Review of the Sustained Yield Plan / Habitat Conservation Plan for the properties of The Pacific Lumber Company, Scotia Pacific Holding Company, and Salmon Creek Corporation

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Summary

Downstream impacts to aquatic environments and property generally occur as cumulative watershed impacts, which are usually caused by changes in the transport of woody debris, water, and sediment through a watershed. The downstream cumulative impacts that are likely to accrue from implementation of the Sustained Yield Plan / Habitat Conservation Plan for the properties of The Pacific Lumber Company, Scotia Pacific Holding Company, and Salmon Creek Corporation (referred to here as the “SYP/HCP”) are thus assessed by evaluating the plan’s likely effects on woody debris, water, and sediment.

As currently written, the SYP/HCP will contribute to increased severity of cumulative impacts arising from an inadequate woody debris regime over the 50-year-period considered by the SYP/HCP. This increased level of cumulative impact will occur primarily because (1) a high proportion of the few remaining trees large enough to provide properly functioning wood will be cut from areas of residual old-growth within one old-growth tree height of streams; (2) there will be permanent removal of effective wood from Class III streams; (3) woody debris loadings in Class II channels will be permanently held at 21% or less of the levels that would be present in unmanaged stands; and (4) woody debris loadings in Class I channels will be permanently held at 39% or less of the levels that would be present in unmanaged stands. Existing cumulative impacts that will be aggravated by the plan’s effects on woody debris loadings include (1) increased magnitude and frequency of downstream flooding due to decreased storage of flood waters in upstream channels; (2) increased destabilization and aggradation of downstream habitats important to coho salmon and other Pacific salmonids due to increased incidence and mobility of debris flows and increased incidence of gullying; (3) continued impairment of downstream water quality due to increased gullying of Class III channels; and (4) increased damage to downstream properties due to increased incidence and mobility of debris flows. Mitigation of this suite of impacts will not be possible because it would require that the roles of large wood be fulfilled through other means, but no other means are available for fulfilling those roles.

The discrepancy between the calculated rates of debris input and those reported by the SYP/HCP arise, in part, because the SYP/HCP uses a 100-year-old second-growth tree as the basis for calculations of old-growth woody debris inputs. This is not appropriate.

The SYP/HCP will also contribute to continued increases in the severity of cumulative impacts arising from hydrologic changes. Increased flood magnitudes and frequencies will result from continued high rates of logging, which will maintain uncharacteristically low rates of foliage interception loss of rainfall by increasing the proportion of the area that is at the earliest stages of hydrologic recovery at any given time. This change will also increase landsliding rates because of the resulting increases in effective storm rainfall and seasonal rainfall at potential landslide sites and because of increased undercutting of banks and inner-gorge slopes downstream of the logged areas. Increased flood flows will increase scour of downstream spawning sites, and increased sediment from accelerated landsliding will aggravate this impact by contributing to the overall fining of channel beds, thus increasing their susceptibility to scour. Increased flood discharges will combine with increased downstream aggradation to cumulatively increase flood frequencies and resulting damage to downstream properties. Mitigation of these impacts will not be possible

because their mitigation requires that the hydrological roles of the mature forest cover be fulfilled through other means, and no such means exist.

The SYP/HCP does not consider impacts of hydrologic change, despite the fact that much of the present controversy over land-use practices on the ownership focus on reported increases in flood frequency and magnitude.

Sediment loads will continue to increase as the current high rates of logging continue. Experience with the mass-wasting-avoidance strategy of the SYP/HCP, as implemented under the pre-permit agreement, has shown that the strategy does not result in changes in silvicultural prescriptions that are capable of reducing the incidence of landsliding: existing landslides, inner gorges, and headwall swales continue to be clearcut. In addition, no provision is made in the SYP/HCP for reducing the high rate of landsliding that Pacific Lumber Company consultants have identified on landforms not considered by the mass-wasting avoidance strategy. Furthermore, the increased flood frequencies due to decreased foliage interception loss and aggradation will accelerate rates of bank erosion and undercutting of inner gorge slopes downstream of the areas logged. Chronic turbidity levels will also continue to increase in downstream channels due to lack of forested buffers around Class III channels, increased length of the active road network, and continuation of high levels of winter road use. The changes to the sediment regime will contribute to downstream aggradation, thus further increasing the incidence of flooding and adversely modifying habitats critical to the survival of coho salmon. Continued impairment of water quality due to high suspended sediment loads will directly impact salmon, domestic water use, and agricultural water use.

The SYP/HCP does not adequately account for sediment impacts because it the overlooks the high rate of landsliding on planar slopes; it does not consider impacts from chronic turbidity; and it does not evaluate the effects of the plan on water quality. Further, the absence of a valid cumulative effects analysis prevents the SYP/HCP from assessing the indirect effects of the plan on the sediment regime.

The impacts from altered woody debris, water, and sediment regimes will contribute to increased cumulative adverse impacts to habitat critical to the survival of coho salmon and other components of aquatic ecosystems on and downstream of the ownership. Because coho salmon from throughout the watersheds affected by the SYP/HCP (including fish from throughout the Eel River basin) must migrate through downstream channel reaches and estuaries which will continue to be adversely modified by these cumulative impacts, the SYP/HCP will lead to decreased likelihood of survival for coho salmon throughout the watersheds. The levels of habitat protection available on public lands due to implementation of the Northwest Forest Plan and on Tribal lands are irrelevant if fish spawned and raised under those conditions are killed by adverse conditions in habitats through which they must migrate. Furthermore, requirements for regulatory consistency are likely to ensure that future HCPs and SYPs applicable to this evolutionarily significant unit (ESU) for coho salmon are not more protective than this SYP/HCP. The level of cumulative impact entailed by this plan thus provides an estimate of that which will ensue from foreseeable future SYPs and HCPs for the ESU. These foreseeable future actions will thus contribute to increased cumulative impacts resulting in adverse modifications to downstream and estuary habitat critical to the survival of coho salmon from throughout the watersheds associated with this ESU.

The SYP/HCP does not evaluate the cumulative impact of the plan, in combination with foreseeable future actions, on the likelihood of survival of coho salmon of this ESU. The evaluation of the cumulative impacts contained in this review, however, provides information necessary to do so. For the reasons outlined above, implementation of the proposed HCP will appreciably reduce the likelihood of the survival and recovery of the species in the wild. Unless the HCP can be fundamentally restructured to provide enforceable measures for preventing downstream cumulative impacts, the California Forest Practice Rules, if enforced adequately and if accompanied by guidelines for avoiding impacts to the species and habitats of concern, would provide a higher likelihood that coho salmon in this ESU will not become extinct.

Further, the plan explains that future monitoring of stream conditions will take the place of an analysis of cumulative impacts; there thus is no adequate analysis in the SYP/HCP of the cumulative impacts of the SYP/HCP. There is also no discussion of cumulative watershed impacts as a changed and unforeseen circumstance. It thus appears that, according to the “no surprises” rule, any effort to reduce downstream cumulative impacts in the future will need to be paid for by those whom the company’s activities are damaging: the American taxpayer. No HCP that purports to protect aquatic habitat is complete without inclusion of a technically adequate analysis of cumulative watershed impacts, and deferral of such an analysis until after the plan is accepted is clearly unconscionable when the result is deflection to the taxpayer of fiscal responsibility for any impacts identified later.

Analysis of cumulative hydrologic and sediment impacts indicates that many of the problems expected from implementation of the SYP/HCP will result from continuation of rapid rates of logging. However, because no adequate cumulative impacts analysis was carried out for the plan, no assessment was made of the rates of cut that would be necessary to meet the objectives of the Basin Plan or to make the planned sustained yield be “consistent with the protection of soil, water, air, fish and wildlife resources,” as required by the California Forest Practices Act. The calculations of projected timber yields are thus not valid. Future THPs will need to provide analyses of cumulative impacts, address impacts on fish, and address sustained yield issues.

Feasible alternatives for addressing the problems described above include:

- Expansion of no-cut buffer widths on Class I and Class II streams
- Further expansion of no-cut buffer widths on Site Class 1 lands
- Deferred cutting of residual old-growth within a tree’s height of a stream until no-cut buffers are functioning as intended
- Provision of forested buffers for Class III streams
- Distribution of logging across the ownership in such a way that enough vegetation cover is present at any time in every watershed that flood magnitudes and frequencies are not increased over levels present in the early 1980s
- Deferral of further foliage removal in watersheds already impacted by increased flooding until those watersheds have undergone hydrologic recovery
- Distribution of logging across the ownership in such a way that rates of landsliding on slopes not considered by the mass-wasting-avoidance strategy are less than 20% above background levels in any given watershed.
- Increased restrictions on use of wet roads
- Establishment of an independent technical review board to ensure that management occurs according to the intent of the plan, rather than according to the loopholes that might be found

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Background: cumulative watershed impacts

Cumulative impacts occur when changes caused by multiple activities interact and have an adverse effect on something that people care about. When those impacts involve the transport of water, sediment, or woody debris through a watershed, they are referred to as “cumulative watershed impacts.” Cumulative watershed impacts are of considerable concern because they are responsible for most damage to property or public-trust resources that occurs off of the property on which a land-use activity takes place.

Cumulative watershed impacts occur because of the nature of a watershed: a watershed collects rainfall, drains it into streams, and channels the streamflow out of the watershed. As the water moves through the stream system, it transports sediment and woody debris. Under undisturbed conditions, the size and form of channels is determined primarily by the timing, quality, and amount of water, sediment, and wood that is naturally introduced into the channel. Both Pacific salmon and downstream floodplains evolved under those natural conditions, and their life-cycle strategies and forms, respectively, reflect the sizes and forms of the channels that were adjusted to those natural conditions.

If the amount of water, sediment, or wood introduced into the channel changes, the channel form changes to reflect the new balance among these components, changing both the nature of the habitat available for use by salmon and the stability of downstream channels. In addition, a change in any one of the components—water, wood, or sediment—will induce a change in the other components. Increased flow increases sediment transport and decreases the stability of large woody debris; increased sediment input decreases channel capacity, increasing flood peaks and burying woody debris; decreased woody debris increases sediment transport rates and speeds flow rates. Downstream impacts occur from changes in channel form, sediment transport, water flow, or woody debris load.

Impacts can accumulate both in space and in time. In most cases, the severity of an impact increases as its duration increases. Thus, one month of high sediment loads is a temporary problem for salmon and for domestic water users, while 10 years of increased sediment loads may be a disaster, forcing permanent modifications in water use patterns and loss of genetic diversity through extirpation of locally adapted populations. Maintenance of an adverse environmental change at a given level thus constitutes cumulative aggravation of an existing impact; prolonging the duration of an impact is itself a cumulative impact on the affected beneficial uses or resources.

This review focuses on the effect of the SYP/HCP on cumulative watershed impacts, and, in particular, describes how provisions of the SYP/HCP will influence the severity of off-site damage caused by activities carried out under the SYP/HCP. The review describes expected changes to woody debris, water, and sediment, and discusses how these changes will interact with each other and with downstream land uses and aquatic habitats. This information is then used to evaluate the plan’s ability to meet the requirements of Habitat Conservation Plans and Sustained Yield Plans.

Woody debris

1. Role of woody debris in forested watersheds

Woody debris is a critically important component of streams in forested areas. The role wood plays varies with the size of the stream. In the smallest streams (i.e. “Class III streams” as defined in the California Forest Practices Rules), in-falling wood usually cannot be washed away, so logs remain in place and act as check-dams that store sediment eroded from hillsides. When landslides occur, the wood catches much of the sediment before it reaches larger channels. Where a landslide triggers a debris flow, abundant woody debris just downstream of the initiation site may decrease the mobility of the flow and halt the debris before it reaches a larger channel. Ketcheson and Froehlich (1978; quoted in Swanson et al. 1987), for example, found that debris flows in logged areas traveled 50% farther, on average, than those in forested areas.

Debris flows are the most destructive form of mass wasting because of their ability to travel far from their source and because they grow as they travel. In the Knowles Creek watershed of Oregon, for example, the average landslide (590 yd^3) that triggers a debris flow in a Class III stream has grown to a volume of 6300 yd^3 by the time it has traveled 1800 ft, and the longest travel distance observed was 5250 ft (Benda and Cundy 1990). Flows may achieve velocities of 30 miles per hour. Debris flows from logged areas in the Pacific Northwest have killed downstream residents (Benda and Cundy 1990, Evans 1988), and it was a debris flow from a Pacific Lumber Company clearcut that destroyed or damaged much of the town of Stafford during the winter of 1996-97.

On larger channels (i.e. “Class II streams”—those supporting aquatic life but no fish), wood again stores sediment, and it also provides an important element in the habitat of aquatic life-forms. In addition, debris flows in these channels generally come to a stop behind log-jams. In some cases the jam forms because the debris has stopped flowing, while in others the logs are observed to be wedged behind boulders and standing trees, indicating that the jam itself is likely to have halted the flow. Large, stable pieces of wood in Class II channels are thus likely to decrease the severity of debris flows and contribute to halting some flows before they reach fish-bearing streams or downstream towns. A study contracted by Pacific Lumber Company in 1998 noted that:

> *“In the pre-management period, vegetation in the source areas probably reduced landslide volumes.... In addition, large numbers of whole trees would have been incorporated in debris slides and debris torrent source areas, and entrained as flows passed through heavily wooded downstream channels. This large organic debris would have acted to strictly limit runout distances of debris torrents in the unmanaged watershed. In contrast, harvesting over the last 50 years has removed most of the large wood which would otherwise have been available for transport. As occurred in 1996/97, torrents now travel farther and channel aggradation extends over long lengths of the channel system than in pre-management times.” (PWA 1998a, p.25 ph.5)*

Wood is also important because it increases the roughness of a channel, thus slowing the passage of flood flows and effectively creating a small flood-control “reservoir” of every forested stream. This effect decreases the height of flood peaks in channels downstream.

In fish-bearing streams (“Class I streams”), wood again is important for storing sediment, halting debris flows, and decreasing downstream flood peaks, and its role as a habitat element becomes directly relevant for coho salmon and other Pacific salmon species. In addition to creating pool habitat for summer rearing, large pieces of wood are important for backing up low-gradient water for refuge during winter floods. As the SYP/HCP states, “there is little doubt that large woody debris is important for the production of trout and salmon” (PL 1998 vol. IV part D p.54, noted here as IV-D-54), and the references cited by the SYP/HCP describe the reasons for that importance.

In general, adequate protection of the physical processes in Class II channels is essential for sustaining aquatic habitat in Class I channels, since any disruption of a Class II channel causes disruption in the Class I into which it drains. Because (1) multiple Class II channels usually drain into a Class I, (2) disruption in any one of those Class II’s will affect the downstream Class I, and (3) the likelihood of initiating a disruption in Class II’s is greater than that in Class I’s because Class II’s are closer to the source of debris flows, it might even be argued that protection of the Class II’s is more important than protection of the Class I's, as protection of the Class II's to some extent constitutes protection of the Class I's. In any case, it should be evident that in order for Class I's to be protected adequately, Class II channels should be afforded no less protection than Class I's.

Fish and channel form in redwood country evolved in the context of the woody debris regime characteristic of old-growth redwood forests. The ability of today's forest stands to reproduce the channel conditions that produced Pacific salmon and downstream land-use patterns depends on the input rate of wood to the channels, the size of the individual pieces, and the wood's rate of decay. To the extent that today's stands fall short of supplying the quantity and quality of wood contributed by original forest conditions, channel habitat and downstream floodplain conditions will fall short of those upon which the downstream beneficial uses depended. The effectiveness of the SYP/HCP in reducing further impacts to Pacific salmon and downstream beneficial uses can thus be assessed, in part, by evaluating the extent to which the plan reproduces the woody debris regime to which the land-use patterns and aquatic ecosystem were adjusted.

2. Implications of the SYP/HCP for the woody debris regime

The influence of SYP/HCP prescriptions on the woody debris regime was evaluated by calculating the difference in woody debris input rates expected from a 300-year-old redwood stand on Site Class 2 land and those expected for Class I and Class II channels under the proposed plan (Figure 1). The distribution of wood inputs as a function of distance from a stream was available for second-growth redwood forests in Mendocino County, California (Reid and Hilton 1998; note that this information was available in time for inclusion in the SYP/HCP, as shown by the SYP/HCP's inclusion of other information from the conference at which these data were presented—see the reference to "Lisle 1998, in press" in IV-H-7 ph.1, for example). This distribution pattern was then applied to the stand densities and characteristics described by the SYP/HCP for riparian protection zones, those expected for 300-year stands on the basis of information provided by Lindquist and Palley (1963), and those prescribed by California State Assembly Bill 1986. Inputs were also evaluated according to the distribution of debris sizes expected (Figure 2) by assuming that tree trunks are conical. Calculation methods are described in Appendix 1.

Class III streams are left with no permanent tree cover under the SYP/HCP, so none of the required roles of woody debris will be fulfilled in these streams. The probability of conversion of landslides to debris flows thus will increase at these sites, and the triggered flows will be unlikely to stop within these channels. The proportion of debris flows that reach Class II and Class I streams thus will be higher than under pre-management conditions. The proportion will also be higher than under existing conditions, because existing debris will continue to decompose.

Results of the calculations indicate that the SYP/HCP prescriptions will provide only 21% of the volume of wood characteristic of unmanaged conditions in Class II streams, and that most of the pieces contributed will be small. Under these conditions, debris-flow mobility is expected to increase over that for forested conditions, and the effectiveness of the channels in moderating downstream flood peaks will be reduced. Class I streams will receive approximately 39% of the characteristic volume of woody debris. Here, too, opportunities to halt debris flows and to store flood waters will be reduced in comparison to pre-management conditions and to existing conditions. Winter refuge habitat for salmonids will also be reduced. In addition, the increased incidence of debris flows caused by the permanent depletion of wood in Class III streams will result in aggradation of downstream channels, burying woody debris in the larger channels and thus decreasing its effectiveness.

Conditions prescribed by Assembly Bill 1986 provide a significant improvement over those prescribed by the SYP/HCP. In this case, wood inputs to Class II streams increase to 38% of those in unmanaged stands, and inputs to Class I streams increase to 75% of the unmanaged volumes.

However, Class III streams remain unprotected. Under these conditions, the probability of debris flow initiation remains high due to depletion of wood in the source streams, and the relatively low levels of "high caliber" wood in Class II streams will again decrease the likelihood of flows being halted before reaching fish-bearing streams.

The above calculations were made for streams adjacent to lands of Site Class 2. However, examination of Map 6 in volume V of the SYP/HCP indicates that many portions of the stream systems that are most important to anadromous salmonids are adjacent to Site Class 1 land. The calculations were thus redone for lands with a site index of 200 (see Appendix 2). On these lands, the SYP/HCP prescriptions provide only 34% and 20% of the woody debris volumes contributed under unmanaged conditions for Class I and Class II streams, respectively (Figure 3). Provisions of AB 1986 would produce 62% and 32% of the necessary wood. Site Class 1 lands are generally found on riparian bottomlands, so channels adjoining Site Class 1 lands tend to be larger than those of Site Class 2 lands. It is even more important that woody debris be of sufficient size to remain in place in these larger channels; small pieces are very likely to be washed away.

Examination of Map 5 in volume V of the SYP/HCP discloses that the projected wood inputs will not be achieved for a very long time on most parts of the property: logging has progressed rapidly enough that most areas within 170 feet of stream channels have already been logged. Even if the prescriptions of the SYP/HCP or AB 1986 are fully implemented, woody debris inputs will be severely depressed in volume and caliber until these areas regrow. According to Lindquist and Palley (1963), it will require about 80 years to grow a stand with trees of an average basal area of 3 ft^2, and the SYP/HCP notes that it "may require 100-200 years before [woody debris loading] returns to levels present under pre-harvest conditions" (IV-D-55, ph.1). In the interim, the only source for wood of large-enough size to function appropriately is the residual old-growth still present in stands that had originally been partially logged. Residual old-growth has been ignored by the SYP/HCP, despite its critical importance for sustaining properly functioning aquatic habitats and its potential ability to slow the rate of accumulation of downstream impacts. If the remaining residual trees that are located within falling-distance of a stream continue to be cut, the cumulative impact on woody debris loadings in channels will continue to increase. To prevent this increased impact, it would be necessary to leave the residual trees in place until the buffer strips regrow to the point that they begin to function as required. If this is not done, impacts will continue to increase for the next 80 years or so as the last remaining sources of functional wood are depleted and while regrowing stands are too small to begin to function appropriately.

3. Interactions of altered woody debris regimes with other watershed components

The woody debris regime expected to result from implementation of the proposed SYP/HCP would contribute to adverse changes in both the hydrologic regime and the sediment regime. The maintenance of woody debris loads at lower than natural levels would decrease the flood storage capacity in small channels by maintaining low roughness in these channels. Flood flows thus would move more quickly into downstream channels and contribute to higher-than-natural flood frequencies.

Woody debris in streams retards gullying of channels. Gullying has been found to be a major problem after road building and logging in Redwood Creek watershed (Weaver et al. 1995), and a study contracted by Pacific Lumber Company found gullying of small channels to be a problem in North Fork Elk River watershed (PWA 1998b). Lack of any future significant wood input to Class III streams will increase the susceptibility of these sites to gullying as existing wood decays. This effect has been aggravated to the extent that recent logging practices include pulling marketable debris from Class III streams. The increased susceptibility to gullying will occur at the same time that hydrologic alterations on hillslopes (see below) increase peak flows in these channels, also increasing the propensity for gullying. Increased gullying will also increase the efficiency with which water is routed to downstream areas, further increasing the potential for downstream flooding.

Increased gullying will also increase sediment inputs to downstream channels, adding to the increased sediment expected from increased debris-flow activity, as described above. Increased sediment loads in downstream channels contribute to downstream aggradation, further increasing flood peaks and adversely modifying salmon habitat. Occurrence of a major debris flow from a logged unit in the Bear Creek watershed on Pacific Lumber Company land, for example, obliterated more than 75 habitat improvement structures (Dudik 1997), filling the channel with more than 8 feet of sediment at some locations (PWA 1998a). As mentioned above, a study contracted by Pacific Lumber Company (PWA 1998a) indicated that the impact of the debris flow was aggravated by the lack of large woody debris in the channel when the flow was triggered. It should be noted that the 1998 SYP/HCP erroneously reports the structures destroyed during the winter of 1996-97 as "functioning" (II-G, p.1-3).

4. Comments on the SYP/HCP's analysis of the woody debris problem

The SYP/HCP's misapprehension of the woody debris problem appears to arise from several problems in its analysis. First, the evaluation of source distances is flawed because the height of the trees contributing wood is not adequately considered. It should have been obvious, for example, that 300-foot-tall redwoods would contribute wood from greater distances than the 170-foot trees assumed in the SYP/HCP's Figure 1, p.IV-D-56. The conditions that must be used for comparison are those that had proved to be adequate to sustain aquatic ecosystems—the pre-management conditions. It makes no sense to use a 100-year-old stand as the basis for describing an "unmanaged stand": the continued decline in salmon populations suggests that conditions afforded by 100-year-old stands are inadequate to sustain coho salmon populations.

Second, the SYP/HCP's concern about the shape of the FEMAT woody debris recruitment curve appears to reflect a misunderstanding of the processes of woody debris input. Where trees fall downhill and stands include a range of tree heights, debris recruitment (in terms of number of pieces) approximates a linear function of distance. In northwest California, stream channels commonly flow through steep-walled "inner gorges," and data from a second-growth redwood forest at Caspar Creek, Mendocino County, California, indicate that trees characteristically fall downhill on these slopes (Reid and Hilton 1998). The relation depicted by FEMAT is a relatively good characterization of the measured distribution of debris sources in this setting (Figure 4). In contrast, the modeling work of McDade et al. (1990) and Van Sickle and Gregory (1990) assumes a random orientation of tree falls, which is clearly not the case at Caspar Creek; their results do not appear to be applicable where streams are adjacent to steep slopes.

