleman et al. 1994, Peters et al. 1995, Sidle et al. 1995)....Montgomery et al. (1997) demonstrated that saturated water flow through bedrock is important at CB1. The near-surface development of exfoliation fractures in the underlying bedrock of this site has created complex, locally highly conductive hydrologic environment capable of conveying nearly all storm runoff..."

"The study of runoff generation for many years focused on identifying subsurface flow mechanism fast enough to produce storm discharge (Dunne 1978). The variable source area conceptual model identified dynamic regions near streams where rapid saturation overland flow paths (both return flow and direct precipitation onto saturated areas) could be established quickly during storms to produce the runoff response. The use of isotopic tracers led to recognition that old or "prevent" water often dominates storm runoff in humid catchments with high infiltration capacities (Slash 1990, Bonell 1993, Buttle 1994), implying relatively long residence times (greater than one storm event) for much of the water in catchments..."

"Runoff generation in the catchment is entirely produced from subsurface stormflow (Montgomery et al. 1997). Water flows vertically down through the vadose zone during rainfall events (R. Torres et al.) and reaches the subsurface saturated zone in either the colluvium or bedrock. The water table does not reach the soil surface anywhere on CB1.

The pattern of saturation within colluvium implies that most water travels through the bedrock during its transit through the catchment."

"...the flow path bringing water out of the bedrock, into the partially saturated colluvium near the weir, and then into runoff, contributes a greater proportion of the total discharge as the discharge declines. The flux from this pathway varies directly with the discharge...but the relative contribution of this flow path to runoff varies inversely with discharge...The runoff is extremely sensitive to changes in these flow path contributions, as shown by the synchronicity and opposing directions of concentration trends of both the bromide and deuterium tracers..."

"Flow in the saturated zone at the base of the colluvium is rapid and, taking advantage of exfoliation fractures, crosses back and forth between rock and colluvium in the zone of convergent topography (of both the surface and the bedrock/colluvium interface) down the axis of the catchment. The area of subsurface saturation in the colluvium near the channel head expands and contracts during storm events and, in so doing, exerts important control on the flow paths contributing runoff…."

"As Hewlett and Hibbert (1967) predicted in their conceptual model, we see a greater contribution to storm runoff from the colluvium near the channel, while other parts of the slope contribute a higher proportion of base flow runoff. Moreover, the timing of generation of runoff does not appear to be tied to the rate at which water moves through the catchment. We believe that this type of subsurface variable source area is likely to be important in runoff generation and stream chemistry of other steep lands with shallow soils overlying fractured bedrock."

Ref ID: 97

Aubertin, G.M. 1971. **The nature and extent of macropores in forest soils and their influence on subsurface water movement.** Pp.1-32**. in** Research paper NE-172. USDA Forest Service Northeastern Forest Experiment Station. Upper Darby, PA.

Keywords : soil; macropores; soil pipe; subsurface flow; management; watershed

Rain, falling on a sloping forested soil, may enter the soil quickly and move considerable distances through the soil by way of macropores. A macropore is a large

pore, cavity, passageway, channel, tunnel or void in the soil, through which water usually drains by gravity.

Large quantities of water can move through the soil by way of these macropores--without appreciably wetting the soil mass. This phenomenon complicates the study and management of forested watersheds.

A series of studies was undertaken to provide information about the nature, extent, and influence of macropores, as an aid to future studies and management of forest soils. This is a report on those studies.

Ref ID: 118
Beven, K. 1981. **Kinematic subsurface stormflow.** Water Resources Research 17 (1):1419-1424.

Keywords : models; subsurface flow; soil pipe; kinematic wave; soil; hydraulic; co; water table; hydrograph; slope

This paper builds on the analysis of Henderson and Wooding (1964) in comparing simplified models of subsurface stormflow for the case of a sloping soil mantle in which the hydraulic conductivity is constant throughout. It is shown that models based on a kinematic wave formulation may be good approximations for those based on the extended Dupuit-Forchheimer assumptions for values of the non-dimensional parameter lambda =4**i** cos □/(K $\sin^2$ □) less than about 0.75 in terms of predicting both water table profiles and subsurface stormflow hydrographs. By using this critical value of lambda, the range of values of slope angle and saturated hydraulic conductivity for which the kinematic approximation is valid can be specified. A comparison is made with slope angles and hydraulic conductivities at field sites where subsurface stormflow has been shown to be an important component of catchment storm response. It is concluded that the kinematic approximation may be useful for cases of practical interest.

Ref ID: 123
Binns, N.A. 1994; **Long-term responses of trout and macrohabitats to habitat management in a Wyoming headwater stream.** North American Journal of Fisheries Management 14 (1):87-98.

Keywords : trout; habitat; management; instream structures; structures; pools; flow; Wyoming; streams; drought; floods

After 111 habitat improvement devices and 2,150 ft of riprap were installed (1973-1977) in Beaver Creek, northeast Wyoming, the stream developed a narrower channel with deep pools that helped brook trout *Salvelinus fontinalismn* survive low flows. After 7 years, brook trout 6 in and longer had increased 1,814%, brook trout less than 6 inches had increased 1,462%, and the total population density had reached 2,074/mi (268lb/acre). By 1990, after extended drought during the 1980's, the brook trout population had dropped to 222/mi (41lb/acre), but this level was 90% better than

before habitat development. Over 90% of the devices remained fully functional 18 years after installation, even though some of them were esthetically displeasing due to exposure of logs and planks. Wooden plunges were comparatively easy to install and dug good pools. Deflectors worked better directing currents than digging pools. Wood bank overhangs and overpour (Hewitt) ramps provided variable results, were hard to install, were apt to be damaged by floods, and are not recommended for Wyoming streams.

Bosch, J. M., and J. D. Hewlett. 1982. **A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration.** Journal of Hydrology 55: 3-23.
From NCASI

Effects of Management Practices

As cited in Ziemer and Lisle (1998): Bosch and Hewlett summarized 94 catchment experiments world-wide and found that the largest increases in water yield due to vegetation removal may occur in coniferous forests, with incrementally lesser in deciduous hardwoods, brush, and grasslands. They also found that the largest increases in water yield occurred in areas with high rainfall during wet years.

Ref ID: 114
Bonell, M. 1993; **Progress in the understanding of runoff generation dynamics in forest.** Journal of Hydrology 150 (1):217-275.

Keywords : runoff; hillslope; models; management; hydrology; streams

This work reviews the runoff generation process in forest. A survey of the delivery mechanisms of hillslope runoff and the difficulties of incorporating some of them in recent physically based models is considered. The research challenge in reconciling the results from recent stream hydrogeochemistry studies with the results from previous hillslope hydrometric experiments is also highlighted. 'Physically based' runoff process models for application to forest land management problems are then summarized. The work concludes by proposing a new, intensive phase in experimental hydrology which should support the continued development of new algorithms in runoff process modeling. Particular attention should be given to tropical forests and the need for additional hillslope hydrology research to address the important issues associated with hillslope management and conversion.

Ref ID: 45
Brater, E.F. 1937; **The unit hydrograph principle applied to small water-sheds.** Transactions of the American Society of Civil Engineers 2083 :1154-1192.

Keywords : hydrograph; runoff; hydrologic analysis; watershed

Tests of the applicability of the unit hydrograph principle on 22 small watersheds ranging from 4 to 1,877 acres lead the author to conclude that this method is one of the best practical devices for predicting flood flows.

Brown, David Lawrence. 1995. **An analysis of transient flow in upland watersheds: interactions between structure and process.** Berkeley, CA: University of California; 225 p. Ph.D. dissertation.

Key Words: PSW4351, Caspar Creek, watershed, flow, rainfall, soil

The physical structure and hydrological processes of upland watersheds interact in response to forcing functions such as rainfall, leading to storm runoff generation and pore pressure evolution. Transient fluid flow through distinct flow paths such as the soil matrix, macropores, saprolite, and bedrock may be viewed as a consequence of such interactions. Field observations of pore pressure responses to rain events at two diverse experimental watersheds further reflect the importance of heterogeneous soil and geologic materials as they affect storm runoff responses. An existing physically-based numerical subsurface flow model was modified to incorporate infiltration partitioning and overland flow.

Ref ID: 92
Brown, D., Keppeler, E.T. 1998. **Subsurface drainage processes and management impacts.** pp.11 **in** Conference on Coastal Watersheds: The Caspar Creek Story. California Department of Forestry and Fire Protection, USDA Forest Service, University of California Cooperative Extension. Ukiah, CA. May 6-7, 1998.

Keywords : subsurface flow; pipeflow; soil pipe; management; timber harvest; impacts; watershed

Abstract: Storm-induced streamflow in forested upland watersheds is linked to rainfall by transient, variably saturated flow through several different flow paths. In the absence of exposed bedrock, shallow flow-restrictive layers, or compacted soil surfaces, virtually all of the infiltrated rainfall reaches the stream as subsurface flow. Subsurface runoff can occur within micropores (voids between soil grains), various types of macropores (structural voids between aggregates, plant and animal-induced biopores), and through fractures in weathered and consolidated bedrock. In addition to generating flow through the subsurface, transient rain events can also cause large increases in fluid pressures within a hillslope. If pore pressures exceed stability limits of soils and shallow geologic materials, landslides and debris flows may result. Subsurface monitoring of pipeflows and pore pressures in unchanneled swales at North Fork Caspar Creek in the Jackson Demonstration State Forest began in 1985. Four sites have been established to investigate the effects of timber harvest (K1 and K2) and road building (E-road) for comparison with an unmanaged control drainage (M1). Flow through large soil pipes at these sites is highly transient in response to storm events, reaching peak discharges on the order of 100 to 1,000 L min^{-1}. Pore pressures at these sites also respond dynamically to transient rain events, but to date have not exceeded slope stability limits. Most soil pipes cease flowing in the dry summer period and hillslope soil moisture declines to far below saturation. The clearcut logging and skyline-cable yarding of the K2 site resulted in dramatic increases in soil pipeflow and subsurface pore pressures. During the first 4 years after timber harvest, pore pressures increased 9 to 35 percent for the mean peak storm event in the control M1 site. Peak soil pipeflow response was far greater,

increasing 400 percent in the 4-year postlogging period. These results suggest that the soil pipes are a critical component of subsurface hillslope drainage, acting to moderate the pore pressure response. As the subsoil matrix becomes saturated and pore pressures build, soil pipes efficiently capture excess water and route it to the stream channel. This logging does not appear to have impaired the hillslope drainage function. Methods and results at the E-road site are quite different. Here, the mid-swale road construction and tractor yarding have resulted in large changes in the pore pressure response. Positive pore pressures were negligible in the upper portion of this instrumented swale before disturbance. Subsequent to the road construction in May 1990, there was little indication of immediate impacts. But, after the completion of felling and tractor yarding in late summer 1991, dramatic changes in pore pressure response were observed beginning in hydrologic year 1993 and continuing to date (1998). Largest pore pressure increases have occurred at sensor locations in and up-slope of the road prism. Below the road, the response is muted. These data support previous studies documenting the profound effects of roading and tractor logging on watersheds and provide special insight into these effects for this region.

Ref ID: 18
Cambray, J.A. 1994; **Effects of turbidity on the neural structures of two closely related redfin minnows, Pseudobarbus afer and P. asper, in the Gamtoos River system, South Africa.** South Africa Journal of Zoology 29 (2):126-131.

Keywords : Pseudobarbus; turbidity; permanent stream; minnows; Cyprinidae; neural structure; fish

The neural structures of the sister species *Pseudobarbus afer* and *P. asper* were compared. *P. afer*, a redfin minnow which inhabits clear, perennial mountain streams, was found to have larger neural structures related to vision than *P. asper*, which inhabits turbid, intermittent streams of the Gamtoos River system. *P asper* did not show any compensation to inhabiting a turbid environment. Overall, *P. afer* males had the largest neural structures, most notably the optic lobes and cerebella, and *P. asper* females had the smallest neural structures.

Ref ID: 23
Chapman, L.J., Kramer, D.L. 1991; **Limnological observations of an intermittent tropical dry forest stream.** Hydrobiologia 226 (3):153-166.

Keywords : limnology; tropical stream; Costa Rica; dissolved oxygen; water level; pools; flooding; temperature

This study examines aspects of the seasonal limnology of an intermittent stream in the dry forest region of northwest Costa Rica. It focuses on annual water level fluctuations and both seasonal and among pool variation in dissolved oxygen concentration and water temperature. Dry season pools differed in morphometry and the rate of decline in water levels subsequent to the seasonal floods. Rate of water level decline was related both to pool depth and to the exposure of the pool to the sun. Oxygen concentration was generally low in the dry season, but increased during the

rainy season in association with rain events and seasonal flooding. A repeated-measures analysis of variance indicated that seasonal effects accounted for 40% of the variance in oxygen concentration for residual pools. Differences among pools were also significant. However, there was strong evidence for a significant interaction between seasonal and spatial influences on oxygen values in the system. Variation in water temperature was small, but differences among pools, sampling dates, and their interaction were all significant. Periphyton production increased significantly between the late wet season sample in November and the dry season sample in February. Incident light intensity explained 76% of the variation among pools in net periphyton production in the dry season.

Cheng, J. D., D. E. Reksten, and P. F. Doyle. 1989**. Defining hydrologic characteristics of headwaters forested watersheds in the southern interior of British Columbia.** Pages 579-588 *in* W. W. Woessner and D. F. Potts, editors. Proceedings of the symposium on headwaters hydrology. American Water Resources Association, Bethesda, Maryland.
From NCASI

Flow Paths

The authors examine the hydrology of headwater streams in the Okanagan River basin, British Columbia. They do not define the area of their study watersheds, although it appears they are examining perennial streams. They indicate that higher elevation watersheds produce greater streamflow due to higher precipitation and lower temperature, which reduces evapotranspiration. They also indicate that smaller streams have lesser groundwater contributions than larger streams, resulting in lower summer flows. They conclude that in general, streamflow characteristics between adjacent watersheds are sufficiently similar to allow extrapolation of data from gaged to adjacent ungaged basins.

Corbett, E. S., and J. A. Lynch. 1989. **Hydrologic production zones in a headwater watershed.** Pages 573- 578 *in* W. W. Woessner and D. F. Potts, editors. Proceedings of the symposium on headwaters hydrology. American Water Resources Association, Bethesda, Maryland.
From NCASI

Flow Paths

The authors applied simulated rainfall to a 20-acre experimental watershed in central Pennsylvania. They applied 0.96 inches of rain with both dry and wet antecedent soil moisture over varying portions of the watershed, including in the channel area only (13% of the watershed), in an area covering the channel and the bases of hillslopes (27% of the watershed), in an area covering the lower slopes as well (56% of the watershed), and over the entire watershed. With dry antecedent soil moisture, the rising streamflow limb and the peak were primarily produced by contributions from the channel and hillslope-base zones in the lower 30% of the watershed. In the channel-base slope application, 22% of applied rainfall was converted to stormflow, compared to about 10% for the total watershed application. With wet antecedent soil moisture, 56% of applied rainfall was converted to stormflow for the channel-only application (including

50% quickflow and 6% delayed flow, compared to about 83% for the channel-lower slope application (including 70% quickflow and 13% delayed flow). Runoff to the channel system from applied rainfall resulted from a temporarily saturated zone in the soil, rather than from an overall rise in the groundwater table during the stormflow period.

Subsurface stormflow was the primary means of watershed stormflow generation; surface runoff on slopes did not appear to be a factor, although saturation overland flow did contribute to stormflow with wet antecedent soil moisture. About 3 times as much applied rainfall was translated into stormflow from channel and base-slope zones with wet antecedent soil moisture as from those with dry antecedent conditions.

Ref ID: 140
Cross, D. 1981. **Restoration of an ephemeral stream Dry Creek, tributary to the Klamath River.** pp.141-143**. in** Hassler, T.J. (ed.). Propagation, enhancement, rehabilitation of anadromous salmonid population and habitat in the Pacific Northwest symposium. California Cooperative Fishery Research Unit, Humboldt State University. Arcata, California.

Keywords : restoration; habitat; enhancement; salmonid; trout; Steelhead; Salmon gairdneri; fish; spawning; spawning gravels; gravel; Klamath River; California; Pacific Northwest; streams; riffles

In 1977, eight gabion weirs were constructed in Dry Creek, an ephemeral tributary to the Klamath River, to improve spawning habitat for wild steelhead trout *(Salmo gairdneri).* Although successful in flattening stream gradient and reducing the loss of spawning gravels utilization of the spawning areas by adult fish was limited. Modification of the riffles will hopefully increase utilization and subsequent production of wild steelhead fry.

Ref ID: 73
Delucchi, C.M. 1988; **Comparison of community structure among streams with different temporal flow regimes.** Canadian Journal of Zoology 66 :579-586.

Keywords : community structure; flow regimes; benthic; invertebrates; permanence; adaptations; refuge; streams; watershed; structure; flow; riffles; pools; function; hyporheic zone

A study was conducted in four streams in the same watershed in New York to determine whether the benthic invertebrate community structure varied among streams with different temporal flow regimes. Timed kick samples were taken from 13 riffles and 4 pools once a month from June to November 1982. Riffle sites were classified according to temporal flow regime as permanent, intermittent (dry for less than 3 months), or dry (dry for over 3 months), and varied in size and function of discharge. Ordination analysis (detrended correspondence analysis) showed that the structure of the benthic invertebrate communities in these streams was related not only to riffle permanence, but

also to other abiotic and biotic parameters. Differences community structure were greater between adjacent pools and riffles than between temporary and permanent riffles. Stream size, seasonal changes in taxa, how recently the riffle had dried, and the length of the dry period contributed to differences in community structure among riffles. It appears that differences in community structure between permanent and temporary riffles are…

Dewey, Nicholas J., Thomas E. Lisle, and Leslie M. Reid. 2003. **Channel incision and suspended sediment delivery at Caspar Creek, Mendocino County, California.** EOS Transactions AGU 84(46), Fall Mtg. Suppl., Abstract H52A-1159.

Tributary and headwater valleys in the Caspar Creek watershed, in coastal Mendocino County, California, show signs of incision along much of their lengths. An episode of incision followed initial-entry logging which took place between 1860 and 1906. Another episode of incision cut into skid-trails created for second-entry logging in the 1970's. Gullies resulting fromboth of these episodes of incision are sensitive to hydrologic fluctuations and feature active headcuts, deepening plungepools, and unstable banks, which continue to contribute sediment to the Caspar Creek channel network. Headcuts are numerous in each channel. In some cases headcuts define the upstream extent of an incised reach; in many cases headcuts migrate up previously incised reaches, increasing the depth of incision. Surveys indicate that bank retreat, plunge pool deepening, and headcut retreat all contributed sediment to the channels between 2000 and 2003. Since bank walls have considerably more surface area than headwalls per given length of channel, and headcuts have largely migrated into positions temporarily constrained by resistant lips, bankwall retreat appears to be a more significant chronic source of sediment than headwall retreat. Stream gage records show that some channels consistently deliver higher levels of suspended sediment than others. In comparing channels, ongoing levels of suspended sediment delivery correlate well with total amount of exposed channel bank (depth of incision integrated over length of channel) in the reaches upstream of stream gages. On an annual to decadal time-scale, rates of suspended sediment delivery per unit area of catchment correlate better with the amount of exposed bank area in reaches upstream of stream gages, than with the volume of sediment delivered by landslide events, with total catchment area, or with peak stormflow per unit area. The correlation between amount of exposed bank area and ongoing levels of suspended sediment delivery is attributable to the importance of bank erosion as a sediment source to these gullied channels.

Dickerson, B.P. 1976. **Soil compaction after tree-length skidding in northern Mississippi.** Soil Science Society of America Journal 40: 965–966.
From NCASI

Flow Paths, Effects of Management

As cited in Reid (1993): Dickerson found that infiltration capacity is impaired on skid roads, including those that have only been used for a short time.

Dietterick, B. C., and J. A. Lynch. 1989**. The cumulative hydrologic effects on stormflows of successive clearcuts on a small headwater basin.** Pages 473-485 *in* W. W. Woessner and D. F. Potts, editor. Proceedings of the symposium on headwaters hydrology. American Water Resources Association, Bethesda, Maryland**.**
From NCASI

Effects of Management Practices on Hydrologic Regimes

This study examines effects on stormflow of a series of clearcuts in a 106-acre basin in central Pennsylvania. Areas of 21, 27, and 42 acres were progressively clearcut and herbicided, moving in an upstream direction. Cumulative increases in total stormflow volumes and peakflows were recorded in the first year following each cut, suggesting that expanding the logged area increased the magnitude of the observed hydrologic effects, although increases in flow were not directly proportional to clearcut size. Flows appeared to become flashier for a temporary period following logging, with water yield increases being more sustained. The authors suggest that increased flashiness (increased frequency and magnitude of stormflows) could increase the occurrence of channel-scouring events.

Fisher, Jason C. 1997. **A one-dimensional model of subsurface hillslope flow.** Final Report. Redwood Sciences Laboratory, Pacific Southwest Research Station, USDA Forest Service, Arcata, CA. 64 p.

A one-dimensional, finite difference model of saturated subsurface flow within a hillslope was developed. The model uses rainfall, elevation data, a hydraulic conductivity, and a storage coefficient to predict the saturated thickness in time and space. The model was tested against piezometric data collected in a swale located in the headwaters of the North Fork Caspar Creek Experimental Watershed near Fort Bragg, California. The model was limited in its ability to reproduce historical piezometric responses.

Fisher, Jason C. 2000. **Simulation of partially saturated - saturated flow in the Caspar Creek E-road groundwater system.** Arcata, CA: Humboldt State University; 107 p. M.S. thesis.

Key Words: PSW4351, Caspar Creek, watershed, subsurface hillslope flow, rainfall

A one-dimensional, finite difference model of saturated subsurface flow within a hillslope was developed. The model uses rainfall, elevation data, a hydraulic conductivity, and a storage coefficient to predict the saturated thickness in time and space. The model was tested against piezometric data collected in a swale located in the headwaters of the North Fork Caspar Creek Experimental Watershed near Fort Bragg, California. The model was limited in its ability to reproduce historical piezometric responses.

Gurtz, M.E., Marzolf, G.R., Killingbeck, K.T., Smith, D.L., and McArthur J.Vaun. **"Hydrologic and riparian influences on the import and storage of coarse particulate organic matter in a prairie stream."** *Canadian Journal of Fisheries and Aquatic Science* 45 (1988): 655-665

Keywords: sedimentation/ organic matter/ particle size/ riparian/ hydrology/ prairies/ biota/ woody debris/ ***headwaters***

The hydrologic regime and zonation of riparian vegetation influenced the quantity and quality of coarse particulate organic mater (CPOM; >1 mm) stored in the channel and upper bank of prairie stream. In a 5.4-km intermittent reach of the South Branch of Kings Creek on Konza Prairie, Kansas, total annual import was lowest in headwater reaches and increased downstream. Total storage of benthic CPOM in the dry channel and on the bank before the flow period was highest in the fourth- and fifth-order galley forest zone (999 g ash-free dry mass ·m-2) and less in upstream reaches (320-341 g $\cdot m^{-2}$). These longitudinal patterns of CPOM annual import and storage (before the flow period) were opposite those predicted by the river continuum concept for streams draining forested regions Following flow, headwater channels had more CPOM (291 g $\cdot m^{-2}$) than downstream reaches. On the bank, storage was always highest in downstream reaches. Composition of CPOM both in the channel and on the bank varied with changes in riparian vegetation: grass tissues dominated in headwater channels, while wood and leaves of trees and shrubs were more abundant downstream. During the flow period, storage of CPOM increased only in headwater channels, where retention was high despite the lack of woody debris. In this intermittent prairie stream, benthic CPOM may not contribute consistently to the terrestrial/aquatic linkages that are suggested in the river continuum concept because of (1) a paucity of large CPOM sources (e.g. trees, shrubs) in the upper reaches and (2) a hydrologic regime that reduces the amount, as well as the predictability, of stored CPOM. The biota of prairie streams must have opportunistic food gathering and reproductive strategies to take advantage of food resources in a flow environment that is itself very unpredictable.

