Review of Green Diamond Resource Company's Timber Harvest Operations and Forest Management Activities As They Relate to Rate of Harvest and Cumulative Watershed Effects

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Historically, unregulated timber operations have been shown to negatively impact water quality and aquatic species and their habitats. Modern regulated timber harvesting and best management practices have been designed to eliminate, reduce or mitigate these negative impacts, but concerns remain that some negative impacts still occur and additional mitigations are required to more fully protect aquatic resources. Green Diamond Resource Company (Green Diamond) developed and employs a variety of management practices designed to avoid, minimize and mitigate the impacts of Green Diamond's operations on the aquatic system. These management practices are regulated by the California Forest Practice Act and Forest Practice Rules (CFPRs), Green Diamond's Aquatic Habitat Conservation Plan (AHCP) approved by the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS), the Consistency Determination and the Master Agreement for Timber Operations (MATO) approved by the California Department of Fish and Game (CDFG), the Road Management Waste Discharge Requirements (RMWDRs) approved by the Regional Water Board and the Forest Management Waste Discharge Requirements (FMWDRs) pending approval by the Regional Water Board.

Collectively Green Diamond's timber and forest management operations include all the activities described in the Project Description for the FMWDRs. These activities include those necessary to grow and harvest trees (road construction, road reconstruction, timber harvest and transport, silviculture and timber stand regeneration and improvement), and others designed to mitigate potential or avoid negative impacts and improve aquatic resources (road maintenance, road upgrading and decommissioning, instream and riparian restoration projects). These activities also include all the management practices and measures incorporated into Green Diamond's operations as part of the NEPA and CEQA reviews that produced the EIS and IS/MND to accompany approval.

This paper provides a review of the potential effects of Green Diamond's operations on the hydrologic cycle, sediment delivery and transport, water temperature and large woody debris recruitment. We review potential cumulative watershed effects of Green Diamond's operations at the expected harvesting levels utilized during the development of the documents described above (which remain current). Our analysis takes into account all current regulatory restrictions as described in the FMWDRs project description and, as addressed in the CEQA and NEPA documents accompanying the permits and approvals summarized above. Our review demonstrates that the implementation of Green Diamond's management practices and the current regulatory provisions in place—that establish and control the rate of Green Diamond's timber harvesting—avoid, minimize and mitigate potential negative impacts of Green Diamond's operations on the aquatic system and protect, and in some cases improve, water quality. This review confirms that there are no new impacts that have not previously been addressed by and considered in the Final Environmental Impact Statement for approval of the AHCP, the CDFG Consistency Determination for the AHCP, and the IS/MND prepared to support the MATO approved by CDFG and the RMWDR approved by the Regional Water Board.

I. Forest Management Effects on the Aquatic System and Green Diamond's Conservation Strategies to Minimize, Mitigate or Avoid Impacts on Water Quality and Aquatic Species

The potential effects of forest management on the aquatic system include altered hydrologic cycle, solar insulation and stream temperature, habitat complexity, large wood delivery and accumulation, sediment yield, and channel morphology (Bilby and Ward 1991, Chamberlin et al. 1991, Everest et al. 1987, Gregory et al. 1987, Ice et al. 2004, MacDonald et al. 1991, Naiman et al. 1998, Rice et al. 2004). The scale and magnitude of these environmental effects depend on factors such as the extent and intensity of the harvest and logging methods that can be modified with management practices tailored to avoid, minimize and mitigate potential negative impacts of timber management activities. However, other factors such as geology, topography, watershed size, and the timing and magnitude of large, infrequent storm events (Hicks et al. 1991) are inherent characteristics of a watershed or stochastic events that sometimes complicate the application of best management practices and may make the potential impacts more difficult to predict and properly mitigate or avoid. Understanding the effects of forest management activities on natural processes of Green Diamond watersheds aids in developing specific management practices to protect and improve the aquatic resources. Green Diamond developed and employs a variety of management practices designed to avoid, minimize and mitigate the potential impacts of Green Diamond's operations on the aquatic system.

A. Forest Management Effects on the Hydrologic Cycle and Green Diamond's Conservation Strategies to Minimize, Mitigate or Avoid Those Impacts on Water Quality and Aquatic Species

1. Potential Forest Management Effects on the Hydrologic Cycle

Timber harvesting can alter the hydrologic process within a watershed. The primary effects of timber harvest on surface water hydrology pertain to annual water yield, low flows, and peak flows. Annual water yield generally increases following timber harvest with the greatest increase occurring during the fall period. However increases in water yield tend to diminish with forest regrowth over time. Timber harvesting typically increases summer low flows but this effect also diminishes with regrowth. The hydrologic processes affecting peak flows include evaportransportation, interception, fog drip, snow accumulation and melt rates, and soil compaction. Timber harvest typically increases peak flows but the increases are generally only detectable for events with return periods of 5 years or less. At Caspar Creek in northern California, increases in peak flow magnitude were about 27% for two-year storm recurrence interval events. The effect of timber harvest on peak flows generally diminishes with increasing watershed size and increasing time since harvest. Timber harvest activities that compact or disturb the soil can reduce the infiltration capacity of soils and alter the process of subsurface water movement. Compacted soils found on roads and landings are relatively impermeable and water runs off them quickly. Reduced soil infiltration capacity and the interception of surface flow caused by roads may lead to increases in surface runoff, peak stream flows, and sediment inputs to watercourses.