The method used in the SYP/HCP to design buffer strip widths is inappropriate because it is founded on the two erroneous assumptions discussed above. When results are recalculated using a more appropriate characterization of pre-management conditions and using measured distributions of debris sources in a redwood forest in northwest California, the SYP/HCP's predictions of woody debris input rates, in terms of volume of debris, are found to be in error by 210% and 265% for Class I and Class II streams, respectively.

5. Potential alternatives to decrease cumulative impacts from altered woody debris

In order to bring buffer strip widths into compliance with the design goals described in IV-D-58 ph.6 ("PL's riparian buffers are expected to provide 79.8 and 55.6 percent of the total LWD recruitment expected in unmanaged forests in Class I and Class II streams, respectively"), it is clear that no-cut buffers would need to be widened. The levels of loading described in IV-D-58 ph.6 were considered necessary by PL and NMFS in preparation of the plan, and they are the levels upon which the assumptions of the SYP/HCP are based. Achieving these levels will require no-cut buffer strip widths of 100 feet for Class I streams and 75 feet for Class II streams on Site Class 2 lands. On Site Class 1 lands, no-cut buffer widths of 120 feet would be needed on Class I streams and 85 feet on Class II streams. If these levels are not achieved, then the assumptions upon which the rest of the SYP/HCP is based will not be met, and other elements of the plan will need to be modified to make up for the shortfall in the expected level of protection. However, the level of protection for Class II streams would need to be increased to provide more than 55.6% of the unmanaged wood inputs if the level of disruption in Class I streams is actually going to reflect the 79.8% wood-loadings that provide the stated objective of the SYP/HCP. In any case, the 70- to 140-foot exterior band of selective logging is likely to improve the stability of the inner, no-cut buffer (Reid and Hilton 1998), and would need to be included in any plan.

Second, it is clear that if the level of significant cumulative impacts is not to be increased in the affected areas, some provisions will need to be made for maintenance of a supply of stable (i.e. large diameter) woody debris in Class III streams. These are also often the sites of unstable “headwall swales” that produce landslides. A strategy that maintains the stability of the headwall swales by leaving root strength intact is also likely to provide a source of woody debris. Where slope stability is not an issue along Class III streams, a silvicultural strategy of low-intensity, selective logging in these areas might be designed to satisfy woody debris needs.

Third, if inputs of large-diameter wood are not to decrease further over the period of the SYP/HCP, all residual old-growth within a tree’s height of a channel will need to be retained until the second-growth trees that now make up the potential riparian areas attain equivalent diameters at the point of entry to the channel. This should not represent much of a change in the plan, as the areas of residual old-growth were not important enough to be considered by the plan.

Water

1. Hillslope hydrology and streamflow in forests

Water is the principal medium for translating environmental changes on hillslopes into downstream cumulative watershed impacts. If the volume or timing of runoff is altered, downstream ecosystems and channel forms change to reflect the change in water availability and the change in the frequency and magnitude of flooding. Such changes also affect availability of water for human and agricultural use and modify the severity of flood damage to downstream properties and infrastructure.

Forests influence runoff by intercepting and evaporating rainfall before it hits the ground and by extracting water from the soil and evaporating it through foliage (Dunne and Leopold 1978, Waring and Schlesinger 1985). Data from a variety of locations (Figure 5) indicate that forests capture and evaporate 20% to 30% of the total storm rainfall during large storms in areas with storm-season climates similar to those of Eureka, California (Fahey 1964, Kelliher et al. 1992, Rowe 1979, Rowe 1983). Measurements of interception loss in a redwood forest on land owned by Pacific Lumber Company in Freshwater watershed (Rains 1971) indicate that local rates of interception loss are similar to those measured elsewhere (Figure 5). Data from Caspar Creek, California (Ziemer 1998) show that clearcutting of second-growth redwoods in coastal California has resulted in an average of a 27% increase in flood peaks in 100% clearcut watersheds, and that the effect in larger watersheds varies linearly with the proportion of the forest cover removed in the watershed (Figure 6). The magnitude of the change in peakflow measured at Caspar Creek approximately equals the magnitude of the expected interception loss during large storms.

Rates of evapotranspiration, although an important influence on the water budget during the dry season, are less important during the height of the storm season. Evapotranspiration, by maintaining lower levels of soil moisture under forests, provides increased storage capacity for early- and late-season storm rainfall, thus decreasing the runoff from autumn and spring storms. Foliage interception loss, in contrast, is important throughout the year when rainfall occurs, and is also influential in maintaining lower levels of soil moisture by decreasing soil moisture recharge from storms of all sizes.

Undisturbed forest growth also leads to the development of deep, porous soils conducive to efficient infiltration of rainfall, and produces organic-rich soils that are capable of storing large volumes of water. Duff layers that form under long-established forest stands provide considerable surface area for storing infalling rain, and the surface roughness created by the duff layer greatly retards the velocity of any surface runoff that is generated.

As described earlier, forests slow rates of water conveyance to downstream channels because of the accumulation of woody debris in streams. Woody debris greatly increases the roughness of forested channels, thus slowing the velocity of flood flows and allowing some of the runoff to be temporarily “stored” because of its slow progress. This effect attenuates downstream flood peaks, distributing the peak runoff over a longer period and thus decreasing the height of the flood peak.

In comparison to recently logged land, then, the presence of forest vegetation is expected to decrease overall runoff volumes, decrease average soil moisture levels, and decrease flood peaks. These conditions are important in controlling the composition and dynamics of downstream aquatic ecosystems. For example, a study in Washington State found that sockeye salmon smolt production per spawner is inversely proportional to peak discharge during incubation (Thorne and Ames 1987). High peak flows increase the depth of scour in stream gravels, thus destroying salmon redds (which are the “nests” that salmon dig in stream channels to protect and nurture their eggs). High peaks also contribute to accelerated bank erosion and pervasive modification of channel forms. Flooding damages downstream properties, lowering property values, and accelerated channel migration provoked by high flows can undermine and destroy structures. If flood frequency increases, the boundaries of the 100-year floodplain expand, thus increasing sanctions on downstream property rights through restricted access to flood insurance and loans for properties now located within the new boundaries.

Downstream land uses established when forest cover was present in a watershed would have been tuned to frequencies and distributions of flooding and to rates of channel change that existed at that time. To the extent that forest land use modifies flood frequencies and magnitudes, channel habitat and downstream floodplain conditions will shift away from those upon which the downstream beneficial uses depended. As was the case with the woody debris component, the effectiveness of the SYP/HCP in preventing cumulative impacts to public trust resources, downstream beneficial uses, and downstream property can be evaluated in part by determining the extent to which the plan reproduces the hydrologic regime to which the land-use patterns and aquatic ecosystem were adjusted.

2. Implications of the SYP/HCP for the hydrologic regime

The extent of the hydrologic impact caused by a logging strategy depends strongly on the proportion of a watershed’s forests present in “immature” hydrologic condition at any given time. The SYP/HCP provides for a near-term continuation of the rates of cut established over the past several years, and this allows calculation of the hydrologic changes that will be associated with implementation of the plan due to alteration in rates of foliage interception of storm rainfall. Calculations are described in Appendix 3. In essence, the effective area without canopy cover is calculated for each year by adding the acreage clearcut to one-half the acreage logged using other strategies, and adding to this value a proportion of the area cut during previous years according to the level of recovery of each of the previous cuts. Recovery is calculated assuming that recovery is complete after 15 years, and that the rate of recovery is uniform through the 15-year period. Effective storm rainfall is then calculated by applying the measured storm rainfall to the effective canopy-free area, and applying 77.5% of the storm rainfall to the forested area. Effective storm rainfall for 1975 canopy conditions (calculated by assuming that rates of cut evident in the early 1980s were characteristic of the preceding decade) can then be compared with that for 1997 conditions for a storm of a given size. The change in recurrence interval for rainstorms is then calculated by comparing the recurrence intervals for the effective storm rainfall.

Results of calculations using rainfall records from Kneeland (Conroy 1998), located at the eastern margin of Freshwater watershed, indicate that the change in effective storm rainfall causes changes in flood frequency that vary with the size of the flood (Figure 7), and that the effects are largest for the largest floods. A 50-year flood in 1975 is now expected to recur, on average, every 18 years, and by 2007 it will be recurring an average of once every 11 years. A 10-year flood now recurs every 6 years, and by 2007 will recur every 5 years, on average.

These effects are even more pronounced in smaller tributary watersheds, where a higher proportion of the watershed is cut over a shorter period. Flood frequency increases on the scale of those expected in 2007 for Freshwater as a whole are thus already likely to be present in the Cloney Gulch, Little Freshwater, and Graham Gulch tributaries of Freshwater Creek, where logging is 70% complete. At the scale of Class III channels, where the entire watershed is cut over a single season, the effect will be even more profound.

Decreased interception loss is also important on hillslopes, where landslide incidence has been shown to be associated with the size of storms. In the central California coast range, for example, the areal frequency of shallow debris slides—those which most commonly trigger debris flows—was found to depend on a function of the storm rainfall raised to the third power (Reid 1998a). Application of the equation defined for those hillslopes suggests that the 22.5% increase in effective storm rainfall expected for clearcut hillslopes in the Freshwater area would be capable of increasing landslide frequency by 240% for a 15-inch storm, which has a recurrence interval of about 9 years at Kneeland. Data from forested areas in New Zealand also show a dependence of landslide intensity on storm magnitude (Reid et al., in press). Application of the New Zealand relationship would indicate a 63% increase in landslide rate for a 22.5% increase in effective rainfall from a 15-inch storm.

The altered hydrologic regime on hillslopes is also expected to increase the activity of deep-seated slides and earthflows (“earthflows” differ from “debris flows” in that an earthflow moves more slowly, behaving somewhat like a glacier of mud). Earthflow activity, for example, varies with seasonal precipitation (Swanston et al. 1987, Swanston et al. 1995). Total seasonal foliage interception loss is higher than that measured for individual major storms. Results of the studies cited above (Fahey 1964, Kelliher et al. 1992, Rowe 1979, Rowe 1983) suggest that 20% to 50% of the total annual precipitation is captured and evaporated by forest foliage. Logging of an earthflow or deep-seated slide is thus likely to increase the effective seasonal rainfall by 25% to 100% (as calculated from the ratio between the intercepted and effective rainfalls: 20/80 = 25%), and seasonal increases considerably smaller than this have been observed to accelerate earthflow velocities markedly (e.g. Zhang et al. 1993). Earthflow velocities have been observed to increase after logging at the head of, and to either side of, a previously near-dormant earthflow (Zhang et al. 1993), also indicating that hydrologic change associated with canopy removal is an important influence on earthflow erosion rates. Swanston et al. (1987) also found the rate of earthflow activity to increase after logging of a flow.

3. Interactions of altered hydrologic regimes with other watershed components

Because stormflow is the major transport medium for both sediment and woody debris, a change in peak flows can strongly influence downstream sediment and wood regimes. The expected further increase in flood frequency and magnitude will tend to move sediment from tributaries in which flood peaks are most affected. Some of the sediment will then be deposited downstream where flood peaks are less affected, thus contributing to aggradation of the downstream reaches important to salmonids and to downstream property owners. Aggradation at these sites will decrease channel capacity, further aggravating the flood damage by making it possible for smaller peak flows to reach greater heights.

Sediment is scoured from channel beds during periods of high flow, and new sediment is deposited to take its place as flows recede. The depth of scour increases with the size of the flow. Salmon spawning behavior evolved to fit the conditions of their customary spawning sites. Salmon thus dig their redds to a depth that would have protected them from scour during all but the largest natural flows. If peak flows increase over natural conditions, redds will be destroyed and coho salmon alevins (newly hatched salmon which still reside in the gravel) killed more frequently than under pre-management conditions.

Increased peak flows will also increase the mobility of woody debris. Larger pieces of wood thus will be necessary if they are to stay in place, but the SYP/HCP's provisions will result in removal of many of the remaining sources for large wood, leading to an overall reduction in potential inputs of the largest woody debris over the period considered by the plan. The combination of increased flood peaks, increased mobility of small wood, and increased proportion of small wood inputs is likely to lead to increased damage to downstream structures by wood-laden flood flows.

Increased effective rainfall on logged hillslopes will increase sediment input from landsliding. This effect will be compounded by the depletion of woody debris in Class III channels, since the increased landsliding will produce landslides that travel farther before coming to rest and which are more likely to become debris flows.

Increased flood flows also increase the extent of undercutting of inner-gorge slopes, thus increasing the incidence of inner-gorge landslides and bank erosion even in unlogged areas downstream. High flows also increase downstream earthflow rates by undercutting earthflow toes (Nolan and Janda 1995), leading to increased upslope erosion on downstream properties.

The greatest increase in flood peaks is expected in Class III channels. These are also the sites that will be left most susceptible to flow-related channel change because implementation of the SYP/HCP will result in depletion of all effective wood. In effect, peak flows increase at the same time that the channels' protection from scour is removed. Gullying is expected at these sites. This effect has already been reported in the North Fork Elk River watershed, where small channels filled with sediment during first-cycle logging are now forming gullies (PWA 1998b).

Because the overall pattern of logging established over the past decade will not change with the SYP/HCP, and because provisions described by the SYP/HCP for assessing and managing cumulative watershed impacts do not address hydrologic change or flooding, the trends of increasing cumulative impacts due to silviculturally related hydrologic change will continue.

4. Comments on the SYP/HCP's analysis of hydrologic cumulative impacts

Hydrologic impacts are not considered by the SYP/HCP. This omission is surprising, given the fact that much of the controversy surrounding recent land-use activities on the properties in question focuses on flooding.

5. Potential alternatives to decrease cumulative impacts arising from altered hydrology

If cumulative impacts on flooding are to be minimized, decreases in canopy cover must occur at a low-enough rate that flood frequencies remain at a tolerable level. In the case of Freshwater and Elk River watersheds, cutting rates that pertained from the 1960s through the early 1980s provided a flood regime that was not considered a nuisance or damaging by downstream residents and which supported economically important populations of coho salmon. These cutting rates also maintained an economically viable logging industry in the area. Rate of cut during 1983-1986 averaged 1.5% of the watershed per year, of which approximately one third was equivalent to clear-cutting. If other silvicultural strategies remove approximately 50% of the canopy, then this rate is equivalent to a 100-year rotation (calculated as 1.5% x 1/3 x 100% removed + 1.5% x 2/3 x 50% removed = 1.0% removed each year). As most of the silvicultural prescriptions listed in III-B-8ff are for selective logging or for clearcutting with 70-year rotation or longer, restriction of the rate of cut to 1.5% of a watershed per year, assuming 1/3 clearcutting, would not appear to change overall yields much. The only major change would be in where the cutting is taking place. To maintain flood frequencies at a tolerable level would require that the cutting in a watershed be distributed evenly through the cutting rotation rather than being concentrated in the first 20 years of the cycle. This distributed approach would also ensure that the level of employment and wood production does not fluctuate through time. To ensure that individual tributary watersheds are not disproportionately impacted, the 1.5% annual rate would also need to be applied to the tributaries.

In Freshwater and Elk River watersheds, and in others where flooding is of concern, deferring further logging over the short-term would be necessary if the current level of cumulative impacts to flood frequencies is to be diminished.

Hydrologic change at a site-scale would be most readily managed through silvicultural strategies. If no-cut or low-intensity selective cut buffers are left around Class IIIs to provide woody debris, decrease sediment inputs, maintain slope stability, and decrease debris flow incidence, then a useful by-product of the practice will be protection of the hydrologic integrity of Class III water courses and potentially unstable sites.

Sediment

1. Erosion and sediment transport in forested watersheds

Under natural conditions, most sediment eroded from forested hillslopes in coastal Humboldt County would have originated from landslides, channel bank erosion, and uprooting of near-channel trees. Large storms would generate much of the sediment by triggering landslides, while smaller storms would gradually mine away the landslide debris and shift it downstream. Coarse sediment would move as “bedload” that could ordinarily be transported only by flows approaching bank-full. Finer sediment was transported in suspension, moving quickly through the channel system and out of the watershed.

The form of the steepest hillslopes developed to be marginally stable under the climatic, geologic, and vegetation conditions present locally. The strength of the hillslope materials, as buttressed and reinforced by intertwining old-growth forest roots, was sufficient to keep the soil and bedrock in place during all but the largest storms. When a landslide did occur, it would carry with it the large-diameter boles that would themselves contribute to trapping and stabilization of the landslide debris. Shallow landslides would also occur at the toes of slopes when channel erosion undercut the slopes and over-steepened them. In both cases, landslides would be associated with large storms because it is at these times that soils are wettest and subsurface pore-water pressures are highest. High pore pressures decrease the strength of the hillslope materials and the load of water increases the force pushing soil downslope.

Shallow landslide rates increase where the strength of hillslope materials decreases, where topographic modifications over-steepen slopes, and where water inputs to a slope increase. Logging modifies hillslope material strength by decreasing the strength contributed by roots. Ziemer (1981) found that root-strength falls to a minimum about 7 years after logging, when much of the residual root mass has decomposed and new-growth roots—in this case provided by ceanothus—have not fully developed. With stump-sprouting redwoods the low point in the curve may occur earlier and recovery will occur more quickly because a portion of the original root mass remains alive. If redwood forest is converted to Douglas-fir, rates of sliding would increase because Douglas-fir does not sprout from roots. Where brush regrowth is suppressed by herbicides or vegetation is completely removed by burning, root strength is likely to be further depressed. Road and skid-trail construction is the primary source of topographic change associated with logging in a watershed, and oversteepened roadcuts are often the sites of small landslides. Road construction also provides a source of low-strength hillslope materials in the form of road-fills, and these are frequent sources of landslides. Water inputs to slopes are changed primarily by changes in foliage interception loss, as described above, and by modification of hillslope drainage through road construction.

The overall effect of these influences is a general increase in landsliding rate in areas managed for timber, and Sidle et al. (1985) document as much as a 41-fold increase in landslide frequency after clearcutting and a 346-fold increase after road building. In most locations, roads account for the largest proportion of the increase. However, studies contracted by Pacific Lumber Company in Bear Creek watershed (PWA 1998a) and North Fork Elk River watershed (PWA 1998b) demonstrate that this is not the case in these areas: sediment inputs from road-related landsliding are minor compared to those from recently logged hillslopes. At Bear Creek, 228,500 yd^3 of sediment has been produced between 1994 and 1997 by landsliding on recently logged slopes, while only 53,520 yd^3 of sediment has been contributed from *all* road-related sources between 1990 and 1997 (PWA 1998a). The report contracted by Pacific Lumber Company states that:

> *"In 1996/97, over thirty years after the 1964 storm, approximately 37% of the Bear Creek watershed was in a state of "recently" harvested condition (<15 year old harvested slopes). In response to the 1996/97 storm event, 34 landslides (78% of the total) occurred on this recently managed part of the basin.... Approximately 85% of the 1996/97 landslide sediment delivery came from this 37% of the watershed." (PWA 1998a p.18 ph.4)*

Using this information to calculate the rate of input per unit area shows that rates of landsliding on lands logged within the last 15 years are 9.6 times higher than those on lands that were last cut 30 or more years ago (Reid 1998b). Note that in these calculations, the size of the storm generating the landsliding is irrelevant, as the effects of the same storms are being compared on the recently logged and the partially recovered land. Note also that the 9.6-fold increase in landsliding rates on recently logged land is occurring despite implementation of the California Forest Practice Rules.

A similar pattern is evident from the study contracted by Pacific Lumber Company in North Fork Elk River watershed (PWA 1998b). In this case, rates of landsliding on the recently logged lands are 13 times higher than those on forested slopes (Michlin 1998).

In some cases, entry of a shallow landslide into a Class III channel can trigger the formation of a debris flow, as described above. In Japan, standing trees are recognized as an important protection against damage from debris flows because trees can block the flows, and experiments have been carried out to determine what tree spacing is most effective for halting debris flows that are already in motion (e.g. Omura and Hara 1984). Under forested conditions, debris flows are more likely to be stopped by standing trees and large woody debris before they reach downstream channels. The earlier a flow stops, the less it erodes and the less its sediment impacts downstream habitats and property.

In a stable channel, average rates of channel bank erosion are determined by the rate at which banks encroach into the stream through soil creep. Erosion is most rapid during high flows, but the average form of the channel remains relatively constant. Rates of down-cutting are usually low compared to rates of bank erosion. If peak discharges increase, erosion rates will also increase. Incision may occur if the bed is erodible under the new flow conditions, and bank erosion may increase until a new channel form is achieved that is stable under the new flow regime.

Surface erosion is not widespread under natural conditions unless a relatively intense fire has occurred. The most effective surface erosion occurs where water flows on a soil surface unprotected by organic material. Soils in forests tend to be highly permeable and covered by a layer of sponge-like duff. Under these conditions, any surface runoff which does form tends to flow so slowly that it has little erosive power and it is rarely exposed to erodible soil. During the largest storms, saturation can cause surface flow even on very permeable soils, but intact duff still limits the flow’s opportunity to erode.

The size and shape of stream channels is strongly influenced by the quantity, size, and timing of the input of sediment to those channels. If the nature of the sediment input changes, the form of the channel will change in response. If large quantities of sediment enter a channel over a short period, much of the sediment will usually be stored in the channel, and in forests much of the storage is behind in-stream logs. Where logs are not present, sediment moves more readily downstream to be deposited in low-gradient reaches.

Under natural conditions, the balance between channel form and sediment input is generally such that flood-related deviations from the average form are relatively short-lived. With a chronic increase in sediment load, however, the deviation becomes the norm: there may no longer be enough time between sediment input events for the channel to recover. Similarly, if a single storm’s sediment input greatly exceeds that characteristic of a storm of that size, the length of time needed to recover from that single storm may be very long. For example, the major storm in 1964 triggered very high rates of landsliding on and downstream of logged slopes in Redwood Creek, producing a sediment input far larger than that produced by similar storms before logging (Harden et al. 1995). The earlier storms left little evidence of aggradation, while extensive terraces remain from the 1964 storm. Downstream sites are still experiencing aggradation resulting from the 1964 storm, 30 years after the storm occurred (Madej and Ozaki 1996). It is clear, then, that maintenance of adequate aquatic habitat and downstream channel stability requires that sediment inputs during any given storm are similar to those that were present under pre-management conditions. This is a situation where prevention of downstream channel changes is imperative, because once those changes occur, they will persist for a very long time and will themselves provoke further adverse changes. Cumulative effects are assured when the recovery time for the impact is longer than the recurrence interval for the activity that triggers the impact.

There is recent evidence that such cumulative impacts are now occurring to Freshwater Creek. Data from Freshwater Creek (USACE 1975, Cafferata and Scanlan 1998) show that aggradation since 1975 has resulted in a loss of about 30% of the channel cross-sectional area in the downstream reaches likely to be most sensitive to sediment inputs. Flood-routing calculations (see Appendix 4) demonstrate that the observed change in cross-sectional area would lead to approximately a 1-foot increase in flood heights for a given discharge (Figure 8). This change is equivalent to approximately doubling the frequency of flooding at these sites (Figure 9). Locations of the cross sections showing aggradation suggest that the aggradation may be associated with the extensive road- and logging-related landsliding and debris-flow activity that occurred in the winter of 1994-95 in Little Freshwater Creek watershed. In addition, the recent increases in logging intensity and road use have been accompanied by increased erosion elsewhere in the watershed as well, and sediment from these sources would have accumulated along with that from the Little Freshwater Creek landslides at downstream sites.