Harr, R. D., W. C. Harper, J. T. Krygier, and F. S. Hsieh. 1975. **Changes in storm hydrographs after road building and clear-cutting in the Oregon coast range.** Water Resources Research 11: 436-444**.**
From NCASI

Effects of Management Practices on Hydrologic Regimes

In a study in headwater areas of the Alsea River basin, Oregon, the authors found that peakflow increases occur where roads and other compacted areas cover more than 12% of a watershed, primarily due to compaction rather than effects on evapotranspiration. The smallest subwatersheds examined in this study were 39, 100, and 138 acres; the 100-acre watershed was the only one where significant increases in peakflows were observed (and is the only studied watershed in which more than 12% is occupied by roads). Increases in peakflows in other watersheds, 3-5% of which were roaded, were smaller and not statistically significant. The largest flow increases typically were observed in fall, when differences between soil water content between logged and unlogged watersheds was greatest.

Harr, R. D. 1976a. **Forest practices and streamflow in western Oregon.** General Technical Report PNW- 49. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.
From NCASI
Effects of Management Practices on Hydrologic Regimes

Harr summarizes the findings of other watershed studies and hydrologic research conducted in four study areas in the Coast and Western Cascade Ranges of Oregon (e.g., Rothacher 1970, 1971). The paper begins with a summary of the hydrologic processes in the forest environment (infiltration, evaporation, overland flow, subsurface flow, peak flows and base flow), as a foundation for understanding the effects that forest practices can have on these processes. Harr then summarizes the effects of timber harvest and roads on annual yield, seasonal yield and storm runoff in the four study areas. The author concludes that "certain aspects of stream flow in small watersheds in headwater areas in western Oregon were changed by road building, clearcutting, and other timber harvesting activities. Annual yields and summer low flows were increased significantly after clearcutting. Such increases however, have only onsite importance because under sustained yield forest management, increases in water yield from clearcut areas are greatly overshadowed by water flowing from uncut areas. Thus yield increases in large basins are extremely small. Both road building and clearcutting increased small peak flows. Large peak flows appeared to be increased where at least 12 percent of a watershed was seriously compacted by road building, tractor skidding, or tractor windrowing of slash. Timber harvesting practices that do not severely modify the soil on more than 5% of headwater basins in western Oregon, probably do not have any appreciable effect on low-frequency runoff events which cause extensive downstream flooding" (Pg. 17). Harr concludes that "the supposed relationship between increases in annual yield and increases in peak flow currently serving as the basis for regulating timber harvest in the Northern Rocky Mountains...does not exist for western Oregon (pp. 16- 17)."

Harr, R. D. 1976b. **Hydrology of small forest streams in western Oregon.** General Technical Report PNW- 55. USDA Forest Service, Pacific Northwest Forest and Range Station, Portland, Oregon.
From NCASI

"The hydrology of small forest streams in Western Oregon varies by time and space in terms of both streamflow and channel hydraulics. Overland flow rarely occurs on undisturbed soils. Instead water is transmitted rapidly through soils to stream channels by displacement of stored soil water. Drainage networks expand and contract according to the interaction between precipitation characteristics and soil's capability to store and transmit water. Drainage networks are more extensive in winter than in summer. Stream flow may be 1,000 to 5,000 times greater during winter storms than during summer low flow. A stream's kinetic energy varies along with stream flow. Channel width and depth, heterogeneity of bed materials, and the accumulation of large organic debris affects the dissipation of kinetic energy.

Clearcutting can increase relatively small peak flows but forest roads and extensive areas of soil compacted by other means may increase larger peak flows. Both

road building and clearcutting may cause soil mass movements which can drastically alter a stream's channel hydraulics by adding debris or scouring the channel to bedrock. Removal of naturally occurring organic debris that has become part of a stable channel can accelerate bed and bank erosion."

Harr, R. D., and F. M. McCorison. 1979. **Initial effects of clearcut logging on size and timing of peak flows in a small watershed in western Oregon.** Water Resources Research 15: 90-94.
From NCASI

Effects of Management Practices on Hydrologic Regimes

This study examined the effects of clearcutting (with skyline yarding) on the magnitude and timing of peakflows in a 10.2-ha headwater basin in the H.J. Andrews Experimental Forest, Oregon. The authors found that for annual peakflows (>2.2 l/s/ha) decreased in magnitude by 32% following clearcutting and annual peakflows resulting from rainon- snow events decreased 36%. Clearcutting altered peak flow timing, as measured by the pre- and post-logging difference in peakflow timing between control and treated watersheds, with an average delay of nearly 9 hours for annual peaks and 12 hours for annual rain-on-snow peaks. No significant difference in pre- and post-logging peakflow magnitude and timing were observed for rainfall-generated peakflows. Decreased peakflow magnitude and delayed peakflows following logging were likely related to alterations in soil water movement and in snowmelt and accumulation dynamics. Clearcutting eliminated snow interception by trees and increased accumulation on the ground, reducing the surface area of snow exposed to moist air and subsequent condensation-convection melt, which is the major snowmelt process in the region. Snow accumulations on the ground therefore melted more slowly than snow intercepted by tree crowns (which melts quickly and reaches the forest floor as rain), delaying hydrologic response to storms in the clearcut area.

Harr, D. R. 1980**. Streamflow after patch logging in small drainages within the Bull Run Municipal Watershed, Oregon.** Research Paper PNW-268. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.
From NCASI

Effects of Management Practices on Hydrologic Regimes

Harr studied the effects of patch logging in 3 experimental basins in the Bull Run watershed on streamflow timing and magnitude. He found that logging in small, clearcut patches (totaling 25% of watershed area) caused a significant decrease in low flows and no significant change in annual water yield or instantaneous peak flows. A change in annual water yield was expected based on past studies; the lack of change in annual water yield may have been due to obscure groundwater divides between adjacent control and treatment basins or effects of forest canopy interception of fog or clouds, although fog drip was not measured. Reduced summer flows may have also been related to fog drip effects; other studies in the region had found increased summer flows following logging. The lack of increase in peak flows was

expected given the small areas logged (25%), the small area of soil disturbance, and the gentle topography in the logged areas. A subsequent study to this one provided evidence that reduced fog drip following logging was likely responsible for the observed decreases in summer low flows (Harr 1982, as cited in Keppeler and Ziemer 1990).

This study was conducted in a watershed that supplies water to Portland and was designed in part to examine whether logging could increase water supplies. The areas of the watersheds examined were 59 ha (146 acres), 253 ha (625 acres, control), and 71 ha (175 acres) and they had relatively gentle topography (average hillslope gradients of 5–9%). Harr cites studies by himself (1976, 1979), Harris (1977), and Rothacher (1970) that found substantial increases in water yield in the first year following logging in "small, upland watersheds," with the largest relative increases during summer and the largest absolute increases in winter (p. 1).

Hewlett, J. D., and A. R. Hibbert. 1967. **Factors affecting the response of small watersheds to precipitation in humid areas.** Pages 275-290 in W. E. Sopper and H. W. Lull, editors. International symposium for hydrology. Pergamon Press, New York.
From NCASI

Flow Paths

As cited in Ward (1984): Hewlett and Hibbert (1967) proposed that precipitation percolates down through soil layers, travels horizontally as subsurface through flow, may travel vertically upwards, (at the base of slopes or when encountering an impermeable soil or bedrock layer), and emerges later as saturated overland flow.

Ref ID: 24
Hill, B.H., Gardner, T.J., Ekisola, O.F., Henebry, G.M. 1992; **Microbial use of leaf litter in prairie streams.** Journal North American Benthological Society 11 (1):11-19.

Keywords : litter; prairie stream; microbial use; perennial stream; decomposition; hydrologic influences; microbial respiration; Quercus; Celtis; Maclura; Ulmus; Populas; oak; hackberry; bois d'arc; elm; cottonwood

Mass loss and microbial oxygen consumption on decaying leaves from five species of gallery forest trees were measured in six prairie streams (three perennial, three intermittent) ranging in size from 2nd to 4th order. Leaf decay was monitored for 56 d in late fall and early winter 1987-1988. Mass loss was greatest for bois d'arc *(Maclura pomifera)*, followed by hackberry *(Celtis laevigata),* cottonwood *(Populus deltoides),* elm *(Ulmus rubra)* and Shumard oak *(Quercus shumardii).* Breakdown rates in the six streams fell into two groups: decay in 3rd-order intermittent, 3rd-order perennial and 4th-order perennial streams all exhibited faster breakdown rates than the 2nd-order intermittent, 2nd-order perennial, and 4th-order intermittent streams. These differences appear to be related to stream order and hydrologic regime. Microbial respiration was strongly correlated with mass loss for the first 28 d. This period of rapid mass loss from the leaf litter was followed by a period in which mass loss and respiration were poorly correlated. Respiration was greatest on bois d'arc and hackberry, followed by cottonwood, elm, and oak. Microbial respiration accounted for 10% to 66% of the

decaying leaves. Overall, leaf species seemed to be the most important factor controlling breakdown rates, followed by stream order and hydrologic regime.

Johnson, E.A. and Kovner, J.L. **"Effect on Streamflow of Cutting a Forest Understory."** *Forest Science* 2, no. 2 (1956): 82-91.

Keywords: water yield/North Carolina/ Appalachian Mountains/ hardwood/ streamflow/ ***headwaters***/ drainage/ evapotranspiration/ resource management/ streamflow depletion

For small headwater drainages or watersheds, the water loss to the atmosphere through evapotranspiration (including interception) is influenced by changes in vegetation characteristics and root depth. Various artificial devices such as lysimeters have been used to measure evapotranspiration directly and have provided comparative data for herbaceous plants, grass, and agricultural crops. Comparative data for trees, however, are extremely difficult to obtain by these methods. Since trees occur on the headwaters of many streams, there is considerable interest in watershed experiments involving measurement of forest cover, precipitation, and streamflow, particularly where the data afford a measure of evapotranspiration. Publications by Hoover (1944), Dunford and Fletcher (1947), Lieberman and Hoover (1951), the Southeastern Station (1953), Johnson and Kovner (1956), and Kovner (1955) report on changes in streamflow following the cutting of forest vegetation at the Coweeta Hydrologic Laboratory in the mountains of western North Carolina. This paper deals with the effects upon streamflow of cutting a dense understory of laurel and rhododendron on a forested watershed at the Coweeta laboratory. The paper also describes later changes in flow as the understory was allowed to grow back. An understory of mountain-laurel (Kalmia latifolia L.) and rosebay rhododendron (Rhododendron maximum L.) is associated with hardwood stands on 1 1/2 million acres in the Southern Appalachian Mountains. Generally, mountain-laurel occupies the drier sites such as ridges and south-facing slopes, while rosebay rhododendron is found on north slopes and along streambanks. The common shrubby understory averages around 10 feet in height, although an arborescent form may reach a height of 25 feet, with stems up to 9 inches d.b.h. (Fig. 1). The foliage is evergreen and extensive and the roots are concentrated in upper layers of the soil. During the growing season the dominant canopy of trees intercepts the major portion of the incoming solar radiation, and wind movement is reduced near the ground. Under these conditions it is not easy to estimate the contribution to the over-all water loss made by the understory vegetation. Forest managers recognize laurel and rhododendron as economically worthless and favor removal of this aggressive competitor with valuable timber.

Ref ID: 13

Leopold, L.B., Miller, J.P. 1956; **Ephemeral streams-- Hydraulic factors and their relation to the drainage net.** pp.1-34**. in** Physiographic and hydraulic studies of rivers. 282-A. Department of the Interior. Washington D.C.

Keywords : hydraulic; flow; drainage basin; sediment; velocity; slope; headwaters; adaptations

The hydraulic factors of width, depth, velocity and suspended-sediment load of ephemeral streams near Santa Fe, New Mexico, were measured during flood flow. Later, channel slope was measured. These flood-flow data, in conjunction with an analysis of drainage-basin configuration by the methods proposed by Horton, are used to determine the generalized interrelation of stream order and hydraulic variables. The methods developed for determining this interrelation allows an integration of the geographic and physiographic characteristics of a drainage basin with the channel characteristics; specifically, the interrelation of the length, number, and drainage area of streams of various sizes with their respective discharge, width, depth, velocity, slope, channel roughness, and suspended-sediment load.

These interrelations show that stream order is related to stream length, number of streams, drainage area, and discharge by simple exponential functions. The relation of discharge by width, depth, velocity, slope, and other hydraulic factors can be estimated by simple power functions. Thus, any pair of these factors is related by exponential or power functions.

The data indicate that suspended-load measurements made during various stages of a few individual floods provide a close approximation to the suspended-load rating curve obtained from periodic measurements taken at a sediment station over a period of years.

The analysis of the hydraulic data shows that in the ephemeral streams studied, velocity increases downstream at a faster rate than in perennial rivers. This appears to be associated with an increase in suspended-load concentration downstream in these ephemeral channels.

The tendency for stream channels to maintain a quasi-equilibrium with imposed discharge and load is shown to be characteristic of ephemeral channels in the headwaters of the drainage basin, even to the most headward rill.

The formation of a discontinuous gully is analyzed in terms of this tendency. This type of gully is characterized by a gradient of the channel bed flatter than the gradient of the valley floor in which the gully is cut. The low gradient is explained as a hydraulic adaptation of channel slope to quasi-equilibrium with the narrow gully width. Examples indicate that as a discontinuous gully widens, its gradient steepens and its length consequently increases. Thus a series of discontinuous gullies tends to coalesce into a continuous trench having a bed gradient nearly equal to the slope of the original valley floor.

Jones, J. A. A. 1997. **Pipeflow contributing areas and runoff response.** Hydrological Processes 11: 35-41.
From NCASI

Flow Paths

The author looks at the role that shallow ephemeral pipeflow and deeper perennial pipeflow play in the hydrograph response to rainstorm events within micro-basins of different sizes in the Maesnant basin in Wales. Jones used rainfall and pipeflow

hydrograph data from a few hundred storms throughout the basin, and "no pipeflow gauge with less than 20 complete storm records was included in the analysis....In all, nine perennial pipes and three ephemeral pipes were used in the analysis" (p. 36). Results of Jones's monitoring research indicate that "pipeflow has response characteristics intermediate between throughflow and saturation overland flow. Peak lag times are 30-40% shorter for pipeflow than for normal throughflow, although they are still 15–20 times longer than Hortonian overland flow.... However, when overland flow is absent, pipeflow will tend to provide a runoff peak before throughflow" (p. 37). When linked to basin size, the following trend was noted: "peak lag time increases as the contributing area increases, and peak discharges per square meter of contributing area decrease as drainage area increases" (p. 37).

Ephemeral pipe networks differ from perennial pipe networks in distance below the ground and transmission of runoff characteristics. Jones found that ephemeral pipes were located approximately 150 mm below the surface, and perennial pipes were located at approximately 0.5 meters or deeper. Ephemeral pipes were found to be efficient at collecting and transmitting rainfall, with short lag times and "some of the highest peak discharges in proportion to the size area that they drain of all the pipes"(pg. 37). On average the shallow ephemeral pipes transmitted nearly 50% of rainfall or 'rainfall equivalent', this latter term referring to the 'old water' that is stored in the basin and emerges as runoff via translatory flows. Jones notes that regardless of how efficient shallow ephemeral pipes are at transmitting stormflow, because of the small size of their contributing area they typically are not as important as perennial pipes in contributing stormflow to the stream (in Maesnant basin). Conditions may differ in other basins and shallow ephemeral pipes may account for a larger proportion of the hydrograph peak response.

Jones concludes that runoff response due to pipeflow typically falls between throughflow and saturation overland flow: "In the smallest catchment areas, pipeflow responses tend to be closer to overland flow, but there is a slight tendency for pipeflow to converge towards throughflow as catchment area increases" (pg. 40).

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

From NCASI

"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. [The authors] 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 (p. 959)."

This study examines the same basins previously assessed by Rothacher (1973); Jones and Grant have a longer period of record and use different methods for evaluating peakflow response.

Kattelmann, R. 1989. **Hydrology of four headwater basins in the Sierra Nevada.** Pages 141-147 *in* W. W. Woessner and D. F. Potts, editors. Proceedings of the symposium on headwaters hydrology. American Water Resources Association, Bethesda, Maryland**.**
From NCASI

Hillslope Runoff Processes

Kattelmann describes the hydrology of 4 catchments in the Teakettle Experimental Forest in the southern Sierra Nevada (Kings River basin) based on 50 years of intermittent weir data. These catchments range in area from 70–223 ha (173–551 acres) and in elevation from 1920–2470 m, which is in the rain-snow boundary zone of many precipitation events. Runoff efficiencies (% of precipitation translated into streamflow) was approximately 50% for the period of record, being highest in wet years and lowest in dry years. Evapotranspiration appeared to be relatively similar between years. Most annual streamflow was in May and June, and 60% of flows occurred during the April–June snowmelt months. During the period of record, annual peak flows resulted from rain-on-snow events in 13 of 17 years; these peaks were as much as 5 times higher than spring snowmelt peaks. Lowest flows typically occurred in September and October. Differences in exposure, slope, subsurface storage, vegetation, and other factors served to differentiate flow between small adjacent basins.

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.
From NCASI

Effects of Management Processes on Hydrologic Regimes

The authors examine 21 years of flow data to evaluate effects of selective logging and tractor yarding on summer low flow and annual water yield in Caspar Creek. This study does not examine a "headwater" stream, focusing on hydrologic response in the North Fork and South Fork Caspar Creek basins (483 and 424 ha, respectively). They found statistically significant increases in both annual water yield and summer low flows following logging, with the largest relative increases occurring for summer low flows. Increases in annual water yield averaged about 15% and appeared to be correlated with percent of area converted to roads, landings, and skid trails; most of this annual yield increase occurred in the high-flow season. Increases in summer low flows lasted for about 5 years following logging, with possible decreases compared to pre-logging levels after this initial 5-year period. Harr (1979) found similar results, with summer low flow increases lasting 2–3 years following logging. An exception to this pattern appears to occur in areas where fog is an important source of moisture; in such areas, logging reduces fog drip, resulting in decreased summer low flows (Harr 1982).

The authors provide a review of other studies on logging effects on streamflow with respect to variables such as harvest practices, site conditions, precipitation, season, and fog interception. They indicate that construction of roads, landings, and skid trails

causes soil disturbances, including reductions in infiltration, increases in soil bulk density, and compaction of soil macropores and conversion into micropores.

Keppeler, E. T., R. R. Ziemer, and P. H. Cafferata. 1994**. Changes in soil moisture and pore pressure after harvesting a forested hillslope in northern California.** Pages 205-214 in Effects of human-induced changes on hydrologic systems. American Water Resources Association.
From NCASI

Effects of Management

This study compares pre- and post-logging pore pressures and soil moisture in a 0.83-ha zero-order swale in the North Fork Caspar Creek basin, California. A 1.69-ha control swale was also monitored; both swales had elevations of about 300 m, second-growth redwood/Douglas-fir forests, and Franciscan greywacke sandstone lithologies. Pipeflow was measured and piezometers and soil tensiometers were monitored. The treatment swale was clearcut and skyline yarded; heavy logging equipment was excluded and no site preparation occurred following harvest. The authors point out that while many studies have examined logging effects on streamflow, little research has been conducted on effects on subsurface flow processes.

The authors found that in the 4 years following harvest in the treated swale, pore water pressures increased at the soil bedrock interface during winters. Following logging, storm response in piezometers, as indicated by surface levels measured in piezometers, were higher than prior to logging, with the most uniform responses occurring in lower hillslope areas and the largest increases in surface level occurring in upslope areas (p. 211-212). Increased pore pressure was likely caused by changes in evapotranspiration; other factors may include reduced canopy interception, compaction (resulting in reduced pore space), or soil pipe collapse caused by tree-felling and yarding. While elevated saturated subsurface flows persisted into the spring, no change was observed in piezometric levels in summer, when most piezometers are dry. Soil moisture in the upper layer of soil also increased, although the duration of increases was short in the shallower, unsaturated area of the soil due to new redwood sprouts using most excess water. The authors did not observe landslides or potential slope failures following logging, although they suggest that logging-induced increases in pore water pressures on unstable slopes could exacerbate landslide risk. Other studies (list on p. 206) have found reduced hydraulic conductivity and increased soil bulk density following logging, including tractor and cable yarding.

Flow Paths

This study supports the findings of other Caspar Creek suggesting that pipes capture and efficiently route substantial subsurface stormflow. Pipeflow was found to account for nearly all stormflow at the base of the swale, and pipeflow routing of stormflow through a piping network appeared to continue after logging. The authors indicate that logging or other disturbances that cause collapse of pipes could compromise slope stability, and they suggest that the use of heavy where pipes are present (formed by interconnected structural voids in the soil matrix), the soil matrix's hydraulic conductivity is less important in stormflow generation due to the strong influence of pipes (they cite Kirkby 1978, Whipkey 1965, Mosley 1979).

Ref ID: 51
Montgomery, D.R., Dietrich, W.E. 1988. **Where do channels begin?** Nature 336 :232-234.

Keywords : headwaters; slope; landscape; watershed; growth; models; runoff; flow

The closer channels begin to drainage divides, the greater will be the number of channels that occupy a unit area, and consequently the more finely dissected will be the landscape. Hence, a key component of channel network growth and landscape evolution theories, as well as models for topographically controlled catchment runoff, should be the prediction of where channels begin. Little field data exist, however, either on channel head locations or on what processes act to initiate and maintain a channel. Here we report observations from several soil-mantled regions of Oregon and California, which show that the source area above the channel head decreases with increasing local valley gradient for slopes ranging from 5 to 45 degrees. Our results supports a predicted relationship between source area and slope for steep humid landscapes where channel initiation is by landsliding, but they contradict theoretical predictions for channel initiation by overland flow in gentle valleys. Our data also suggest that, for the same gradient, drier regions tend to have larger source areas.

Montgomery, D.R., Dietrich, W.E. 1992. **Channel initiation and the problem of landscape scale.** Science Report 255 :826-830.

Keyword : landscape

Since the 1940's it has been proposed that landscape dissection into distinct valleys is limited by a threshold of channelization that sets a finite scale to the landscape. This threshold is equal to the hillslope length that is just shorter than that necessary to support a channel head. A field study supports this hypothesis by showing that an empirically defined topographic threshold associated with channel head locations also defines the border between essentially smooth, undissected hillslopes and the valley bottoms to which they drain. This finding contradicts assertions that landscapes are scale-independent and suggests that landscape response to changes in climate or land use depends on the corresponding changes in the threshold of channelization.

Ref ID: 46
Montgomery, D.R. 1994. **Road surface drainage, channel initiation, and slope instability.** Water Resources Research 30 (6):1925-1932.

Keywords : roads; road surface drainage; slope instability; road design; runoff; management; models; slope; flow

Field surveys of road drainage concentration at three sites in the western United States are used to test simple models relating channel initiation and shallow landsliding to ground slope and contributing area thresholds. The form of boundaries between data for locations where road drainage concentration is associated with either shallow landsliding, channel initiation by overland flow, or no observable geomorphic effect is

consistent with theoretically derived drainage area-slope relations. Comparison of survey data with results of previous studies in these areas indicates that the drainage area required to support a channel head is smaller for road-related runoff than for undisturbed slopes. Contrary to current land management paradigms in the Pacific Northwest, drainage concentration from ridgetop roads may cause both landsliding and integration of the channel network and strongly influences the distribution of erosional processes in each of the study areas. The approach of using field reconnaissance to thresholds for erosion associated with road drainage provides a useful method to define regional criteria for road design that should reduce impacts on downstream channel systems.