The effects of timber harvest on annual water yield, peak flow magnitude and timing, and summer low flows on aquatic species and habitat characteristics are difficult to assess. The life-cycles of salmonids have adapted to temporal variations in flow conditions by timing the phases of their life cycles to take advantage of seasonal discharge characteristics. Increased runoff in the early part of the rainy season may, in some cases, benefit salmonids by reducing water temperatures, improving water quality, and providing more flow for immigrating adult spawners. However, a harvest-related increase in peak flows may increase the number of times that channel substrates are mobilized by storm events and potentially impact developing eggs and alevins in redds. Channel-forming flows may occur more frequently as a result of an increase in peaks flows; however, the effects are generally confined to low gradient channel reaches that are less than approximately 2% gradient and with streambed and banks that are composed of gravel and finer material. Increased peak flows may also affect the survival of over-wintering juvenile salmonids by displacing them out of preferred habitats. These flow increases could also have beneficial effects by increasing available aquatic habitat. Short-term increases in summer low flows will also increase the amount of aquatic habitat. However, these hydrologic effects are temporary and diminish with regrowth of forest vegetation.

In addition to the summary above, see Appendix A for a more detailed description of timber harvest impacts on the hydrologic cycle.

2. Green Diamond's Conservation Strategies for Minimization of Altered Hydrology

The conservation measures that limit or avoid the effects of altered hydrology and associated impacts to water quality are Harvest Rate, Unit Size and Distribution

Measures; Riparian Management Measures; Slope Stability Measures; and Road Management Measures.

a) Harvest Rates, Unit Size and Distribution Measures

The hydrology of a watershed is controlled by many complex interacting factors. Increases in runoff and peak flows could result from harvesting activity and road construction (either from individual harvesting activities or from the combined effects of multiple harvesting operations in a watershed that are temporally or spatially related). Green Diamond's AHCP measures augment existing California FPRs that constrain the timing, location, and intensity of timber harvesting operations, and thus limit the hydrologic effects that might result from such operations. Four CFPR Sections are the primary sources of these constraints: those dealing with canopy retention along watercourses (14 CCR 916 et seq.), those restricting the size and spacing of even-age management harvest units (14 CCR 913.1(a)(3) and (4)(a)), and those limiting harvest rotation age (14 CCR 913.1(a)(1) and 913.11 et seq.).

Green Diamond utilizes a combination of even-age and uneven-age timber harvest methods. At a landscape level, Green Diamond's ownership within the AHCP area is composed of a mosaic of multiple age classes created by small even-age regeneration harvest areas set within a dendritic network of selectively harvested older stands that coincides with the watercourse network.

Before AHCP implementation (prior to 2007) the defined watercourse protection zone widths under the California FPRs, in concert with provisions of the Northern Spotted Owl HCP, resulted in approximately 12% (48,800 acres) of Green Diamond's ownership within the AHCP area in riparian buffers and habitat retention areas (HRAs). These riparian and other HRAs ranged in retention standards from no-cut to a minimum 70% post-harvest canopy retention.

Under the AHCP provisions, approximately 25% of a watershed is retained in RMZs and other partial or no harvest retention areas. The selection harvest and no harvest areas within these RMZs and unstable areas consist of older forests with high basal area and dense canopy cover. Over the life of the AHCP the current average stand age for these RMZ and unstable areas will increase from approximately 42 years (in 2010) to an average of approximately 92 years (in 2060). The even-age harvest areas create a mosaic of small openings that result in multiple age classes distributed as small patches across a watershed. Over the life of the AHCP, 75% of Green Diamond's ownership within the AHCP area will be occupied by these small even-age stands. The average opening created by even-age timber harvest under the AHCP has been calculated to be 15.0 acres in the Maple Creek watershed (discussed further below), which has been subjected to the most intensive harvesting on Green Diamond's ownership in the last decade. These small harvest unit openings will produce a mosaic of even-age 0-20 year old stands that average approximately 30 acres and include a matrix of riparian and in unit retention areas.