Altered sediment loads also change the nature of channel bed materials. Under conditions where sediment inputs are less than the transport capacity of channels, channel beds tend to become covered by a layer of coarse sediment: finer sediment on the surface is efficiently removed during a range of flows, while the coarser sediment remains until mobilized by the highest flows. Underneath the coarse layer is sediment that reflects the full distribution of grain sizes available, but this sediment is protected from scouring by the presence of the coarser “armor.” Where sediment inputs increase, not as much opportunity exists for winnowing of the surface layers, and the average grain size of the surface layer tends to decrease (Dietrich et al. 1989). Under these conditions, channel beds can be scoured to a greater depth during moderate to large flows because the protective armor layer is not well developed. Salmonid spawning behavior evolved during a period when sediment loads were lower than at present, and the depths to which salmon dig their redds reflect the scouring regime present under pre-management conditions. Increased sediment loads, accompanied by decreased surface grain sizes on channel beds, lead to increased destruction of salmon spawning redds and newly hatched salmon through scour.

The finest sediment is carried relatively quickly through a watershed, but it contributes to increased turbidity as it travels. Under natural conditions, forested streams tend to clear quickly after a storm, and small storms do not generally provoke noticeable increases in turbidity because the primary sediment sources (landslides, bank erosion, and uprooting) are rarely activated by small storms. In watersheds managed for timber production, in contrast, large areas of bare soil are present on road surfaces, road cuts, tractor skid trails, and landslide scars, and these areas are susceptible to surface erosion during even small storms. Durations of high-turbidity flow tend to be lengthened, and the turbidities attained tend to be higher than under unmanaged conditions.

Turbidity data provided by Salmon Forever’s Watershed Watch program (J. Noell, unpublished data) demonstrate this effect. These data were used to construct relationships between turbidity and streamflow for unlogged or recovered tributaries in Humboldt Redwoods State Park (Franciscan sedimentary rocks and Yager formation), for logged and partially logged tributaries intersected by Shively Road (Wildcat Group rocks), and for the 70% logged Graham Gulch tributary watershed of Freshwater Creek (primarily Franciscan sedimentary rocks). The relationships were then applied to a flow-duration curve constructed for a 2.45-mi^2 watershed (i.e. the size of Graham Gulch) using US Geological Survey data (Jorgensen et al. 1971) from upper Jacoby Creek, which shares a divide with Freshwater Creek (Figure 10). Bisson and Bilby (1982) found that juvenile coho salmon actively avoided water with turbidity higher than 70 NTU. Turbidity monitoring results show that this level would have been exceeded for an average of 3 days every year if Graham Gulch were experiencing the sediment regime characteristic of pristine areas in Humboldt Redwoods State Park (Figure 10). Under disturbed conditions represented by the Graham Gulch data and the Shively Road data, however, this level would be exceeded for 43 days and 130 days, respectively. Under pre-management conditions, avoidance of these turbidity levels was possible because of the wide distribution of clear-water Class III channels which provided plumes of clean water where they entered larger, more turbid tributaries. Under present conditions, however, the Class III tributaries consistently carry high suspended sediment loads because they receive road-surface runoff and they have no forested buffer strips to reduce entry of surface-erosion sediment. Salmon are thus being adversely impacted both by the increased turbidity levels and by reduced opportunities to escape from high turbidities.

Because coho salmon and other Pacific salmon rely on sight to find their food, a decrease in water clarity can interfere with their ability to feed. These chronic, sub-lethal impacts on feeding success carry serious implications for the ability of coho salmonids to grow and survive. Working with walleyes, Jonas and Wahl (1998) found that starvation not only directly impacts the fitness of the fish, but also increases their vulnerability to predation. A variety of studies discuss the ranges of turbidity that adversely impact salmonids; these are tabulated and described by Lloyd (1987) and Newcombe and MacDonald (1991). Sigler et al. (1984), for example, found that their attempts to evaluate coho salmon and steelhead behavior at turbidities of 100-300 NTUs were unsuccessful: “fish either left the channels or died” (Sigler et al. 1984), and subsequent experiments at lower turbidities demonstrated lower growth rates with increased turbidities. Figure 10 indicates that although turbidity levels in excess of 300 NTU were not likely to have been attained under pre-management conditions, they are expected to occur for 3 to 14 days each year in tributaries the size of Graham Gulch that are being intensively logged, suggesting that some mortality may already be occurring due to high turbidity.

Increased sediment loads can also have serious impacts on estuaries, causing infilling that decreases the volume of water that courses in and out of the estuary as the tide changes. Such changes have long been a concern for estuary navigation because a decrease in tidal flow allows shoaling of the estuary mouth (e.g. Gilbert 1917). Frequent dredging is now needed near Eureka to keep navigational channels open; some of the sediment that needs to be dredged is contributed directly from tributaries to Humboldt Bay, while some originates from the coast beyond the bay. Aggradation-induced reduction of tidal flow would produce shoaling of the channel from both sediment sources because current velocities would decrease at the bay’s mouth.

As was the case for the woody debris and hydrology regimes, the pre-management sediment regime was an important influence on the development of downstream aquatic ecosystems and land uses. Characteristic sediment loads led to characteristic habitat distributions, and characteristic levels of turbidity permitted both the maintenance of those ecosystems and the development of domestic and agricultural use of the water. To the extent that forest land use modifies sediment loads in streams, channel habitat and downstream water quality will be modified away from those upon which the downstream beneficial uses depended. The effectiveness of SYP/HCP in preventing cumulative impacts can thus in part be assessed by evaluating the extent to which the plan reproduces the sediment regime to which the land-use patterns and aquatic ecosystem were adjusted.

2. Implications of the SYP/HCP for the sediment regime

The SYP/HCP addresses the sediment regime by prescribing measures that are asserted to be sufficient to decrease sediment inputs to levels that will not aggravate existing cumulative sediment impacts. These measures include:

a. Inspection of areas of “extreme” landsliding potential by a licensed geologist
b. “Storm-proofing” of existing roads, to be carried out over the next 50 years
c. Watershed assessment

Unfortunately, each of these provisions is inadequate for reasons described below. In addition, several other sediment-related problems fall outside these categories, and are considered below in section d:

d. Other sediment-related problems

a. geological inspection

First, areas of “extreme” landslide hazard are defined using a procedure described in II-D of the SYP/HCP. No documentation is provided to justify the values assigned to the various sensitivity factors used; no basis was given for equating values between factor classes (i.e. why is presence of Yager formation considered to equal the effect of a 35 to 50% slope?); and results of the classification were not tested. Standard practice for developing such a classification system (e.g. Lewis and Rice

1989) would have been to identify factors (including type of silviculture) potentially influencing landsliding rates, to statistically test the association of landsliding with each factor or combination of factors, and to use standard statistical methods to determine the relative weightings of the factors or combinations of factors found to be significant. The resulting method would then be tested against a known distribution of landslides to determine whether landslide hazard was adequately described by the method. Levels of tolerance would be identified based on the observed levels of impact for given values of the hazard index. However, no part of the standard approach appears to have been used to develop the method presented by the SYP/HCP, the method was not tested to determine whether it is valid, and boundaries between stability classes are arbitrary.

Comparison of the locations of the major problem-causing landslides known on lands addressed by the SYP/HCP (the largest Bear Creek slide, the slide that partially destroyed the town of Stafford, the slides that resulted in issuance of a water quality abatement order for North Fork Elk River, and the slides that resulted in the requirement for remedial work in Little Freshwater Creek watershed) with the map of landslide hazard index included in the SYP/HCP (vol. V, map 13) demonstrates that *none* of those slides are located on land classified by the SYP/HCP index as being of “extreme” landslide potential. Under the SYP/HCP, none of these sites would have required geological inspection on the basis of the landslide hazard index.

Examination of the map also indicates that management practices on the ownership appear to have pervasively increased the landslide hazard for a given rock type. In the Bear Creek area, for example, the boundary between “high/very high” and “very low” landslide hazard is exactly colinear with the boundary between PL lands and Humboldt Redwoods State Park. The same rock type produces “very low” landslide hazard under old growth and “high” to “very high” landslide hazard under second growth and recently logged conditions, strongly implicating silvicultural practice as an important control on landslide hazard in the area.

Slope stability provisions of the SYP/HCP call for geological evaluation of sites before logging if those sites fall into the “extreme” category. The rationale for selecting this threshold of concern is nowhere explained, and is troublesome given the fact that the original agreement between NMFS and the company provided for examination of all sites that fell into “high,” “very high,” or “extreme” categories (IV-D-sec.3-p.15).

Areas of inner gorges, headwall swales, and existing landslides are also subject to geologic review before they are logged. However, experience from past implementations of the pre-permit agreement indicate that the kind of geological evaluation to be used will not be effective. THP 1-97-307 HUM was reevaluated under the provisions of the pre-permit agreement, for example, and analysis by a licensed geologist hired by Pacific Lumber Company resulted in no changes to the silvicultural prescription on the basis of slope-stability concerns:

> *“Note, also, that a significant portion of lands indicated on THP 97-307 page 122.7 (revised 6/11/98) to be of special concern for slope stability are to be clearcut. Silvicultural prescriptions were not modified for areas outside of WLPZs on the basis of the new slope-stability considerations: the silvicultural prescription described on the 10/24/97 revision of page 5 of the plan (THP 97-307 p.5) is identical to that on the version of the same page revised on 6/11/98, which accompanies the revised landslide hazard map (THP 97-307 p. 122.7, revised 6/11/98). About 64% of THP 97-307 is to be clearcut even though 80% of the plan area is mapped as being inner gorge or headwall swale (THP 97-307 p. 122.7, revised 6/11/98).” (Reid 1998c, p.2)*

Changes that were incorporated into the plan resulted from implementation of mandated buffer zones and the presence of a spotted owl.

The implication here is that standard prescriptions from 1996 plans are considered by the company's geologists and by California Division of Mines and Geology (CDMG) geologists to be sufficient to meet the slope stability requirements of the SYP/HCP, irrespective of the results of Pacific Lumber Company's Bear Creek study (PWA 1998a), which demonstrated that those standard prescriptions result in a 9.6-fold increase in landsliding rate on the same rock type. The CDMG has indicated that they will allow only state-licensed geologists to assess the slope-stability-related prescriptions, and state licenses are generally held only by state employees and private consultants. The most widely recognized experts in landscape-scale slope stability generally work for universities and so do not have the necessary license. Because the mass-wasting-avoidance prescription for areas of "extreme" landslide hazard, inner gorges, and headwall swales thus rests on the opinions of those who have been unable to prevent the 9.6-fold to 13-fold increase in landsliding rates that is currently occurring, the provision for geologic review is essentially meaningless.

b. "storm-proofing" roads

The storm-proofing program is very important, as it brings the road system into line with accepted practices for construction of new road systems: diversion potentials are reduced at culverts and perched fills are pulled back, among other provisions. However, the effectiveness of these practices in decreasing overall sediment input from roads has not been measured. Even though the practices are highly likely to reduce the amount of sediment contributed from roads, there is no indication of whether the reduction will account for 5% or 50% of the total road-related sediment inputs. Indications from recent storms in Redwood Creek indicate that during lengthy, low-intensity storms, high rates of landsliding can occur from failure of what had appeared to be stable road fills, while failures due to over-topping or diversion at culverts are relatively infrequent (M. Madej, US Geological Survey, personal communication). "Storm proofing" does not modify the frequency of failure of what appear to be stable road fills. High intensity storms, in contrast, tend to cause problems at culverts without destabilizing fills at other locations, and these culvert-related problems are the ones that "storm proofing" is best able to address. "Storm-proofing" thus is a very good idea, but it is certainly not a panacea. Roads will continue to fail even after "storm-proofing," and the overall effectiveness of the method will need to be evaluated to determine the extent to which it redresses road-related problems.

In any case, scheduling of storm-proofing to progress at a rate slower than that at which most of the roads were originally constructed does not seem reasonable. Improperly designed and maintained roads are a known controllable source of sediment, downstream nuisance, and water quality impairment. Ordinarily, unnecessary postponement of repairs needed to prevent damage to others' properties would not be considered an appropriate management policy. If the slow pace of road repair is intended to provide the "currency" for mitigation banking, the effort is misplaced. As demonstrated by the Bear Creek study (PWA 1998a), prevention of all road-related sediment production between 1990 and 1997 would have offset less than 25% of the sediment produced from silviculturally related landslides during that period.

c. watershed assessment

The SYP/HCP calls for future watershed assessments to provide additional information about landsliding and other sediment inputs. However, the SYP/HCP also makes it clear that the company cannot be "compelled" to exceed the maximum limits listed on IV-D-47. These limits are internally inconsistent: a maximum limit for the no-cut zone along Class I and Class II streams is given as 30 feet and 10 feet, respectively, yet the 30- to 170-foot and 10- to 100-foot zones beyond these maximum limits of "no-cut" are indicated to include the possibility of "exclusion of all harvest." It is not clear which provision would be cited as the intended maximum if a watershed assessment were to suggest that a 150-foot no-cut buffer should be left. Although the company's listing of three situations in which it "may" agree to exceed the maximum limits is laudable, the past record of its ability to attain the *minimum* limits provided by California Forest Practice Rules would need to be examined before its likelihood of voluntarily agreeing to exceed *maximum* limits of the SYP/HCP could be assessed.

The watershed assessment procedure now being used in Freshwater Creek watershed (Koler 1998a, Koler 1998b) calls for sediment sources to be assessed only with respect to their ability to contribute sediment to Class I and Class II streams. However, approximately half the length of a stream network is in Class III streams, so these small streams provide the single most important route for conveying sediment from hillslopes to the channel system. Any assessment procedure that ignores sediment input to Class III streams will provide invalid results. This issue is particularly important in view of the lack of forested buffers around the Class III streams: these are stream channels that will be logged. Equipment exclusion is not sufficient to prevent surface erosion at such sites or sediment transport through them. Work by Megahan (1987), for example, demonstrates that sediment yields can double after helicopter logging and burning of 23% of a watershed even when a forested 25-foot buffer is left around all adjacent streams. Surface erosion processes become active during smaller storms than do landsliding or channel erosion, so surface erosion is a particularly important influence on chronic turbidity levels.

It should be noted in this context, also, that surface erosion on seasonal, unrocked roads is also a major problem in the area. Casual observations of unused, unrocked roads in the area mid-way through the wet season of last year showed the presence of extensive rilling to depths of as much as 12". During large storms, soils are saturated enough that even flow diverted onto hillslopes by water bars may travel overland far enough to contribute their sediment load to streams. On these slopes, separation from a Class III channel is not a guarantee that sediment will not be delivered to the channel by surface flow. In particular, unchannelled swales are often the site of saturation overland flow during moderate to large storms in the area, and sediment-laden waters discharged into such features then will enter downstream channels.

d. other sediment-related problems

In addition to these problems, other aspects of the SYP/HCP will further aggravate existing sediment-related problems. First, the SYP/HCP does not adequately address the role of logging itself in triggering landslides, despite the data presented in studies contracted by Pacific Lumber Company that demonstrate a 9.6-fold increase in landslide rates after logging in Bear Creek watershed (PWA 1998a) and a 13-fold increase in North Fork Elk River watershed (PWA 1998b). About 10% of the most recent logging-related Bear Creek landslides were not associated with features that would require geological evaluation, and these alone would have increased the landsliding rate by at least 86% over background conditions. Reduction of the frequency of these landslides to levels that would meet the objectives of the Basin Plan could be achieved only through control of the rate of cut in a watershed and through consistent protection of sites likely to be destabilized by logging. The only provision for modifying rate of cut under the SYP/HCP is through the "disturbance index," but the threshold value of the disturbance index that elicits concern is high enough that the rates of cut that caused the Bear Creek and Elk River problems are not at all constrained.

Second, the SYP/HCP appears to call for a long-term conversion of vegetation from a redwood-dominated to a Douglas-fir dominated forest. Because redwoods resprout from their roots after being cut, root strength is not diminished to the same extent after cutting as it is for non-sprouting species such as Douglas-firs. There thus will be a long-term increase in the frequency of logging-related landsliding and debris flows as the vegetation conversion takes place.

Third, the provisions specified for winter road use will result in continued high inputs of suspended sediment from road-surface erosion during storms. Even though use is proscribed during and immediately after rainstorms, use is not constrained on wet road-beds at other times. Fine sediments are brought to the surface of roads in part by the "pumping" of fine-grained subgrade materials up through the surfacing gravels by traffic on a wet road bed. Mud on the surface is then washed off during the next storm, irrespective of whether the road is being trafficked during the storm. In-storm traffic increases sediment production rates over those on temporarily non-used roads, but erosion rates remain high even on the temporarily non-used roads (Reid and Dunne 1984). Continued high rates of winter road use under the SYP/HCP thus will prolong the period of high chronic turbidity in coho-bearing streams.

3. Interactions between the altered sediment regime and other watershed components

An altered sediment regime strongly influences both the woody debris and hydrologic regimes. The expected continuation of accelerated erosion rates will continue to increase downstream aggradation, further burying woody debris and making it ineffective in meeting habitat needs. Increased debris flow incidence due to the further depletion and eventual complete absence of effective woody debris in Class III channels will likely be an important factor in the aggradation. The expected increase in downstream aggradation will also continue to cause increases in flood heights such as those illustrated in Figure 8.

Other interactions have been discussed in previous sections.

4. Comments on the SYP/HCP's analysis of sediment-related cumulative impacts

Provisions of the SYP/HCP for sediment control appear to be weak primarily because the analysis does not account adequately for geomorphological conditions characteristic of this area and because the implications of the studies cited in IV-D-72ff are not adequately considered in the design of the SYP/HCP. For example, the importance of a forested buffer is discussed in IV-D-72 to 75, and an argument is made that a forested buffer strip is necessary for trapping surface erosion sediment and that a width of 100 to 170 feet is sufficient. Yet half the stream network—and thus half the opportunities for introducing surface erosion sediment—is in Class III channels, and there are no forested buffer strips prescribed on Class III channels. A "mitigation" of not using heavy equipment adjacent to the channel while it is being clearcut is not a mitigation for minimizing controllable sources of sediment to levels required by Basin Plan objectives. By that argument, dumping only half a can of paint-thinner in a creek is a mitigation for reducing paint thinner in creeks, since a whole can *could* have been dumped. The fact that not dumping the can in the first place is a reasonable alternative—and one that would attain the desired objectives—needs to be taken into account.

The SYP/HCP's lack of sufficient controls for road-surface erosion appears to be based, in part, on a lack of appreciation of the likely impacts of high levels of chronic turbidity on salmonids; these impacts do not appear to have been discussed in the SYP/HCP. Impacts of turbidity on salmonids have been demonstrated by research carried out by Dr. Jeffrey Barrett (Barrett et al. 1992), among others. In addition, the SYP/HCP does not adequately recognize the importance of various practices in causing high turbidity levels. For example, the SYP/HCP (IV-D-77) cites the Bear Creek study (PWA 1998a) as having established that only 1% to 2% of the erosion in Bear Creek watershed was from road surface erosion. In reality, the study's "analysis" of the contribution of road-surface erosion to the overall sediment is described *in toto* by the sentence, "However, in light of the large volumes of sediment delivered by both mass wasting and fluvial erosion outlined in Table 6, as well as inner gorge and stream side landslides described earlier (Table 5), we estimate that surface erosion processes account for no more than 1% to 2% of all sediment production and delivery in the watershed" (PWA 1998a, p.22 ph.4). This does not constitute a valid analysis of the input rate from this source.

The discussion of sediment input from mass wasting is based primarily on information from studies by PWA in Bear Creek (PWA 1998a) and the lower Van Duzen and Eel River watersheds (PWA 1998c). Unfortunately, the latter study did not evaluate the proportion of the sampled area devoted to different management practices, so results cannot be used to identify relative rates of landsliding. Discussion of the Bear Creek report focuses on the analysis of rates of occurrence of large landslides. As described by Reid (1998b), however,

> *"The report implies that rates of landsliding during the second cycle of logging have decreased to near background levels: 'In 1997, the frequency of large and very large landslides triggered by the 1996/7 storm had dropped to levels close to that seen in the 1947 photography' (p.17 ph.3). This assertion was based on a simple comparison between the number of landslides of greater than 5000 yd^3 assumed to be generated between 1897 and 1947 (10 slides) and the number generated between 1966 and 1997 (11 slides). However, 70% of the latter (or 8 slides) were presumably (on the basis of Table 5) generated between 1994 and 1997. Thus, an estimated rate of 11 slides in 50 years is being compared to a present rate of 8 slides in 3 years, actually 'demonstrating' a 12-fold increase in large landslides." (Reid 199b)*

Of particular importance in the Bear Creek study is the discovery that 12% of the slides were associated with planar slopes and 12% with "breaks in slope", which will not be protected through the mass-wasting avoidance strategy. This important information was not considered in the SYP/HCP's discussion of sediment input from mass wasting. It is likely that this oversight is partially responsible for the lack of any mechanism in the plan to address the overall increase in landslide rate that will be triggered by intensive silviculture even in watersheds where the landforms of known susceptibility to landsliding are fully protected.

5. Potential alternatives to decrease cumulative impacts arising from altered sediment

Given the dominating importance of silviculturally related landsliding in this area, as demonstrated by studies contracted by Pacific Lumber Company (PWA 1998a, PWA 1998b), it is evident that any effort to decrease cumulative impacts arising from sediment inputs would need to address the relation between silvicultural practices and landsliding. Data from Pacific Lumber Company's study in Bear Creek (PWA 1998a) have been used to show how such an approach might be designed (Appendix 5). In this case, calculations demonstrate that a cutting cycle of about 64 years (using the average proportions of different silvicultural strategies employed between 1985 and present) could be sustained in Bear Creek watershed to reduce excess landslide inputs to comply with the Basin Plan if—and only if—all inner gorge slopes, headwall swales are not cut and cutting progresses no more rapidly than at a rate of 1.5% per year. In other words, cutting would need to be distributed evenly through the cutting cycle in the watershed, rather than being concentrated in the first portion of the cycle.

If levels of chronic turbidity are not to be increased in the future, measures would be needed to protect Class III channels from inputs of surface-eroded sediment, and more effective controls would be needed on wet-season road use. The first could be accomplished by prescribing a low-intensity selective harvest for the immediate vicinity of Class III channels, while the latter could occur through increasing the duration of proscribed road use to allow road beds to dry more thoroughly after storms. Since the intensity of winter operations has only recently increased, it is clear that a lower intensity of winter operations is compatible with a viable timber industry.

Given the difficulties in obtaining compliance that are already evident through the company's recent history of violations of the Forest Practices Act, and given the difficulties already experienced by the agencies and the company in reconciling differing interpretations of the pre-permit agreement, it would be very useful to establish an independent technical review board to determine whether the intent, rather than the letter, of the provisions is being adhered to. Such a board would be necessary if provisions such as the mass-wasting avoidance strategy and watershed assessment procedure outlined by the SYP/HCP are to be considered credible.

Cumulative watershed impacts

1. Cumulative influences of expected changes in watershed components

Changes in the production and transport of water, woody debris, and sediment due to implementation of the SYP/HCP will interact to cause a variety of impacts on downstream aquatic ecosystems and beneficial uses, as described below:

a. cumulative impacts to coho salmon and other anadromous salmonids

Spawning gravels would be increasingly infiltrated by fine sediments, thus killing salmon eggs and newly hatched fry, as rates of sediment input continue to increase. Increased erosion rates—and eventual perpetuation of rates at a high level—would lead to fining of downstream stream-bed gravels, thus increasing their susceptibility to scour during high flows. Increased peak-flows due to the increased proportion of each watershed's forest cover that is maintained at an early stage of hydrologic recovery would also increase the frequency and depth of scour at these sites. Salmon eggs and newly hatched fry thus would be killed more frequently by scour than in the past.