Montgomery, D. R., and W. E. Dietrich. 1995. Hydrologic processes in a low-gradient source area. Water Resources Research 31: 1-10.
From NCASI

"Discharge, piezometric, and other field observations from a 3-year monitoring program indicate that runoff from a lowgradient source area in Marin County, California, is controlled by the interaction of throughflow, macropore flow, and saturation overland flow. Throughflow response integrates multiple storm events and exhibits both seasonal trends and rapid response to midwinter storms upon saturation of highly conductive near-surface soils. After saturation of the deeper colluvium along the hollow axis, macropore flow responds rapidly to individual storm events and locally provides a ceiling to piezometric response. Saturation overland flow occurs along the axis of the unchanneled valley only during large storms when both soil matrix and macropores transmissivity are exceeded. During large, runoff-producing storms, saturation overland flow extends continuously over most of the unchanneled valley axis. During smaller runoff-producing events, however, ground surface saturation may be discontinuous, reflecting either variations in the conductivity of the underlying soil/bedrock or a variable soil thickness along the hollow axis. Results of this study document a sequence of flow path activation in which the temporal distribution of rainfall events within a season determines both the mechanism and magnitude of runoff generation" (p. 1).

A 3-year record of discharge and precipitation showed that "runoff response is not directly related to individual storm events, but rather reflects both antecedent conditions and the magnitude of individual storms" (p. 3).

Pearce, A. J., M. K. Stewart, and M. G. Sklash. 1986. **Storm runoff generation in humid headwater catchments. 1. Where does the water come from?** Water Resources Research 22: 1263-1272.
From NCASI

Flow Paths

Results from storm runoff research conducted in two highly responsive catchments (M6 and M8) in New Zealand indicates that the dominant forces responsible for "quickflow" hydrograph generation is rapid throughflow which delivers "old water" to the stream channel. The authors used oxygen 18, electrical conductivity and chloride as measures to monitor runoff outflow in catchments M6 and M8, on a weekly basis, for

three years. During the study, catchment M8 was clearcut using a skyline cable system; a narrow (3–10 m) buffer of riparian vegetation that included the full width of the incised valley bottom was left undisturbed. Pearce compared the unlogged control catchment M6 runoff volumes with runoff volumes in M8 and noted that volumes after logging had increased by amounts and proportions closely equivalent to the interception losses that would have occurred in the presence of the forest.

"The two study headwater catchments are small (<4ha), with short (<300m), steep (average 34 degrees) slopes and (p. 1263) "The catchments are highly responsive to storm rainfall; 100 mm (65%) of the mean annual runoff is quickflow (QF) as defined by Hewlett and Hibbert's [1967] separation method. Quick flow is 39% of annual total rainfall...[c]ombined with the high responsiveness of the catchments, the frequent storms with large quickflow responses make the study area ideal for testing the relative importance of new and old water components of the storm runoff response" (pg. 1266). Previous studies in these basins indicated that subsurface flow, via macropores with new water as the dominant constituent in the flow, dominated the production of storm runoff in all events yielding more than a few millimeters of quickflow. Results from this more recent tracer study conducted by Pearce et al. indicate that the leading mechanism for water movement through the catchments and subsequent outflow into the stream channel is the displacement of old water stored in the basin. In catchment M8, the water was calculated to have a mean residence time of approximately 4 months (±1 month), implying dynamic storage of about one third of the annual runoff. This study is significant in that, at the time of publication it was the first comprehensive test of the importance of stored water, displacement, and translatory flows in generating storm runoff in a highly responsive area.

Ref ID: 77
Pool, D.R., Eychaner, J.H. 1995; **Measurements of aquifer-storage change and specific yield using gravity surveys.** Groundwater 33 (3):425-432.

Keywords : aquifer; aquifer-storage; water level; water table; ground water; Arizona; streams; hydraulic

Pinal Creek is an intermittent stream that drains a 200-square-mile alluvial basin in central Arizona. Large changes in water levels and aquifer storage occur in an alluvial aquifer near the stream in response to periodic recharge and ground-water withdrawals. Outflow components of the ground-water budget and hydraulic properties of the alluvium are well-defined by field measurements; however, data are insufficient to adequately describe recharge, aquifer-storage change, and specific yield values. An investigation was begun to access the utility of temporal-gravity surveys to directly measure aquifer-storage change and estimate values of specific yield.

The temporal-gravity surveys measured changes in the differences in gravity between two reference stations on bedrock and six stations at wells; changes are caused by variations in aquifer storage. Specific yield was estimated by dividing storage change by water-level change. Four surveys were done between February 21, 1991, and March 31, 1993. Gravity increased as much as 158 microGal $\pm$ 1 to 6 microGal, and water levels rose as much as 58 feet. Average specific yield at wells ranged from 0.16 to 0.21, and variations in specific yield with depth correlate with lithologic variations. Results

indicate that temporal-gravity surveys can be sued to estimate aquifer-storage change and specific yield of water-table aquifers where significant variations in water levels occur. Direct measurement of aquifer-storage change can eliminate a major unknown from the ground-water budget of arid basins and improve residual estimates of recharge.

Reid, L. 1993. **Research and cumulative watershed effects. General Technical Report PSW-GTR-141.** USDA Forest Service, Pacific Southwest Research Station, Albany, California.
From NCASI

Effects of Management

Reid reviews effects of land use on watershed processes, including runoff generation. Table 11 in Reid's text (p. 58 59) consists of a detailed list of studies of effects of roads and logging on hydrologic processes, including descriptions of location, approach (e.g., long-term monitoring study, survey of multiple sites), scale (e.g., paired basins, process study), treatment (e.g., roads, timber management), and measurements (e.g., soil compaction, peak flow). Reid notes that "compaction of soil decreases pore space and collapses conduits between pores, reducing solid porosity and permeability and increasing rates of overland flow.... Unsurfaced roads and construction sites are often highly compacted and readily generate runoff. Even briefly used skid roads show impaired infiltration (e.g., Dickerson 1976)"
(p. 61).

Reiter, M. L., and R. L. Beschta. 1992**. Subsurface flow dynamics of a forested riparian area in the Oregon Coast Range.** Pages 485-501 *in* M. E. Jones and A. Laenen, editors. Interdisciplinary approaches in hydrology and hydrogeology. American Institute of Hydrology.
From NCASI

Flow Paths

In this paper the authors examined flow direction and stream recharge from adjacent areas for a terrace-lined unconstrained reach of the Deer Creek watershed, in the Oregon Coast Range. They tested the assumption made by most previous research that "a uniform hydrologic link between the hillslope and stream." They hypothesized that this might not be the case when terraces, floodplains, or alluvial fans were present.

In order to examine the flow dynamics the authors installed 27 piezometers in 3 transects that extended from the stream through the terraces to the hillslope. They found that mid-terrace vectors did not show a consistent flow direction pattern, and that flow direction changed as a result of precipitation. In general, the authors found that riparian areas are "areas of hydrologic diversity compared to upslope areas."

Ref ID: 54
Riggs, H.C. 1978. **Streamflow characteristic from channel size.** Journal of the Hydraulics Division 104 (HY1):87-97.

Keywords : streamflow; channel size; mean flow; flow; flood frequency; methodology; streams

A common hydrologic problem is the estimation of the mean flow or the flood-frequency characteristics of an ungaged stream. Traditional methods include estimation from rainfall records, and use of relations between streamflow records and basin characteristics. These traditional methods are inadequate in arid or semiarid regions, in regions where precipitation is highly variable in space, or where geologic controls are dominant. For streams in such regions, some flow characteristics can be estimated from channel size. This method does not require the detailed basin information needed for the traditional methods because the channel size is the result of all the topographic, geologic, and climatic characteristics upstream. The method does usually require a field visit to the site.

This paper describes the need for such a method, its origin and development, the manner in which it has been used by the United States Geological Survey (USGS), reliability of flow estimates, some proposals for improvement and practical applications.

Rothacher, J. 1973**. Does harvest in west slope Douglas-fir increase peak flow in small streams?** Research Paper PNW-163. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Effects of Management

As cited in Jones and Grant (1996): Examines 148-, 237- and 250-acre watersheds in H.J. Andrews, OR (Watersheds 1, 2, and 3 in Lookout Creek); examines about 40 peak flows exceeding 40 m3/s/km2 for 5-10 year post-treatment period, same basins subsequently analyzed differently by Jones and Grant (1996).
Ref ID: 55

Rosgen, D.L. 1985. **A stream classification system.** pp.10-16**. in** Johnson, R.R., Ziebell, C.D., Patton, D.R., Ffolliott, P.F., and Hamre, R.H. (ed.). Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. RM-120. USDA Forest Service, Rocky Mt. Forest and Range Experiment Station. Fort Collins.

Keywords : morphology; classification; management; streams; habitat; hydraulic; sediment; transport

A stream classification system is presented which categorizes various stream types by morphological characteristics. Delineation criteria are stream gradient, sinuosity, width/ depth ratio, channel material, entrenchment, confinement, and soil/ landform features. Applications include riparian management guidelines, fisheries habitat interpretations, hydraulic geometry and sediment transport relationships.

Schlosser I.J. and Ebel, K.K. **"Effects of flow regime and cyprinid predation on a headwater stream."** *Ecological Monographs* 59, no. 1 (1989): 41-57.

Keywords: fish/ habitats/ aquatic insects/ behavior/ carp/ predation/ benthic fauna/ Minnesota/ minnows/ ***headwaters***/ streams/ flow

This article discusses the impact of hydrology on invertebrate and cyprinid density in Gould Creek, a first-order tributary of the Mississippi River in Minnesota. The results suggest that the hydrological regime has and effect on the colonization dynamics and abundance of invertebrates and fishes in headwater streams. Also, cyprinid predation has weaker but variable effects on the abundance of stream organisms.

Sendek, Karen Hardison. 1985. **Effects of timber harvesting on the lag time of Caspar Creek watershed.** Arcata, CA: Humboldt State University; 46 p. M.S. thesis.

Hydrograph lag time was analyzed to determine changes after road construction and after selective, tractor-yarded logging in a Caspar Creek watershed, Mendocino County, California. The paired watershed technique was used. Hydrograph lag time for each storm was the time separation between the midpoint of precipitation and the time coordinate of the runoff centroid. No significant change in lag time was detected after road construction. After logging, the lag time generally increased for small, early fall storms and decreased for larger storms.

To determine whether the change after logging was influenced primarily by the rising or falling limb of the hydrograph, each hydrograph record was split at the peak and the lag time was measured to the centroid time coordinate of each segment. A statistically significant reduction in both the rising and falling limb lag times was observed.

Six hydrologic variables were examined as predictors of the effect of logging on lag time. Proportion of area logged and the ratio of proportion of area logged divided by the storm sequence number were the best predictors. Other variables examined were North Fork peak flow, storm sequence number, storm size, and antecedent precipitation.
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Sklash, M. G., M. K. Stewart, and A. J. Pearce. 1986**. Storm runoff generation in humid headwater catchments. 2.** A case study of hillslope and low-order stream response. Water Resources Research 22: 1273-1282.
From NCSAI

Hillslope Runoff Processes

"Previous hydrometric and dye tracer studies in Maimai 8, a highly responsive catchment in the Tawhai State Forest, Westland, New Zealand, suggest that storm run-off generation is by rapid transmission of "new" (current storm) water to the stream via macropores. [The authors] used hydrometric and natural tracer (oxygen 18, deuterium, electrical conductivity and chloride) observations in two first- and one second-order streams and in six throughflow pits, to evaluate the roles of 'old' (stored) and new water during three storm events (return periods from 4 weeks to 3 months) in September 1983. New water contributions were small (<25% of the hydrograph volume) and could be accounted for by saturation overland flow. Hillslope response varied aerially but all sites issued old water-dominated throughflow. Ridge top sites had higher new water contributions (approx. 30-40%) than valley sites (<10%). Macropore flow of new water therefore cannot explain streamflow or throughflow response in the Maimai catchments" (p. 1273).

Sidle, R.C., Tsuboyama, Y., Noguchi, S., Hosoda, I., Fujieda, M., and Shimizu, T. **"Stormflow generation in steep forested headwaters: a linked hydrogeomorphic paradigm."** *Hydrological-Processes* 14, no. 3

Keywords: Japan / ***Headwaters*** / Geomorphology / Experimental Basins/ Preferential Flow/ Storm Runoff/ Forests / Catchment Areas/ Monitoring / Water Yield/ ***Headwaters*** / Runoff / Water yields

Headwater catchments are sources of sediments, nutrients, and biota for larger streams, yet the hydrologic pathways that transport these materials remain unclear. Dynamics of stormflow generation related to landform attributes and antecedent rainfall were investigated in a steep forested headwater catchment at Hitachi Ohta Experimental Watershed, Japan. Such headwater catchments are deeply incised: the narrow riparian corridors have limited capacities to store and transmit water to streams. Storm runoff was monitored at several nested scales within the catchment: (1) 2.48 ha first-order drainage (FB); (2) incipient 0.84 ha first-order drainage (FA) comprised of two zero-order basins; (3) 0.25 ha zero-order basin (ZB); and (4) 45 m super(2) hillslope segment (HS), including subsurface matrix flow (MF) and preferential flow (PF). Results from applied tracer and staining tests as well as observations of piezometric, tensiometric, and subsurface temperature responses were also employed to elucidate hydrologic pathways during storms. During the driest conditions, water yield from FB was only 1%; runoff occurred as saturated overland flow from the small riparian zone and direct channel interception. For slightly wetter conditions, subsurface flow from the soil matrix augmented stormflow. As wetness increased, two significant non-linear hydrologic responses occurred: (1) threshold response in geomorphic hollows (zero -order basins) where runoff initiated after an accumulation of shallow groundwater; and (2) self-organization and expansion of preferential flow pathways, which facilitate subsurface drainage. Stormflow increases observed during periods of increasing antecedent wetness depend upon temporal and spatial linkages and the unique hydrologic behavior of three components: (1) narrow riparian corridors; (2) linear hillslopes; and (3) geomorphic hollows. These linkages form the basis for an emerging hydrogeomorphic concept of stormflow generation for steep forested headwaters. Knowledge of stormflow response is critical to the assessment of management practices in these headwater areas as well as the routing of water and materials to larger stream systems.

Ref ID: 90
Statzner, B., Higler, B. 1985; **Questions and comments on the River Continuum Concept.** Canadian Journal of Fisheries and Aquatic Sciences 42 (1):1038-1044.

Keywords : River Continuum Concept; Ecology; river continuum; streams; insects; hydraulic; slope; stream order

The River Continuum Concept (RCC) is a generalized conceptual framework for characterization of pristine running water ecosystems. Of the numerous tenets of the concept we particularly reevaluated the following: biological analogues of energy equilibrium and entropy in the physical system; maximization of energy consumption

through continuous species replacement over a year; absence of succession in stream ecosystems, which can thus be viewed in a time-independent fashion; and maximization of biotic diversity in midreaches of streams as a result of the occurrence of highest environmental variability there together with spatial abundance shifts of insects, mollusks, and crustaceans. When emphasis is placed on rapid changes in the downstream hydraulics dependent on discharge and slope (both of which are expressed by stream order in the RCC and are key factors of the concept) and on results from tropical studies, some of these tenets are partly refuted or need extension. Some of them are in conflict with the current state of knowledge in other domains of stream ecology or are at least open to various interpretations. Therefore, we advocate modifications of the theoretical background of the RCC.

Swanson, M. L., G. M. Kondalf, and P. J. Boison. 1989. **An example of rapid gully initiation and extension by subsurface erosion: coastal San Mateo County, California.** Geomorphology 2: 393-403.
From NCASI

Subsurface Erosion Processes

As cited in Ziemer 1992: In a larger basin (50 ha) in coastal central California, Swanson et al. (1989) found that nearly 70% of stormflow during a 25-year event consisted of pipeflow and that piping and subsurface erosion were the main mechanism resulting in gully formation.

Tanaka, T. and Ono, T. **"Contribution of soil water and its flow path to stormflow generation in a forested headwater catchment in central Japan."** *Hydrology,-Water-Resources-and-Ecology-in-Headwaters Kovar,-K.; Tappeiner,-U.; Peters,-N.E.; Craig,-R.G.-(eds.) IAHS no.248 pp.181-190*.

Keywords: Japan / Hydrographs / Soil Water/ Storm Runoff/ ***Headwaters*** / Tracers / catchment areas/ Discharge Measurement/ Streams / Runoff / catchment areas/ Rivers / Hydrology / Japan

Hydrometric observations and natural tracer analysis were carried out in a small forested headwater catchment in central Japan in order to clarify the source component in stormflow generation and the actual flow path of the main component. The storm hydrograph produced by a total rainfall of 45.9 mm was separated into two and three physically-based source components. For the storm event, soil water contributed around 36% of the event discharge and nearly 52% of the peak discharge. Successive potential distribution maps of both soil and groundwater zones confirmed the flow path of soil water contributing to stormflow generation. The results show the important role of soil water in stormflow generation and illustrate the important place near the stream, maybe the riparian zone, for considering the mechanism of stormflow generation and the process by which the stream-water quality is formed.

Ward, R. C. 1984. **On the response to precipitation of headwater streams in humid areas.** Journal of Hydrology 74: 171-189.
From NCASI

Hillslope Runoff Processes

Ward reviews evolving theories and explanations of the temporally and spatially variable response of streamflow to precipitation, with a focus on the peak response or quickflow. Streamflow response to precipitation is defined as either: (1) a rapid response in the hydrograph after a storm event, termed *quickflow*, accounting for approximately 10% of discharge, or (2) the slower response from *baseflow*, accounting for approximately 90% of discharge. Delivery paths of precipitation to the stream channel include: (1) direct precipitation onto water surfaces, (2) overland flow, (3) shallow subsurface flow (throughflow), and (4) deep subsurface flow (groundwater flow).

In previous research, quickflow has been thought to be caused by overland flow. Traditional Hortonian theory
postulates that overland flow occurs when rainfall intensity exceeds infiltration capacity, in a thin layer at the soil surface,
and rainfall flows overland to the stream channel. While Hortonian theory remains valid for some soils, particularly in areas where human impacts create severe compaction, sparse vegetation cover or thin degraded soils, an alternate hypothesis emerged in the 1960s (Hewlett and Hibbert 1967). Hewlett and Hibbert proposed that precipitation percolates down through soil layers, travels horizontally as subsurface throughflow, may travel vertically upwards, (at the base of slopes or when encountering an impermeable soil or bedrock layer), and emerges later as saturated overland flow. While subsurface flows were originally thought to travel too slow to cause quickflow, the rapid response of the hydrograph is explained by a translatory flow mechanism driven by an input which creates a subsurface saturation pressure, and causing subsurface waters further downslope to emerge as overland flow at a distance closer to the channel. Thus the saturated wedge of subsurface water acts as a conduit rather than a source of quickflow. Variable sites of emerging saturated overland flow can be located throughout a catchment, resulting from convergent forces due to slope concavities and variable soil retention capacities. Ward briefly touches on the relative importance of saturated and unsaturated subsurface flow and turbulent pipeflow in the response of headwater streams to precipitation and acknowledges the need for further research to be able to identify and quantify the individual flow paths of water in the runoff process.

Wright, K. A., K. H. Sendek, R. M. Rice, and R. B. Thomas. 1990. **Logging effects on streamflow: storm runoff at Caspar Creek in northwestern California.** Water Resources Research 26: 1657-1667.
From NCASI

Effects of Management Practices

The authors evaluate effects of selective logging, tractor yarding, and road building on storm runoff in Caspar Creek. This study does not examine a "headwater" stream, focusing on hydrologic response in the North Fork and South Fork Caspar Creek basins (483 and 424 ha, respectively). This study is similar to the analysis in Ziemer (1981) but uses different data analysis techniques and considers lag times. Wright et al. found no significant increases in channel-forming flows (which they defined as peak flows occurring less than 8 times per year) following logging activities in South Fork

Caspar Creek that resulted in compaction of approximately 15% of the watershed in skid trails, landings, and roads. They also found that logging-related disturbances appear to result in shifts in the timing of peak discharge forward in time by approximately 1.5 hours (i.e., lag time decreases). Small storm volumes and storm peaks increased by approximately 132% and 111%, respectively.

Ziemer, R. R. 1981**. Storm flow response to road building and partial cutting in small streams of northern California.** Water Resources Research 17: 907-917.
From NCASI

Effects of Management Practices

Ziemer evaluates the effects of selective logging, tractor yarding, and road building on storm flow response. This study does not examine a "headwater" stream, focusing on hydrologic response in the North Fork and South Fork Caspar Creek basins (483 and 424 ha, respectively). Small peak flow events, particularly those occurring in the fall, were observed to increase by up 300% after logging. This concurs with results of other studies indicating that hydrologic response following logging is greatest for small, fall peakflows (Rothacher 1971, 1973; Harr et al. 1975). Logging and associated road construction were not found to significantly affect large peak streamflows in the Caspar Creek basin at the weirs. Ziemer found that road construction alone (covering 5% of the watershed) did not appear to affect stormflows. He indicates that where roads and landings cover larger portions of watersheds, they can likely increase storm peaks by soil compaction, which reduces interception and increases surface runoff, and by capture of surface runoff and rapid routing to streams. Ziemer also concluded that skid trails, covering 8% of the watershed, did not appear to affect stormflows. Ziemer suggests that "the effect of logging on peak flow was best predicted by a variable representing the percentage of the area logged divided by the sequential storm number within the year" (p. 907).

Ziemer, R. R. 1992. Effect of logging on subsurface pipeflow and erosion: coastal northern California. Pages 187-197 *in* Proceedings of the international symposium on erosion, debris flows and environment in mountain regions. Publication No. 209. International Association of Hydrologic Sciences.
From NCASI

Effects of Management Practices

This article reports the findings of a study of 3 zero-order swales in the North Fork Caspar Creek and the effects of clearcuts on pipeflow and pipe sediment transport. Two of the swales studied (M [control] and K2 [treatment]) are the same as those studied in Keppeler et al. (1994). Pipes in these swales range in size from 2-4 cm for small pipes to 80 cm high by 60 cm wide for the largest pipe. The largest pipe retains a small summer baseflow. Each swale had a drainage area of about 1 ha. Logging of the treatment swales involved clearcutting with cable yarding and exclusion of heavy equipment from hillslopes. Nearly all stormflow in the swales consisted of pipeflow. In a larger basin (50 ha) in coastal central California, Swanson et al. (1989) found that nearly 70% of stormflow during a 25-year event consisted of pipeflow and

that piping and subsurface erosion were the main mechanism resulting in gully formation.

Subsurface Erosion Processes

After clearcut logging of two of the swales, peak pipeflow was approximately 3.7 times higher than pre-logging peak pipeflow. Ziemer notes that whereas Ziemer (1981) found that peakflows increased following logging only for smaller storms in South Fork Caspar Creek, a similar pattern was not observed with pipeflow in swales, suggesting that smaller catchments may have relatively larger hydrologic responses to logging (although other factors varied between the two studies, including yarding practices). Little sediment transport was observed through pipes before logging, with suspended sediment concentrations below 20 mg/l and infrequent transport of coarse grains. Following logging, sediment transport increased substantially in some pipes during certain storm events, particularly the first storm following logging, although other pipes exhibited no change in sediment transport following logging.

Flow Paths

Ziemer indicates that piping is a critical but poorly understood hydrologic process in forested steeplands that must be considered in land use planning. He notes that the presence of subsurface piping networks can allow capture and efficient routing of matrix interflow, reducing pore water pressures and lowering landslide risk. Ziemer observed one location where enlargement of a pipe due to subsurface erosion following logging appeared to undermine a large tree that had been left standing, eventually toppling the tree and resulting in formation of a gully.

Ziemer, R. R., and T. E. Lisle. 1998**. Hydrology.** Pages 41-66 in R. E. Bilby and R. J. Naiman, editors. Ecology and management of streams and rivers in the Pacific Northwest. Springer-Verlag, Berlin.