Summer rearing habitat for coho salmon would be increasingly impaired through expansion of the number of stream channels that have been affected by debris flows. In addition, continued removal of much of the last remaining sources of old-growth woody debris (i.e. residual old-growth within falling distance of streams) would continue the trend of decreased presence of woody debris of sizes characteristic of the environment in which the salmonids evolved. Loss of such wood, and decreased opportunity for infall of smaller pieces due to inadequately sized and managed riparian buffers, would lead to a pervasive decrease in the ability of downstream environments to provide the cover, food, and channel conditions upon which the fish depend.

Removal of the remaining sources for old-growth-sized wood would also mean that winter rearing habitat will be adversely impacted, as large wood has in the past provided refuge sites capable of remaining stable even in the highest flows. Winter habitat would also be increasingly subject to high levels of chronic turbidity as the road system continues to expand and winter operations continue at a high intensity. Levels of turbidity already present in some of the most intensively logged watersheds reach values associated with death of coho salmon (Figure 10), so expansion of the area subjected to high levels of turbidity would both directly impact the fish and reduce the opportunity for escape to cleaner water.

Out-migration and in-migration would be impacted through downstream changes. Continued accumulation of sediment in downstream channels reduces cover and reduces opportunities for thermal refuge by filling downstream pools. Increased flood peaks would cause increased bank erosion in downstream channels, widening and shallowing the channels. These changes impact all fish that migrate through the affected downstream reaches. Thus, coho salmon that are spawned and reared under more advantageous conditions on National Forests or Bureau of Land Management lands upstream in the Eel basin or Mattole would suffer increased mortality during their out-migration due to the downstream cumulative impacts from lands managed under the SYP/HCP.

Both out-migration and in-migration also would be impacted through changes to estuaries. Aggradation due to continued high sediment loads would decrease access to protective cover and increase estuary temperatures. Decreased tidal flow increases aggradation at the bay-mouth, prolonging the period during which the estuary is cut off from the sea. Closure of the bay mouth may prevent out-migration of some stocks if the timing is disadvantageous. Predation rates would increase due to loss of cover.

b. cumulative impacts to other components of the aquatic ecosystem

Any change affecting salmonid habitat would also affect the suitability of the habitat for other components of the aquatic ecosystem. In particular, balances in competition between different species may shift, provoking a change in relative abundance of species. Sturgeon may be severely impacted in downstream reaches through filling of pools by sediment and sediment-related impairment of estuary habitats.

Changes in estuary conditions also seriously impact coastal fish that spawn and rear in estuaries. Shoaling of the estuary increases water temperature and increases the risk of predation by birds and marine mammals. Eureka is home to one of California’s most important bottom-fishing fleets, and the impact of accelerated infilling of Humboldt Bay on the economic viability of this remaining fishery will need to be evaluated. Humboldt Bay is also the site of most oyster production in California, and sedimentation is a major problem for oyster farms. Impacts of continued high sediment loads on the future viability of the oyster industry will also need to be evaluated.

c. cumulative impacts to downstream water quality

Continued high levels of chronic turbidity due to continuation of accelerated rates of landsliding, debris flows, and surface erosion would continue to impair water quality in downstream rivers.

d. cumulative impacts to downstream property and infrastructure

Downstream property and infrastructure would be susceptible to damage by increased flood magnitudes and frequencies caused by the decreased average hydrological maturity of the watersheds’ vegetation cover in combination with continued aggradation due to continued high rates of sediment input.

e. cumulative impacts to harbor use

Continued high rates of erosion due to landslides, debris flows, and surface erosion processes would continue to cause accelerated aggradation of Humboldt Bay, thus perpetuating the need for frequent dredging of navigational channels. Aggradation would occur due to both the direct effects of the high sediment loads and to their indirect effects on the volume of tidal flow.

2. Comments on the SYP/HCP’s analysis of cumulative impacts

The SYP/HCP implies that no adequate method is available for analysis of cumulative watershed impacts (IV-D-109). This is clearly not the case, as the preceding 20 pages of review constitute a major portion of a cumulative effects analysis conducted according to provisions of the Board of Forestry Technical Rule Addendum No. 2 (CDF 1997). Further, the SYP/HCP implies that future “trend monitoring” will take the place of cumulative effects analysis (IV-D-109). This is inappropriate unless the intention is to halt all management activities until results of the trend monitoring are available. The approach used by the SYP/HCP implies that it is not currently possible to follow the provisions of the California Forest Practices Act as they relate to the required cumulative effects analysis. If this is the case, the validity of all cumulative impact assessments carried out for previous THPs on PL lands is called into question.

With Technical Rule Addendum No. 2 in mind, it is necessary to mention the use of mitigation in the management of cumulative watershed impacts. Examination of recent THPs filed in the areas covered by the SYP/HCP indicates that “mitigation” of expected sediment inputs by repair of known likely sources is a method commonly used to offset sediment inputs that are acknowledged to result from the THP. Unfortunately, examination of the methods used to calculate the appropriate levels of mitigation shows that expected sediment inputs are being underestimated by as much as 10,000% (see, for example, discussions in Reid 1998c and Reid 1998d). In addition, mitigations do not necessarily take place in the watershed in which the plan’s sediment will be discharged. This means that individual streams will continue to experience cumulative aggravation of sediment-related impacts with each plan. Furthermore, offsetting mitigations have been carried out strictly through road and landing repairs and upgrades. Because both the Bear Creek (PWA 1998a) and North Fork Elk River (PWA 1998b) studies demonstrate that rates of road-related erosion are considerably lower than rates of silviculturally related erosion in this area, complete solution of road-related sediment problems would not be sufficient to offset the sediment inputs associated with logging. The “storm-proofing” program, however, cannot even completely solve the road-related problems.

Furthermore, it is not possible to mitigate the impacts caused by hydrological changes. Increased flooding due to altered vegetation cannot be lessened by any means other than a decrease in the area of vegetation affected in a watershed each year. Similarly, the roles played by large woody debris cannot be fulfilled through any form of mitigation. When cumulative impacts are to be addressed by off-setting mitigations, it is necessary not only to lessen the impact, but to cancel it out fully. If this is not done, then the level of downstream impact will be prolonged, thus constituting aggravation of an existing cumulative impact.

Analysis of cumulative watershed impacts is intended in part by the SYP/HCP to be accomplished through watershed assessment. However, the method upon which the intended assessments are to be based is not itself a method for assessment of cumulative watershed impacts; instead, it is a procedure for design of “best management practices” (Reid 1998e). The Washington State Department of Natural Resources watershed analysis procedure simply assesses several components of the existing process regimes in a watershed, and uses the results to design management practices. It does not assess the likely effects of planned practices, it does not consider impacts other than those to fisheries and capital improvements, and it does not consider impacts outside of the boundaries of the assessment area. Cumulative impact rules were added to the California Forest Practices rules in part because of recognition that the previous strategy of designing “best management practices” was not adequate to address cumulative watershed impacts. Appeal to the future design of a procedure to assess cumulative watershed impacts based on an existing method that does not itself assess cumulative watershed impacts does not constitute an adequate solution to the cumulative impacts problem. It is not reasonable that such a procedure should be accepted as adequate before it exists and without the opportunity for public review. As was demonstrated by the recent ruling in Oregon concerning NMFS’ decision not to list coho in that area, survival of the species cannot be allowed to rest on promises of better things to come.

Increases in the rates of logging over the past decade appear to be the major cause of the impacts currently of concern, as described above. Management of cumulative impacts will thus need to be carried out, in part, through management of the intensity of logging. The only mechanism available in the SYP/HCP for control of the cutting rate in a watershed is use of the “disturbance index” (DI) described in vol. II, part E: logging plans apparently are to be redesigned or deferred if the disturbance index surpasses a threshold.

However, the disturbance index suffers from the same major deficiency as the “landslide hazard index” described above: no documentation is provided to explain the values assigned to the various management activities. To construct a valid index, it would have been necessary to use data to determine what relative ratings are appropriate and to test the resulting rating against known levels of impact. Levels of tolerance would be identified based on the observed levels of impact for given values of the index. In this case, an effort was made to test the validity of the index, and results demonstrated that there was no correlation between the disturbance index and a presumed measure of the level of impact (II-H-24 ph.5). Ordinarily, if a test shows an index to be ineffectual in meeting its intended objectives, it would not be used as a basis for decision-making.

The disturbance index also does not incorporate a realistic description of the time necessary for recovery, and the description of how the recovery period was derived is highly troublesome: II-E-2 ph.3 states: “For simplicity, 10 and 20 year recovery periods were selected for analysis....” Later, at II-E-5 ph.1, we learn that “...a 10-year DI time factor was selected for reasons connected to SYP planning and implementation.” On this basis, full recovery is assumed by the SYP/HCP to require 10 years. Simplicity and convenience, however, have no valid basis for being the principal factors governing an index that controls the level of damage to downstream residents and aquatic ecosystems. A 10-year recovery period for the disturbance index is obviously inappropriate in an area with documented recovery periods of longer than 30 years (e.g. Madej and Ozaki 1996). When cumulative impacts are of concern, it is absolutely essential that the recovery period needed for the impact be the basis of a recovery curve, not that for the impacting activity. If the period of recovery for the impacted resource is longer than the period of recovery assumed for the disturbance index, it is not possible to use the index to evaluate the potential for cumulative impacts. This is a widely reported problem of the ERA method (e.g. Reid 1993), and it is distressing that the SYP/HCP’s modifications of the ERA method made this well-recognized problem worse rather than correcting it.

Disturbance index methods, such as the ERA method, have also been identified as deficient because they do not recognize the potential for multiple and interacting mechanisms of impact, or for the existence of multiple impacts with different patterns of causality. It is assumed that a particular activity has the same relative effect and the same recovery time for one kind of impact as it does for every other possible impact. In reality, if more than one kind of impact is important, then a set of coefficients and recovery times would need to be developed for each (Reid 1993).

In addition, application of the DI for the sustained yield projections results in continuation of current logging rates, despite the fact that these rapid rates are associated with the levels of cumulative impacts that led to the declaration of Freshwater, Elk, Bear, Jordan, and Stitz watersheds as being cumulatively impacted by the California Department of Forestry and Fire Protection, that led to the declaration of Freshwater, Elk, Eel tributaries, Van Duzen tributaries, and the Mattole as being sediment-impaired by the Environmental Protection Agency, and that led to reports of increased flooding in Elk and Freshwater by local residents. Any disturbance index that cannot identify existing problems is clearly in error.

Finally, the disturbance index is applied at the scale of “Watershed Assessment Areas.” This scale is clearly inappropriate for evaluating the potential impacts to beneficial uses that depend on smaller-scale watersheds. Complete disturbance of a 3 mi^2 watershed that is necessary for coho rearing habitat would not even be noted by a disturbance index averaged over the 476-mi^2 Bear-Mattole watershed assessment area, for example. Use of any disturbance index would need to be keyed to the scale relevant to the impacted resource or beneficial use. If coho are using 3 mi^2 watersheds, then that is the scale relevant to impacts on coho; if domestic water use occurs at the mouth of a 10 mi^2 watershed, then that is the scale relevant to the water users. For estuary impacts, the portions of any assessment areas that drain into the estuary of concern would need to be evaluated.

3. Potential alternatives to reduce cumulative impacts

Because many of the hydrologic and sediment-related impacts of concern arise from the intensity of logging in a watershed, use of disturbance indices that are based on an understanding of the mechanisms of impact of concern in a watershed would be appropriate. The calculations described above for determining appropriate rates of cutting on the basis of rates of landsliding in Bear Creek watershed (Appendix 5) and on the basis of alterations of flood frequencies in Freshwater watershed (Appendix 3) could provide the basis for defining such indices. In any case, however, the indices would have to be based on recovery rates defined for the impacted resource or beneficial use, and provisions would need to be made for modifying indices due to the interactions of impact mechanisms. For example, if a series of management-related landslides led to increased aggradation hazard downstream, rates of cut would need to decrease for a period to ensure that interception-loss-related hydrologic changes would not combine with a decrease in channel conveyance to increase flood frequency. Also, disturbance indices would need to be defined separately for each potential mechanism of impact. Because of differences in geology through the ownership, changes in landslide rate would not be directly correlated with hydrologic changes, so a single index could not be used to describe both.

Of particular importance is the need to key application of a disturbance index to the geographic scale relevant to each of the resources or beneficial uses in question. Thus, rates of cutting would need to be evaluated and managed on the scale of the smallest watersheds inhabited by coho salmon or other species of concern. At the same time, evaluations would also need to be carried out at larger scales relevant to domestic and agricultural water use, downstream flood hazard, and harbor and estuary sedimentation.

Implications for meeting the objectives of Habitat Conservation Plans

Other SYP/HCPs will be developed for much of the rest of the private land holdings throughout the area of the evolutionarily significant unit (ESU) for coho salmon, and it is unlikely that the standards established by this SYP/HCP will be strengthened in those to follow. Were subsequent SYP/HCPs to be held to higher standards, accusations of “unequal protection of the law” and “inconsistency” would almost certainly be leveled at the regulatory agencies. A determination of whether such complaints would be upheld would need to be based on an evaluation of case law concerning inconsistent application of federal and state regulatory requirements. The HCP legislation requires that an HCP not lead to the extinction of the ESU, and thus indicates that there is an implied requirement to evaluate the cumulative impact of this HCP, in combination with foreseeable future actions, on the species in question. In this case, the foreseeable future actions are the application of similar standards for the rest of the industrial timberland holdings in this ESU. No such analysis has been done.

The HCP is thus fundamentally incomplete: it has not accomplished the single task that is most central to its purpose. However, the analysis of cumulative impacts described in the previous pages of this review allows some indication of what the results of such an analysis will be. The provisions of the SYP/HCP will lead to an expansion of the area of adversely impacted habitat throughout the property considered; they will lead to an increase in the severity of the existing cumulative impacts; and they will prolong the duration of exisiting impacts, thus aggravating the temporal cumulative impact. Projection of these results to foreseeable future actions—the SYPs and HCPs that will follow in other parts of the ESU area—thus indicates that application of these standards will lead to expansion of the area of adversely impacted habitat, increased severity of existing cumulative impacts, and prolonging of the duration of impacts throughout and downstream of industrial timberlands of the ESU. This area constitutes a significant proportion of the lands now depended on for habitat by the coho salmon. These lands, then, can no longer be relied upon to consistently provide habitat necessary for the survival of coho salmon.

It will thus be necessary for public lands to bear the major responsibility for preventing extinction of this ESU. Unfortunately, because the impacts that will accrue from the foreseeable future actions on industrial timberlands include off-site cumulative impacts, the habitat being impacted by the foreseeable future actions is habitat depended upon by fish that originate on tribal and public lands. It does little good to protect fish on National Forest or Bureau of Land Management lands through institution of the Northwest Forest Plan, only to have those fish destroyed by lethal downstream conditions caused by off-site cumulative impacts from industrial timberland management. What makes anadromous salmonids, and other denizens of aquatic ecosystems, different from many terrestrial species is that their survival depends on conditions throughout the watershed upstream of the habitats they physically occupy. Because they occupy habitats from their natal streams to the mouth of the estuaries, this means that the entire watershed must be in tolerable condition if impacts are not to accrue to the species everywhere in that watershed: it takes a watershed to raise a salmon.

Industrial timberlands tend to be located downstream of tribal and public lands in this ESU. Offsite cumulative impacts from those lands produce aggradation, increased flood frequencies, and increased chronic turbidity in the larger rivers downstream of both the lands in question and the tribal and public lands. All of these changes decrease the chances for survival of coho salmon as they migrate through the affected channel reaches. Tribal and public-land fish must migrate through the gauntlet of degraded habitats produced by activities on private lands. It should be noted that the foreseeable future actions, in this case, will themselves be influenced by the action for which evaluation is required—institution of this SYP/HCP.

Further, the plan contains no analysis of cumulative watershed impacts, and it contains no discussion of cumulative watershed impacts as a changed and unforeseen circumstance. It thus appears that, according to the “no surprises” rule (IV-H-1), any effort to reduce downstream cumulative impacts in the future will need to be paid for by those whom the company’s activities are damaging: the American taxpayer. It might even be argued that the taxpayers would become responsible for all downstream damages caused by the permitted activities on the ownership. No HCP that purports to protect aquatic habitat is complete without inclusion of a technically adequate analysis of cumulative watershed impacts, and deferral of such an analysis until after the plan is accepted is clearly unconscionable when the result is deflection of fiscal responsibility to the taxpayer. If the company is incapable of making such an analysis at this time, as they state (IV-D-109), then either acceptance of the HCP would need to be deferred until completion of the monitoring said to be necessary by the company (IV-D-109), or there would need to be provision made in the plan for the company’s acceptance of all fiscal responsibility for measures found to be necessary in the future for managing downstream cumulative impacts.

For the reasons outlined above, this proposed HCP will appreciably reduce the likelihood of the survival and recovery of the species in the wild. Unless the HCP can be fundamentally restructured to provide enforceable measures for preventing downstream cumulative impacts, the California Forest Practice Rules, if enforced adequately and if accompanied by guidelines for avoiding impacts to the species and habitats of concern, would provide a higher likelihood that coho salmon of this ESU will not become extinct. In addition, Forest Practice Rules will be improved over the next 50 years. The HCP will not, unless at taxpayers’ expense.

Implications for meeting the objectives of Sustained Yield Plans

Under provisions of the California Forest Practices Act, an SYP must address issues of sustained timber production, watershed impacts, and fish and wildlife (CDF 1997, p. 174). To the extent that these issues are addressed by the SYP, they will be considered addressed in the THP to follow. In the case of this SYP/HCP, none of these issues is satisfactorily addressed according to the requirements of the Forest Practice Rules.

First, the sustained yield plan must, “Consistent with the protection of soil, water, air, fish and wildlife resources...clearly demonstrate how the submitter will achieve maximum sustained production...” (CDF 1997, p.175). In other words, the ability of the SYP to address the issue of sustained timber production is contingent upon its ability to address issues of watershed impacts and fish and wildlife. In this case, the SYP/HCP overtly does not address cumulative watershed impacts: “PL does not believe any cumulative effects assessment methodology is available that can identify the incremental impact of a given amount of management activity” (IV-D-109), so no analysis of cumulative watershed impacts is attempted. Instead, a monitoring program is planned to allow future determination of whether implementation of the plan has caused cumulative impacts. In this case, however, analyses described in previous sections of this review have shown that the rate of logging currently implemented on these lands has had a major influence on the expression of cumulative watershed impacts. Protection of soil, water, and fish will thus require some constraint on the rate of cut. Without consideration of this need, it is not possible to predict what level of yield is sustainable. A cumulative effects analysis thus must be done before the long-term projections of yield required for the SYP are possible. The existing calculations for sustained yield are thus invalid, as they do not consider the changes that will be necessary to address silviculturally related cumulative impacts.

Second, the SYP must include a fish and wildlife assessment that “shall address threatened, endangered, and sensitive species and other fish and wildlife species which timber operations could adversely impact, resulting in significant adverse individual or cumulative impacts” and it shall address the impacts of harvesting on habitats needed by those species (CDF 1997, p.176). As discussed in earlier sections, however, the SYP/HCP has not attempted to assess the cumulative impacts of the plan on coho salmon or on other aquatic species.

Third, the SYP must include a watershed assessment that “shall include an analysis of potentially significant adverse impacts, including cumulative impacts, of the planned operations and other projects, on water quality, fisheries, and aquatic wildlife” (CDF 1997, p.176). As described by IV-D-109, the SYP has included no such analysis. Instead, pages III-H-4 and 5 simply provide lists of beneficial uses, possible impacts, and possible attributes to measure. Descriptions of measurements of specific attributes are referred to as they appear in volume II, section H of the SYP/HCP. This section, however, is simply a description of in-stream measurements made over a 4-year period, as interpreted on the scale of multi-watershed “watershed assessment areas;” it is a characterization of present conditions, not an analysis of cumulative watershed impacts, and certainly not an analysis of the cumulative impacts that will be caused by implementation of the plan. These measurements appear to be the foundation for those that are intended to be made to take the place of a cumulative impacts analysis, as described by IV-D-110. Furthermore, water quality was not considered in volume II, except insofar as water temperature was discussed. An analysis of cumulative impacts on water quality would include an evaluation of influences on chemical contamination and suspended solids, among other considerations.

The SYP thus does not provide a valid assessment of any of the three issues considered. All three will thus need to be evaluated for individual future THPs.

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Appendix 1. Calculation of woody debris input rates for Site Class 2

1. Unmanaged stand volume is estimated by extrapolating the Lindquist and Palley (1963) growth curves to a 300-year stand age for site indices (SI) of 160 and 180 and averaging the resulting values (equivalent to Site Class 2). Use of characteristics present in a 300-year-old stand may underestimate tree sizes present under old-growth conditions. Volumes are calculated for an "average" dominant tree in the stand by assuming a conical form for the tree:

160-SI stand basal area (ft^2) = 625 log (age) - 733 $r^2 = 1.00$ BA at 300 yr = 815 ft^2
180-SI stand basal area (ft^2) = 628 log (age) - 651 $r^2 = 1.00$ BA at 300 yr = 905 ft^2
estimate for 170 SI = 860 ft^2
160-SI canopy tree height (ft) = 181 log (age) - 203 $r^2 = 1.00$ height at 300 yr = 245 ft
180-SI canopy tree height (ft) = 195 log (age) - 210 $r^2 = 1.00$ height at 300 yr = 273 ft
estimate for 170 SI = 260 ft
160-SI trees/acre = -113 log (age) + 374 $r^2 = 1.00$ #/ac at 300 yr = 94
180-SI trees/acre = -144 log (age) + 440 $r^2 = 1.00$ #/ac at 300 yr = 83
estimate for 170 SI = 89
average basal area per tree = 860 ft^2 / 89 trees/ac = 9.66 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 9.66 ft^2 * 260 ft = 837 ft^3
average volume per acre = 837 ft^3 * 89 trees/ac = 74,500 ft^3/ac

2. Stand volume for "late seral prescriptions" is calculated from stand composition listed on p.65 of volume I of the SYP/HCP, assuming a dominant-tree height characteristic of 60-year-old SI 170 stands (130 ft) as calculated from data provided by Lindquist and Palley (1963). This height is used rather than the 170-foot height expected for a 100-year-old tree a it is clear from the stand composition tables on p.65 of volume I of the SYP/HCP that very few trees older than 60 years will be present. Given the intended preponderance of smaller trees (vol. I p.65), this approximation will overestimate the wood input likely from these stands.

average BA per acre = 276 ft^2/ac
average trees per acre = 126
average BA per tree = 276 ft^2/ac / 126 trees/ac = 2.19 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 2.05 ft^2 * 130 ft = 94.9 ft^3
average volume per acre = 94.9 ft^3 * 126 trees/ac = 12,000 ft^3/ac

3. Stand volume for "late seral, high residual prescriptions" is calculated in the same way as for "late seral prescriptions." In this case, too, wood input will be overestimated because of the preponderance of young age classes in the stands (vol. I p.65); the underestimate will not be as significant as for the "late seral" stands, however, because approximately 5 trees per acre with diameters of up to 40" will also be present.

average BA per acre = 345 ft^2/ac
average trees per acre = 108
average BA per tree = 345 ft^2/ac / 108 trees/ac = 3.19 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 3.19 ft^2 * 130 ft = 138 ft^3
average volume per acre = 138 ft^3 * 108 trees/ac = 14,900 ft^3/ac

4. Total potential input volume is volume per unit area in a unit-wide strip times the length of the strip that could contribute wood, estimated as the average canopy height:

unmanaged = 74,500 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 260 ft = 445 ft^3 per foot of channel
"late seral" = 12,000 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 130 ft = 35.8 ft^3 per foot of channel
"high residual" = 14,900 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 130 ft = 44.5 ft^3 per foot of channel

In reality, total potential input volume would equal a uniform fraction of these values, as only the upper portions of trees far from the creek can reach the channel and only the lower portions of those near the creek can do so. Because only ratios are considered in the following calculations and because the proportion of the potential input will be the same for each stand type, use of the uncorrected total potential input volume makes no difference to the results of the following calculations.