From NCASI

Ziemer and Lisle review hydrologic processes and logging influences in the PNW. They point out that the influences of forest practices on streamflow are particularly controversial, given that the variability of runoff responses with factors such as watershed size, climate, and logging practices make extrapolation of study results difficult between areas. They also note that mitigation of road and logging effects on hydrology may be more difficult than sediment-related mitigation. Whereas sediment impacts may be strongly mediated by location and methods of land use, hydrologic responses are largely related to extent of area affected by logging or roads. They cite Harr's (1981) findings on the dominant influence of rain-on-snow events in generating large peak flows, both in large (Willamette River) and small (60-ha basin in H.J. Andrews Experimental Forest) watersheds in Oregon. They note that detailed understanding of rain-on-snow events is lacking because data on factors such as snow depth and density during such events is typically unavailable.

Hillslope Runoff Processes

They describe the major components of hillslope runoff, including subsurface flow, saturated overland flow, Hortonian overland flow, and runoff in channels. On undisturbed forested hillslopes, nearly all water is delivered to stream channels by subsurface flow (Harr 1977), including shallow subsurface flow and groundwater-replenishing deep seepage. Flow paths in the soil include micropores (i.e. the soil

matrix) and macropores (pipes, holes formed by roots or animals), with subsurface flow velocities substantially higher in macropores (particularly pipes). Macropores can comprise up to 35% of soil volume in forests (Aubertin 1971), and interconnection of macropores causes pipe formation. Numerous studies have found that pipeflow can account for large proportions of stormflow in headwater basins.

Saturated overland flow (SOF) occurs when soil becomes saturated, causing exfiltration of subsurface flow, and additional precipitation runs off over the ground surface. This process is most common in areas of flow convergence (i.e., topographic depressions, swales) or where hillslope gradients decrease (e.g., at the base of hillslopes or near stream channels), allowing flow to accumulate. SOF zones grow during wet periods and can contribute disproportionate amounts of stormflow; the phenomenon of expanding and contracting SOF zones is referred to as the *partial-area concept* of runoff during storms (Betson 1964, Dunne and Leopold 1978). This process is less likely to occur on straight, steep hillslopes with highly permeable soils. Disturbances of SOF zones can reduce slope stability.

A second type of overland flow, Hortonian overland flow (HOF), occurs when precipitation rates exceed soil infiltration rates, causing excess runoff to flow over the ground surface. This process is unusual in undisturbed forests in the PNW because soil infiltration rates (including of wetted soil) are typically higher than rainfall rates. HOF can occur following fires when hydrophobic conditions are present. "Land use can increases areas of Hortonian overland flow and saturated overland flow and thereby increase hillslope erosion and stormflow magnitude in headwater channels (p. 48)." HOF may occur following soil compaction, specifically on roads, skid trails, and landings. In addition, SOF often can emerge in roadcuts, augmenting direct runoff to streams via road ditches and increasing erosion (Megahan 1972). Roads therefore cause stream network extension by causing HOF and intercepting subsurface flow, thereby increasing stormflows (Wemple 1994). Conversion of subsurface flow to overland flow has the greatest effect on stormflows where micropore flow dominates subsurface processes, since the velocity of runoff can be increased by up to 5 orders of magnitude when such conversion occurs. Because the velocity of flow through pipes or large macropores is much higher than through micropores, conversion of subsurface macropore flow to overland flow results in smaller changes in runoff velocity.

Subsurface flow in channels and the riparian zone can be an important component of total discharge during summer lowflow periods. Subsurface flow in Little Lost Man Creek, an undisturbed, low-order, cobble-bedded channel in northern coastal California, was found to be about 25% of summer surface flow (Zellweger et al. 1989). Subsurface channel flow is also referred to as flow in the hyporheic zone ("the saturated sediments beneath and beside a river channel that contain both surface and ground water" [p. 52], this definition is from Edwards chapter in same book as Z&L article but no listing in their references). Coarse sediment inputs to streams resulting in aggradation can increase the proportion of total discharge that flows subsurface in channels. Triska et al. (1993) found that channel and riparian subsurface flow velocities ranged from 0.4 to 13 m/hr. Emergence of subsurface flow into pools can contribute to summer temperature refugia (Nielsen et al. 1994); streambank seeps can also be a source of cool water during summer.

Effects of Management Practices on Hydrologic Processes

Ziemer and Lisle discuss the effects of land-use practices on runoff, including variation with basin size. They note that "effects of forest practices on storm runoff are generally more pronounced and easier to detect in small basins than in large basins." This is in part due to the difficulties of measuring effects and isolating variables in large basins but also due to differences in physical processes between small basins, where stormflow response is driven largely by hillslope processes, whereas channel network geomorphology is the primary control on response in larger basins (Robinson et al. 1995). Land uses are more likely to affect hillslope processes, and therefore hydrologic response in small basins, than overall morphology of channel network. Channel network extension due to land uses has a proportionately small effect in large basins (Beven and Wood 1993), and storage of runoff attenuates peakflow increases in progressively higher order channels. If land use effects on peakflows and lag times in multiple tributaries within a watershed are similar, the probability of altered peakflows in mainstem channels due to synchronous tributary inputs is increased. They also discuss variation in land-use effects on peakflows with season, citing numerous studies (as described elsewhere in this annotated bibliography) showing that effects are largest for fall storm events but insignificant for large winter peak events.

Hydrologic processes typically require varying periods to recover from land use effects. Ziemer and Lisle review logging effects on summer lowflows, including North Fork Caspar Creek studies showing up to 200% increases in summer lowflow, with returns to pre-logging levels expected to take 8 to 10 years. Road-related effects may be long-term, while logging-related effects on evapotranspiration may recover within about five years due to vegetation regrowth (Harr 1979). Effects on snow accumulation and melt processes typically require longer periods to recover, since these effects are controlled by tree canopy cover and snow retention.

Ziemer, Robert R. 1998. **Flooding and stormflows.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 15-24.

The effects of road building and timber harvest on storm flow were evaluated at the North and South Forks of Caspar Creek in north coastal California. From 1963 through 1975, a total of 174 storms that produced peak discharges larger than 0.016 L s-1ha-1 in the untreated North Fork were studied.

Storms producing flows this size and larger occur about 14 times each year and about 10 percent of the time. They are responsible for 83 percent of the annual water discharge and transport 99 percent of the suspended sediment. Selection cutting and tractor yarding second-growth redwood and Douglas-fir in the 424- ha South Fork did not significantly change peak streamflows that occur about eight times a year — those larger than about 1 L s-1ha-1. For flows smaller than 1 L s-1ha-1, the first peaks in the fall increased by 300 percent after logging. The effect of logging on peak flow was best predicted by the percent of area logged divided by the sequential storm number, beginning with the first storm in the fall. For example, the second storm of the fall produced half the response to logging than the first storm. In 1985, the second stage of the Caspar Creek study began with the installation of an additional 13 gaging stations in the North Fork. From 1985 through 1996, 59 storms and 526 peak flow events were

measured. There was a mean peak flow increase of 35 percent in entirely clearcut and 16 percent in partially clearcut tributary watersheds for the class of flows greater than 4 L s-1ha-1 — those that occur less frequently than twice a year.

When the unlogged South Fork was used as the control, peak streamflows in the North Fork after clearcut logging were not significantly larger for flows greater than about 1 L s-1ha-1, as was also observed after selection cutting the South Fork. However, when the more sensitive uncut North Fork tributaries were used as controls, an increase in peaks was detected at the North Fork weir after logging.

Ziemer, R.R.; Albright, J.S. 1987. **Subsurface pipeflow dynamics of north-coastal California swale systems.** *In:* Beschta, R.; Blinn, T.; Grant, G.E.; Swanson, F.J.; Ice, G.G., eds. Erosion and sedimentation in the Pacific Rim, Proceedings of the Corvallis Symposium, 1987 August. International Association of Hydrological Sciences Publication No. 165. Wallingford, UK: IAHS; 71-80.

Pipeflow dynamics are being studied at Caspar Creek Experimental Watershed in north-coastal California near Ft. Bragg. Pipes have been observed at depths to 2 m within trenched swales and at the heads of gullied channels in small (0.8 to 2 ha) headwater drainages.

Digital data loggers connected to pressure transducers monitor discharge using calibrated standpipes. During storms, pipeflow up to 8 l s-1 has been measured, while, within the same swales, no surface channel flow occurred. Pipeflow discharge has been correlated with antecedent precipitation.

Ziemer, R.R.; Rice, R.M. 1990. **Tracking rainfall impulses through progressively larger drainage basins in steep forested terrain.** *In:* Lang, H.; Musy, A., eds. Hydrology in mountainous regions. I - Hydrological measurements; the water cycle, proceedings of two Lausanne symposia, 1990 August. International Association of Hydrological Sciences Publication No. 193. Wallingford, UK: IAHS; 413-420.

The precision of timing devices in modern electronic data loggers makes it possible to study the routing of water through small drainage basins having rapid responses to hydrologic impulses. Storm hyetographs were measured using digital. tipping bucketraingauges and their routing was observed at headwater piezometers located mid-slope, above a swale, and near the swale. Downslope, flow was recorded from naturally occurring soil pipes drainingg the 0.8-ha swale, Progressing downstream from the swale, streamflow was measured at stations gauging nested basins of 16, 156, 217, and 383 ha. Peak lag time significantly ($p = 0.035$) increased downstream. Peak unitareadischarge decreased downstream, but the relationship was not statistically significant ($p = 0.456$).

V. Riparian Canopy Cover, Microclimate, Stream Temperature

Beschta, R. L., and J. Weatherred. 1984. **TEMP-84: A computer model for predicting stream temperatures resulting from the management of streamside vegetation.** WSDG

Report WSDG-AD-00009. U. S. Forest Service, Watershed Systems Development Group, Fort Collins, Colorado.
From NCASI

"TEMP-84 is a computer model developed to simulate temperature responses in small mountain streams that result from shade removal. Stream temperature responses to alternative combinations of cutting unit proposals can be evaluated. Conceptual descriptions of the processes related to the operation of the model, user instructions describing the input data formats, directions for executing the model, and example output are provided. Supporting information about the computational procedures, physical processes, and data sensitivities are also included."

Ref ID: 136
Beschta, R.L. 1989; **The effects of riparian vegetation on channel morphology, sediment, and temperature in streams.** pp.1-8**. in** Paper presented at the COPE workshop "Silvicultural management of riparian areas for multiple resources". U.S. Forest Service Pacific Northwest Research Station, Portland and Oregon State University College of Forestry, Corvallis. held at Salishan Lodge, Gleneden Beach, Oregon. 12-13 December 1989.

Keywords : riparian vegetation; vegetation; morphology; sediment; temperature; stream order; biota; streams; function; woody debris; debris; nutrients; structure; headwaters

Vegetation along streams functions in a variety of ways. The quality of energy inputs, coarse woody debris inputs, nutrient regulation, algal and macrophytic production, structure and function of biotic communities, and channel morphology are largely controlled by streamside vegetation. Streamside vegetation allows stream ecosystems to function in ways that structural additions alone to channels cannot replicate.

The geomorphic features of stream and river channels change in a downstream direction (i.e., with increasing stream order). Streams in headwater reaches are characterized by V-shaped valleys, relatively steep gradients, coarse bed sediments, and little floodplain development. Bedrock channels may be common. Downstream reaches have lower gradients, finer sediments and broader alluvial floodplains. As a result, the function and type of stream biota respond to the changing downstream influence of vegetation and the changing physical characteristics of a stream system.

Beschta, R. L., R. E. Bilby, G. W. Brown, L. B. Holtby, and T. D. Hofstra. 1987. **Stream temperature and aquatic habitat: fisheries and forestry interactions.** Pages 191-232 in E. O. Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. Contribution No. 57. College of Forest Resources, University of Washington, Seattle**.**
From NCASI

The authors review several stream temperature issues that are of relevance to small, headwater streams:

- The temperature of water entering the stream via subsurface pathways generally reflects that of the watershed's subsoil environment. For forested streams in the Pacific Northwest, this subsurface water is predominantly received as snowfall (£0°C) or from winter rainstorms (³0°C).
- As water moves downstream, its change in temperature is directly proportional to surface area and inversely proportional to discharge. Thus higher-discharge streams, while having proportionally more surface area, will tend to show less temperature changes than small headwater streams with reduced discharges.
- Streambed conduction is important for small, exposed bedrock streams. The substrates in these environments have a high heat capacity and 15-20% of the net all-wave radiation absorbed by the stream may be lost to the bed (Brown, 1972).
- Incoming solar radiation is the principle source of energy heating a stream. Exposed streams receive commensurately more solar heating. Energy transfers via convection or evaporation are less important. Both require wind movement and temperature and vapor pressure gradients at the stream surface.
- Warm air temperatures tend to be highly correlated with water temperatures, although the former are not the cause of the latter. Warm air temperatures reduce vapor pressure gradient differences between the water and air interface reducing or eliminating heat loss from the water surface.
- Pacific Northwest watershed studies show increases of mean monthly maximum temperatures of 3 to 8°C associated with timber harvest in the riparian zone, with another 1°C potentially added by burning. Diurnal fluctuations can increase by more than 15°C if riparian canopy is completely removed.
- Buffer strips are important for controlling stream temperature increases. Effective buffer strips control the amount of incoming solar radiation striking the stream. Woody plant species composition, age (or size), and canopy density are important buffer characteristics.
- Streams passing through shaded reaches tend not to lose heat (unless there are cool water inflows) because direct and diffuse solar radiation remains proportionally greater than long wave radiation heat losses. As a consequence, temperature increases in headwater streams can increase the temperature regimes of downstream reaches. The magnitude of these increases depends on the temperature and discharge of the headwater streams. Unpublished data for Salmon Creek in the Oregon Cascades (Beschta and Taylor, 1988, as reported in this article) show a summer maximum temperature increase at the mouth from 16°C to 22°C over a period of 30-years following clear-cut logging in the headwaters.

Ref ID: 128
Beschta, R.L., Taylor, R.L. 1988; **Stream temperature increases and land use in a forested Oregon watershed.** Water Resources Bulletin 24 (1):19-25.

Keywords : temperature; stream temperature; watershed; roads; management; forestry; logging practices; Oregon; streams; flow; soil

The Salmon Creek Watershed drains 325 km^2 of forested terrain in the Cascade Mountains of Western Oregon. Over a 30-year period (from 1955 to 1984) average daily maximum and minimum stream temperatures, calculated from the 10 warmest days of each year, have risen 6 degrees Celsius and 2 degrees Celsius respectively. In contrast, a small decrease in maximum air temperatures was found over the same period. Regression analysis indicated a highly significant ($p<0.01$) relationship between a cumulative index of forest harvesting and maximum stream temperatures. Maximum temperatures also tended to increase between harvest activity (logging and road construction), changing forest riparian management practices and the occurrence of natural hydrologic events (peak flows and associated mass soil movements) tend to obscure specific cause-and-effect relationships regarding long-term changes in maximum stream temperature.

Brosofske, K. D., J. Chen, R. J. Naiman, and J. F. Franklin. 1997. **Harvesting effects on microclimatic gradients from small streams to uplands in western Washington.** Ecological Applications 7: 1188-1200.
From NCASI
Abstract (abridged)

Riparian zones are vital components of the landscape. We sampled five small streams before and after clear cutting in western Washington. Buffers ranging from 17 to 72 m wide were left intact at all sites. Our objectives were: (1) to characterize preharvest microclimatic gradients across riparian ecosystems; (2) to identify effects of harvesting on these gradients; and (3) to describe effects of buffer width and local microclimate on stream microclimate. Weather stations measuring air temperature, soil temperature, surface air temperature, relative humidity, short-wave solar radiation, and wind speed were installed along transects running across the stream and into the upland. Reference stations were established in an upland clear-cut and an upland interior forest. Pre-harvest riparian gradients existed for all variables except solar radiation and wind speed. After harvesting, microclimate values at the buffer edge and each subsequent location toward the upland began to approximate clear-cut values instead of forest interior values, indicating an interruption or elimination of the stream-upland gradient. Regression analyses showed that stream microclimate was affected by buffer width and local microclimate. We conclude that a buffer at least 45 m on each side of the stream is necessary to maintain a natural riparian microclimatic environment along the streams in our study, which were characterized by moderate to steep slopes, 70-80% over story coverage (predominantly Douglas-fir and western hemlock), and a regional Mediterranean-like climate. Required widths may need to extend up to 300 m, which is significantly greater than standard widths currently in use. Our results indicate that even some of the more conservative standard buffer widths may not be adequate for preserving an unaltered microclimate near some streams.
Experimental Design
Microclimates were sampled across small streams in western Washington in the foothills of the western slope of the Cascade Mountain Range. Streams of similar size, vegetation, and physical characteristics were chosen to allow for between stream

comparison. Stream widths ranged from 2 to 4 m, elevations ranged from 150 to 600 m, and canopy coverage was approximately 75%. The sites did differ in buffer width, valley formation, and orientation.

Microclimate Impacts

The authors observe: "1) Riparian microclimate gradients existed for air temperature, soil temperature, surface air temperature, and relative humidity. Short-wave solar radiation displayed no apparent riparian gradient, and wind speed, though differing along the transect, showed no definite pattern. Generally, pre-harvest gradients approached upland forest interior values within 31-47 m from the stream, although surface temperature and humidity gradients often extended further (31-62 m)." Soil temperatures were strongly correlated with stream temperatures for pre-harvest conditions. The relationship persists in post-harvest states, although the slope of the regression line is significantly reduced (0.667 for pre-harvest versus 0.2705 for post-harvest). The authors noted that, "Buffer width did not appear to affect stream water temperature at our sites, except in the case of almost complete absence of streamside trees." The diminished relationship between soil temperature and stream temperature in the post-harvest scenario appears to be due the enhanced diurnal fluctuations of soil temperatures on cleared land. The authors observe that, "…soils were relatively coarse and slopes were moderate to steep, which could help explain why soil temperature at locations closer to the upland was more influential than that at locations nearer the stream.

The other primary harvesting impact on near-stream microclimate was from reductions in the relative humidity and elevated solar radiation receipt. Relative humidity increased exponentially with increasing buffer width. The relationship is reversed for solar radiation, demonstrating a negative exponential relationship against buffer width (Figure 8). Coefficients of determination for the two relationships are r2=0.60 and r2=0.46 for solar radiation versus buffer width, and relative humidity versus buffer width respectively.

Ref ID: 115

Brown, G.W. 1969; **Predicting temperatures of small streams.** Water Resources Research 5 (1):68-75.

Keyword : temperature

Hourly temperatures of small streams can be accurately predicted using an energy balance. Micrometeorological measurements are required to assess the environment of the small stream accurately. The temperature-prediction technique was tested on three streams in Oregon. On unshaded stretches, net all-wave radiation is the predominant energy source during the day; evaporation and convection account for less than 10% of the total energy exchange. Conduction of heat into the stream bottom is an important energy balance component on shallow streams having a bedrock bottom. Up to 25% of the energy absorbed by such a stream may be transferred into the bed. Hourly temperature changes of 0-16°F were predicted to within 1°F more than 90% of the time.

This technique permits foresters to control water temperature through manipulation of streamside vegetation.

Brown, G. W. 1970**. Predicting the effect of clear cutting on stream temperature.** Journal of Soil and Water Conservation 25: 11-13.
From NCASI

"The temperature change that occurs between two points on a stream is directly proportional to the surface area of the stream and the heat load applied between these points. It is inversely proportional to the flow. Good estimates of the heat load can be made with solar radiation data if the stream is uniformly exposed to sunlight. Foresters can use this technique to predict the effect of clear-cutting on stream temperature."

Experimental Strategy

The author applies the *Brown model* (Brown 1969) to address clear-cutting impacts on stream temperature. Solar radiation receipt at the stream surface is calculated from standard curves, multiplied by solar angle and a term for reflection from the water surface. Measured values of stream flow permit calculation of travel time and thus maximum exposure to solar radiation input. These values are inserted into the *Brown model* to predict temperature change as a result of clear-cutting.

Stream Temperature Impacts

Temperature changes of 16°F for two streams in Oregon, were predicted within 1°F. The author outlines three limitations with this approach. Firstly, it assumes that no tributaries flow into the reach. This issue may be addressed by applying a simple mixing ratio equation. Secondly, variable low-flow discharge rates, and varying groundwater temperatures, are not accounted for. This issue may be addressed, in part, by adjusting stream surface area. Thirdly, the model assumes complete exposure to solar radiation receipt (i.e., no topographic or vegetation shading of the stream surface).

Brown, G. W., and J. T. Krygier. 1967. **Changing Water Temperatures in small mountain streams.** Journal of Soil and Water Conservation 22: 242-244.
From NCASI

The authors present data for Flynn Creek (control) and Needle Creek (clear-cut) in the Alsea research basin in Oregon.

Stream Temperature Impacts

Temperatures were monitored for 2-years, from 1965-1966 and showed mean monthly maximum temperatures increases of up to 14°F in the clear-cut basin. A similar study in the H.J. Andrews Experimental Forest showed a 16°F increase in stream temperature as water migrated from full cover to full exposure through a 1,300-feet section.

Conclusions

The authors note that "….these small stream systems, with low summer flows and a large surface area in relation to water volume, reflect changes in microclimate brought about by clear cutting to a degree not often noticed on larger systems."

Cafferata, P. 1990**. Watercourse Temperature Evaluation Guide.** JDSF Newsletter No. 39. Jackson Demonstration State Forest, California Department of Forestry and Fire Protection, Fort Bragg.
From NCASI

This guidebook outlines the main physical parameters that affect stream temperature and describes a simple predictive model (the *Brown model*; Brown 1969, 1970) and the field techniques and instrumentation necessary to parameterize the model and thus to measure the impact of land use practices on stream temperatures.

Chen, D. Y., Carsel, R. F., McCutcheon, S. C., and W. L. Nutter. 1998. Stream **temperature simulation of forested riparian areas: I. Watershed-scale model development.** Journal of Environmental Engineering 124(4): 304-315.
From NCASI

To simulate stream temperatures on a watershed scale, shading dynamics of topography and riparian vegetation must be computed to estimate the amount of solar radiation that is actually absorbed by water for each stream reach. A series of computational procedures identifying the geometric relationships between the sun position, stream location and orientation, and riparian shading characteristics were used to develop a computer program called SHADE. The SHADE-generated solar radiation data are used by the Hydrologic Simulation Program-FORTRAN (HSPF) to simulate hourly stream temperatures. A methodology for computing the heat flux between water and streambed was selected, evaluated, and implemented in the HSPF code. This work advances the state-of-the-art in watershed analysis by providing a quantitative tool for relating riparian forest management to stream temperature, which is a vital component of aquatic habitat. This paper describes the modeling strategies, the SHADE program in terms of algorithms and procedures, the integration of SHADE with HSPF, and the algorithms and evaluation of the bed conduction of heat. A companion paper presents an application of the SHADE-HSPF modeling system for the Upper Grande Ronde watershed in northeast Oregon.

Chen, D. Y., McCutcheon, S. C., Norton, D. J., and W. L. Nutter. 1998. **Stream temperature simulation of forested riparian areas: II. Model application.** Journal of Environmental Engineering 124(4): 316-328.
From NCASI

The SHADE-HSPF modeling system described in a companion paper has been tested and applied to the Upper Grande Ronde (UGR) watershed in northeast Oregon. Sensitivities of stream temperature to the heat balance parameters in Hydrologic Simulation Program-FORTRAN (HSPF) and the riparian shading parameters in SHADE were analyzed for stream temperature calibration. Solar radiation factors (SRF), as well as diurnal seasonal and longitudinal variations, were evaluated to verify the accuracy and reliability of SHADE computations. Simulated maximum values of stream temperature, upon which the riparian restoration forecasts are based, are accurate to 2.6–3.0°C compared with 8–10°C exceedances over stream temperature goals for salmon habitat restoration under the present riparian vegetation conditions. Hourly simulations have approximately the same accuracy and precision. Stream temperature regimes were simulated for different hydroclimatic conditions and hypothetical restoration scenarios of riparian vegetation. Regardless of natural weather cycles, the restoration of riparian vegetation is needed along many headwater streams to significantly alleviate the lethal

and sublethal stream temperatures currently associated with salmon habitat in the UGR basin.

Stream Temperature Modeling

Based on sensitivity analyses performed by the authors, the solar radiation factor (SRF) was found to be the most sensitive parameter to daily maximum temperatures and 7-day average daily maximums. The SRF parameter is the ratio of 'effective' solar radiation available for stream heating versus the total incoming radiation. The SHADE model described in the companion paper was developed to better account for topographic and vegetation shading and stream orientation. Those landscape and vegetation attributes are not explicitly accounted for in the HSPF model. Statistical correlations between reach-based (ranging in length from approximately 2 km to 24 km) and segment-based (1000-meter discretizations of the reach-segments) mean daily averaged SRF's versus highest maximum and highest 7-day average maximum stream temperatures were not significant (segment-based r2 values of 0.526 and 0.554 for highest maximum and highest 7-day maximum for 1991 data, and 0.417 and 0.386 for 1992 data). Resolution and scale may account for the variability in correlation. For example, the correlation between segment-based SRF's were more significant than correlations between reach-based SRF's, likely because of the shorter stream lengths compared.

Ref ID: 66

Closs, G.P., Lake, P.S. 1996; **Drought, differential mortality and the coexistence of a native and an introduced fish species in a south east Australian intermittent stream.** Environmental Biology of Fishes 47 (1):17-26.

Keywords : trout; Salmo trutta; Galaxiidae; Galaxias olidus; drought; fish; biotic interaction; streams; flow; temperature; headwaters; pools

The longitudinal distribution of *Salmo trutta* and *Galaxias olidus*, a small salmoniform fish, was mapped over four summers (1985-1988) in the upper reaches of the Lerderderg River, an intermittent stream in central Victoria. Over the four successive summers of the study, the distribution of *S.trutta* expanded upstream. Coincident with the expansion of *S. trutta* was a contraction in the distribution of *G. olidus* upstream. In the summer of 1988, an extended dry spell resulted in high levels of *S.trutta* mortality at the upstream limits of their distribution. This suggested that the upstream distribution of *S. trutta* could ultimately be constrained by an inability to tolerate prolonged periods of low stream flow and high temperatures that tended to occur in the headwaters of the stream. A study of summer mortality was conducted over three successive summers (1989-1991) at three reaches along the river. The two downstream reaches contained only *S. trutta*, the upstream reach contained both *S. trutta* and *G. olidus. Salmo trutta* mortality was consistently higher at the most upstream reach compared with lower reaches. High levels of *S. trutta* mortality at the two downstream reaches were observed in 1991, a particularly dry year. In contrast, *G. olidus* survived in scattered small pools throughout the upper reaches of the stream. The results of the study suggest a shifting pattern ***of S trutta*** and *G. olidus* distribution determined by the duration of low stream flow periods and summer high temperatures.

Ref ID: 132
Cooper, A.B. 1990; **Nitrate depletion in the riparian zone and stream channel of a small headwater catchment.** Hydrobiologia 202 (1):13-26.

Keywords : riparian zone; streams; headwaters; New Zealand; soil; sediment; hydrology

A mass balance procedure was used to determine rates of nitrate depletion in the riparian zone and stream channel of a small New Zealand headwater stream. In all 12 surveys the majority of nitrate loss (56-100%) occurred in riparian organic soils, despite these soils occupying only 12% of the stream's border. This disproportionate role of the organic soils in depleting nitrate was due to two factors. Firstly, they were located at the base of hollows and consequently a disproportionately high percentage (37-81%) of the groundwater flowed through them in its passage to the stream. Secondly, they were anoxic and high in both denitrifying enzyme concentration and available carbon. Direct estimates of *in situ* denitrification rate for organic soils near the upslope edge (338 mg N m^{-2} h^{-1}) were much higher than average values estimated for the organic soils as a whole (0.3-2.1 mg N m^{-2} h^{-1}) and suggested that areas of these soils were limited in their denitrification activity by the supply of nitrate. The capacity of these soils to regulate nitrate flux was therefore under-utilized. The majority of stream channel nitrate depletion was apparently due to plant uptake, with estimates of the *in situ* denitrification rate of stream sediments being less than 15% of the stream channel nitrate depletion rate estimated by mass balance.

This study has shown that catchment hydrology can interact in a variety of ways with the biological processes responsible for nitrate depletion in riparian and stream ecosystems thereby having a strong influence on nitrate flux. This reinforces the view that those seeking to understand the functioning of these ecosystems need to consider hydrological phenomena.

DeNicola, D. M., Hoadland, K. D., and S. C. Roemer. 1992. **Influences of canopy cover on spectral irradiance and periphyton assemblages in a prairie stream.** Journal of the North American Benthological Society 11(4): 391-404.
From NCASI

Influences of the transmission properties of the riparian canopy and the water column on spectral irradiance and periphyton composition were examined in a small spring-fed stream in western Nebraska. Above canopy, below canopy, and underwater irradiances were measured at 2-nm intervals from 300–800 nm throughout the day at each site on a clear day in June. Photosynthetically active radiation (PAR) incident at the stream surface did not consistently correspond to percent sky values at the sites because of temporal changes in the penetration of direct sun through small openings in the canopy (sunflecks). The relationship of solar path to canopy structure and orientation chiefly determined sunfleck activity. The proportion of blue light (400–500 nm) increased at all sites by late afternoon. At the shaded sites, the amount of red light (600–700 nm) was proportionally lower underneath the canopy than above it. Underwater PAR was always greater at the open site than at the more shaded sites. The relationship between canopy cover and underwater irradiance for the more shaded sites varied temporally. The spectral distribution of PAR at the mean depth of 39.7 cm showed only

a slight maximum transmission in green wavelengths (approximately 550 nm). Temporal variability in the underwater spectral distribution at a site was often greater than differences between sites because of sunflecks and surface reflection by ripples. Algal chlorophyll *a* concentrations at the site were significantly correlated with percent sky (skyview factor) for gravel substrata but not for sand substrata. The flora on both substrata was dominated by diatoms, and the distributions of several species were related to the degree of canopy cover at the sites.

Edinger, J. E., Duttweiler, D. W., and J. G. Geyer. 1968. **The response of water temperatures to meteorological conditions.** Water Resources Research 4: 1137-1143.
From NCASI

The exchange of heat across the air-water interface is one of the more important factors that govern the temperature of a water body. The net rate of heat exchange at the water surface is the sum of the rates at which heat is transferred by irradiative processes, by evaporation, and by conduction between water and overlying air. The net rate can be evaluated in terms of a thermal exchange coefficient and an equilibrium temperature, both of which depend on observable meteorological variables.

Any one of the many evaporation formulas and mathematical descriptions of the other heat exchange coefficient and equilibrium temperature. Such equations are useful in developing relations that describe the temporal and spatial temperature distributions in a water body. They provide additional insight into the effects of meteorological conditions on water temperatures, and they facilitate estimates of various terms of the heat budget.

Hetrick, N. J., Brusven, M. A., Meehan, and W. R. Bjornn. 1998. **Changes in solar input, water temperature, periphyton accumulation, and allochthonous input and storage after canopy removal along two small salmon streams in southeast Alaska.** Transactions of the American Fisheries Society 127(6): 859-875.
From NCASI

The paper addresses the issues of riparian vegetation management strategies. To this end, the authors measure changes in solar radiation, water temperature, periphyton accumulation, and allochthonous inputs after vegetation removal in small streams in Alaska. The authors suggest that removal of riparian vegetation will result in increased periphyton production due to increased exposure to light, and this increased productivity will more than compensate the reduction in allochthonous inputs.

Stream Temperature Impacts

The two-year study showed significant impacts on stream temperatures when flow rates were low. At higher discharges, the relationship is not significant.

Conclusions

The authors note, "…from a management perspective, net radiation may be the most feasible parameter to alter via partial or total riparian canopy removal or addition." Although the study did demonstrate an increase in periphyton productivity as a result of canopy removal, it appears that variability in discharge rates will result in lethal stream temperatures during low-flow years offsetting any benefits of increased periphyton production.

Hewlett, J. D., and J. C. Fortson. 1982**. Stream temperature under an inadequate buffer strip in the Southeast Piedmont.** Water Resources Bulletin 18(6): 983-988**.**
From NCASI

Abstract

"A paired watershed experiment on the southeastern Piedmont to determine the effect of clearcutting loblolly pine on water quantity, quality, and timing has shown that stream water temperatures were increased by as much as 20°F even though a partial buffer strip of trees and shrubs were left in place to shade the stream. Winter time minimum stream temperatures were lowered as much as 10°F by the same treatment. A stream temperature model now in use did not predict such elevated temperatures. The authors suggest that forest cover reductions in areas of gentle relief may elevate the temperature of shallow ground water moving to the stream, even with a substantial buffer width in place."

Experimental Design

Two proximal, Southwesterly-flowing Georgia streams of 32.5 and 42.5 hectares were used for the study. The former was clear-cut, leaving a 20-foot buffer on either side, and the latter was left fully forested.

Stream Temperature Impacts

"Daily maximum water temperature at the mouth of the clear-cut basin was increased in nearly all months of record, averaging 12°F increase during June and July for the first four years after clear cutting. The average increases were surprisingly persistent and rose to 14°F in the hot summer of 1978." [p.985]. Using the Brown model (Brown 1969, 1970), stream temperatures were only predicted to be 7°F higher in the clear-cut area.

A multiple regression found no significant causes of the elevated temperatures. However, a heat-loading index using maximum hourly temperatures correlated with the elevated stream temperatures in the clear-cut watershed. Figure 5 [p.987] illustrates the strong correlation with monthly stream temperature regimes in the control and experimental watershed compared with air temperatures.

Conclusions

The authors conclude that even after several years regeneration, the clear-cut watershed has an inadequate buffer strip to control summertime stream temperatures. They suggest that the gently sloping relief allows significant heating of shallow subsurface groundwater as it migrates to the stream. They further suggest a "…1) re-examination of the idea that evaporation and radiant cooling under shade may be neglected in computing stream temperature change due to over story manipulations; and 2) that the temperature of effluent groundwater should be monitored to determine whether, in addition to direct solar radiation, elevated soil temperatures outside the buffer may be affecting stream temperatures."

Holtby, L. B. 1988. **Effects of logging on stream temperatures in Carnation Creek, British Columbia, and associated impacts on the Coho Salmon (*Oncorhynchus kisutch*).** Canadian Journal of Fisheries and Aquatic Sciences 45: 502-515.
From NCASI

The author presents data showing stream temperature increases resulting from clear cutting 41% of the Carnation Creek basin. Stream temperatures were correlated

with air temperatures from a proximal weather station. Following logging, this correlation was significantly degraded, and multiple regression analysis indicated that increased stream temperatures, up to 3°C above historical maxima during the summer, were attributable to logging impacts.

Hostetler, S. W. 1991. **Analysis and modeling of long-term stream temperatures on the Steamboat Creek basin, Oregon: implications for land use and fish habitat.** Water Resources Bulletin 27: 637-647**.**
From NCASI

Twenty years of stream temperature and flow data from four tributaries and two reaches of Steamboat and Boulder Creeks are analyzed.
Stream Temperature Modeling
The author develops a time-series, auto-regressive moving average (ARMA) model to test the relationships of the seasonal cycle of solar radiation, air temperature, streamflow, and two other variables, to summer stream temperatures. The six parameter model (for which only one parameter is constant) apparently shows a significant relationship with the linear trend variable. It is difficult, however, to discern cause and effect using statistical models with freely varying parameters.
The author fitted the model to observed stream temperature data for the various tributaries and reaches. The linear trend parameter shows the best correlation with summer stream temperatures for five of the reaches. The sixth, Boulder Creek, was unlogged and shows no positive relationship with this parameter. The author concludes that this linear trend parameter is associated with the loss and subsequent regrowth of riparian vegetation and shading canopies and that the stream temperatures in five of the reaches are reflective of this canopy removal and regrowth. Because pre-harvesting temperature data are not available, however, more information may be necessary before confirming this conclusion.

Larson, L. L., and S. L. Larson. 1996**. Riparian shade and stream temperature: a perspective.** Rangelands 18(4): 149-152.
From NCASI

The authors present a theoretical analysis of stream temperature physics and riparian shading to demonstrate that, "Streamside vegetation can improve bank stability, increase habitat for some species of wildlife, and serve as a component in the system as a whole, but shade does not control stream temperature." The heat budget is divided into a heat input equation and a diffusion equation. The approach, however, does not address the role of direct solar radiation receipt, convection, conduction, and evaporation as important variables contributing to stream temperature and the significant role of riparian shade.

Ref ID: 109
Ledwith, T.S. 1998; **The effects of buffer strip width on air temperature and relative humidity in a stream riparian zone.** The Watershed Management Council Networker 6 (1):6-7.

Keywords : buffer; temperature; relative humidity; riparian zone

Streamside buffer strips have been used for years as a management tool in protecting riparian environments from the adverse effects of timber harvesting. Still, questions about what constitutes adequate buffer widths persists. This study examines the effects of buffer width on air temperature and relative humidity in riparian zones. This relationship is important because a buffer strip of an insufficient width may allow an increase in direct and reflected solar radiation into a stream environment, increasing air temperature and lowering humidity on warm days. These effects are most pronounced during the afternoon hours of the summer months when the high west concentration of solar radiation is present. From June 7 to August 31, 1994, air temperature and relative humidity in a stream riparian zone were measured at two sites in the Mad River Ranger District, Six Rivers National Forest, California. Measurements were collected over each stream at six collection sites where the buffer widths were 150 meters, 90 meters, 30 meters, 15 meters, and 0 meters (clearcut). The results showed the air temperature above the streams increased exponentially with decreasing buffer width, and the relative humidity was inversely proportional to air temperature.

Changes in microclimate conditions can alter the ecosystem of the riparian environment. If measurements move beyond the tolerance levels of terrestrial riparian flora and fauna, species may perish or be forced to find other suitable habitat to complete their life cycle. Increased solar radiation and air temperature may also raise the water temperature in a stream to sublethal or lethal levels for resident aquatic life.

Establishing a buffer width necessary to maintain a functioning riparian ecosystem is dependent on many factors including local climatic conditions, topography, geology, and vegetation.

Lynch, J. A., Rishel, G. B., and E. S. Corbett. 1984. **Thermal alteration of streams draining clearcut watersheds:** Quantification and biological implications. Hydrobiologia 111: 161-169.

From NCASI

The authors elaborate upon their earlier published study (Rishel et al. 1982) of three watersheds in Central Pennsylvania that experienced differing levels of timber harvesting activity, including: (1) clearcutting with herbicide post-treatment, (2) commercial harvesting leaving approximately 30-meter buffers either side of the channel, and (3) an unlogged, control watershed. Summer maximum stream temperatures averaged 1°C higher in the commercial clearcut, and 9°C in the clearcut herbicide watershed.

Ref ID: 58

McBride, J.R., Strahan, J. 1984; **Establishment and survival of woody riparian species on gravel bars of an intermittent stream.** The American Midland Naturalist 112 :235-245.

Keywords : colonization; vegetation; riparian vegetation; gravel bar; Salix spp. willow; Populus fremontii; cottonwood; Baccharis; co; sediment; streams; flow

Factors influencing seedling establishment and survival were studied on gravel bars of lower Dry Creek, Sonoma Co., California. Gravel bar species became established from May to July. Seedling establishment was correlated with sediment texture. *Salix* spp. established preferentially on areas where surface sediment size was less than 0.2 cm. *Populus fremontiiI* established more densely on areas of intermediate and large-sized sediments (0.2-1.0 cm). *Baccharis viminea* dominated on the larger sediment sizes. Drought-induced mortality of seedlings was highest on bars where the stream had dried up completely prior to 1 September 1981. The high winter flows of the 1981-1982 season scoured the sediments and killed the vast majority of remaining seedlings. Seedlings which established in areas protected from the swifted current were, however, able to withstand the winter flows. At specific locations, changes of gravel bar landforms resulted in significant losses of established trees as well as young seedlings and saplings.

McGurk, B. J. 1989. **Predicting stream temperature after riparian vegetation removal.** USDA Forest Service General Technical Report, PSW-110**.**
From NCASI

The author builds on previous research (Brown, 1970) indicating that 90% of stream temperature in small streams was accounted for by solar insulation after clearcutting. This study reports on field studies in two streams in California where the 'Brown equation' and the 'Schloss model' have been applied to predict the observed stream temperatures.

Models

The Brown equation is described elsewhere in this bibliography. The Schloss model is a regression-type equation developed in Western Oregon for basins below 610 meters in elevation:

$T°C = 11.9 - 0.0013E + 0.206L + 0.676R + 1.814(S/50 + 1)$

E = midbasin elevation (meters)

L = distance from junction of next higher-order stream (kilometers)

R = stream order

S = Shade % (percent of channel that is < 100% shaded within 1600-meters upstream of the point of interest)

Conclusions

The study highlights several difficulties in applying overly-simplified temperature models (the Brown model) and statistical models where the parameters are appropriate for somewhat different environments. In the former case, the author acknowledges the problems of instrumentation and measurement error by marking only approximate temperature changes.

When propagating the reported measurement errors for the 6.6°C temperature change for McGill Creek, the result becomes 6.6°C ± 3.9°C (mean ± SE)—a 60% uncertainty. The Schloss model is likely inappropriate for the two California streams because the study sites are at 915 meters and 2,100 meters in elevation and at more southerly latitudes than the streams in Western Oregon where the equation was originally developed. Moreover, both models rely on qualitative estimates of stream shading, necessarily introducing uncertainty in model predictions.

Mitchell, S. 1999**. A simple model for estimating mean monthly stream temperatures after riparian canopy removal.** Environmental Management 24(1): 77-83**.**
From NCASI

Temperature Modeling Strategy

The author develops a simple linear regression model for stream temperature, using published data from a variety of temperate, Northern hemisphere watersheds. The model is intended to illustrate the impacts of stream temperature as a result of harvesting practices. Although simple and easily implemented, the model does not account for varying temporal scales and only analyzes temperatures between 0.7–17°C, limiting the model's usefulness for biological application.

Morse, W. L. 1970**. Stream temperature prediction model.** Water Resources Research 6(1): 290-302.
From NCASI

Given certain meteorological and hydraulic-hydrologic data a dynamic deterministic one-dimensional model, based on evaluation of the heat exchange across the air-water interface, predicts the water temperatures of streams. The model itself is a quasi-linear partial differential equation that represents an abbreviated energy conservation equation. For an extended upper reach (200 miles) of the Columbia River during July 1966, it has predicted water temperatures within 0.3°F on average. Moreover, this model has been subjected to a statistical validity test which indicates a certain level of acceptance.

Murphy, M. L., and J. D. Hall. 1981. **Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Canadian** Journal of Fisheries and Aquatic Sciences 38: 137-145.
From NACSI

Experimental Design

A paired watershed study in the H.J. Andrews Experimental Forest in the Western Cascades, Oregon, with a loosely constrained comparison between clearcut, second-growth, and old growth forest. No pre-logging information was available so the authors assumed comparable conditions in the respective, pre-logged watersheds. Any conclusions drawn from this study must be qualified by these generalizing assumptions.

Conclusions

The authors only found a 0.1–1.0°C mean weekly temperature difference between the clear-cut and the adjacent old growth forest. However, only 50–200 meters of exposed channel existed upstream of the temperature gauge on the clear-cut site, potentially explaining the minimal temperature differences between clear-cut and old growth sites. The authors note, "Thus clear-cutting may be a direct stimulus to secondary production in some regions if other detrimental effects, such as temperature increase, reduction in pool quality, or sedimentation, are not severe."

Rishel, G. B, Lynch, J. A., and E. S. Corbett. 1982**. Seasonal stream temperature changes following forest harvesting.** Journal of Environmental Quality 11(1): 112-116.

From NCASI

The study documented changes in stream temperature regimes for three proximal East Coast watersheds that had experienced different timber harvesting practices (fully forested; commercially harvested with a 30-meter buffer on perennial streams but cutting was allowed on intermittent streams; and clearcut-herbicide treated). Those headwater streams that experienced clearcut-herbicide treatments had maximum stream temperatures at 12°C higher than adjacent forested streams while minimum stream temperatures were up to 2°C higher for those clearcut-herbicide streams versus fully forested.

Stream Temperature Impacts

Diurnal temperature fluctuations show marked differences for the control versus the clearcut-herbicide treated watershed. Fluctuations of 6°C or more occurred an average of 27 days during June, July and August. Fluctuations of 11°C occurred for 18 days and 11 days in June and July, respectively.

There was little difference in maximum daily temperatures for commercially clearcut versus control streams, averaging approximately 1°C higher for the former in July, August and September. Diurnal fluctuations show similarly little difference between commercially clearcut and forested watersheds. The authors note the importance of clearcutting intermittent streams. In their study, one intermittent stream became a perennial channel due to the altered hydrologic regime, and thus was exposed to full solar radiation.

Royer, T., V. Minshall, and G. Wayne. 1997. **Temperature patterns in small streams following wildfire.** Archiv fuer Hydrobiologie 140(2):237-242.

From NACSI

Experimental Design

The study, "examined the influence of a moderately severe wildfire on the thermal regime of five small streams in Central Idaho." Three of the streams were burned and the other two untouched. The authors hypothesized that loss of shading due to burning would lead to elevated summer temperatures and decrease thermal stability, and more degree days. Temperature loggers were deployed on all 1st and 2nd order tributaries to the Salmon River 10 months after the burn.

Results

Daily maximum temperatures were 2–3°C higher for burned versus unburned streams, while diel temperature ranges were 2–3 times greater in the burned streams.

Rowe, L. K., and C. H. Taylor. 1994. **Hydrology and related changes after harvesting native forest catchments and establishing *Pinus radiata* plantations**. Part 3. Stream temperatures. Hydrological Processes 8: 299-310.

From NCASI

The authors present an analysis of stream temperature changes in 8 small (1.63–8.26 Ha), mountainous watersheds following various timber-harvesting treatments. Stream temperatures were measured for 11 years, including 4 years before harvesting.

While winter temperatures remain similar between post- and pre-harvested watersheds, weekly average summer temperatures are up to 11°C greater for completely clearcut watersheds.

Stream Temperature Impacts

Summer weekly averages for watersheds that contained 20%, 10%, and 0% riparian cover were greater than the preharvested watersheds by 0°C, 1.0°C, and 4.7°C, respectively. Subsequent removal of slash by debris scour removal compounds elevated stream temperatures by exposing the stream surfaces to full direct solar radiation input. The authors note that weekly averages may mask the considerably higher daily maxima. They further note that the mixing effects of small tributaries, when taken individually, may have negligible impacts on larger trunk streams, but that the cumulative impacts of many small streams may be important.

Rutherford, J. C., Blackett S., Blackett C., Saito L., and R. J. Davies-Colley. 1997. **Predicting the effects of shade on water temperature in small streams.** New Zealand Journal of Marine and Freshwater Research 31: 707-721.

From NCASI

"A computer model for stream water temperature was developed, and tested in a small pasture stream near Hamilton, New Zealand. The model quantifies shading by riparian vegetation, hillsides, and stream banks using three coefficients: canopy angle, topography angle, and canopy shade factor. Shade was measured directly and found to vary significantly along the channel. Using the maximum measured shade, a close match was achieved between observed and predicted daily maximum and minimum water and bed sediment temperature. Model predictions of incoming and outgoing long-wave radiation flux closely matched measurements, but there were unexplained discrepancies in short-wave radiation flux. Model predictions indicate that moderate shade levels (c. 70%) may be sufficient in temperate climates to restore headwater pasture stream temperatures to 20°C, an estimate of the thermal tolerance for sensitive invertebrates."

Swift, L. W., Jr., and J. B. Messer. 1971. **Forest cuttings raise temperatures of small streams in the southern Appalachians.** Journal of Soil and Water Conservation 26: 111-116.

From NCASI

The authors report on stream temperature changes in 5 Appalachian (in the experimental Coweeta Hydrological basin) streams following varying levels of forest clearance. Cutting methods ranged from individual tree removal to complete clearcutting.