5. Annual mortality is assumed to be a constant percentage of the total potential input volume per unit area per year (Waring and Schlesinger 1985, p.212 ph.4), but that value is unknown for these stands. Total annual input is thus calculated as a ratio to that of an undisturbed stand, which is represented as 1.0:

unmanaged = M * 445 ft^3/ft = 1.0
"late seral" = M * 35.8 ft^3/ft / M * 445 ft^3/ft = 0.0804
"high residual" = M * 44.5 ft^3/ft / M * 445 ft^3/ft = 0.100

6. The distribution of falls contributing wood to the stream as a function of distance from the stream is described by the distribution measured in a second-growth redwood forest at Caspar Creek (Reid and Hilton 1998). This relation is expressed as a function of tree height, so the abcissa is multiplied by average tree height in each kind of stand. The ordinate is multiplied by the ratio of total annual input relative to that of the unmanaged stand.

7. Most trees at Caspar Creek fell downhill. Because of this, the bole diameter at the point of entry to the stream can be estimated as the diameter at a height equal to the distance of the source from the channel. This diameter is calculated by assuming the bole to be conical in form. Because the channel is narrow relative to tree height, and because channel width is variable, and because only the ratios between the stand types are of concern, the volume of wood input from the fall is indexed by the diameter at the stream bank. The ordinate of the graph described in (6) is thus also multiplied by the expected piece diameter at that distance from the bank. The resulting curves describe the volume input as a function of distance from the stream for uniform stands of each silvicultural prescription, relative to that for an unmanaged stand.

8. The effects of each buffer strip design are then calculated by combining the portions of the distribution curves relevant to the prescription. Thus the SYP/HCP prescription for Class I stream buffers includes the first 30 feet of the relation for unmanaged stands, the 30- to 100-foot segment of the relation for "high residual" stands, and the 100- to 170-foot segment of the relation for "late seral" stands.

Appendix 2. Calculation of woody debris input rates for Site Class 1

1. Unmanaged stand volume is estimated by extrapolating the Lindquist and Palley (1963) growth curves to a 300-year stand age for site indices (SI) of 200 (equivalent to Site Class 1). Volumes are calculated for an "average" tree in the stand by assuming a conical form for the tree:

200-SI stand basal area (ft^2) = 628 log (age) - 558 $r^2 = 1.00$ BA at 300 yr = 998 ft^2
200-SI canopy tree height (ft) = 207 log (age) - 214 $r^2 = 1.00$ height at 300 yr = 299 ft
200-SI trees/acre = -177 log (age) + 510 $r^2 = 1.00$ #/ac at 300 yr = 72
average basal area per tree = 998 ft^2 / 72 trees/ac = 13.9 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 13.9 ft^2 * 299 ft = 1385 ft^3
average volume per acre = 1385 ft^3 * 89 trees/ac = 123,000 ft^3/ac

2. Stand volume for "late seral prescriptions" is calculated from the stand composition listed on p.65 of volume I of the SYP/HCP, assuming a canopy height characteristic of 60-year-old SI 200 stands (154 ft) as indicated by Lindquist and Palley (1963):
average BA per acre = 276 ft^2/ac
average trees per acre = 126
average BA per tree = 276 ft^2/ac / 126 trees/ac = 2.19 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 2.19 ft^2 * 154 ft = 112 ft^3
average volume per acre = 112 ft^3 * 126 trees/ac = 14,100 ft^3/ac

3. Stand volume for "late seral, high residual prescriptions" is calculated in the same way as for "late seral prescriptions":
average BA per acre = 345 ft^2/ac
average trees per acre = 108
average BA per tree = 345 ft^2/ac / 108 trees/ac = 3.19 ft^2
average volume per tree = 1/3 BA * height = 1/3 * 3.19 ft^2 * 154 ft = 164 ft^3
average volume per acre = 164 ft^3 * 108 trees/ac = 17,700 ft^3/ac

4. Total potential input volume is volume per unit area in a unit-wide strip times the length of the strip that could contribute wood, estimated as the average canopy height:
unmanaged = 123,000 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 299 ft = 846 ft^3 per foot of channel
"late seral" = 14,100 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 154 ft = 49.8 ft^3 per foot of channel
"high residual" = 17,700 ft^3/ac * (1/43,560 ac/ft^2) * 1 ft * 154 ft = 62.6 ft^3 per foot of channel
As was the case for Site Class 2 lands, because only ratios are considered in the following calculations and because the proportion of the potential input will be the same for each stand type, use of the uncorrected total potential input volume rather than a constant proportion of those values makes no difference to the results of the following calculations.

5. Annual mortality is assumed to be a constant percentage of the total potential input volume per unit area per year (Waring and Schlesinger 1985, p.212 ph.4), but that value is unknown for these stands. Total annual input is thus calculated as a ratio to that of an undisturbed stand, which is represented as 1.0:
unmanaged = M * 846 ft^3/ft = 1.0
"late seral" = M * 49.8 ft^3/ft / M * 846 ft^3/ft = 0.0589
"high residual" = M * 62.6 ft^3/ft / M * 846 ft^3/ft = 0.0740

6. The distribution of falls contributing wood to the stream as a function of distance from the stream is described by the distribution measured in a second-growth redwood forest at Caspar Creek (Reid and Hilton 1998). This relation is expressed as a function of tree height, so the abcissa is multiplied by average tree height in each kind of stand. The ordinate is multiplied by the ratio of total annual input relative to that of the unmanaged stand.

7. Most trees at Caspar Creek fell downhill. Because of this, the bole diameter at the point of entry to the stream can be estimated as the diameter at a height equal to the distance of the source from the channel. This diameter is calculated by assuming the bole to be conical in form. Because the channel is narrow relative to tree height, and because channel width is variable, and because only the ratios between the stand types are of concern, the volume of wood input from the fall is indexed by the diameter at the stream bank. The ordinate of the graph described in (6) is thus also multiplied by the expected piece diameter at that distance from the bank. The resulting curves describe the volume input as a function of distance from the stream for uniform stands of each silvicultural prescription, relative to that for an unmanaged stand.

8. The effects of each buffer strip design are then calculated by combining the portions of the distribution curves relevant to the prescription. Thus the SYP/HCP prescription for Class I stream buffers includes the first 30 feet of the relation for unmanaged stands, the 30- to 100-foot segment of the relation for “high residual” stands, and the 100- to 170-foot segment of the relation for “late seral” stands.

Appendix 3. Calculation of change in foliage interception loss

Calculations were carried out for Freshwater watershed, for which a cutting history is available for the past 15 years. Map 14 of vol. V of the SYP/HCP indicates that first-cycle logging of the watershed was essentially complete by about 1950. Significant reentry did not begin until the late 1980s, and rates of cut in the interim were relatively low (Figure A3-1). The proportion of the watershed's forest canopy removed each year was calculated from a tabulation of areas subject to each silvicultural method each year. Clearcutting and seed-tree preparation cuts were assumed to remove the entire canopy, seed-tree removal was assumed to represent no canopy loss, and all other silvicultural methods were assumed to represent a 50% canopy loss.

Hydrologic recovery was then assumed to be complete in a 15-year period, with recovery occurring uniformly through that period. In reality, recovery of foliage biomass (and therefore of the rate of foliage interception of rainfall) is expected to take considerably longer, and the values used were selected as an overly-conservative estimate. Each year's change in canopy area was then diminished sequentially by 1/15 for the following 14 years, and the total area of new canopy loss for each year was summed with the partially recovered areas from previous years to estimate the effective level of foliage depletion for each year.

Data from Freshwater watershed indicate that interception relations measured by Rowe (1983) are likely to provide a good characterization of local conditions, and the lower of the two rates was adopted for calculations to provide an estimate of the minimum interception loss. Foliage interception was thus assumed to account for 22.5% of storm rainfall for storms larger than 8 inches (Figure 5 of review); effective rainfall on a clearcut tract would thus be expected to increase by a corresponding value.

Rain gauges are situated to avoid interception loss, so the storm rainfall frequency curve measured at Kneeland (located on the eastern margin of Freshwater watershed; data from Conroy 1998) describes the rainfall that would hit the ground in the absence of intervening foliage. The effective precipitation that would be experienced under 1975 conditions in Freshwater watershed was thus calculated by applying the 22.5% loss for each storm to the area of Freshwater with fully recovered forest cover at that time, applying no loss to the area with fully depeleted foliage, and applying proportional values to areas with different stages of recovery. Summing results over the watershed indicates that, on average, the watershed received 80.2% of the rainfall that would have been measured in a gauge for a storm of greater than 8 inches. Similar calculations for 1997 conditions show that the watershed currently receives 84.5% of the gauged rainfall, and projections for 2007 conditions indicate that effective rainfall will be 87.9% of gauge rainfall in 2007. In effect, current cutting practices have resulted in a 5% increase in effective storm rainfall since 1975, and most of this increase has occurred since 1990. By 2007, effective storm rainfall will have increased 10%.

The effect of these increases on flood frequencies can be estimated by assuming that, on average, a 10-year recurrence interval storm will generate a 10-year recurrence interval flood. This assumption is likely to be valid as a description of long-term average associations between storms and floods. However, the relation between storm size and flood size for any specific event is not necessarily consistent because the size of a flood is also influenced by the timing of a storm. Storms falling on already-wet ground are likely to generate higher floods than expected, while those falling onto dry ground will generate lower flows. Because reduced interception loss also increases average soil moisture, however, the assumption that storm and flood recurrence intervals are equivalent is likely to underestimate the actual increase in flood peaks that would result from the change in vegetation cover.

The change in flood frequency is calculated by assuming that the 1975 effective rainfall frequencies are represented by a curve of the form of that measured for the Kneeland gauge, multiplying the 1975 effective rainfalls by the proportional increase calculated for 1997 and 2007, and looking up the recurrence interval of the resulting effective rainfall on the 1975 curve. In other words, a 12-inch effective storm rainfall in 1975 has a recurrence interval of 9.1 years, as read from the corresponding gauge rainfall of 15 inches from the Kneeland record. In 1997, the same gauge rainfall of 15 inches would produce an effective rainfall of 12.7 inches, averaged over the Freshwater watershed. An effective rainfall of 12.7 inches, under 1975 conditions, would have occurred with a recurrence interval of 18 years. The flood resulting from what, in 1975, would have been an 18-year storm is now recurring every 9 years.

Appendix 4. The influence of cross-sectional changes on flood frequency, Freshwater Creek

Over the past several years, residents along Freshwater Creek, which is located immediately north of Eureka in Humboldt County, have reported an increased incidence of flooding during storms they would have considered to have been benign in the past. Possible mechanisms for altering flood frequencies have been discussed, including (1) aggradation of the lower Freshwater channel due to accelerated forest-management-related sediment inputs and (2) hydrologic changes on hillslopes that result in increased runoff and heightened peak flows. Opposing arguments suggest that recent floods simply result from a series of larger-than-normal storms clustered in the years immediately following the protracted drought of the late 1980s and early 1990s. Because of strong gradients in storm precipitation in the area, the paucity of rain gauges, and the lack of stream gauges, the storm hypothesis is difficult to test. However, the potential magnitude of the other influences can be calculated. This report describes calculations of the effect of observed cross section changes along Freshwater Creek on expected flood frequency.

The cross sections

Cross-sections had been surveyed along lower Freshwater Creek in 1975 by the Army Corps of Engineers to aid in the demarcation of the 100-year floodplain (USACE 1975). Of the seven cross sections measured, three were diagrammed in the report. Staff of the California Department of Forestry and Fire Protection determined the approximate location of these three sections and remeasured them in 1998. The exact locations of the original cross-sections could not be determined, but the 1998 sections were estimated to be within about 100 feet of the originals along reaches of relatively uniform character (P. Cafferata, personal communication), and vertical control was provided by matching surveyed elevations of topographic features that were not likely to have changed, such as stable terrace surfaces (Cafferata and Scanlan 1998). Comparisons between the two sets of cross sections thus will not be exact in detail, but general patterns of change are expected to be reliably represented (Figure A4-1).

The downstream-most cross section (XS-3) is located approximately 1400 feet downstream of the confluence of McCready Gulch and 4600 feet downstream of the Little Freshwater confluence. The channel has narrowed and aggraded at this point. The Army Corps reports water-surface slope during floods in the reach downstream of Little Freshwater to be approximately half that above the confluence (USACE 1975), suggesting that this lower portion of Freshwater valley may be particularly susceptible to aggradation.

The middle cross section (XS-5) is located 600 feet upstream of the confluence of Little Freshwater Creek. Results show a 2-foot decrease in maximum depth and a constriction of the channel width, with the almost complete disappearance of a high-flow channel. Storms during the winter of 1995-96 triggered numerous management-related landslides and debris torrents along the east ridge of Little Freshwater watershed, and examination of 1996 aerial photographs indicates that a substantial portion of the displaced sediment was delivered to the channel system. Little Freshwater is expected to have aggraded following the concentrated influx of sediment. Channel-bed gradient along the reach between the mouth of Little Freshwater and XS-5 was measured to be 0.21% in 1975, indicating that the channel bed at XS-5 is approximately a foot higher than at the confluence. Any aggradation at the mouth of Little Freshwater is thus likely to cause a backwater effect at XS-5, thereby promoting deposition of sediment.

The upstream-most cross section (XS-7) is reported to have been the most precisely reoccupied of those resurveyed (Cafferata and Scanlan 1998). Comparison of the 1975 and 1998 cross sections indicates that the section has changed little in area or form. This section is located 300 feet

Table 1. Changes in cross-sectional area. In each section, the highest stage is that identified as the 100-year recurrence-interval flood on the USACE (1975) figures; the second highest stage is that identified as the 50-year flood on those figures.

XS-3				XS-5				XS-7			
stage (ft)	1975 area (ft^2)	1998 area (ft^2)	Percent change	stage (ft)	1975 area (ft^2)	1998 area (ft^2)	Percent change	stage (ft)	1975 area (ft^2)	1998 area (ft^2)	Percent change
32	417	273	-34	42	107	19	-82	68	217	266	23
33	496	324	-35	43	165	52	-69	69	277	316	14
34	598	388	-35	44	229	104	-55	70	396	420	6
35	797	527	-34	45	328	207	-37	71	539	552	2
36	1153	842	-27	46	488	331	-32	72	685	687	0
37	1562	1236	-21	47	699	480	-31	73	849	846	0
38	2002	1653	-17	48.2	1068	698	-35	74	1094	1079	-1
38.8	2417	2043	-15	49	1346	869	-35	75	1362	1332	-2

downstream of a seasonal dam constructed after the Army Corps survey (W. Stringer and R. Langlois, personal communication). Battens are emplaced between the concrete abutments in early summer of each year to provide a swimming pond at Freshwater Park. At the time of the original survey, similar ponding was effected through annual construction of an earthen embankment. Examination of the existing structure indicates that the new abutments constrict the original high-flow channel cross section, suggesting that hydraulic damming may occur during flood flows, thus raising the water-surface gradient in the reach immediately downstream and promoting local incision.

Change in cross-sectional areas

Data were first analyzed to determine the change in channel cross-sectional area for a sequence of flow stages at each cross-section location. Data points from 1975 were read from cross sections plotted by the US Army Corps of Engineers (1975). Locations of points falling on stage elevations to be evaluated were interpolated linearly from the measured points, and cross-sectional areas for each stage were then calculated by summing the areas of polygons defined by the stage elevations and each sequential pair of surveyed or interpolated points (Table 1). The stages shown in Table 1 and used throughout this report are equivalent to elevations of the water surface above mean sea level, as reported by the US Army Corps of Engineers (1975).

The 1998 data points were measured from the figures presented by Cafferata and Scanlan (1998). Unfortunately, dense riparian vegetation at XS-3 and XS-5 had prevented resurvey of the full length of the sections defined by USACE (1975). The elevation of the XS-5 left bank at 0 distance is assumed to equal the elevation at a distance of 100 feet. In the case of XS-3, aggradation of 1” to 1.5” of silt was observed after a flood two winters ago at the 37-foot level on the left-bank floodplain of XS-3 (G. Sack, personal communication). Three survey benchmarks emplaced at grade in 1992 were disinterred at the 37-foot level on the floodplain; mean depth of burial in the 6-year period was 6.2 cm with a range of 5.5 to 7 cm; a single benchmark at the 39-foot level showed burial of 3 cm. The depth of aggradation is expected to be greater lower on the floodplain and additional aggradation is expected to have occurred prior to 6 years ago, but an average aggradation of 6.2 cm is assumed in the following calculations. The resulting calculations are thus expected to underestimate the actual change in cross-sectional area for flood stages greater than 35 feet at this section. The method described above for analysis of the 1975 data was then used to calculate the channel area beneath stage elevations for the 1998 data.

As suggested by Figure A4-1, results show a marked decrease in channel area in sections XS-3 and XS-5, while section XS-7 has changed little. Section XS-3 shows a consistent increase in percent channel constriction with decreasing stage, but this trend is likely to be partially an artifact of the assumption of minimal floodplain sedimentation since the 1975 survey. This assumption is moot for stages at or below 35 feet, and at a 35-foot stage, the 34% reduction in channel area is similar to the magnitude of change observed at XS-5. Aggradation of an additional average of 20 cm of sediment over the 50-year floodplain would have been sufficient to decrease the cross-sectional area of the 50-year flood by 30%.

Estimation of channel roughness

Cross-sectional data can be used in conjunction with other information provided by USACE (1975) to estimate the channel discharge that can be conveyed at each of the stages shown in Table 1. Such calculations require information about channel roughness and channel form. In this case, discharge is already known for the 100-year flood (USACE 1975), and the required information about channel form is known. These data can thus be used to calculate the channel roughness factor for the 100-year flood, and this value can then be used along with cross-section information to calculate discharges for each of the other stages for which discharge is not known.

First, each cross section is partitioned into sections of overbank flow and in-channel flow. The reported stage of the 100-year recurrence interval flood at each site is used to calculate average depth for that discharge on the floodplain and in the channel, and these depths are assumed to approximate the hydraulic radius *(R)* for each component of the flow (Dunne and Leopold 1978, p.592). The Manning's roughness values *(n)* for the floodplain and channel are first assumed to be equal, and each is described by Manning's equation:

$$n = \frac{1.49 R_f^{2/3} S^{1/2}}{u_f} \tag{1}$$

$$n = \frac{1.49 R_c^{2/3} S^{1/2}}{u_c} \tag{2}$$

where S is the energy gradient, as approximated by the water surface gradient, and u_f and u_c are the average velocities for floodplain flow and channel flow, respectively.

The discharge *(Q)* for the 100-year flood is also known, and must equal the sum of the floodplain and in-channel components of the flow, which are themselves equal to the product of the velocity and cross-sectional area *(A)* for each component:

$$Q = u_f A_f + u_c A_c \tag{3}$$

There are thus three equations and three unknowns, allowing solution for the flow velocities and the roughness factor at each cross section. Results suggest overall roughness factors on the order of 0.05 to 0.085 (Table 2).

Values of Manning's *n* were also estimated by comparing the Freshwater Creek channel with photographs of channels having known values of *n* (Barnes 1967). Illustrated channels similar to

Table 2. Characteristics at locations of measured cross sections

	XS-3	XS-5	XS-7
Drainage area (mi^2)	28.5	20.9	15.9
Water-surface slope	0.0026	0.0044	0.0042
100-year discharge (cfs)	9500	7400	5700
100-year cross-section area (ft^2)	2417	1345	1362
100-yr width (ft)	550	350	274
overall Manning's *n*	0.062	0.049	0.084
field estimate of channel *n**	0.045-0.059	0.045-0.052	0.060-0.070

* Values estimated by comparison of channel and floodplain characteristics observed in the field (October 1998) with those depicted by Barnes (1967)

Freshwater showed *n*-values of 0.045 (Barnes 1967, p.130) to 0.059 (p.178) for XS-3. XS-5 was not directly accessible as the landowner could not be found, but the channel 3700 feet upstream at Steele Land Bridge was similar to channels with n-values of 0.045 (p.130) to 0.052 (p.144); this site appears smoother than XS-3 because of the greater height of bank lacking vegetation. In addition, the site of XS-5 supports a more complete riparian canopy than at XS-3 and undergrowth is not dense; channel-bank vegetation is sparse compared to the other locations, and channel roughness is thus expected to be lower. XS-7 was comparable to channels with measured values of 0.060 (p.188) to 0.070 (p.200).

Comparison of the field-based estimates and calculated estimates of Manning's *n* suggests that the values calculated for the 100-year flood are likely to provide reasonable estimates, also, for the in-channel portion of the flood at XS-3 and XS-5. At XS-7, however, overall roughness is greater than that estimated for the channel, suggesting that overbank flow conditions are influential at this site. The single example of an overbank flow illustrated by Barnes has an *n* of 0.097 for the floodplain flow, which passed through a dense stand of hardwoods with diameters of up to 6" (Barnes 1967, p.138). Although the upper channel banks at XS-3 and XS-7 are densely overgrown by brambles and alders, the floodplains are very smooth, the first being a grazed pasture and the second a mown lawn and a parking lot. In contrast, the floodplain at XS-5 is wooded, but less densely so than that depicted by Barnes on p.138, and overflow channels maintain a sparsely vegetated, channel-like character. Overbank roughness is expected to be substantially lower than 0.097 at each cross section, and may even be lower than channel roughness at sections XS-3 and XS-7. However, XS-7 is located along a floodplain that is widening after an upstream constriction; flow at this location thus diverges across the floodplain. It is likely that the anomalously high roughness reflects the decreased velocity imposed by the diverging flow paths rather than the properties of the floodplain surface.

Calculation of flood conveyance

Once the roughness parameters can be estimated, Manning's equation can be used to calculate the velocity of flow for each of the tabulated stages (Table 1) at each cross section. In each case, the flow is partitioned into overbank and in-channel flow, and the overall roughness values calculated above are used along with gradient (USACE 1975) to solve Manning's equation for velocity of each component. Average velocity is then multiplied by cross-sectional area to calculate discharge (Table 3). In each case, roughness values are assumed to have remained constant between 1975 and 1998. The principal contribution to roughness appears to be riparian vegetation, and the 1959 topographic

Table 3. Changes in discharge for tabulated stages. In each cross section, the highest stage is that identified as the 100-year recurrence-interval flood on the USACE (1975) figures; the second highest stage is that identified as the 50-year flood on those figures.

XS-3				XS-5				XS-7			
stage (ft)	1975 discharge (cfs)	1998 discharge (cfs)	% chg	stage (ft)	1975 discharge (cfs)	1998 discharge (cfs)	% chg	stage (ft)	1975 discharge (cfs)	1998 discharge (cfs)	% chg
32	1590	1110	-30	42	334	34	-90	68	603	972	61
33	1942	1399	-28	43	647	132	-80	69	863	1215	41
34	2244	1466	-35	44	1049	292	-72	70	1249	1533	23
35	2828	1855	-34	45	1384	669	-52	71	1797	2045	14
36	3997	2679	-33	46	2150	1222	-43	72	2474	2706	9
37	5694	4035	-29	47	3204	2109	-34	73	3273	3494	7
38	7583	5576	-26	48.2	5289	3265	-38	74	4325	4512	4
38.8	9433	7141	-24	49	7342	4577	-38	75	5627	5779	3

map depicts a distribution of riparian vegetation and pasture that appears identical to that present now at the cross section sites.

Because the same values of Manning's *n* are used for each of the surveys of a given cross section, results are not particularly sensitive to inaccuracies in the estimate of the value of *n*; the proportional change in flow will be similar. To test the sensitivity, discharges were recalculated assuming channel roughnesses equal to the maxima and minima of the ranges of values estimated in the field and shown in Table 2. In each case, solution for the reported 100-year discharge allowed back-calculation of the roughness value for the overbank flow. Calculations were then carried out separately for overbank and in-channel components of the flow, and values were summed to calculate total discharge at each stage. Values calculated for 1975 and 1998 cross sections were then compared as previously, and the percentage change in discharge that can be conveyed at each stage is shown in Table 4. In each case, results show the same pattern as depicted in Table 3. In essence, although inaccuracies in the estimate of Manning's *n* may alter the details of the results, the overall pattern is clear: channel conveyance has decreased by more than 24% for over-bank discharges at the two downstream cross sections.

Stage can now be plotted as a function of discharge to provide an indication of the extent to which flood severity has been altered as a result of channel changes occurring between 1975 and 1998 (Figure 9 of review). The shift in the discharge-stage relationships for the two downstream cross sections indicates that flood heights for a given discharge have increased approximately 0.8 feet at XS-3 and 1.0 feet at XS-5. At both sites, the USACE (1975) report indicates that the stage of the 50-year-recurrence-interval flood was approximately 0.8 feet lower than that of the 100-yr flood. The calculated 0.8- to 1-foot increase in flood stages due to channel aggradation is thus responsible for approximately doubling the frequency of the 100-year flood at the downstream sites. In contrast, flood stages at the upstream site are not appreciably modified.

Table 4. Test of the sensitivity of discharge calculations to values of Manning's n. Calculations are made for the highest and lowest values of n estimated in the field for each cross section. The Manning's n for overbank flow (n_o) is back-calculated from the 100-yr discharge, given the estimated value of n for in-channel flow (n_c).

XS-3			XS-5			XS-7		
	% discharge change			% discharge change			% discharge change	
Stage (ft)	n_c=0.045 n_o=0.3	n_c=0.059 n_o=0.068	Stage (ft)	n_c=0.045 n_o=0.064	n_c=0.052 n_o=0.041	Stage (ft)	n_c=0.06 n_o=0.24	n_c=0.07 n_o=0.12
38.8	-33	-25	49	-34	-41	75	6	4
38	-34	-27	48.2	-35	-41	74	7	6
37	-35	-31	47	-32	-36	73	10	8
36	-37	-35	46	-42	-44	72	13	11
35	-37	-37	45	-52	-52	71	16	15
34	-38	-38	44	-72	-72	70	24	23
33	-31	-31	43	-80	-80	69	41	41
32	-34	-34	42	-90	-90	68	61	61

Calculation of flood recurrence intervals

A more precise estimate of the alteration in flood frequency can be obtained using gauging records from nearby channels. Jorgensen et al. (1971) tabulate summaries of daily flows for 7 to 15 years on Elk River, Jacoby Creek, North Fork Mad River, Little River, and Redwood Creek. An approximate regional flood frequency curve can be constructed by dividing the annual maximum discharge by the mean discharge for the period of record for that stream (A. Lehre, personal communication), and then calculating recurrence intervals using standard methods (Dunne and Leopold 1978). Thus normalized, curves for the various channels are nearly colinear (Figure A4-2). In each case, the largest flood during the period was excluded from the analysis because its recurrence interval is unlikely to have been validly represented by the period of record.

Freshwater Creek lies between Jacoby Creek and Elk River, and bedrock in the watershed is approximately half that characteristic of upper Jacoby Creek and half that which comprises the dominant bedrock of Elk River watershed. Rainfall is also expected to be intermediate between the two adjacent watersheds. Mean discharge per unit area of Freshwater Creek watershed (2.1 $ft^3s^{-1}mi^{-2}$) thus was estimated by calculating mean discharge per unit area for Elk River (1.83 $ft^3s^{-1}mi^{-2}$) and Jacoby Creek (2.34 $ft^3s^{-1}mi^{-2}$) and averaging the two values. Flood discharges reported by USACE (1975) for 100-year-recurrence interval flows at each cross section and those calculated above for 50-year flows were then divided by mean discharge per unit area, multiplied by the basin area above each cross section, and added to the plot (Figure A4-2). A least-squares regression of the data set then provides a relation from which the recurrence interval *(RI,* yr*)* can be calculated for a given discharge *(Q)*:

$$\log\frac{Q}{Q_{avg}} = 0.595\log RI + 1.07 \qquad r^2 = 0.97 \qquad (4)$$

where Q_{avg} is the mean discharge at the location, 59.9 cfs at XS-3, 43.9 at XS-5, and 33.4 at XS-7. Recurrence intervals can now be plotted against stage for the 1975 and 1998 cross sections at each site (Figure 10 of review) to show the frequency with which particular stages are exceeded. Results generally show a doubling of flood frequencies at XS-3 and XS-5. In contrast, the site influenced by recently constructed dam shows decreased frequencies of exceedence at lower stages and little change during the largest floods.

Appendix 5: Calculation of cutting rate for Bear Creek watershed

Adapted from a report prepared for the California Regional Water Quality Control Board

Objectives:

Calculate the rate of cut that would provide a hillslope landsliding rate that is <20% over background
Calculate the effect of no-cut zones on inner-gorge slopes, stream-side slopes, and headwall and swales

Information used:

85% of the landslide-derived sediment originates on the 37% of the area cut within the previous 15 years (PWA 1998a, p.18 ph.4)
69% of the hillslope landslides are on inner gorges, 13% are "streamside" failures, and 9% are on headwalls and swales (PWA 1998a, p.13, Table 2)
Not many of the Bear Creek units were clearcut: "Most logging during the period resulted in the removal of large conifers and the retention of understory vegetation and 20 year old conifer regeneration" (PWA 1998a, p.12, ph.3)
The Basin Plan calls for an increase in turbidity of no more than 20% above background levels

Assumptions:

Landslide rates on areas cut >15 years earlier are the best available estimate of background rates
An increased landslide rate of <20% provides an average turbidity increase from landsliding of <20%
15 years is sufficient to return to background landsliding rates after logging
Land-use activities upslope of a landslide-prone site do not affect the landslide rate at that site

1. Maximum rate of cut that would provide a hillslope landslide rate of <20% over background, assuming no areas are protected by no-cut buffers

Since 85% of the landslide-derived sediment came from the 37% of the watershed that was recently cut, and the remaining 15% came from the 63% that was cut more than 15 years ago, the rate of landslide sediment production on <15-yr-old cuts is (.85/.37)/(.15/.63) = 9.6 times higher than the rate on older cuts.

Under "background" conditions (i.e., the entire watershed cut more than 15 years previously), the annual sediment delivery per square mile from hillslope landsliding is denoted as R ($\text{yd}^3\ \text{yr}^{-1}\ \text{mi}^{-2}$) If a proportion N of the watershed is cut within a 15-year period, that proportion will be producing hillslope landslide sediment at a rate of 9.6R, and the total average hillslope landslide sediment delivery per square mile (S, $\text{yd}^3\ \text{yr}^{-1}\ \text{mi}^{-2}$) from the watershed will be the sum of the background rate from the (1.0-N) of the watershed not recently cut, plus the increased rate from the proportion recently cut:

$$S = (1.0 - N)\,R + N{*}9.6\,R \qquad (1)$$

The value of S is to be kept at no more than 1.2 times the original value (S_o), as calculated assuming the entire watershed remains uncut:

$$S_o = 1.0\,R \qquad (2)$$

Thus, the ratio of equations (1) and (2) must equal 1.2:

$$\frac{S}{S_o} = 1.2 = \frac{(1.0 - N)R + 9.6NR}{1.0R} \qquad (3)$$

R can then be canceled out, and the equation rearranged to solve for N:

$$N = \frac{0.2}{8.6} = 0.023 \qquad (4)$$

This result indicates that if 2.3% of the watershed is cut in a 15-year period, the resulting landslide rate will average 1.2 times the background rate. This cutting rate is equivalent to 0.15% of the area per year, or a rotation cycle of 645 years.

This rate assumes that no areas are protected by no-cut buffers.

2. The effect of no-cut zones on inner-gorge slopes, stream-side slopes, and headwall and swales

Inner gorges, streamsides, swales, and headwalls were identified as the major sources of hillslope landslides; together, these landforms account for 90% of the total number of slides identified by PWA (1998a). The maximum rate of cut that would provide a hillslope landslide rate of <20% over background can be recalculated assuming that these areas are not logged.

In this case, the initial landsliding rate can be expressed as the sum of two components: 90% of the slides are from the area of inner gorges, streamside slopes, swales, and headwalls, and 10% are from the remaining area[1]:

$$S_o = 0.9R + 0.1R \qquad (5)$$

Any areas recently cut would not include the protected areas, so the rate on those landforms remains the same as before, while the rate on the remaining area is substituted in from equation (1):

$$S = 0.9R + 0.1\,[(1.0 - N)\,R + N{*}9.6\,R] \qquad (6)$$

The value of S is again to be kept at no more than 1.2 times the original value (S_o), as calculated assuming the entire watershed remains uncut, so the ratio of equations (5) and (6) must equal 1.2:

$$\frac{S}{S_o} = 1.2 = \frac{0.9R + 0.1\left[(1.0 - N)R + 9.6NR\right]}{1.0R} \qquad (7)$$

As before, *R* can then be canceled out, and the equation rearranged to solve for *N*:

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[1] It should be noted that Dr. Daniel Opalach of Pacific Lumber Company, in a letter to Mr. Lee Michelin of the California Regional Water Quality Control Board dated 12 November 1998, expressed concern that equation (5) was in error and should be replaced by the expression, $S_o = aR + (1-a)R$, . The suggested replacement, however, is inappropriate as the rate variables S_o and R had been defined to represent a rate per unit area. Analysis of units for Dr. Opalach's equation demonstrates the problem:

$$\text{yd}^3\text{-yr}^{-1}\text{-mi}^{-2} \neq \text{mi}^2 \times \text{yd}^3\text{-yr}^{-1}\text{-mi}^{-2} + \text{mi}^2 \times \text{yd}^3\text{-yr}^{-1}\text{-mi}^{-2}$$

$$\text{yd}^3\text{-yr}^{-1}\text{-mi}^{-2} \neq \text{yd}^3\text{-yr}^{-1}$$

The mis-match of units suggests that the definitions of the variables had not been clearly understood. Part of the reason for confusion, I believe, is the fact that equation (5) is simple enough that it begs for a more subtle interpretation. None is necessary. It was simply necessary to partition 90% of the slides per unit area (0.9*R*) into the sensitive sites and 10% of them (0.1*R*) into the rest of the sites as a lead-in to equation (6). The partitioning had to be on the basis of the proportion of slides on the site types rather than on the rate per unit area of the site types, since no information about the area represented by each site type was provided in the PWA report.

$$N = \frac{0.2}{0.86} = 0.23 \qquad (8)$$

This time, the result indicates that if 23% of the watershed is cut in a 15-year period, the resulting landslide rate will average 1.2 times the background rate. This cutting rate is equivalent to 1.5% of the area per year, or a rotation cycle of 64.5 years.

This rate assumes that the full area of inner gorge, streamside slopes, headwalls, and swales is excluded from the area logged. Decreased levels of protection would require increased duration of the cutting cycle to compensate for increased rates of landsliding on unprotected or less-protected slide-prone areas. Because little of the recent logging in the area was reported to be clearcutting (PWA 1998a p.12), even selective cutting is assumed to be capable of increasing landsliding rates on the sensitive portions of the landscape.

Example

This calculation may be easier to follow through the use of a more concrete example. Consider a watershed in which landsliding rates are 9.6 times higher on recently logged land than on land logged more than 15 years previously. If that watershed had remained uncut over the past 15 years, let it be characterized by a landslide count of 10 for a hypothetical storm. If that watershed had been completely cut within the past 15 years, it would then be characterized by a landslide count of 96 for the same storm.

Now, consider that 90% of the landslides were identified to occur on inner gorges, streamside slopes, swales, and headwalls. Under conditions with forests older than 15 years, there would thus be one landslide on the hillslopes outside of these areas, while under recently cut conditions, there would be 9.6 landslides outside of these areas.

If all areas of inner gorge, streamside slopes, swales, and headwalls are left forested, and thus assumed to experience the rate present for forested conditions, there will be 9 landslides in these areas under either cut or uncut conditions.

The total number of landslides under uncut conditions would then be 10, and under recently logged conditions, 18.6 (9 in the protected areas and 9.6 outside of those areas).

If the objectives of the Basin Plan were to be attained, management would be designed to reduce landsliding rates to less than 20% over background, so a target number of 12 slides or less would be desired (assuming that landslide sizes are distributed randomly among the site types). To achieve this level, an excess number of 6.6 slides would need to be prevented. Thus, 6.6 / 8.6 (equal to 77%) of the area outside of the protected areas would need to be covered by forests older than 15 years at any time. This means that 23% of the watershed (exclusive of the protected areas) can be cut over a 15-year period, which is equivalent to 1.5% of the unprotected area of the watershed per year.

Discussion

These results indicate that cutting cycles on the order of those described by the SYP/HCP can be maintained only if the logging is dispersed through time in any given watershed and only if the areas most susceptible to landsliding are well-protected. If the cut is more intensive than 1.5% of the watershed area per year, then the likelihood of sediment inputs of more than 20% over background from landsliding is relatively high, as storms capable of generating landslides have a recurrence interval of about 10 years (Reid 1998b). If landslide inputs are substantially higher than background rates for a particular storm of a given size, then the likelihood of persistent aggradation—and long-term habitat degradation—is significantly increased. In other words, it is important that the average increase in sediment input in any given year is not large, since it may require many decades for a system to recover from one year's sediment overload (e.g. Madej and Ozaki 1996). Maintenance of sediment input levels at rates below those that might trigger pervasive aggradation could result in the maintenance of tolerable habitat in perpetuity, while several years' input at very high rates could result in prolonged periods of inadequate habitat, even if the long-term average input rates are the same in both scenarios.

Note that the assumptions used to calculate these values may not sufficiently conservative from the point of view of protection of public trust resources. In the first place, rates of landsliding on cuts older than 15 years are expected to remain significantly higher than rates in old-growth forests on similar rock-types. This assumption could be tested by evaluating rates in areas on similar rock-types that have remained undisturbed for longer periods. Second, field observations by T. Spittler (personal communication, 21 August 1998) suggest that upslope logging can contribute to destabilization of uncut inner gorges downslope of the logged areas; rates of sliding on uncut inner gorges may thus remain higher than background rates. Third, the proportional increase in turbidity for landslides in managed basins is likely to be higher than in unlogged basins because woody debris loadings are expected to be lower, over the long-term, due to selective logging of trees that would otherwise have fallen into streams and provided storage for landslide-derived sediment. This effect will be particularly important in small, intermittent channels.

In any case, the report prepared by PWA (1998a) provides the information required to estimate the logging intensity required to meet the objectives of the Basin Plan for sediment derived from non-road-related landslides. To the extent that other sediment sources are also accelerated by logging, the rate of cut might need to be further decreased to provide mitigation for other sediment sources, such as surface erosion and road-related erosion.

Figures

1. Expected volumes of woody debris input for various riparian management strategies as a function of distance from Class I and Class II streams in Site Class 2 redwood forests.

2. Expected distribution of woody debris sizes for various riparian management strategies for Class I and Class II streams in Site Class 2 redwood forests.

3. Expected volumes of woody debris input for various riparian management strategies as a function of distance from Class I and Class II streams in Site Class 1 redwood forests.

4. Comparison of woody debris source distances measured in a second-growth redwood forest at Caspar Creek, California, with the distribution described in the FEMAT report (FEMAT 1993)

5. Measured relations between in-storm interception loss and total storm rainfall for areas with storm-season climates similar to that of Eureka, California. Data are from Fahey 1964 (New Zealand old pines), Kelliher et al. 1992 (New Zealand young pines), Rowe 1979 (New Zealand beech-podocarp-hardwood forest), Rowe 1983 (New Zealand evergreen beech forest), and Rains 1971 (California redwood forest).

6. Relationship between peak-flow change and percent of watershed logged at Caspar Creek, California

7. Expected recurrence intervals for over-bank floods at the XS-3 cross section site on Freshwater Creek for watershed vegetation conditions present in 1975 and 1997 and expected to be present in 2007. Differences in expected flood frequencies reflect the change in average foliage interception loss of rainfall throughout the watershed.

8. Stage-discharge relationships for three locations on Freshwater Creek as calculated from cross sections measured in 1975 and in 1998. The two lowermost cross sections (XS-3 and XS-5) are located along an aggradational reach, while the upper-most section is located 300 feet downstream of a dam abutment constructed between 1975 and 1998.

9. Recurrence intervals for over-bank floods at three locations on Freshwater Creek as calculated from cross sections measured in 1975 and in 1998. The two lowermost cross sections (XS-3 and XS-5) are located along an aggradational reach, while the upper-most section is located 300 feet downstream of a dam abutment constructed between 1975 and 1998.

10. Duration of exceedence of given turbidity levels for a 2.45-mi^2 watershed calculated using data from old-growth streams (Humboldt Redwoods State Park) and recently logged watersheds (Shively Road tributaries and Graham Gulch).

A3-1. Recent logging history for Freshwater watershed, California (Information provided by California Department of Forestry and Fire Protection)

A4-1. Cross-sections of Freshwater Creek for 1975 and 1998 at (A) XS-3, (B) XS-5, and (C) XS-7. Stages identified by USACE (1975) for floods with 100-year and 50-year recurrence intervals are indicated. Cross sections are viewed as looking downstream.

A4-2. Regional flood frequency curve for coastal Humboldt County.

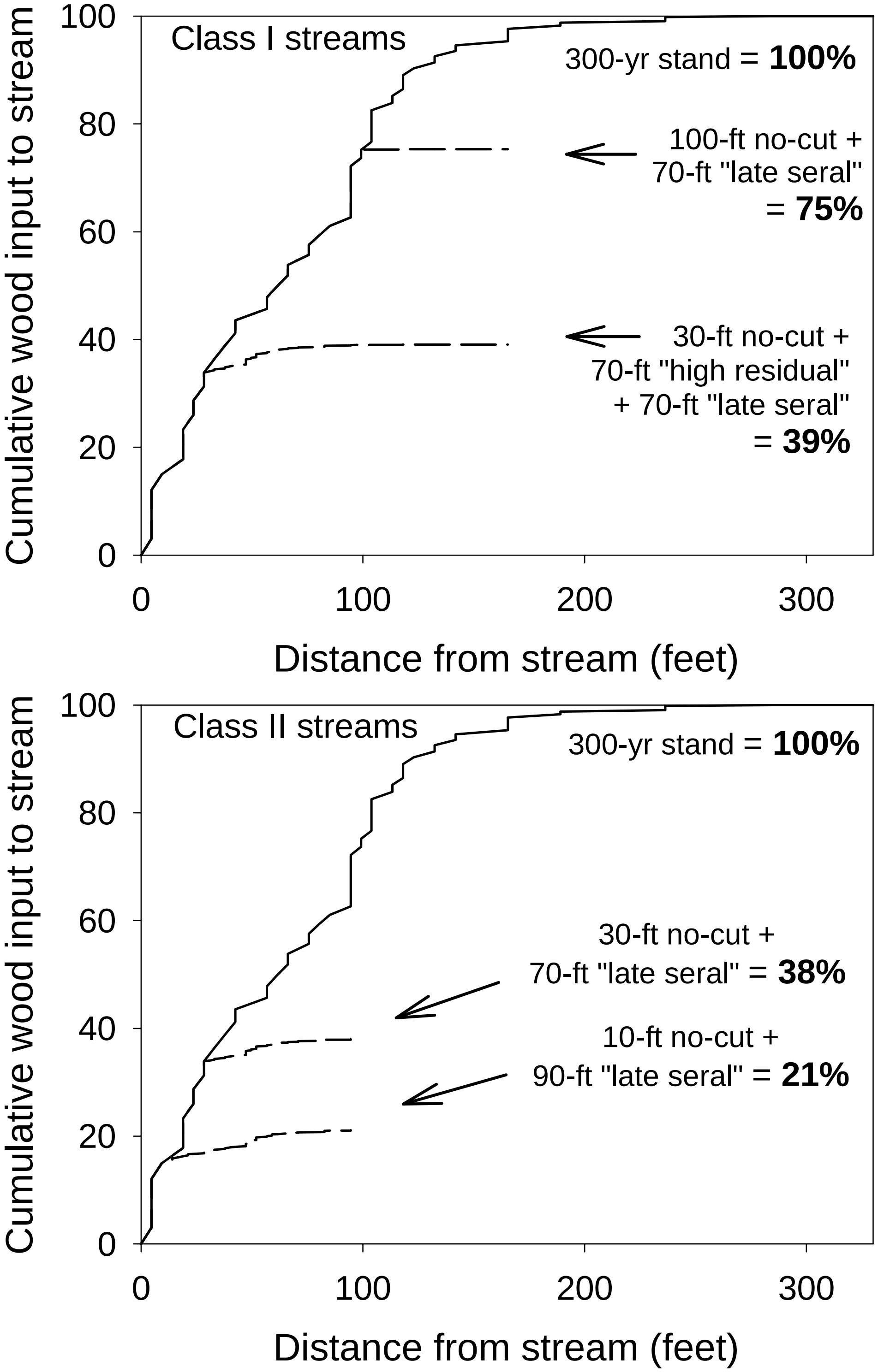

Figure 1. Expected volumes of woody debris input for various riparian management strategies as a function of distance from Class I and Class II streams in Site Class 2 redwood forests.