Results

Weekly maximum temperatures of the farm streams showed the greatest difference (9–12°F) between forested stream temperatures. Clearcut watersheds showed up to 5–6°F increases in summer weekly maximums. More pronounced changes were identified in the diel temperature ranges between clearcut and forested watersheds. The authors observe, "Experience at Coweeta suggests that Southern Appalachian forests which surround small streams having summer low flows of 0.1. cfs or less cannot be completely clearcut without seriously raising stream temperatures."

[the number seems off—need to check]

Swift, L. W., and S. E. Baker. 1973. **Lower water temperatures within a streamside buffer strip.** USDA Forest Service Research Note SE-193.
From NCASI

"The removal of streamside vegetation increases the water temperature in mountain streams. Clearcutting and farming have been found to raise temperatures beyond the tolerance level for trout (68°F). Within the sale area of a commercial clearcut in the mountains of North Carolina, a narrow buffer strip of uncut trees and shrubs was left beside a stream. Although water temperatures within the sale area may have exceeded 68°F, the stream immediately below the sale area was never warmer than 62°F."

Stream Temperature Impacts

Buffer strip widths averaged 40 feet in the cut zone. Where the stream emerged into clearcut areas and exposed rock, stream temperatures rose 13°F, illustrating the importance of direct solar radiation receipt and heat conductance from large clasts. Stream temperatures cooled when flowing from clearcut to fully shaded areas. The authors suggest this is a function of cool groundwater influx, rather than cooling due to the reduction in direct solar radiation receipt.

Young, K. A., S. G. Hinch, and T. G. Northcote. 1999**. Status of resident coastal cutthroat trout and their habitat twenty-five years after riparian logging.** North American Journal of Fisheries Management 19(4):901-911.
From NCASI

This study builds on previous work that has shown how canopy removal can lead to increases in primary productivity and biomass but may decrease below 'natural' levels after canopy regrowth and closure.

Experimental Design

The authors studied three sections of the same 100-ha watershed in British Columbia: (1) a logged, left, and burned section; (2) a logged, cleared (A), and burned section; and (3) an untouched section. Natural fire and logging early in the century introduce potential legacy effects. Temperature loggers were deployed at the outflow of each section.

Results

Section A showed a change in 15°C between the inflow and outflow temperatures over the 560-meter reach in the first year. Twenty-five years later, that temperature difference declined to 3°C. An important conclusion drawn from this study was that correlations of mean daily maximum water temperature and regional air temperature data showed no statistical significance.

Zwieniecki, M. A. and M. Newton. 1999**. Influence of streamside cover and stream features on temperature trends in forested streams in Western Oregon.** W. J. Appl. For. 14(2): 106-113
From NCASI

Clearcut harvesting along low-elevation western Oregon streams with forest buffers (8.6 to 30.5 m wide) was followed by little direct local effect on water temperature. A study of 14 streams demonstrated that all have a tendency to warm with downstream direction even under full forest cover. After the natural warming trend of the stream water was accounted for, water at slightly higher temperatures within the buffered clearcut zone cooled to the trend line of the temperature downstream.
Because of the natural warming trends in streams, estimating the net temperature effect associated with management practices requires use of a warming trend line for fully covered forests for each generalized level of discharge.

Objectives

The authors develop the notion (advanced by Adams and Sullivan, 1990) that a stream has its own *temperature signature* which reflects the unique environmental conditions specific to that stream.

Experimental Design

Stream temperature data were collected from streams in western and northwestern Oregon above and below harvesting units that extended from 350–1600 meters. Canopy cover, as measured by canopy densiometers, was 78% in the harvested unit and 83% above and below. Using these stream temperature data, the authors develop regression equations to describe the "natural warming trends" of streams. Their results suggest a warming of stream temperature with distance from the divide.
The small difference between canopy cover in the harvested area and above/below the harvest area may limit the applicability of the author's conclusions to other study areas. Furthermore, densiometers may not be the best tool to accurately measure percent vegetation cover (Bunnell and Vales 1989; Cook et al. 1995).

Stream Temperature Impacts

Stream temperature increases in low-flow streams in harvested units showed an average 0.21°C increase (this value refers to the absolute temperature increases subtracted from the best-fit 'natural warming' trend lines developed by the authors). High discharge streams show an average 0.82°C increase in the harvested units. After flowing into non-harvested units, temperatures decreased by 1.39°C and 1.19°C for low-flow and high-flow streams, respectively. Based on these results, the authors assert, "We therefore do reject the general hypothesis that harvesting, with modest buffers and even gaps, leads to an accumulation of heat that persists 300 m below the harvest unit to a greater degree than expected from natural warming."

VI. Nutrient Cycling and Productivity

Bencala, K. E. 1993**. A perspective on stream-catchment connections.** Journal of the North American Benthological Society 12: 44-47.
From NCASI

Hyporheic Zone

The concept and importance of the hyporheic zone are discussed. The concept recognizes the stream as part of an integral part of the catchment system, rather than merely a pipe for transporting water, solutes and sediment.

Cooper, A. B. 1990**. Nitrate depletion in the riparian zone and stream channel of a small headwater catchment.** Hydrobiologia 202: 13-26.
From NCASI

This study describes high denitrification rates in riparian zones of a stream flowing through pastures in New Zealand. High denitrification rates were associated with anoxic organic soils; nitrate supply limited the rate of denitrification. Plant uptake accounted for 85% of the nitrate depletion, however.

Ref ID: 131
Cuffney, T.F., Wallace, J.B. 1988; **Particulate organic matter export from three headwater streams: discrete versus continuous measurements.** Canadian Journal of Fisheries and Aquatic Science 45 (1):2010-2016.

Keywords : particulate organic matter; organic matter; headwaters; flow; transport; streams; Appalachian; bedload

Particulate organic matter (POM) export from three small headwater streams of the Appalachian Mountains was estimated using continuous and discrete (grab) measurement methods for 2 yr. Total annual POM export estimated from continuous measurements was always greater (28-68 kg ash free dry mass (AFDM)) than estimates (8-44 kg AFDM) made discrete measurements (i.e. POM concentrations X total discharge). Continuous export samples were collected using a weir and gaging flume connected to a Coshocton samplers was designed to deliver 0.6% of discharge into a series of three settling barrels. The settling barrels removed a consistent proportion of POM (85-87%). The proportion of stream flow sampled by the Coshocton samplers was constant for each of the samplers (range 0.53-0.6%). The constant extraction efficiencies and proportional sampling of discharge allowed for the calculation of total export independent of discharge measurements (i.e. total export = amount in barrel / Coshocton percentage). The inability of the discrete method to adequately sample storm and bedload transport accounts for the underestimates of total annual export. This underestimation has important implications for studies which use discrete measurements to estimate POM export.

Ref ID: 125
Cuffney, T.F., Wallace, J.B. 1989; **Discharge-export relationships in headwater streams: the influence of invertebrate manipulation.** North American Benthological Society 8 (1):331-341.

Keywords : headwaters; invertebrates; macroinvertebrates; particulate organic matter; organic matter; fine particulate organic matter; coarse particulate organic matter; drought; transport; Appalachian; streams; structure; slope; flow

The role of physical (discharge) and biological (macroinvertebrate communities) factors in the control of coarse (>4mm) and fine (≤4mm > 0.5 m) particulate organic matter (FPOM) transport was studied in three headwater streams of the southern Appalachian Mountains. The role of discharge was determined by relating two years of continuous measurements obtained over discrete (ca. 2-wk) time intervals. The role of macroinvertebrates was examined by treating one of the three streams, C 54, with an insecticide during Year 2 to reduce populations and alter community structure.

Maximum discharge was the only discharge parameter which adequately predicted (linear regressions) FMOP export during a sampling interval ($r^2 \geq 0.70$). These regressions were unique for each stream and were constant between years for the untreated streams, despite a record drought during the second year. Relationships between discharge and export of coarse particulate organic matter (CPOM) were not as strong nor as consistent as those for FPOM. CPOM export was very sensitive to timing of CPOM inputs and storms (e.g., 78 to 88% of CPOM export during Year 2 occurred during a single fall storm). Consequently, CPOM export-discharge relationships differed not only among streams but also between years and did not show treatment effects.

Treating C 54 with methoxychlor during Year 2 resulted in massive invertebrate drift and drastically reduced populations of macroinvertebrates, practically eliminating shredders and collector-filterers. Maximum discharge continued to be a good predictor of FMOP export ($r^2 = 0.83$) for C 54 during the treatment year, but the yield of export per unit of maximum discharge (slope of the discharge-FMOP export regression) decreased by 65%. This contrasts with the untreated streams in which the slopes were constant between years despite the >50 year drought during Year 2. Most (75%) of the decrease in FMOP yield from C 54 is directly attributable to the reduction in macroinvertebrates. Only 25% is attributable to the drought even though streams flows dropped by ca. 40% during Year 2.

Relationships between export and discharge observed in this study are stronger than those reported elsewhere because measurements of export were made independent of discharge over long time intervals (ca. 2 wk). Collecting export over 2-wk intervals clearly shows the effects of storms while avoiding the problem of hysteresis commonly seen in relationships between discharge and export concentration made during single storms.

Dahlgren, Randy A. 1998. **Effects of forest harvest on biogeochemical processes in the Caspar Creek watershed.** Final report to California Department of Forestry and Fire Protection. Agreement Number 8CA17039. December 1998. Department of Land, Air, and Water Resources, University of California, Davis, CA. 153 p. *[2474 kb]*

Water quality and long-term sustainability are major components addressed within the ecosystem approach to forest management. Forest harvest practices are often implicated as having adverse impacts on sensitive aquatic communities and on the long-term sustainability of forest ecosystems. While careless harvest practices can certainly cause adverse impacts, proper forest management practices can minimize or even eliminate these adverse effects. As forest ecosystems become more intensively managed, it is imperative that management practices be developed and utilized to minimize environmental impacts and assure long-term ecosystem sustainability. This research

examined the effects of forest harvest and post-harvest management practices on biogeochemical processes. The biogeochemistry approach examines processes and interactions occurring within and between the atmosphere, hydrosphere, biosphere and geosphere.

Results from this research provide information to help us understand the complex interactions that occur in nutrient cycling processes at the ecosystem scale: This information can be further applied to the development of management practices to maintain long-term forest productivity and to minimize adverse environmental impacts from forest management activities.

The primary objective of this study was to examine the cumulative effects of forest management practices on stream water solute concentrations and on nutrient cycling in a coastal redwood/Doug fir ecosystem. Specific objectives were to:

1. Examine changes in stream water solute concentrations and nutrient fluxes following various harvest and post-harvest forest management practices,
2. Examine the magnitude and spatial pattern of downstream impacts associated with disturbance in headwater catchments,
3. Examine the relationship, between stream water and pipeflow solute concentrations and their relationship to stream discharge, and
4. Compare nutrient cycling within clearcut and non-undisturbed (reference) catchments.

This study examines the cumulative effects of timber harvest and post-harvest practices on stream water solute concentrations and nutrient cycling processes in a coastal redwood/Doug fir ecosystem in northern California. Timber harvest practices are often implicated as having adverse environmental impacts on sensitive aquatic communities and on the long-term sustainability of forest ecosystems. Previous studies examining the impacts of timber harvest often provide conflicting results suggesting that site conditions, specific harvesting techniques, and post-harvest practices have a strong effect on the resulting impacts. Thus, harvest impacts are highly site specific and can not be directly extrapolated from other sites and/or ecosystems. While the effects of forest harvest practices on streamflow and sediment generation have been intensively studied (*e.g.*, Rice et al., 1979; Ziemer, 1981; Keppeler and Ziemer, 1990; Thomas, 1990; Wright et al., 1990), the impacts of harvesting practices on stream water solute concentrations and nutrient cycling processes have not been fully evaluated for the coastal region of northern California. This type of research is becoming increasingly important as forested watersheds become more intensively managed and attempts are made to minimize adverse management impacts. Stream water solute concentrations and ecosystem-scale nutrient cycling are regulated by complex interactions occurring within and between the atmosphere, hydrosphere, biosphere and geosphere (Fig. 1). To gain insights into the important processes regulating stream water solute concentrations and ecosystem nutrient cycling, an integrated study incorporating both watershed-scale and plot-scale investigations was performed. Watershed-scale studies are based on input-output budgets for nutrients and water (Fig. 2).

Watershed manipulations are a powerful approach for studying the effects of forest management practices (*e.g.*, clearcutting, burning) on nutrient cycling processes. Manipulation studies commonly utilize the paired watershed approach in which two watersheds with similar characteristics are employed. One watershed of the pair is

maintained in its original state to serve as a reference while the other watershed undergoes a particular experimental treatment. Studies on the watershed scale integrate all processes occurring within the boundaries of a given watershed. This may include several plant species, several soil types, contrasting microclimates, and complex hydrologic flow paths. Watershed studies provide ecosystem level data that incorporate all ecosystem processes, but do not distinguish between individual processes or their relative importance.

Dahlgren, Randy A. 1998. **Effects of forest harvest on stream water quality and nutrient cycling in the Caspar Creek watershed.** *In:* Ziemer, Robert R., technical coordinator. Proceedings of the conference on coastal watersheds: the Caspar Creek story, 1998 May 6; Ukiah, CA. General Tech. Rep. PSW GTR-168. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 45-53.

The effects of forest harvest on stream-water quality and nitrogen cycling were examined for a redwood/Douglas-fir ecosystem in the North Fork, Caspar Creek experimental watershed in northern California. Stream-water samples were collected from treated (e.g., clearcut) and reference (e.g., noncut) watersheds, and from various locations downstream from the treated watersheds to determine how far the impacts of these practices extended. Additionally, a detailed nutrient cycling study was performed in a clearcut and reference watershed to gain insights into changes in nitrogen cycling after harvesting activities.

Stream-water nitrate concentrations were higher in clearcut watersheds, especially during high stream discharge associated with storm events. Elevated concentrations of nitrate were due to increased leaching from the soil as mineralization (i.e., release of nutrients from organic matter) was enhanced and nutrient uptake by vegetation was greatly reduced after harvest. The elevated nitrate concentration in stream water from clearcut watersheds decreased in the higher-order downstream segments. This decrease is believed to be primarily due to dilution, although in-stream immobilization may also be important. Although elevated nitrate concentrations in stream water from the clearcut watershed might suggest a large nitrogen loss after clearcutting, conversion to a flux indicates a maximum loss of only 1.8 kg N ha-1 yr-1; fluxes decreased to <0.4 kg N ha-1 yr-1 3 years after the harvest. Nitrogen fluxes from the reference watershed over the same period were <0.1 kg N ha-1 yr-1. The increased nitrogen flux was due to both higher nitrate concentrations and an increased water flux from the clearcut watershed.

In contrast to many forest ecosystems that show large nutrient losses in stream water after harvest, this redwood/Douglas-fir ecosystem shows relatively small losses. The rapid regrowth of redwood stump sprouts, which use the vast rooting system from the previous tree, is capable of immobilizing nutrients in its biomass, thereby attenuating nutrient losses by leaching. Rapid regeneration also provides soil cover that appreciably reduces the erosion potential after harvest. Removal of nitrogen, primarily in the harvested biomass, results in an appreciable loss of nitrogen from the ecosystem. These data suggest that nitrogen fixation by Ceanothus may be an important nitrogen input that is necessary to

maintain the long-term productivity and sustainability of these ecosystems.

DeAngelis, D. L., P. J. Mulholland, J. W. Elwood, A. V. Palumbo, and A. D. Steinman. 1990. **Biogeochemical cycling constraints on stream ecosystem recovery.** Environmental Management 14: 685-697.
From NCASI

Nutrient Cycling Recovery

The authors argue both from theory and experimental evidence for an inverse relationship between rate of recovery of a stream ecosystem, and nutrient turn-over time. Tight systems with efficient recycling are expected to be less resilient than more open systems.

Duff, J. H., and F. J. Triska. 1990. **Denitrification in sediments from the hyporheic zone adjacent to a small forested stream.** Canadian Journal of Fisheries and Aquatic Sciences 47: 1140-1147.
From NCASI

Hyporheic Zone

The hyporheic zone is shown to be an important site for denitrification, at two sites: the base of a slope dominated by old-growth redwood, and the base of a slope dominated by alder regenerating from a clearcut. Denitrification potential and O2 concentrations decreased with increasing distance from the channel. Denitrification can modify the chemistry of water during passage through the hyporheic zone. Even though this stream (Little Lost Man Creek) has fish, the biogeochemical principles may apply to smaller streams.

Golladay, S. W., J. R. Webster, and E. F. Benfield. 1987**. Changes in stream morphology and storm transport of organic matter following watershed disturbance.** Journal of the North American Benthological Society 6: 1-11.
From NCASI

Effects of Disturbance

Four streams of the southern Appalachians were surveyed for morphology and sampled to measure transport of POM (aka seston). Two watersheds had been logged (8 yrs and 25 yrs before study); two were undisturbed. Disturbed streams showed fewer debris dams and organic matter accumulations. Concentrations and export (g/m2 of stream channel) tended to be higher is streams draining disturbed watersheds. Baseflow concentrations seem to return to normal levels within a few years of logging, but stormflow concentrations may remain elevated for many years. Although the study was conducted at Coweeta, the same principles may apply to western coniferous forests.

Green, D. M., and J. B. Kauffman. 1989. **Nutrient cycling at the land-water interface: the importance of the riparian zone.** Pages 61-67 *in* R. E. Gresswell, B. A. Barton and J. L. Kershner, editors. Practical approaches to riparian resource management: an educational workshop. U. S. Bureau of Land Management, Billings, Montana**.**
From NCASI

Hyporheic Zone

This review paper discusses the importance of redox potential in the hyporheic zone and its influence on denitrification and phosphorus solubility. Much of the discussion focuses on streams of eastern Oregon, with some examples from elsewhere. Stream order is not much taken into account, and needn't be, at the scale of microbiological processes.

Groffman, P. M., A. J. Gold, and R. C. Simmons. 1992. **Nitrate dynamics in riparian forests: microbial studies.** Journal of Environmental Quality 21: 666-671.
From NCASI

Riparian Zone

In this Rhode Island study of nitrate uptake in the riparian zone, it appeared that different attenuation processes were responsible for nitrate uptake in different seasons: plants and wetland denitrification during the growing season, and microbial uptake during the dormant season.

Haack, S.K., Burton, T., and Ulrich, K**. "Effects of Whole-Tree Harvest on Epilithic Bacterial Populations in Headwater Streams."** *Microbial Ecology* (1988): 165-181.

Keywords: New Hampshire/logging/bacteria/pH/nitrogen/algae/ limiting nutrients/ ***headwaters***

Bacteria attached to rock and glass surfaces were studied in streams draining a whole-tree harvested watershed (WTH) and a nonharvested (CONTROL) watershed in the Hubbard Brook Experimental Forest, New Hampshire, U.S.A. Seasonal trends in numbers of cells/cm2, mean cell volume, cell size-frequency distribution, and bacterial biomass were determined using 4'6-diamidino-2-phenylindole (DAPI) epifluorescent microscopy and scanning electron microscopy (SEM); the response of these parameters to decreased pH and increased nitrate concentration in the WTH stream was assessed via controlled manipulation of stream water chemistry in artificial channels placed in the CONTROL stream. Bacterial distribution varied significantly between the two streams and seasonally within each stream in apparent response to differential availability of dissolved organic carbon from algae and autumn-shed leaves. Decreased pH similar to that in the WTH stream had a significant effect on cell numbers, mean cell volume, and biomass in the CONTROL stream. Decreased pH accounted for some aspects of the altered bacterial distributions observed in the WTH stream. Nitrate at concentrations similar to those in the WTH stream had no effect on bacterial distribution in the CONTROL stream suggesting that headwater stream epilithic bacteria were carbon limited.

Jacobs, T.C. and Gilliam, J.W. **"Headwater Stream Losses of Nitrogen from Two Coastal Plain Watersheds."** *Journal of Environmental Quality* 14, no. 4 (1985): 467-472.

Keywords: nutrients/North Carolina/riparian/ ***headwaters***/ watersheds/ coastal plains

Nitrogen concentrations and water flow were measured for a 3yr period from two watersheds of the Atlantic Coastal Plain in North Carolina to assess sinks for NO3 -N. Both of the areas are typical of the largest agricultural producing area in the region. From the Middle Coastal Plain watershed with 1299 ha of predominantly well- to moderately well-drained soils, the losses of NO3 -N and total N in surface drainage water were 2.5 and 4.5 kg ha-1 yr-1, respectively. The Lower Coastal Plain watershed with 6998 ha of somewhat poorly- to poorly-drained soils had NO3 -N and total N losses of 0.5 and 2.5 kg ha-1 yr-1, respectively. These values were much lower than expected based on agricultural production, fertilizer used, and crop efficiency. The soils included in the study were Typic Paleudults to Aquic Paleudults and Aquic Hapludults to Aeric Paleaquults. Denitrification between the field and stream was concluded to be the primary reason for these low values. However, the concentrations of NO3 -N in streams near the field outlets decreased significantly as N enriched water moved through the transport system. The lowest stream elevations sampled on the Middle and Lower Coastal Plain watersheds averaged 0.6 and < 0.1 mg L-1 NO3 -N with maximum values of 2.5 and 0.6 mg L-1, respectively. Comparing changes in nitrate and chloride concentrations and the reducing Eh in the stream and floodplain sediments suggest denitrification as the loss mechanism in the stream transport system. Ostensibly the stream is responsible for the loss rather than the riparian area; however, the area inundated by the stream is small compared to the flood plain. The Middle and Lower Coastal Plain watersheds have 2.5 and 94 ha inundated by the stream while confined to the channel, but while in a moderate flood these values increase to 20 and 250 ha, respectively. While instream losses of NO3 -N are important in this region to maintain water quality, they are not sufficient to completely counter heavy loading by nonpoint sources.

Jordan, T. E., D. L. Correll, and D. E. Weller. 1997. **Relating nutrient discharge from watersheds to land use and streamflow variability.** Water Resources Research 33: 2579-2590.
From NCASI

This study addresses water quality variation observed at the regional and landscape level, in the Piedmont and Coastal Plain provinces of the Chesapeake Bay drainage.

Meyer, J. L., and C. M. Tate. 1983. **The effects of watershed disturbance on dissolved organic carbon dynamics of a stream.** Ecology 64: 33-44.
From NCASI

Effects of Disturbance

This study was conducted on second order streams at the U.S. Forest Service Coweeta Hydrologic Laboratory, Macon County, North Carolina. One watershed was undisturbed and the other had been clear-cut two years previous to the study. "During the growing season DOC concentration increased from headwater seep to the weir in the undisturbed stream under baseflow conditions." There was no similar upstream to downstream effect in the clearcut stream. Thus, annual DOC export was less in the stream draining the clearcut watershed than the stream draining the undisturbed watershed. Lower DOC in the clearcut stream was due to reduced throughfall and leaching of fresh litter as well as lower inputs from subsurface water sources and lower in-stream generation of DOC. The authors conclude that the recovery of the riparian vegetation and surrounding terrestrial system determines the recovery of the stream after logging.

Meyer, J. L., and J. O'Hop. 1983. **Leaf-shredding insects as a source of dissolved organic carbon in headwater streams.** American Midland Naturalist 109: 175-183**.**
From NCASI

"This study investigated the importance of leaf-shredding insects as generators of dissolved organic carbon (DOC) in a headwater stream. Three common southern Appalachian shredder species (*Peltoperla maria*, *Pteronarcys scotti* and *Tipula* spp.) were allowed to feed on naturally conditioned leaves, and the rates at which DOC was generated were measured. DOC generation rates of actively feeding shredders ranged from 0.2-160 ug C mg shredder AFDW- 1day-1, and 62% of this variation could be explained by organism weight. Weight-specific rates increased as body size decreased, presumably in response to an increase in weight-specific metabolic rate. DOC generation rate per individual increased as animal size increased. DOC generation increased as generation of particulate matter increased, with a mean of 60 ug DOC produced per mg AFDW particles generated. Less than 10% of DOC generated was produced by mechanical breaking up of the leaves. The DOC generated by shredders was predominantly in the high (>10,000 daltons) molecular weight fraction. The rates presented are underestimates of actual rates; experiments with sterilized leaves demonstrated that microbial activity during experiments with natural leaves reduced the amount of DOC accumulating in the chambers. DOC released by actively feeding shredders is a potentially significant source of DOC in a small headwater southern Appalachian stream during low flow conditions. Shredder feeding is potentially an important a source of DOC in small streams as leaching of leaf litter."

Moore, D. G. 1975a. **Effects of forest fertilization with urea on stream water quality--Quilcene Ranger District, Washington.** Research Note PNW-241. USDA Forest Service.
From NCASI

Effects of Fertilization

Two units in the Olympic National Forest were fertilized by helicopter with 200 lbs N/ac. "Applied fertilizer did reach surface streams in the form of urea-, ammonia- and nitrate-nitrogen, but maximum concentrations measured were well below the...(criteria) for drinking water....Fertilizer nitrogen entered streams only in the form of nitrate after the first 3 weeks, and 95 percent of the total loss over 7 months occurred

within the first 9 weeks after application. Fertilizer nitrogen lost during the 7-month monitoring period was about 0.25 percent of the total applied. Introduction of these small amounts of nitrogen into forest streams spread out over a period of several weeks should have little measurable impact on eutrophication." This statement does not seem well supported, since there is no information on the trophic status or nutrient limitation in the streams in question.

Mulholland, P. J. 1992. **Regulation of nutrient concentrations in a temperate forest stream: roles of upland, riparian, and instream processes.** Limnology and Oceanography 37: 1512-1526**.**
From NCASI

"The roles of terrestrial and instream processes in controlling stream-water N and P concentrations were studied over a 2-yr period in a deciduous forest stream in eastern Tennessee. Upper soils horizons were highly effective sinks for inorganic N and P in throughfall, and weathering of the parent dolomite was the dominant source of inorganic P to the stream. The riparian zone was a potential source of NH4 + and P to the stream when dissolved oxygen concentrations in riparian groundwater were low, but a sink for P when dissolved oxygen concentrations were high. High rates of instream immobilization of inorganic N and P were observed from late autumn to spring, primarily as a result of uptake by microbes on decomposing leaves and secondarily by algae. Immobilization of inorganic N and P resulted in longitudinal declines in concentrations with distance downstream from groundwater inputs (springs), thereby increasing the importance of organic forms of these nutrients in stream water in downstream reaches. The seasonal appearance of winter minima and summer maxima in stream-water N and P concentrations observed here is opposite to the pattern observed in many northern streams, suggesting the importance of winter nutrient cycling processes in soils and streams in warmer climates."

Munn, N. L., and J. L. Meyer. 1990. **Habitat-specific solute retention in two small streams: an intersite comparison.** Ecology 71: 2069-2082**.**
From NCASI

Nutrient Uptake

Uptake rates of phosphorus, nitrate, calcium and DOC were measured in two headwater streams, one in Oregon Cascades (Andrews) and one in N. Carolina Appalachians. Nitrate uptake was higher in the Andrews stream than at Coweeta during summer. Debris dam reaches were most retentive of N in Andrews. SRP uptake rates were higher in Coweeta, primarily as a result of biotic uptake. Debris dams greatly enhanced retention of DOC in both streams. High N demand resulted from retention of C-rich FPOM and CPOM, creating high N demand. Differences in N vs. P retention are attributed to relative availability, the Cascade stream being N-limited, and Coweeta stream P-limited.

Naiman, R. J., and J. R. Sedell. 1979. **Benthic organic matter as a function of stream order in Oregon.** Archive fur Hydrobiologie 87: 404-422.
From NCASI

POM (general)

Discusses the CPOM:FPOM ratio as a function of stream order (along the stream continuum). "The CPOM: FPOM ratio appears to increase from 1st to 3rd-5th order streams, and decreases thereafter...The results indicate that the pathway for attaining asymptotic ecosystem stability changes from one of resistance to resilience as stream order increases."

Newbold, J. D., R. V. O'Neill, J. W. Elwood, and W. Van Winkle. 1982. **Nutrient spiraling in streams: implications for nutrient limitation and invertebrate activity.** The American Naturalist 120: 628-653.
From NCASI

POM Transportability

This paper presents a conceptual model arguing that when nutrient limitation in a stream is severe, most of the downstream transport occurs in particulate or unavailable form; transportability of particulates is a major determinant of spiraling length. When nutrient limitation is moderated by density-dependent mechanisms, transport in dissolved phase dominates. Invertebrates may influence spiraling length.

Rhodes, J., C. M. Skau, D. Greenlee, and D. L. Brown. 1985. **Quantification of nitrate uptake by riparian forests and wetlands in an undisturbed headwaters watershed.** General Technical Report RM-120. USDA Forest Service.
From NCASI
Nitrogen Uptake

Riparian areas in the Tahoe basin remove over 99% of the incoming nitrate-nitrogen. The relative importance of denitrification, microbial assimilation and plant uptake were not documented.

Simmons, R. C., A. J. Gold, and P. M. Groffman. 1992**. Nitrate dynamics in riparian forests: groundwater studies.** Journal of Environmental Quality 21: 659-665.

Concludes that both wetlands and transition zones between uplands and wetlands can be important sinks for groundwater nitrate-N. See notes on Groffman et al. (1992), above.

Smock, L. A., G. M. Metzler, and J. E. Gladden. 1989. **Role of debris dams in the structure and functioning of low-gradient headwater streams.** Ecology 70: 764-775.

Importance of Debris Dams

The role of debris dams was investigated by creating and sampling experimental debris dams. Debris dams increase organic matter storage, macroinvertebrate abundance, and relative contribution of shredders to biomass, both in dams and on sediment. Increasing dam abundance increased retention of leaves during both base and stormflow. Although this study pertains to SE coastal plain, the same principles could apply elsewhere (e.g. Bilby, Bilby and
Likens, Trotter).

Triska, F. J., J. H. Duff, and R. J. Avanzino. 1990**. Influence of exchange flow between the channel and hyporheic zone on nitrate production in a small mountain stream.** Canadian Journal of Fisheries and Aquatic Sciences 47: 2099-2111.
From NCASI

Hyporheic Zone

"Variation in local exchange of flows between the channel and hyporheic zone produced temporally shifting concentration gradients of DO, nitrate, and ammonium in subsurface waters of a small, gravel-cobble bed stream. Channel water advected laterally supplied DO and groundwater supplied ammonium to support hyporheic nitrification...Interactions between the channels hydrology, lithology and biology...are probably more common that reported. However, the magnitude of the resulting nutrient flux will depend on factors which determine the depth and lateral extension of suitable hyporheic habitat.

Triska, F. J., V. C. Kennedy, R. J. Avanzino, and K. C. Stanley. 1995. **Long-term effects of clearcutting and short-term impacts of storms on inorganic nitrogen uptake and regeneration in a small stream at summer base flow.** Pages V1-V13 *in* K. M. Nolan, H. M. Kelsey and D. C. Marron, editors. Geomorphic processes and aquatic habitat in the Redwood Creek basin, northwestern California. U. S. Geological Survey Professional Paper 1454. Washington, D. C.
From NCASI

Effects of Logging

"Studies in experimental channels indicated a large diel fluctuation in DIN concentration. Nitrate uptake rates decreased as the community aged"....Canopy closure (alder) reduced the daytime uptake of DIN..."Development of the alder riparian zone is of long-term importance in nitrogen cycling of Little Lost Man Creek. We hypothesize gradual decline of instream production related to reduced synthesis of protein from inorganic nitrogen thus reducing passage of nitrogen to higher trophic levels. Biotic production will remain low until the canopy is reopened by natural mortality of riparian trees." In other words, the stream is shifting from autotrophic to heterotrophic as the canopy recovers.

Ulrich, K. E., T. M. Burton, and M. P. Oemke. 1993. **Effects of whole-tree harvest on epilithic algal communities in headwater streams.** Journal of Freshwater Ecology 8: 83-92. **From NCASI**

Effects of Logging

As with Triska et al.'s (1995) study, tree removal increased light, and stimulated algae growth. Nitrate addition caused an increase in chlorophyll a, by increasing the chlorophyll a content of individual cells, not by increasing the number of cells.

Wallace, J.B., J. R. Webster and J. L. Meyer. 1995**. Influence of log additions on physical and biotic characteristics of a mountain stream.**
From NCASI

Importance of Debris Dams

Adding log debris dams increased retention of FPOM, CPOM leaf detritus, etc. It also increased uptake length for ammonium (i.e. reduced uptake rate), decreased uptake length for nitrate, and had no effect on P uptake length. The paper contains a good synthesis of results reported by leaders in the field of stream ecosystem theory.

VII. Other Water Quality Issues

Binns, N. A. 1967. **Effects of rotenone treatment on the fauna of the Green River, Wyoming. Fisheries Research Bulletin 1.** Wyoming Game and Fish Commission, Cheyenne.
From NCASI

As cited in Norris et al. (1991): Food chain issues "...[i]n streams where pesticides have been released either accidentally or intentionally, standing crops of primary producers have increased."

Ref ID: 111
Cohen, P., Sanders, P., Budd, W., Steiner, F. 1987; **Stream corridor management in the Pacific Northwest: II. Management strategies.** Environmental Management 11 (1):599-605.

Keywords : management; stream corridor; corridor; land-use planning; legislation; Washington

King County, Washington is part of the rapidly growing Pacific Northwest region. Analysis of past and current federal, state and county regulations and administration reveals how stream corridors have been protected to date. This article draws on scientific literature and a case study to suggest future management strategies and guidelines for controlling development in King County watersheds.

Cummins, K.W. and Spengler, G.L. **"Stream ecosystems."** *Water Spectrum* 10 (1978): 1-9.

Keywords: streams/ reclamation/ preservation/ ***headwaters***/ watershed management/ channels/

Water quality of streams and rivers is often a problem of semantics. The most stringent definition is usually viewed as potability. However, a pristine trout stream and a chemically treated one my be equally suitable for human health needs, but totally different biologically. It is the maintenance of biological quality that carries with it many long-term benefits to humans. Reclamation, on the other hand, can be expensive, or even impossible. It is important to ask what functions natural ecosystems perform, before alterations are made which require a long-term commitment of energy-consuming manipulations.

The basic functioning units of headwater streams have been identified, thus reclamation becomes a matter of restoration of the riparian zone, establishment of the appropriate retention characteristics and enhancement of key groups of organisms playing vital functional roles in organic matter processing. An important tool to be used in designing suitable strategies for protection, management and reclamation of headwater stream systems is computer simulation modeling. Such techniques aid in identifying critical problems to be investigated using real stream systems. It must be remembered, however, that such simulation studies have only been possible because an extensive data base exists on a few representative streams. Our best hope in stream management is a combined effort involving protection of critical watershed areas and channel structure, maintenance of appropriate organic inputs and associated organisms and continued testing of the effects of alternate practices using computer simulation techniques.

Delong, M.D., Rhew, R., and Brusven, M.A**. "Classification and Spatial Mapping of Riparian Habitat with Applications to Modeling Instream Impacts of Agricultural Nonpoint Source Pollution."** *Proceedings of the Symposium on Headwaters Hydrology.American Water Resources Association, Bethesda Maryland.1989.p 269-275, 1 tab, 10 ref.* (1989).

Keyword: Agricultural runoff/ Classification / ***Headwaters***/ Model studies/ Nonpoint pollution sources/ Riparian vegetation/ Water pollution effects/ Watershed management/ Idaho / Maps / Tom Beall Creek

Management of riparian habitats has been recognized for its importance in reducing instream effects of agricultural nonpoint source pollution. By serving as a buffer, well structured riparian habitats can reduce nonpoint source impacts by filtering surface runoff from field to stream. A system has been developed where key characteristics of riparian habitat, type, height, width, and bank slope, are classified as discrete categorical units. This classification system recognizes seven riparian types: no riparian, annual herbaceous crop, perennial herbaceous crop, wild herbaceous, herbaceous/shrub mixture, shrubs, and trees. Bank slope and riparian width and height each consist of five categories. Classification by discrete units allows for ready digitizing of information into a geographic information system (GIS). From GIS, the integration of digitized maps of riparian habitat with land use, slope, soil types, and soil erodibility maps can aid in determining areas along a stream that are most susceptible to nonpoint source inputs. Such an integrated system is discussed for Tom Beall Creek watershed, an agriculturally impacted third order stream in the Clearwater River drainage, Nez Perce County, Idaho. (See also W90-08822) (Author 's abstract)

Ref ID: 34
DeLong, L.L., Wells, D.K. 1988; **Estimating average dissolved-solids yield from basins drained by ephemeral and intermittent streams--Green River Basin, Wyoming.** pp.1-14**. in** Water Resources Investigations. 87-4222. U.S. Geological Survey. Denver, Colorado.

Keywords : dissolved solids; perennial stream; slope; water quality; Wyoming

This report describes a method developed to determine the average dissolved-solids yield contributed by small basins characterized by ephemeral and intermittent streams in the Green River basin in Wyoming. Methods routinely applied to perennial streams generally do not provide accurate estimates when applied to ephemeral and intermittent streams. To provide more accurate estimates, dissolved-solids loads were determined from streamflow records and discrete samples of specific conductance.

Arithmetic means were determined from geometric means and standard deviations of the loads. The arithmetic means were adjusted for no-flow days, and the results were divided by the amount of drainage area to estimate dissolved-solids yields.

The dissolved-solids yields from drainage areas encompassed by pairs of sampling sites on a stream system were estimated from the slope of the line connecting the paired points on a plot of average dissolved-solids discharge versus drainage area. Variations of average yield among sites were 10 times smaller than variation of average dissolved-solids discharge. The estimated yields for greater than 50 percent of the drainage area represented by the stations analyzed had a range of less than 15 percent.

Estimates of dissolved-solids discharge at eight water-quality sampling stations range from less than 2 to 95 tons per day. The dissolved-solids yields upstream from the sampling stations range from about 0.023 to 0.107 ton per day per square mile. However, estimates of dissolved-solids yields contributed by drainage areas between the paired stations on Bitter Creek, Salt Wells Creek, and Little Muddy and Muddy Creeks ranged only from 0.081 to 0.092 ton per day per square mile.

Ref ID: 6
Elswick, D., Lydgage, W. 1994; **Information concerning intermittent streams and their study in the Pacific Northwest: a compilation of current literature and observations.** [Unpublished report] Humboldt Interagency Watershed Analysis Center.

Keywords : riparian reserves; Pilot Creek; watershed

This paper is meant to be a guideline to help researchers and land use managers start focusing on the most pertinent questions that need to be addressed regarding impact effects on intermittent streams. Written in the style of a literature review, I have attempted to summarize existing information concerning the study of intermittent streams and ecosystems in general. Many sentences have been "lifted" directly from their respective sources and the reader is encouraged to references these valuable papers. Also included are thoughts and observations from intermittent stream studies conducted during the Summer of 1994 for the Humboldt Interagency Watershed Analysis Center.

Ref ID: 106
Erman, D.C., Hawthorne, V.M. 1976; **The quantitative importance of an intermittent stream in the spawning of rainbow trout.** Transactions of the American Fisheries Society 105 (6):675-681.

Keywords : streams; trout; fish; slope; runoff; competition; floods; Salmo gairdneri; spawning

From 1972 to 1975, an estimated 39-47% of the adult rainbow *trout (Salmo gairdneri)* in Sagehen Creek spawned in an intermittent stream- Kiln Meadow Tributary- while several permanently flowing tributaries attracted only 10-15% of the run. The balance of the fish presumably spawn in the upper reaches of the main stream. Kiln Meadow Tributary drains a south-facing slope, and peak runoff from snow melt occurs early. This may be one factor that attracts spawning fish. The absence of competition from brook trout, which cannot spawn in Kiln Meadow Tributary in the fall, may enhance the value of this watercourse for rearing young rainbow trout.

The number of spawning rainbows in Kiln Meadow Tributary declined from 707 in 1972 to 254 in 1975. Two large year classes were present in 1972 and 1973 following winter floods in preceding winters. Males matured a year earlier than females. Males outnumbered females in every year: the sex ratio in mature fish varied from 2.4:1 to 4.9:1. Repeat spawners to Kiln Meadow Tributary ranged from 25% to 28% of the run.

Fitzhugh, R.D., Furman, T., Webb, J.R., Cosby, B.J., and Driscoll, C.T. **"Longitudinal and seasonal patterns of stream acidity in a headwater catchment on the Appalachian Plateau, West Virginia, U.S.A."** *BIOGEOCHEMISTRY* 47, no. 1 (1999): 39-62.

Keywords: Germany / Neural Networks/ Nitrates / Runoff / Water Management/ Forest Watersheds/ ***Headwaters*** / Catchment Areas

The chemical composition during baseflow was used to elucidate the fundamental processes controlling longitudinal and seasonal patterns of stream acidity in Yellow Creek, a chronically acidic headwater (pH range 3.7--4.2) on the Appalachian Plateau in northeastern West Virginia. Sulfate concentrations controlled the variability of stream acidity within the Yellow Creek catchment. Decreases in stream free H super(+) acidity with decreasing elevation likely resulted from SO sub(4) super(2-) retention in riparian wetland areas as well as spatial variation in dominant tree species. Seasonal variations in free H super(+) and inorganic monomeric aluminum (Al super(n+)) concentrations appeared related to seasonal fluctuations in baseflow discharge which was controlled by vegetative activity. Baseflow stream discharge, as well as H super(+) and Al super(n+) acidity, gradually declined during the growing season (June through October), likely reflecting microbial SO sub(4) super(2-) reduction in saturated anaerobic environments within riparian wetlands. A marked pulse of stream H super(+), Al super(n+), and SO sub(4) super(2-) coincided with an abrupt increase in baseflow discharge resulting from the cessation of transpiration after leaf-fall in November. This seasonal pattern suggests that autumn may be a critical period for eastern brook trout in streams draining wetlands on the Appalachian Plateau.

Froehlich, H.A. **"Natural and man-caused slash in headwater streams."** *Loggers Handbook* 33 (1973).

Keywords: riparian/watershed management/ ***headwaters***/ conservation/ environmental effects/ woody debris/ buffer strips/

Stream protection requirements in our timber producing areas are very much a part of the new "environmental awareness". Demands to maintain or even enhance conditions in the stream systems are likely to continue and will possibly become even stronger. Overcleaning channels may not be in the best interest of stream protection. We must recognize what the stream systems are like in their original condition and also to understand the role of the organic debris in these channels. In the steep, headwater drainages under stands of old-growth Douglas-fir we found that the natural, undisturbed channels commonly contain around 12 tons of organic material within a 30-foot wide zone centered on the water course. Normally about seven percent of this is in fine debris under four inches in diameter. Maximum accumulations of natural debris in the drainages studied were 25.8 tons per 100 feet of channel. Recently "sluiced-out" channels contained about 0.9 tons of debris. Many of the channels observed appeared to have sustained debris avalanches or sluice-outs at varying times in the past. New debris accumulates as snags, windfalls and annual yields of litter collect in and near the water course. In most channels this debris holds back large quantities of sediment delivered to the stream from naturally occurring erosion. Logging, especially at the tree falling stage, can produce large changes in the debris loads. However, under good conditions and with the falling crews having a concern for stream protection the net effect may be quite small. Directional falling with the tree-pulling system can reduce the quantity of material reaching the channel to a very small amount. The steeper and more broken the ground the greater is the advantage in using a tree-pulling system. The debris added during the falling stage on extremely steep ground by the cable-assist falling was about equal to that produced by very careful conventional falling on relatively good terrain. Buffer strips were found to be effective debris barriers even when they were not continuous or of large widths. Possibly part of their effectiveness lies in the fact that the existence of the uncut strip forces the faller to take considerable precaution not to fall into the standing trees. The buffer strips, at times, represent a considerable investment in growing space and usable wood. Unless the buffer is necessary as a shade for stream protection, it appears that tree-pulling could accomplish a nearly equal degree of stream protection. Research is underway by Dale McGreer, masters degree candidate, and I to obtain detailed figures on savings in breakage by the tree pulling system as well as to record costs in man and machine hours. Actual costs of stream cleanup are also being gathered by Dennis Dykstra, Instructor in the Forest Engineering Department. Further study is planned to learn more about the conditions under which debris moves, including natural sluice-outs. Also, conditions are being observed to learn when logging debris actually poses some hazard to downstream uses. Buffer strips are being observed to obtain an understanding of their survival and long term effectiveness.

Gill, R.E. **Sediment delivery to headwater stream channels following road construction and timber harvest in the Blue Mountains, Oregon.** Interagency Committee on Water Data. Vol 2, X38-X45. 1996. US, US Government. 3-10-1996.
Ref Type: Conference Proceeding

Keywords: sediments/ ***headwaters***/ Streams/ channels/ roads/ logging/ Blue Mountains/ Oregon/ sediment yield

The objectives of this study were: 1) to determine the amount and rate of sediment delivery to ephemeral (first and second order) stream channels following road construction and logging, and 2) to evaluate the WWSED sediment yield predictions.

Hammer, R.G**. Forest headwaters riparian road construction and timber harvest guidelines to control sediment.** Woessner, W. W. and Potts, D. F. 127-131. 1989. Bethesda, MD, American Water Resources Association.

Headwaters: sediments/ roads/ logging/ fish/ Montana/ ***headwaters***/ standards/ environmental protection

Two major principles to control forest headwaters sediment are to minimize sediment from road construction and to maintain woody debris stream structures such as log steps which store sediment. Guidelines for road construction in riparian areas include slash filter windrows at the toe of road fill slopes. Studies indicate that slash filter windrows trap 75 percent or more of road sediment at low cost. Guidelines for timber harvest in riparian areas include provision for large woody debris recruitment to headwater streams. Forest headwater stream channels are dependent upon woody materials to form log steps which store sediment, dissipate stream energy, and provide fish habitat.

Ref ID: 56
Hubble, J.D. 1994; **A study of the summer steelhead, Oncorhynchus mykiss in several intermittent tributaries of the Satus Creek basin, Washington.** Northwest Science 68 (2):131

Keywords : Steelhead; Oncorhynchus mykiss; fish; perennial stream; permanent stream; Washington; life history patterns; streams; flow; temperature; genetics

The summer steelhead, *Oncorhynchus mykiss* population was studied in three intermittent tributaries in the Satus Creek basin. Overall study goal was to further understand the life history pattern of the Satus Creek basin summer steelhead population and to contribute to the limited information base that exists for steelhead populations residing in intermittent streams. There was a strong tendency for post emergent fry, resulting from redds located in intermittent reaches to move downstream. However, survival to perennial flow conditions was very low. Steelhead production in Dry Creek (intermittent flow) appears to be lower than in Logy Creek (perennial flow), because of elevated water temperatures and minimal spring and summer stream flow. Electrophoretic analysis indicated that the Satus Creek basin steelhead populations are not distinguishable into genetic substocks.

Hurlbert, S. H. 1975. **Secondary effects of pesticides on aquatic ecosystems.** Residue Reviews 57: 81-148. **From NCASI**

As cited in Norris et al. (1991): "In reviews of secondary effects of pesticides in aquatic systems, Hurlbert considered mortality to aquatic plants to be the only indirect effect of herbicides."