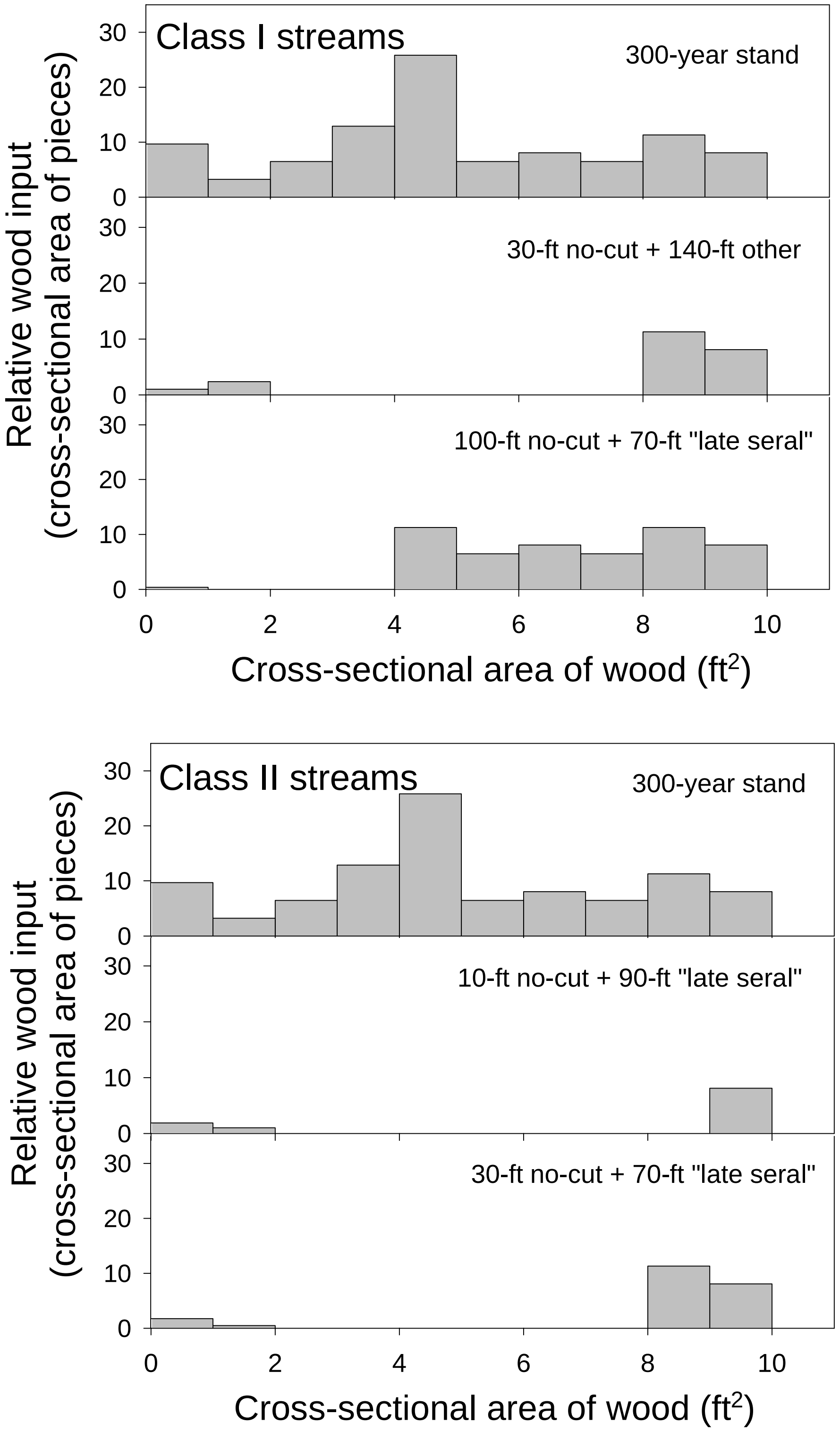

Figure 2. Expected distribution of woody debris sizes for various riparian management strategies for Class I and Class II streams in Site Class 2 redwood forests.

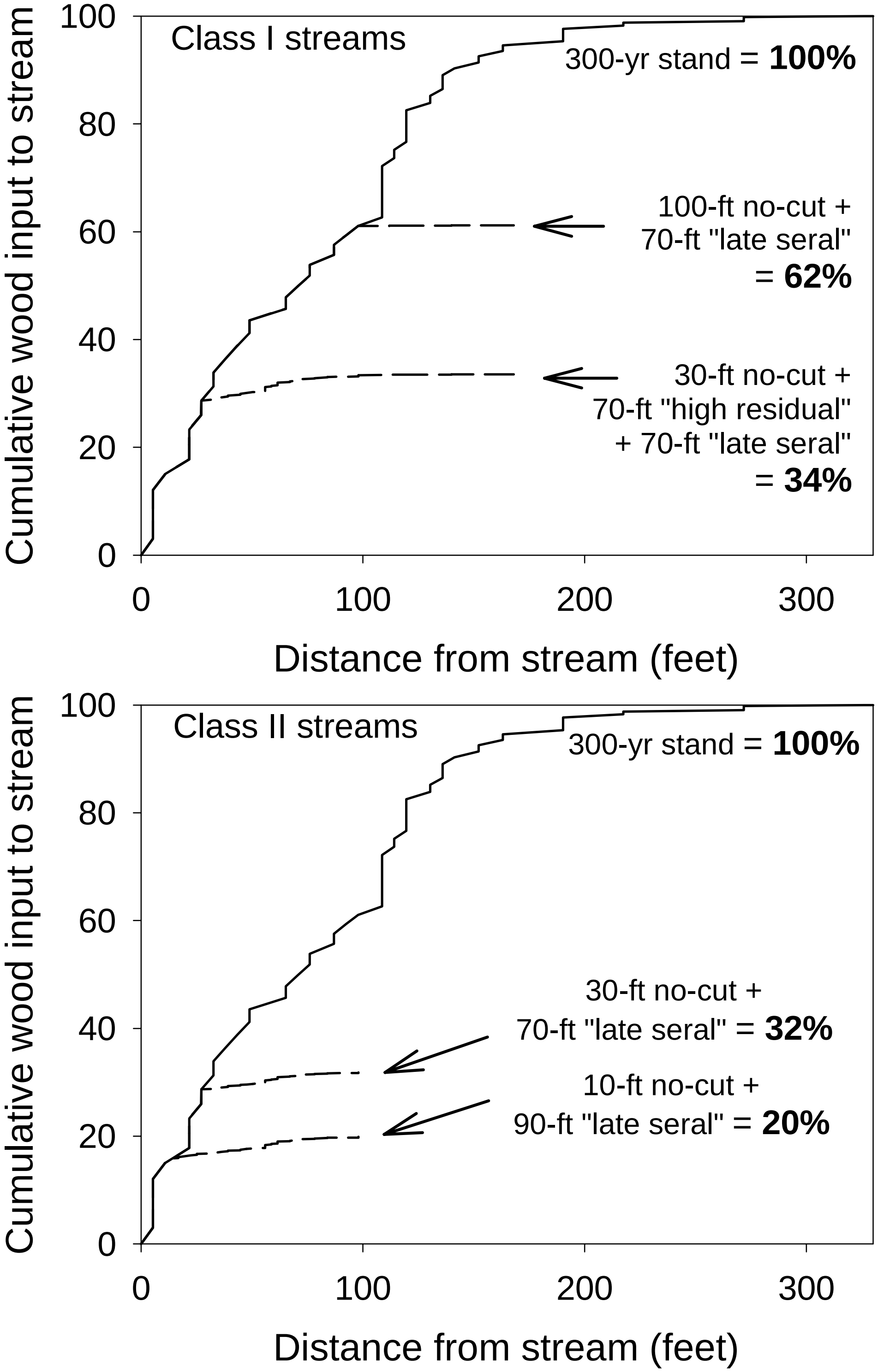

Figure 3. Expected volumes of woody debris input for various riparian management strategies as a function of distance from Class I and Class II streams in Site Class 1 redwood forests.

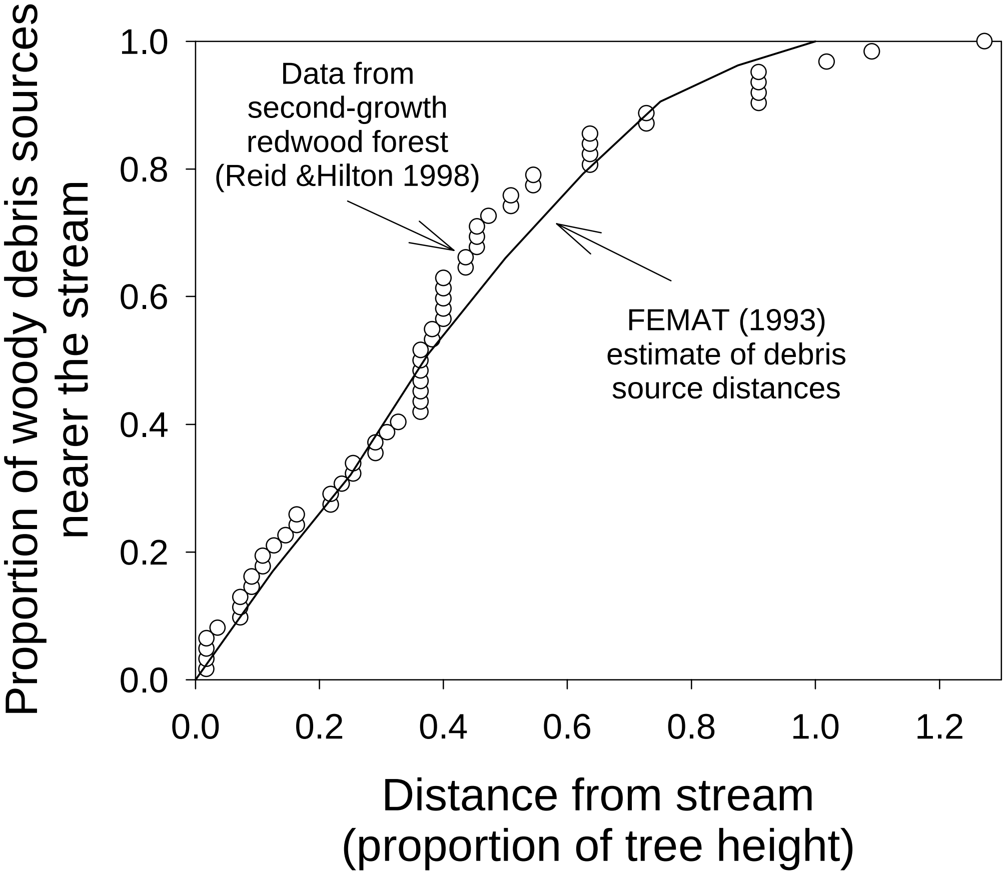

Figure 4. Comparison of woody debris source distances measured in a second-growth redwood forest at Caspar Creek, California, with the distribution described in the FEMAT report (FEMAT 1993)

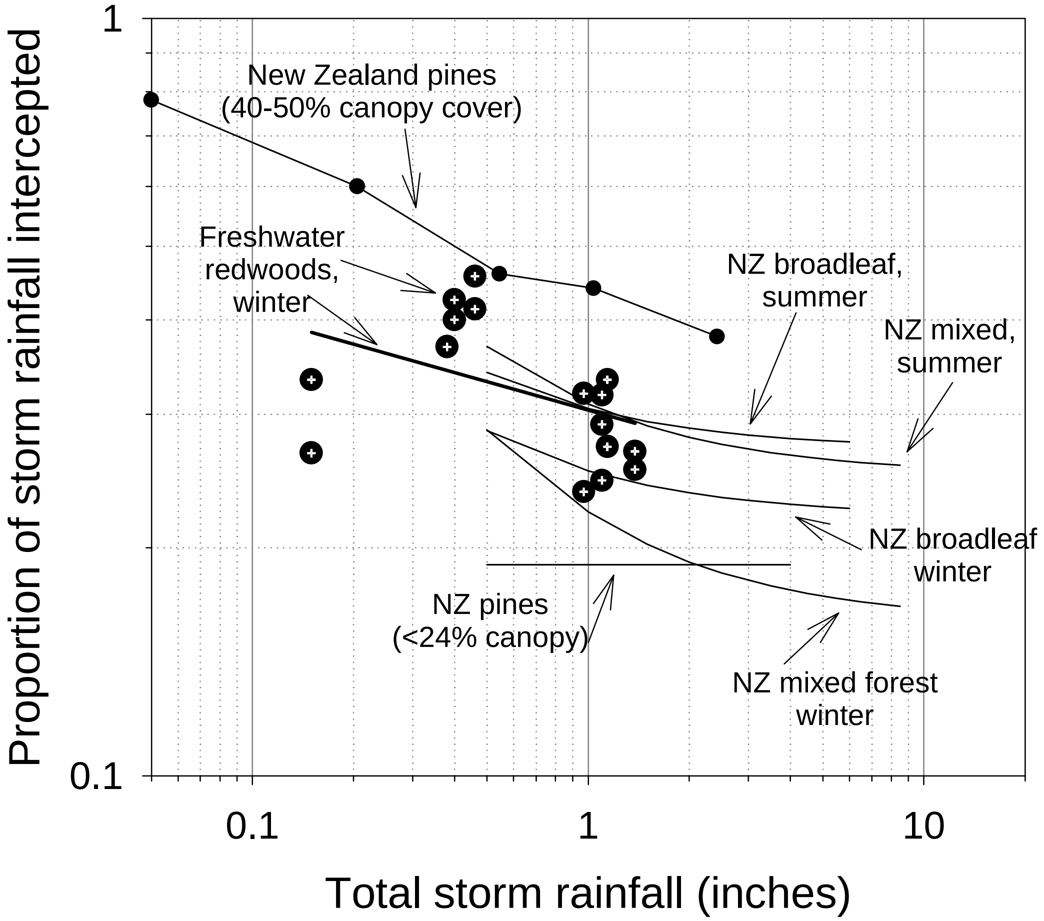

Figure 5. Measured relations between in-storm interception loss and total storm rainfall for areas with storm-season climates similar to that of Eureka, California. Data are from Fahey 1964 (New Zealand old pines), Kelliher et al. 1992 (New Zealand young pines), Rowe 1979 (New Zealand beech-podocarp-hardwood forest), Rowe 1983 (New Zealand evergreen beech forest), and Rains 1971 (California redwood forest).

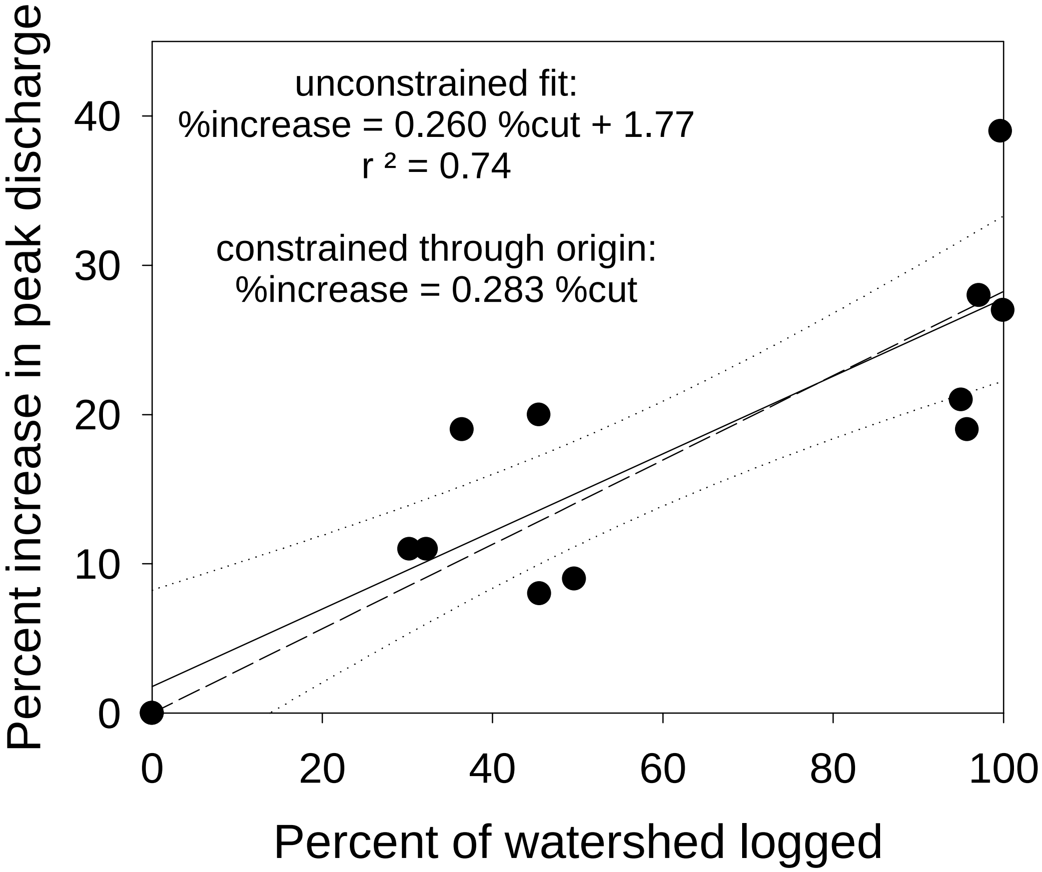

Figure 6. Relationship between peak-flow change and percent of watershed logged at Caspar Creek, California

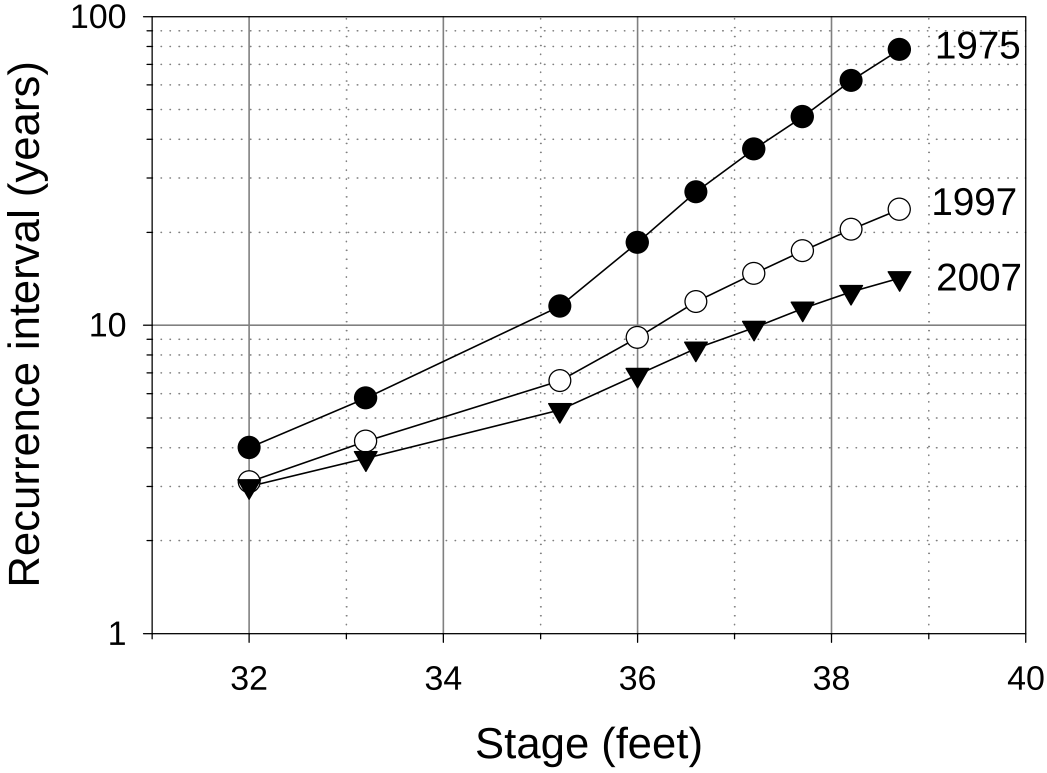

Figure 7. Expected recurrence intervals for over-bank floods at the XS-3 cross section site on Freshwater Creek for watershed vegetation conditions present in 1975 and 1997 and expected to be present in 2007. Differences in expected flood frequencies reflect the change in average foliage interception loss of rainfall throughout the watershed.

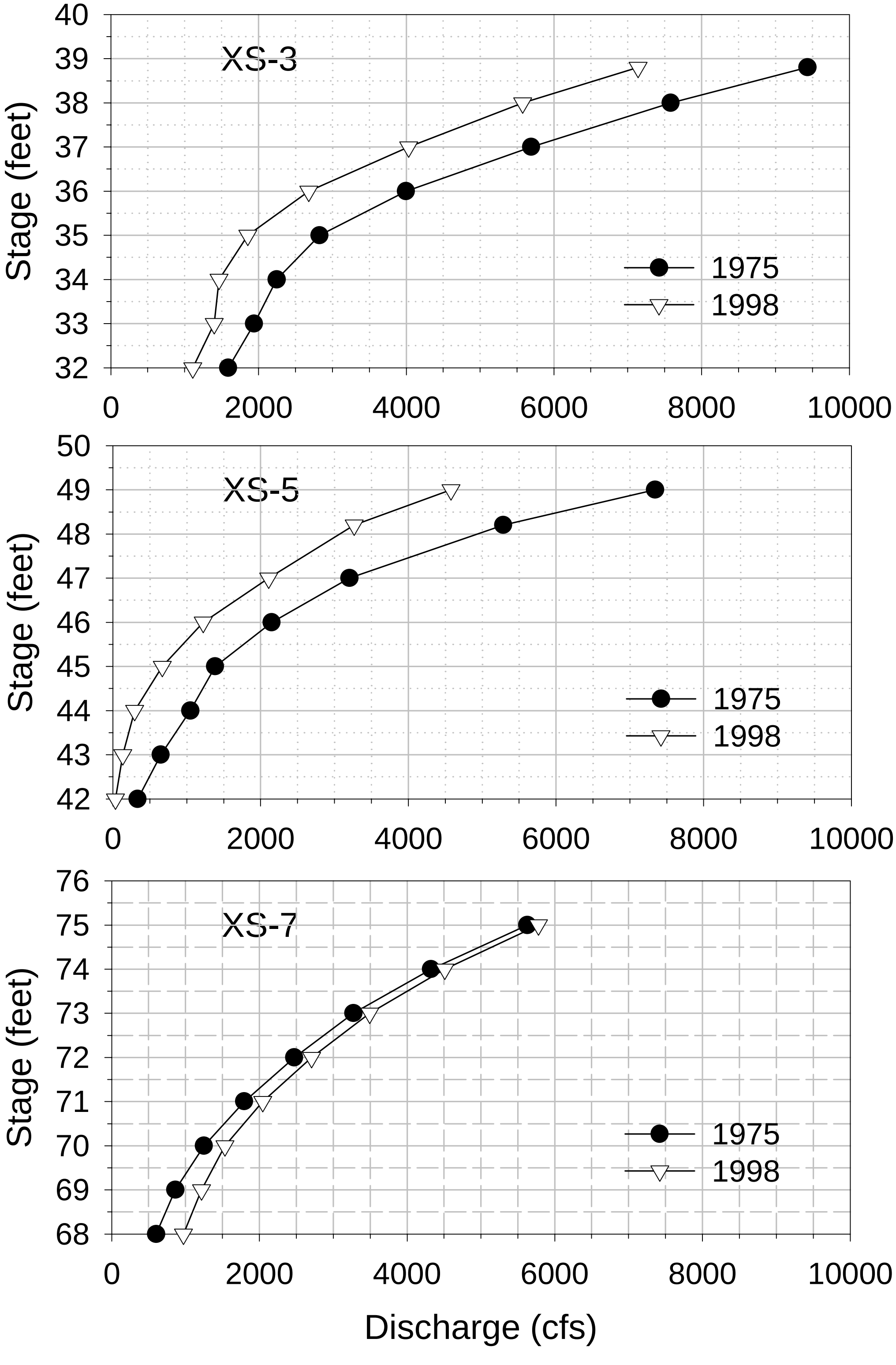

Figure 8. Stage-discharge relationships for three locations on Freshwater Creek as calculated from cross sections measured in 1975 and in 1998. The two lowermost cross sections (XS-3 and XS-5) are located along an aggradational reach, while the upper-most section is located 300 feet downstream of a dam abutment constructed between 1975 and 1998.

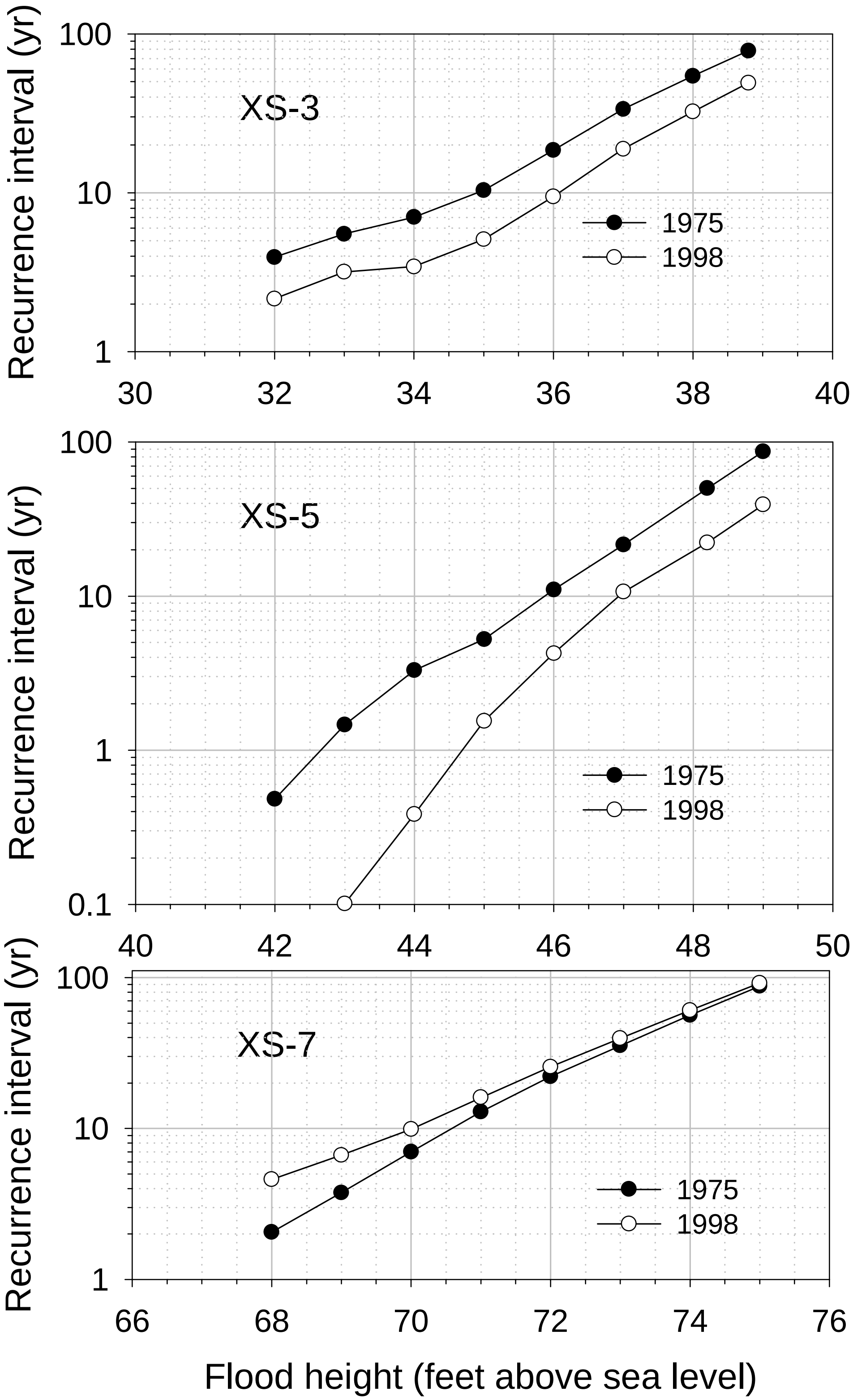

Figure 9. Recurrence intervals for over-bank floods at three locations on Freshwater Creek as calculated from cross sections measured in 1975 and in 1998. The two lowermost cross sections (XS-3 and XS-5) are located along an aggradational reach, while the upper-most section is located 300 feet downstream of a dam abutment constructed between 1975 and 1998.

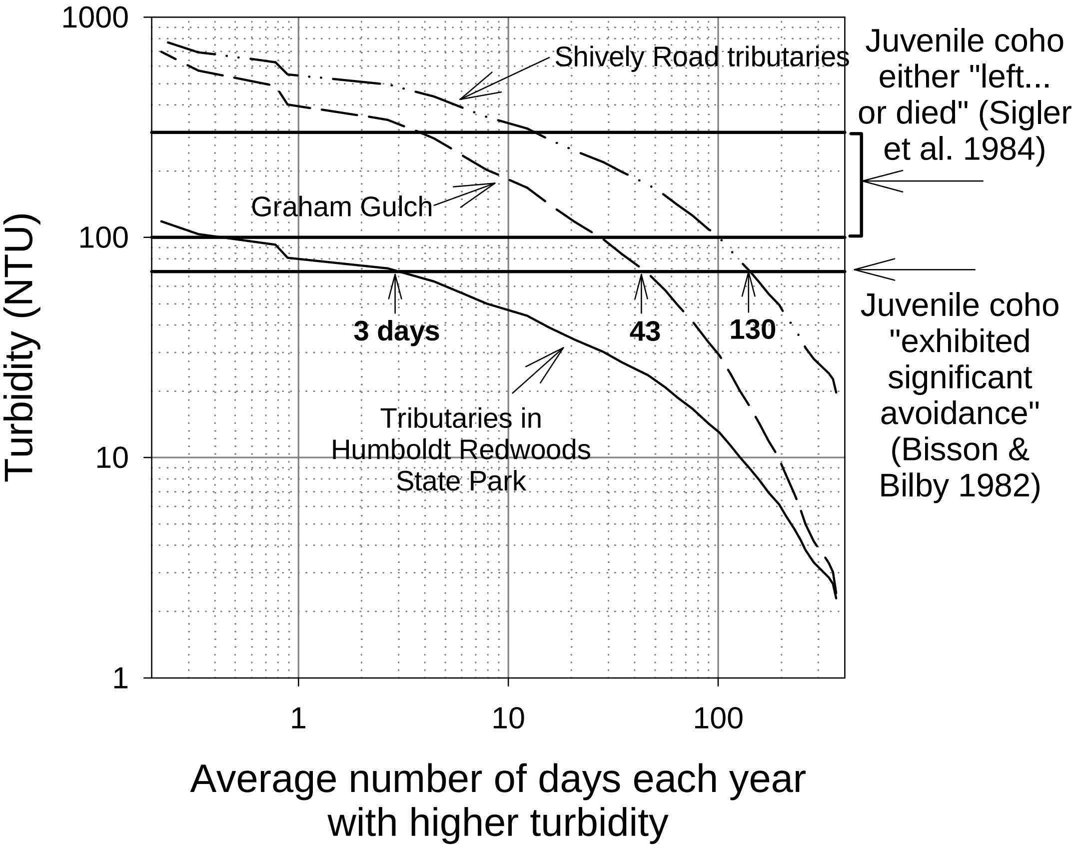

Figure 10. Duration of exceedence of given turbidity levels for a 2.45-mi^2 watershed calculated using data from old-growth streams (Humboldt Redwoods State Park) and recently logged watersheds (Shively Road tributaries and Graham Gulch).

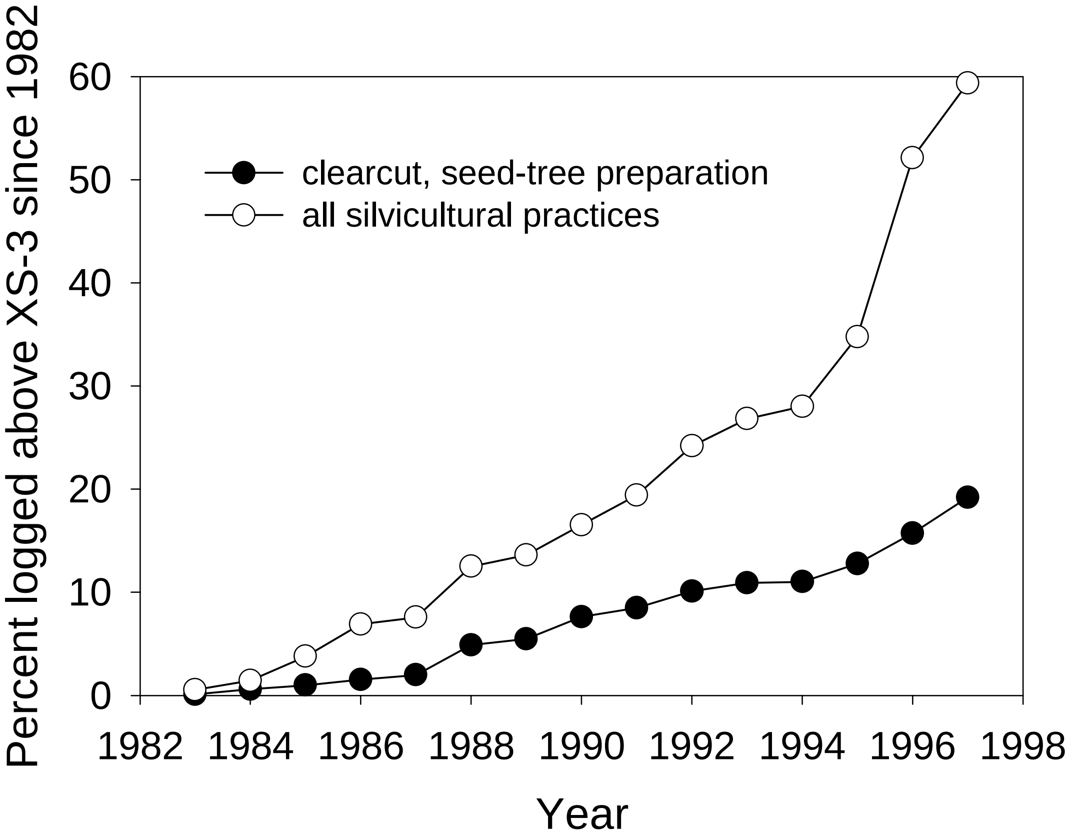

Figure A3-1. Recent logging history for Freshwater watershed, California (Information provided by California Department of Forestry and Fire Protection)

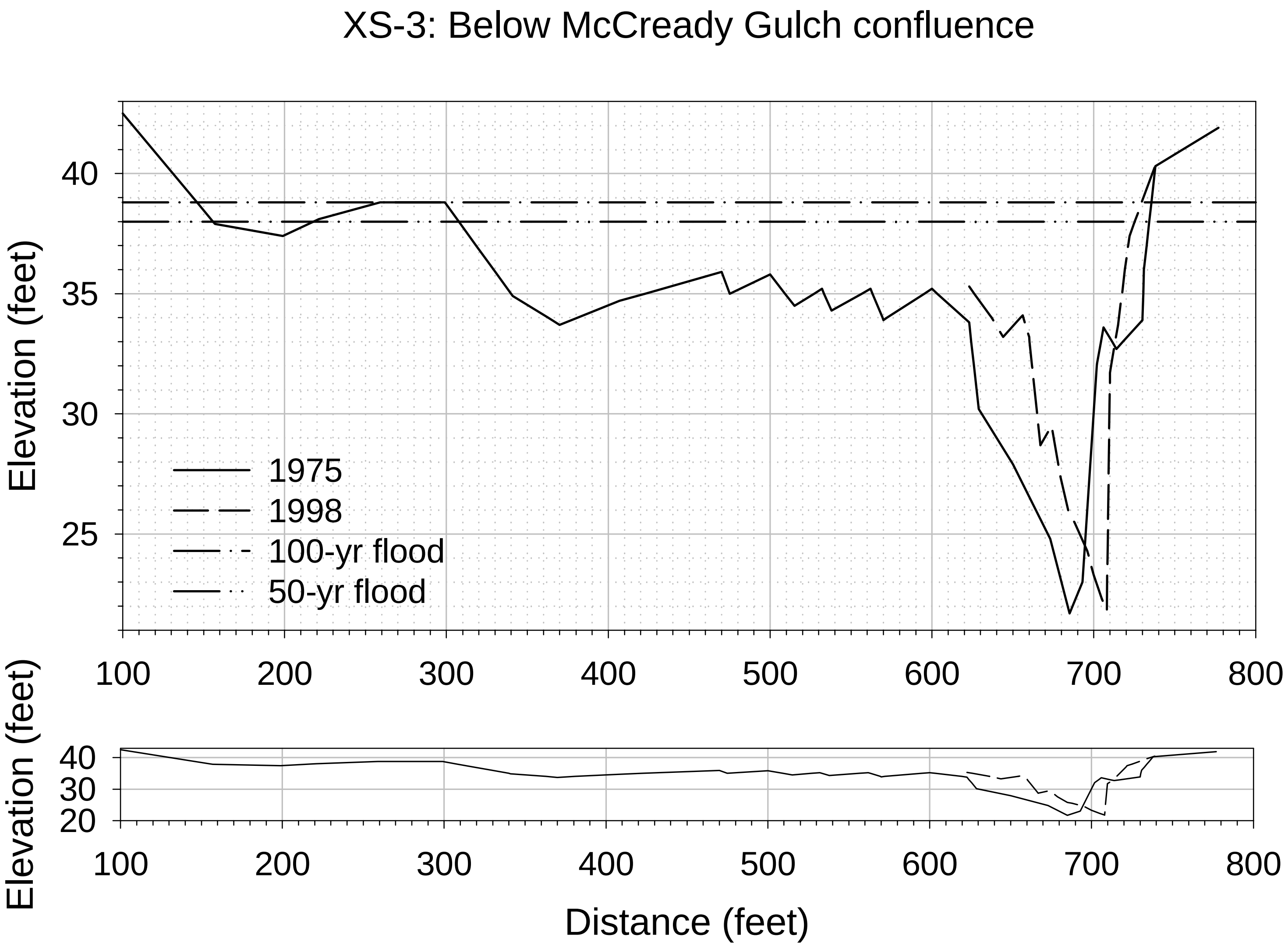

Figure A4-1A. Cross-sections of Freshwater Creek for 1975 and 1998 at XS-3. Stages identified by USACE (1975) for floods with 100-year and 50-year recurrence intervals are indicated. Cross sections are viewed as looking downstream.

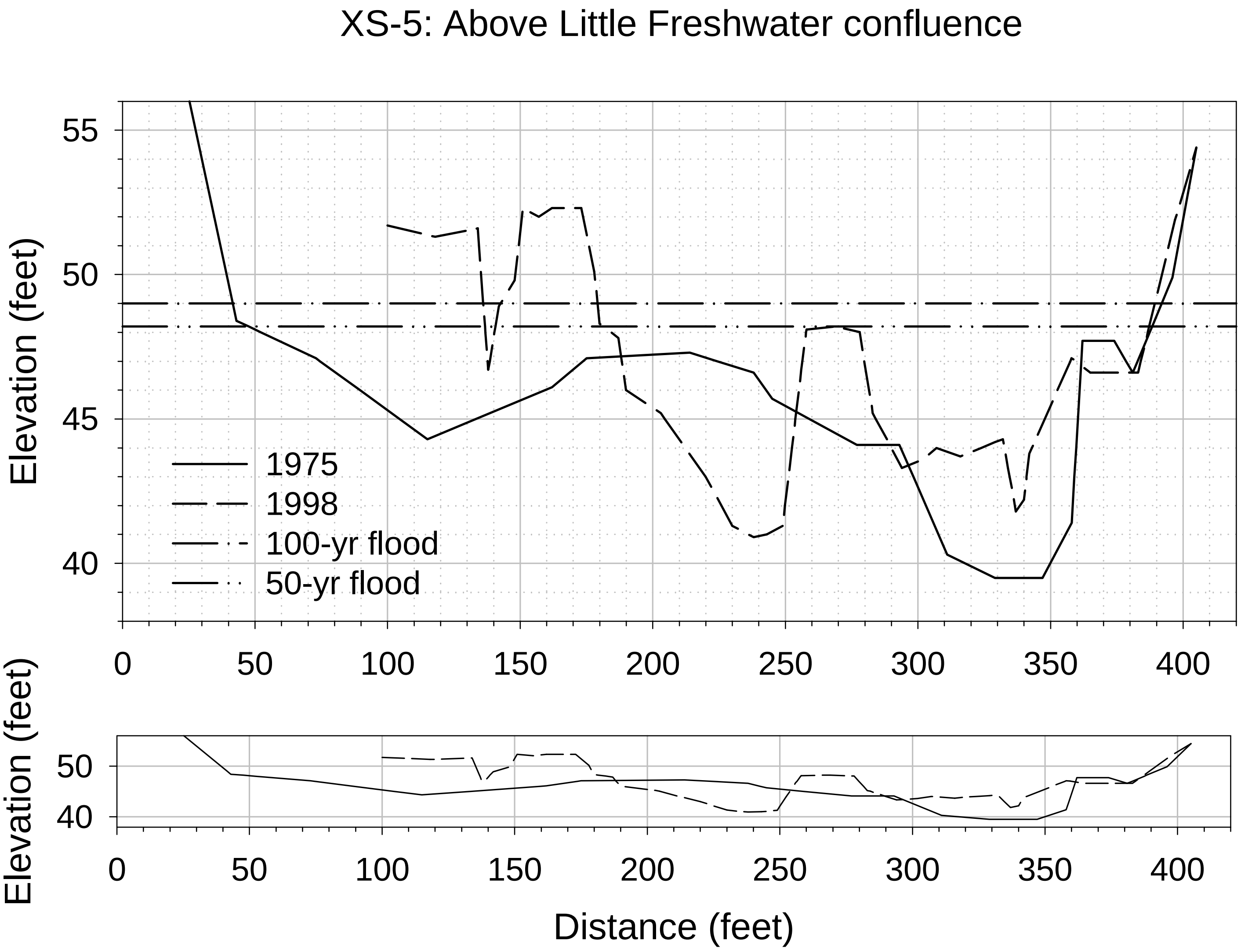

Figure A4-1B. Cross-sections of Freshwater Creek for 1975 and 1998 at XS-5. Stages identified by USACE (1975) for floods with 100-year and 50-year recurrence intervals are indicated. Cross sections are viewed as looking downstream.

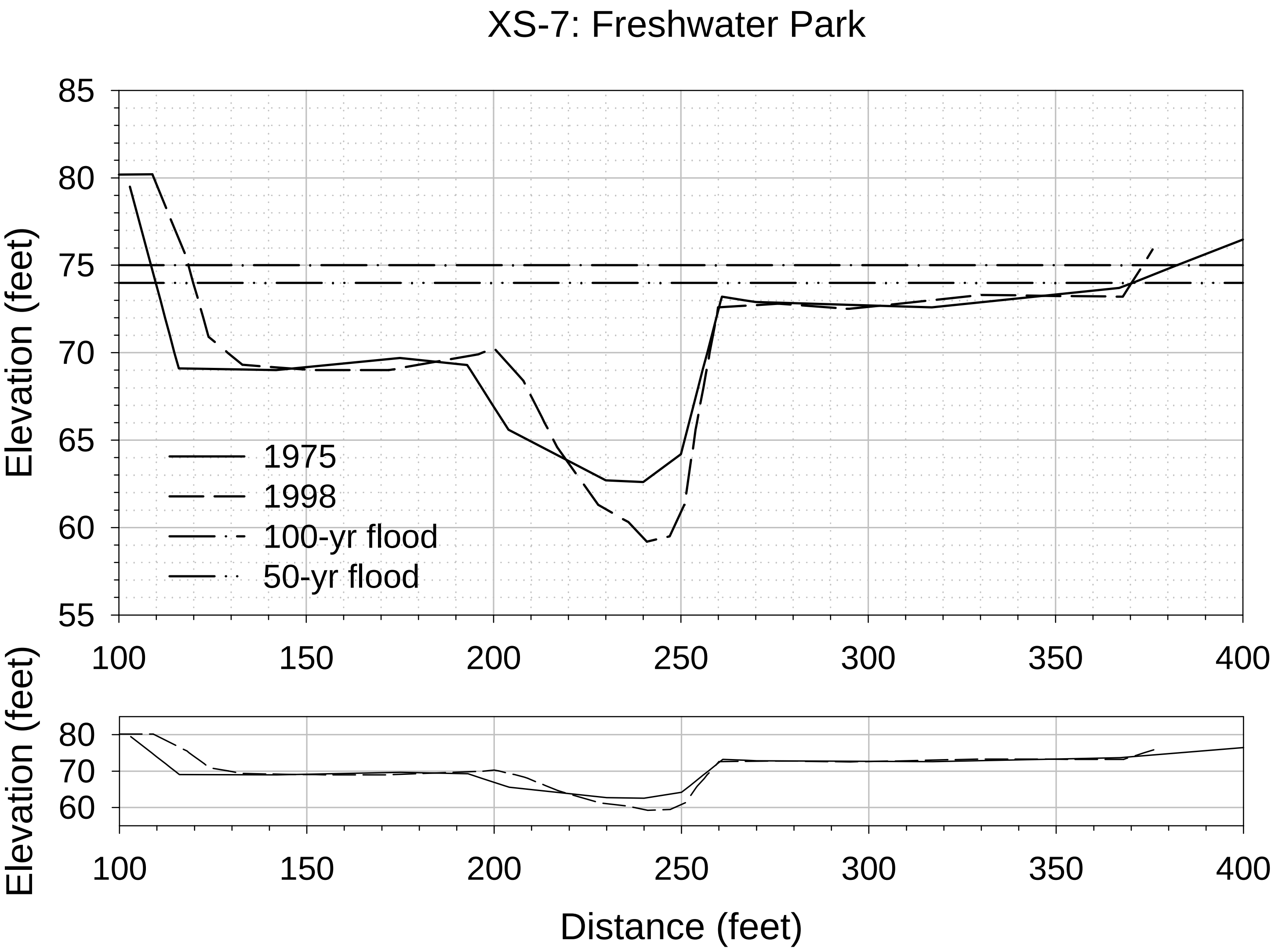

Figure A4-1C. Cross-sections of Freshwater Creek for 1975 and 1998 at XS-7. Stages identified by USACE (1975) for floods with 100-year and 50-year recurrence intervals are indicated. Cross sections are viewed as looking downstream.

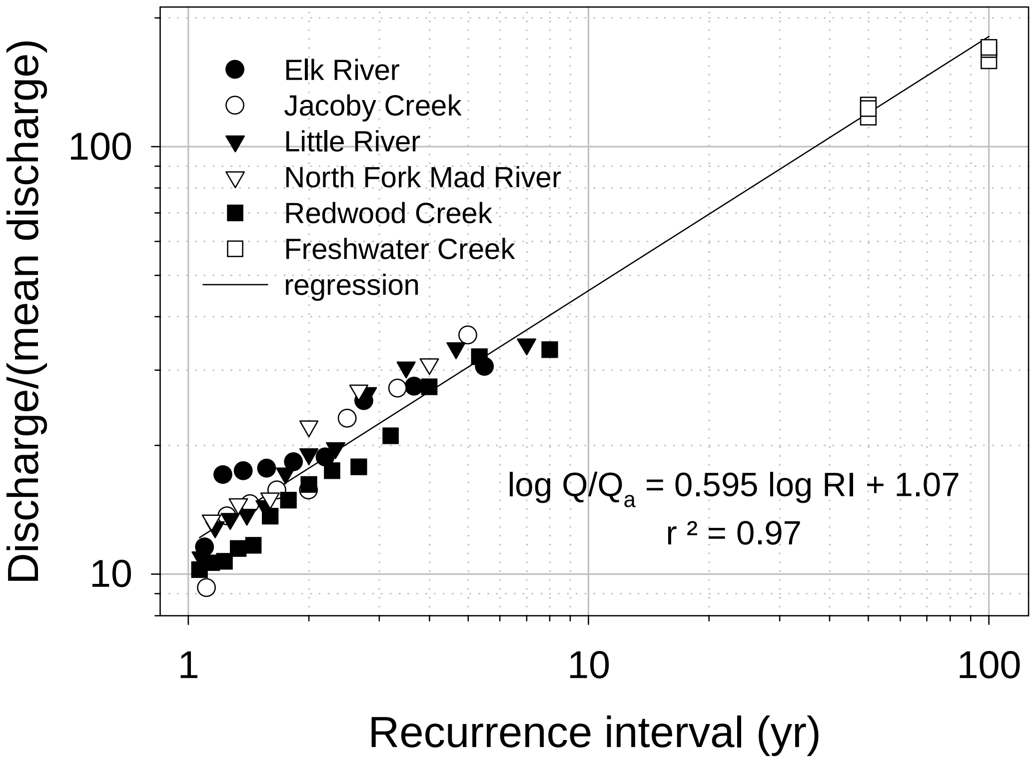

Figure A4-2. Regional flood frequency curve for coastal Humboldt County.