Hurr, R.T. "**Ground-water hydrology of the Mormon Island Crane Meadows wild-life area, near Grand Island, Hall County, Nebraska.**" 16. 1981. USDI, Geological Survey. Open File Report 81-1109.
Ref Type: Report

Keywords: Platte river/ groundwater depletion/ wildlife habitats/ riparian/ Nebraska/ ***drawdown***/ irrigation/ /wildlife management/valleys

The Platte River in south-central Nebraska flows generally eastward in a broad, flat valley. The river banks and many areas adjacent to the river support thick stands of cottonwood and willow tress. Brush, grass, pasture land, and cultivated fields occupy most of the remaining area. This is the habitat for many types of wildlife that live in the area or stop over in the area during annual migrations. Both sandhill cranes and whooping cranes are part of the annual migration. There is concern that water-management changes, such as surface-water diversions or ground-water withdrawals for irrigation, may alter the hydrologic environment of the wetland areas and be harmful to the wildlife habitat. In order to determine what affect changes in water management might have on ground-water levels in the wetland areas, detailed data were collected from Crane Meadows Wildlife Area, which is on an island in the Platte River near Grand Island, Nebr. Ground-water levels beneath the island respond to changes in river stage--usually within 24 hours for distances up to 2,500 feet from the edge of the river. Thus changes in river stage due to changes in surface water diversions will not have a long-term effect on ground-water levels due to changes in drawdown and due to changes in river stage caused by the effects of pumping on river flow. These effects will develop slowly and be long lasting.

Kreutzweiser, D. P. 1982. **The effects of permethrin on the invertebrate fauna of a Quebec forest.** Forest Pest Management Institute Information Report FPM-X-50. Canadian Forestry Service.
From NCASI

As cited in Norris et al. (1991, p. 290): "Insecticide use can not only kill aquatic insects and increase the rate of insect drift, it is likely to greatly increase the number of terrestrial insects that fall on stream surfaces."

Lischeid, G., Lange, H., and Hauhs, M. **"Neural network modeling of NO sub (3) super (-) time series from small headwater catchments."** *Hydrology. Water Resources and Ecology in Headwaters* (1998): 467-474

Keywords: Germany / Neural Networks/ Nitrates / Runoff / Water Management/ Forest Watersheds/ ***Headwaters*** / Catchment Areas

A variety of different processes is known that determine water and solute fluxes in headwater catchments. Water resources management of these systems, however, relies in most cases on empirical experience with respect to its overall response. A promising

method to bridge the gap between comprehensive scientific investigations and the need to manage the systems on the basis of limited data sets seems to be the application of artificial neural networks (ANN). Here, time series of NO sub(3) super(-) concentrations in the runoff of two forested headwater catchments in south Germany are investigated. Furthermore, the application of nonlinear methods presented here reveals a rather intricate behavior also on the temporal scale, and considerable differences between the two catchments. This demonstrates the validity of ANN as universal descriptive tools.

Ref ID: 104
Meador, M.R., Matthews, W.J. 1992; **Spatial and temporal patterns in fish assemblage structure of an intermittent Texas stream.** American Midland Naturalist 127 (1):106-114.

Keywords : fish; Texas

ABSTRACT.—Fish were sampled monthly at seven sites for 1 yr in Sister Grove Creek, an intermittent prairie stream in N-central Texas. Despite drastic seasonal fluctuations in discharge, abundance of individual species varied more spatially among sites than temporally at individual sites. Spatial differences in assemblage structure were attributed to differences in habitat and to migration from a downstream reservoir. The preponderance of spatial variation in species abundances combined with minimal temporal variation suggests: (1) temporal consistency of species abundance throughout the year, and (2) the highly dynamic hydrologic regime may not be a disturbance for Sister Grove Creek fishes.

National Council for Air and Stream Improvement, Inc. (NCASI). 2004**. Forestry Environmental Program News (Vol. 16, No. 05).** Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

Forest road study in Oregon; REQUEST FOR PROPOSAL: Review of fish passage needs to maintain a genetically connected population; REQUEST FOR PROPOSAL: Phased study to assess patterns of trout and salmon population response to land use activities; NCASI climate analyses published in scientific journals; Status review initiated for New England cottontail; Terrestrial and aquatic biodiversity session

The impacts versus values of forest roads have been the subject of recent debate in the United States. Forest roads historically have had substantial adverse effects on streams. Depending on how they are managed, roads can continue to impact streams today. The objectives of this paper are to describe 1) why roads are critical for effective land management; 2) the impacts of historical road construction practices; and 3) how legacy and current effects of roads can be systematically evaluated and managed to reduce impacts to acceptable levels.

In 1997, the debate over roads intensified as a result of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) Assessment of Ecosystem Components in the Interior Columbia Basin (Quigley and Arbelbide 1997). This assessment found that increasing road densities (combined with the activities associated with roads) are correlated with declines in anadromous salmonid species. However, the ICBEMP report also noted that the component contributions (causes) of effects associated with roads could not be identified, and that they were therefore "forced to use roads as a catch-all indicator of human disturbance." Since that time, a number of road mileage control and

reduction efforts have developed. The Forest Service and Bureau of Land Management (BLM) have accelerated road obliteration activities. The Federal Roadless Area Initiative would prohibit construction of new roads in "roadless" areas of Forest Service and BLM lands (implementation is currently in suspension). The Forest Service has also developed a Road Analysis procedure to assess road conditions and management needs (USDAFS 1999). The National Marine Fisheries Service's (1996) "Matrix" includes road density as a screening criteria for considering whether proposed federal actions will have adverse effects on threatened and endangered species. The US Environmental Protection Agency has suggested that road density be used as a means of regulating water quality within its Clean Water Act Section 303(d) regulation of Total Maximum Daily Loads (USEPA 1999).

The focus of this paper is the interaction of forest roads and aquatic ecosystems, and it is written from the perspective of private, for-profit, forest management businesses competing in the international forest products market. We discuss only direct impacts of roads, not secondary effects such as providing access to sportsmen or poachers – these are not road management problems, but people management problems. Most of the information provided herein is from the western U.S. While some of the details may differ slightly for other regions, the fundamental issues and principles that apply to the West remain applicable across the country.

National Council for Air and Stream Improvement, Inc. (NCASI). 2001. **Patterns and Processes of Variation in Nitrogen and Phosphorus Concentrations in Forested Streams.** Technical Bulletin No. 0836. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

Articles describing environmental health hazards appear almost daily in the popular press. The public is concerned about potential health risks associated with the use of agricultural chemicals, solid waste disposal sites, and industrial emissions. Thus, it is not surprising that managers of pulp and paper mills and representatives of the companies that own them periodically receive requests from the residents of mill communities for information on potential health hazards associated with mill operations. This review provides a summary of published reports in which the public health of kraft pulp mill communities has been evaluated. It includes an introduction to the nature of community health studies, brief synopses of specific published reports, and an overall summary of the conclusions reached in the relevant investigations of pulp mill community health. Most kraft pulp mill community studies have focused on respiratory health, but some have examined general health endpoints or mortality associated with cancer. None of the studies described here provides conclusive evidence that the emissions of a modern pulp mill pose any measurable or serious health risk to the residents of surrounding communities.

National Council for Air and Stream Improvement, Inc. (NCASI). 1994. **Forests as Nonpoint Sources of Pollution and Effectiveness of Best Management Practices.** Technical Bulletin No. 0672. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

This report synthesizes available knowledge on the effects-of forest practices on water quality by examining six propositions:

The quality of water draining forested watersheds is normally the best in the nation whether the forests are left untouched or intensively managed. Available information supports this proposition.

Properly implemented Best Management Practices (BMPs)effectively control nonpoint sources of pollution from forestry operations under most circumstances. This proposition is generally true, but in some unstable areas conventional BMPs for road construction and forest harvest may not be sufficient to prevent adverse effects on stream channels and fish habitat.

Effects of present day management activities on water quality are usually transient and are rarely severe enough to cause significant damage to fish populations. Negative impacts of forest practices should be uncommon where conventional BMPs are used. Exceptions to this conclusion would include (a) unstable areas or areas with highly erodible soils; (b) the combination of management activities with extreme storm events and (c)possibly downstream depositional areas where there is potential for cumulative effects.

The potential for water quality impacts from forest management depends upon factors such as climate, soil types, topography, etc. Special control measures can be targeted where there is greater than normal risk for short- or long-term adverse effects (such as areas with high risk for landslides). This proposition is generally true, although we note that extreme storm events can have unavoidable effects on both managed and unmanaged landscapes and streams. The cost of special control measures may in some situations be prohibitive relative to the value of the reduced risk of water quality degradation.

The water draining forest watersheds is not "toxic" (as defined by the Clean Water Act and elsewhere) unless affected by spills or other unusual events. Water quality issues for forest streams do not involve "toxins," with the possible exceptions of high nitrate concentrations and high aluminum concentrations. Both of these water quality parameters very rarely exceed toxic thresholds in forest streams.

The direct effects of forest practices on water quality within a small watershed may be different than the cumulative effects of the same practices on many small watersheds within a basin. This proposition may be generally true, but very little comprehensive information is available. Use of conventional BMPs at the site level to maintain water quality may be effective at minimizing cumulative effects within a basin. More research is needed to fully evaluate this proposition.

Norris, L. A., and D. G. Moore. 1971. **The entry and fate of forest chemicals in streams.** Pages 138-158 in J. T. Krygier and J. D. Hall, directors. Proceedings, forest land uses and stream environment symposium. Continuing Education Publications, Oregon State University, Corvallis**.**

From NCASI

As cited in Norris et al. (1991): "Concentrations of herbicides in surface waters after forest application are much lower than those needed to control aquatic weeds, so forest herbicides are unlikely to cause indirect effects due to the death of aquatic vegetation in streams, except in unusual circumstances."

Norris, L. A., H. W. Lorz, and S. V. Gregory. 1991**. Forest chemicals.** Pages 207-296 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19.

This is a thorough and in-depth book chapter which focuses on the effects of pesticides, herbicides and fire retardants on salmonid fish. The authors define and describe in detail the behavior (movement, persistence, and fate) and toxicity of chemicals typically used in forest management practices.

General Effects of Chemicals/Insecticides

The relationship of chemical use to salmonid habitats was evaluated for both direct and indirect effects. Direct effects include acute and chronic toxicity from direct contact with chemicals or from exposure to chemicals in the aquatic environment via drift, leaching, overland flow, mobilization due to precipitation, and chemicals in the food chain with bioaccumulation effects to aquatic organisms. Indirect effects include alteration of the structure and biological processes of both terrestrial and aquatic ecosystems. "Alteration of terrestrial vegetation and invertebrate communities may change both allochthonous inputs into streams and environmental factors such as light, temperature, water quality, sediment composition, and geomorphology. Land managers must be aware of potential indirect effects of forest chemicals on patterns and processes of stream ecosystems (p. 285). The authors argue that managed forests are already altered ecosystems so indirect effects of applied chemicals need to be considered in this light.

Indirect Effects of Chemicals/Insecticides

Herbicides can modify the natural pattern of terrestrial plant succession, which reduces the duration of early deciduous dominated stages with development of more rapid coniferous vegetation. This alteration of terrestrial systems affects allochthonous organic inputs, tree and shrub canopy over streams, stream chemistry, and sedimentation rates. Fertilizers stimulate vegetation production and may "indeed enhance many of the stimulatory effects of logging on aquatic primary producers. In coniferous forests fertilizers are usually applied after the canopy has closed to avoid stimulating growth of competing species and to allow greater utilization by conifers" (p. 292). Finally, "the indirect effects of fire retardant are generally limited to stimulation of primary production, and even that effect is greatly influenced by the extent to which the fire itself reduces the vegetation canopy over streams" (p. 292).

Conclusions

Norris et al. conclude that indirect effects "are manifested through chemically induced changes in the densities and community organization of aquatic and terrestrial plants and insects. These effects may include alterations of nutrient, sediment, and temperature characteristics of the water and changes in cover, food, or some other environmental characteristic important to the well-being of salmonid fishes. These changes have not been as thoroughly studied as the direct effects, but may be the most likely to occur" (p. 296).

Ref ID: 10

Reeves, G.H., Benda, L.E., Burnett, K.M., Bisson, P.A., Sedell, J.R. 1995; **A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of**

evolutionarily significant units of anadromous salmonids in the Pacific Northwest. American Fisheries Society (17):334-349.

Keywords : habitat; disturbance; salmonids; landscape; adaptations; fecundity; watershed

To preserve and recover evolutionarily significant units (ESUs) of anadromous salmonids *Oncorhynchus* spp. in the Pacific Northwest, long-term and short-term ecological processes that create and maintain freshwater habitats must be restored and protected. Aquatic ecosystems throughout the region are dynamic in space and time, and lack of consideration of their dynamic aspects has limited the effectiveness of habitat restoration programs. Riverine-riparian ecosystems used by anadromous salmonids were naturally subjected to periodic catastrophic disturbances, after which they moved through a series of recovery states over periods of decades to centuries. Consequently the landscape was a mosaic of varying habitat conditions, some that were suitable for anadromous salmonids and some that were not. Life history adaptations of salmon, such as straying of adults, movement of juveniles, and high fecundity rates, allowed populations of anadromous salmonids to persist in this dynamic environment. Perspectives gained from natural cycles of disturbance and recovery of the aquatic environment must be incorporated into recovery plans for freshwater habitats. In general, we do not advocate returning to the natural disturbance regime, which may include large-scale catastrophic processes such as stand-replacing wildfires. This may be an impossibility given patterns of human development in the region. We believe that it is more prudent to modify human-imposed disturbance regimes to create and maintain the necessary range of habitat conditions in space (10^3km) and time (10^1-10^2 years) within and among watersheds across the distributional range of an ESU. An additional component of any recovery plan, which is imperative in the short-term, is the establishment of watershed reserves that contain the best existing habitats and include the most ecologically intact watersheds.

Rinne, J.N**. Problems associated with habitat evaluation of an endangered fish in headwater environments**. Armantrout, Neil B. 202-209. 1982. Portland, OR, American Fisheries Society, Western Division. 10-28-1981.

Keywords: trout/ Gila National Forest/ endangered species/ fish habitat/ ***headwaters***/ streams

Attempted evaluation of habitat for Gila trout, *salmo gilae* Miller, in three headwater tributaries in the Gila National Forest, New Mexico, may have been hampered by small sample size, extreme variability in habitat and fish populations, artificial modification of habitat, stream intermittency, and asynchronous sampling. Prediction of the fish resource (maximum size, number, and biomass) based on physical habitat measurements was more successful in pools than in riffles and more successful for size of trout than for numbers and biomass. However, further developmental testing of methods to evaluate Gila trout habitat is recommended to aid in recovery of this endangered species.

Rutledge, C.J., Beitinger, T.L. 1989; **The effects of dissolved oxygen and aquatic surface respiration on the critical thermal maxima of three intermittent-stream fishes.** Environmental Biology of Fishes 24 (2):137-143.

Keywords : Notropis lutrensis; Pimephales vigilax; Fundulus notatus; temperature; hypoxia; hyperoxia; fish

Critical thermal maxima (CTM) were determined for three species of fish in hypoxic (1.2mgl^{-1}), normoxic (7mg l^{-1}) hyperoxic (12mg l^{-1}) oxygen tensions. All fish were acclimated to 30 degrees Celsius under a regulated photoperiod of 12:12. During each CMT determination, one half of the test fish were allowed free access to the surface (to permit aquatic surface respiration) while the remaining one-half were denied access to the surface. Under hypoxic conditions, CMT of *Fundulus notatus, Notropis lutrensis* and *Pimephales vigilax* given access to the surface were significantly higher than those of conspecifics without access to the surface. With access to the surface, all species had significantly lower CTMs under hypoxic conditions than under normoxic and hyperoxic conditions. CMTs measured under normoxic and hyperoxic conditions were not different for any of the test species. Under all comparable oxygen tensions with surface access, *F. notatus* had the highest CTM, *N lutrensis* intermediate ***and P. vigilax*** had lowest CTM. The critical oxygen concentration for *N. lutrensis* during CTM determinations occurred between 1.2 and 2mg l^{-1}.

Sewards, M.A. and Valett, H.M. **"Effects of livestock grazing on nutrient retention in a headwater stream of the Rio Puerco Basin.**" Shaw, Douglas W. and Finch, Deborah M. 135-142. 1996. Fort Collins, CO, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-272. 9-18-1995.
Ref Type: Conference Proceeding

Keywords: floods/ flood flow/ grazing /effects/ hydrology/ **intermittent** streams/ cycling nutrients/ sediment control/ deposition/ Rio Puerco/ New Mexico/ riparian/ sediment/ Southwest/ United States/ arroyo/ hydrology/

Sediment and nutrient loss from headwater streams of sedimentary basins in the semi-arid Southwest have been attributed to both over-grazing by livestock and to climatic cycles that influence arroyo formation. Considerable effort has been directed toward the influence of livestock grazing on riparian species abundance and diversity. Less work has concentrated on the influence of livestock on in-stream processes and communities. In contrast, considerable research has described the importance of floods as ecological organizers of riparian and benthic communities in lotic ecosystems. Here, we consider the interaction of flooding and livestock grazing on hydrologic and nutrient retention in a headwater stream of the Rio Puerco Basin, NM. We propose that grazing decreases retention of water, sediments, and nutrients by changing physical and biological features of the stream that cause the system to be less resistant to natural floods and by decreasing recovery rates when floods do occur (i.e. less resilience). This work presents our initial studies of the differing nutrient and hydrologic environments created by cattle exclosures on the Rio Senorito, a tributary of the Rio Puerco.

Preliminary results indicate that benthic biomass and transient hydraulic storage are greater in reaches protected from cattle influences. Finally, we propose a conceptual model that predicts the implication of disturbance interaction for streams impacted by flash floods and grazing practices.

Wallace, J. B., D. S. Vogel, and T. F. Cuffney. 1986. **Recovery of a headwater stream from an insecticide induced community disturbance**. Journal of the North American Benthological Society 5: 115-126.
From NCASI

General Effects of Chemicals/Insecticides

Although macroinvertebrate trophic structure recovered two years after treatment and was similar to that of the reference stream, major taxonomic differences remained. Once the shredder functional feeding group regained numbers, leaf litter processing rates and organic matter export rates also recovered to pre-treatment levels. However, as mentioned before, the shredder taxa remained very different from pre-treatment to post-treatment in the insecticide applied stream. See Cuffney et al. (1990) for a more complete review of the study.

Wallace, J. B., and J. R. Webster. 1996. **The role of macroinvertebrates in stream ecosystem function.** Annual Review of Entomology 41: 115-139.
From NCASI

Study Area and Methods

This study was conducted in the southern Appalachian Mountains, North Carolina, at the same location as the study described in Stone and Wallace (1998) (the U.S. Forest Service Coweeta Hydrologic Laboratory). Both study streams are 1st order, with watershed areas of the treatment and control catchments of 5.5 and 7.5 ha, respectively. The average gradient of the treatment and control streams was 33% (33 cm/m) and 20% (20 cm/m), respectively, and average discharge was 1.35 l/s and 1.53 l/s, respectively. The watersheds are vegetated by mixed hardwood forests, and the streams are heavily shaded with riparian *Rhododendron*.

The entire study reach was treated with insecticide 4 times per year for 3 years. Benthic invertebrate biomass, abundance, and production in the study stream were compared before and after insecticide treatment, and compared with an untreated reference stream.

General Effects of Chemicals/Insecticides

The authors state that estimates of aquatic macroinvertebrate biomass and production better describe community dynamics during disturbance and subsequent recovery than do estimates of abundance. Although recovering invertebrate communities experienced hydrologic extremes (drought and high precipitation), cluster analysis of functional group production "showed no pattern of wet-dry years, suggesting that the effects of hydrologic fluctuations in these streams act on specific taxa rather than functional groups." Differences were noted in benthic macroinvertebrate recovery rates between mixed-substrate and bedrock habitats, with bedrock

communities initially appearing to recover rapidly but then varying substantially over the 2 recovery years.

Reduced shredder densities during treatment resulted in large accumulations of unprocessed leaf litter. In contrast to findings that CPOM is a limiting resource in undisturbed Coweeta streams, this study demonstrated that CPOM was not limiting during insecticide treatment. A positive correlation between shredder biomass and CPOM was gradually restored over the 2 years following treatment. Results also suggest that invertebrate predators are an important regulator of community structure in the streams studied, preying on the smaller-bodied collector-gatherer taxa that recolonized soon after treatment. "Taxa with shorter life cycles and (or) extended flight periods were capable of more rapid recolonization than those with longer life cycles and (or) shorter flight periods", a result which agrees with other recovery studies. Persistent differences in taxonomic composition and developmental stage of macroinvertebrate community members were attributed to a positive relationship between life cycle length and recovery time, suggesting possible lingering effects of the insecticide treatment on energy flow. Taxa with high vagility may be of disproportionate importance in the recovery of macroinvertebrate communities in disturbed headwater streams.

Wallace, J. B., M. R. Whiles, J. R. Webster, T. F. Cuffney, G. J. Lugthart, and K. Chung. 1993. **Dynamics of inorganic particles in headwater streams--linkages with invertebrates.** Journal of the North American Benthological Society 12: 112-125**.**
From NCASI

Study Area and Methods

The study was conducted at the Coweeta Hydrologic Laboratory, Macon County, North Carolina (Catchments 53, 54, 55) all of which are first-order.
This study examines the impact of invertebrate consumers on inorganic particle dynamics. Two reference streams and one treatment stream (where insecticide additions altered invertebrate community structure) were studied over a 7-year period. The treatment stream had reduced rates of leaf processing because of fewer invertebrates while microbial processing or abundance did not change. Particulate inorganic matter (PIM) concentration decreased significantly in the treatment stream, while PIM concentrations increased or remained the same in the reference streams. Over the seven years of the study, maximum PIM concentrations were twice as great in reference streams than in treatment streams. Annual PIM export displayed a strong exponential relationship with discharge ($p<0.002$), while the treatment stream did not. A regression of transport values obtained from pretreatment years versus maximum discharge was conducted for each stream (reference and treatment) to test the predictability of export. Comparisons of predicted versus true values of PIM export in the treatment stream suggest a reduction (from expected) of nearly 76%. These results exceed the previously assumed impacts of invertebrates on inorganic particulates.

The authors found that most PIM export occurs during storms. Previous studies have shown the importance of invertebrates shredding CPOM and producing fine particulates through regular feeding activities. There was a reduction of PIM transport in the treatment stream, probably because invertebrate density had decreased resulting in decreased shredder activity, and increased leaf litter standing crop.

Recovery After Chemical Application

Processing rates were up to "normal" within 2 years after treatment ended, with invertebrate recovery underway the first year following treatment. The authors claim there are lingering effects of treatment with decreased PIM export even in the following two years after treatment, but do not present a strong argument for treatment having a substantially detrimental effect on food web dynamics.

Ref ID: 19
Wright, A.F. 1981; **Federal penalties apply to pollution of intermittent streams.** Natural Resources Journal 21 (1):181-183.

Keywords : policy; pollution

A pipeline owned by Texas Pipe Line Company (the Company) was inadvertently broken, spilling 600 barrels of oil into an unnamed creek in Atoka County, Oklahoma. ^The Company was not at fault in any way for the spill, nevertheless, the United States District Court for the Eastern District of Oklahoma entered summary judgment against the Company, upholding a fine of $2500 assessed by the United States Coast Guard under the Federal Water Pollution Control Act (FWPCA) for polluting navigable waters. ^The Company appealed, but the Tenth Circuit Court of Appeals upheld, following the standard interpretation of the commerce clause and relevant portions of the FWPCA. ^In affirming the decision of the lower court, it relied heavily on Coast Guard assessment officers` report. ^The concerns of dissenting Judge Barrett were later partially resolved in United States vs. Ward which held that a fine, like that assessed here, is civil, not criminal in nature. ^An issue still unresolved, however, is whether the penalties must relate to the actual costs of cleanup. ^Future decisions may reach the issue of the relationship between fines and actual cleanup costs.^21 references.

Zale, A.V., Leslie, D.M., Jr., Fisher, W.L., Merrifield, S.G., and Kirby, R.E. **The physicochemistry, flora, and fauna of intermittent prairie streams: a review of the literature.** 58. 1989. US Fish and Wildlife Service . USDI Fish and Wildlife Service Biological Report 89(5).

Keywords: riparian/ vegetation/ wildlife habitats/ water quality/ ***intermittent streams***/ Great Plains/ literature review/ fish/ invertebrates/ prairies/ stream

This is a literature review of intermittent streams and their importance in the dynamics of Great Plains ecosystems. Vegetation, animal species and fish species, macroinvertebrates, and habitat information is included.