The potential for even-age management to alter hydrologic regimes is further constrained by the current FPRs that place strict limits on:

- The size of even-age management units, which can be no more than 20 acres for non-shovel yarded ground-based systems, 30 acres for aerial, cable or shovel yarding systems, and 40 acres when justified according to specified criteria (14 CCR 913.1 (a) (2);

- The distance between even-age management units, which must be "separated by a logical logging unit that is at least as large as the area being harvested or 20 acres, whichever is less, and must be separated by at least 300 feet in all directions" (14 CCR 913.1 (a) (3); and

- The timing of the harvest of contiguous even-age management units, which cannot occur unless regenerating stand in a previously harvested, adjacent clearcut unit is at least five years of age or five feet tall, and three years of age from the time of establishment on the site. (14 CCR 913 (a) (4) (A) (The net effect of this rule is that four to seven years must elapse between initiation of timber harvesting operations on adjacent even-age management units, depending on how long it takes to complete timber harvesting operations and reforestation efforts and the growth rate of subsequent regeneration on the site.)

Green Diamond's Maximum Sustained Production Plan, approved pursuant to the provisions of 14 CCR 913.11(a) (both previous and current Option A documents), also constrain the harvesting rate, limiting even-age harvests to the 50 year (45-55) and older age classes. This provision further limits the frequency with which the hydrologic characteristics of any site can be altered. Even though intermediate treatments such as pre-commercial thinning and commercial thinning may result in transitory and minor changes in the hydrologic regime, this constraint on rotation age ensures that many decades of hydrologic recovery follow any even-age timber harvesting operation. Also, restrictions on the size and spacing of even-age management harvest units, described above, effectively constrain the rotation age on many harvesting units well past the 50 year age class, with some stands reaching to 70 years of age or more before harvest, thus lengthening the cycle of disturbance significantly.

Long-term planning of timber harvesting operations in large tracts of mature timber in compliance with these temporal and spatial constraints becomes a complex challenge. The terrain typical of north coast forests, the need to consider road placement, appropriate harvesting systems, lumber markets, and other operational constraints, as well as varying stand ages and species compositions add complexity to the planning and further constrain Green Diamond's harvest schedule, meaning that it is not even possible to harvest at the pace that the minimum acreage, timing and spacing constraints would, in theory, allow. Even with the most optimistic operational assumptions, Green Diamond's planning efforts have demonstrated that the net effect of these constraints is that large tracts (~ 2000 acres) of relatively homogeneous rotation-aged timber cannot be completely harvested in less than 25 years, even assuming a steady demand for forest products. Larger tracts typically encompass a range of both mature and younger age-classes that will extend this hypothetical harvest rate period to near rotation age length.

Accordingly, existing regulatory requirements and Green Diamond's planning regime significantly limit the potential for increased runoff and peak flows and limit the risk that significant aquatic resource impacts could result from them.

A Case Study: Maple Creek. Green Diamond evaluated the rate of harvest in Maple Creek (tributary to Big Lagoon) to illustrate how these current operational and management provisions work to limit the rate in which a watershed can be harvested. Green Diamond purchased the Maple Creek property from Louisiana Pacific in 1998. Green Diamond owns 29,035 acres in the approximately 30,000 acre watershed. The first intensive old-growth harvesting began in the southern portions of the watershed early in the 1930s and continued in a northerly direction until the 1980s. Early logging was done by steam donkey and hauled to the mill by railroad. Most of the present main haul roads incorporate these old railroad grades. Logging operations were interrupted by the catastrophic fire of 1945 that burned over 60% of the watershed. Most of the railroad trestles burned making much of the area inaccessible. Railroad grades were replaced by truck roads and logs were skidded by tractor instead of steam donkeys. Most of the area burned in the 1945 fire was salvaged and then aerially seeded with conifers. This led to the vast acreage of overstocked pole size stands of Douglas-fir and redwood that currently exist in the drainage. In the 1950s an old-growth sawmill was built near the mouth of Maple Creek to process logs salvaged from the fire. Some second-growth harvesting, consisting of both clearcut and commercial thinning, began in the southern sub-watersheds of Beach Creek and M-Line Creek in the early 1980's, as these sub-watersheds were not burned in the 1945 fire. However, it wasn't until 1999, following the purchase of the LP property by Green Diamond, that even-age second growth harvesting began in the majority of the watershed.

Figure 1 shows the annual rate of harvest over the last 13 years and the projected harvest rate for the next 10 years on Green Diamond's ownership in Maple Creek. The rate of harvest includes all harvesting methods incorporated into THPs such as acres of clearcut, selection, no harvest, commercial thinning, rehabilitation, and sanitation-salvage. By the end of the 23 year period (year 2021) approximately 17,356 acres (59.8 %) of Green Diamond's ownership in the Maple Creek watershed will be incorporated into a THP for even-age harvesting. Over this same time period, approximately 5,940 acres (25.5%) will be in RMZs and other partial or no harvest retention areas within these THPs.

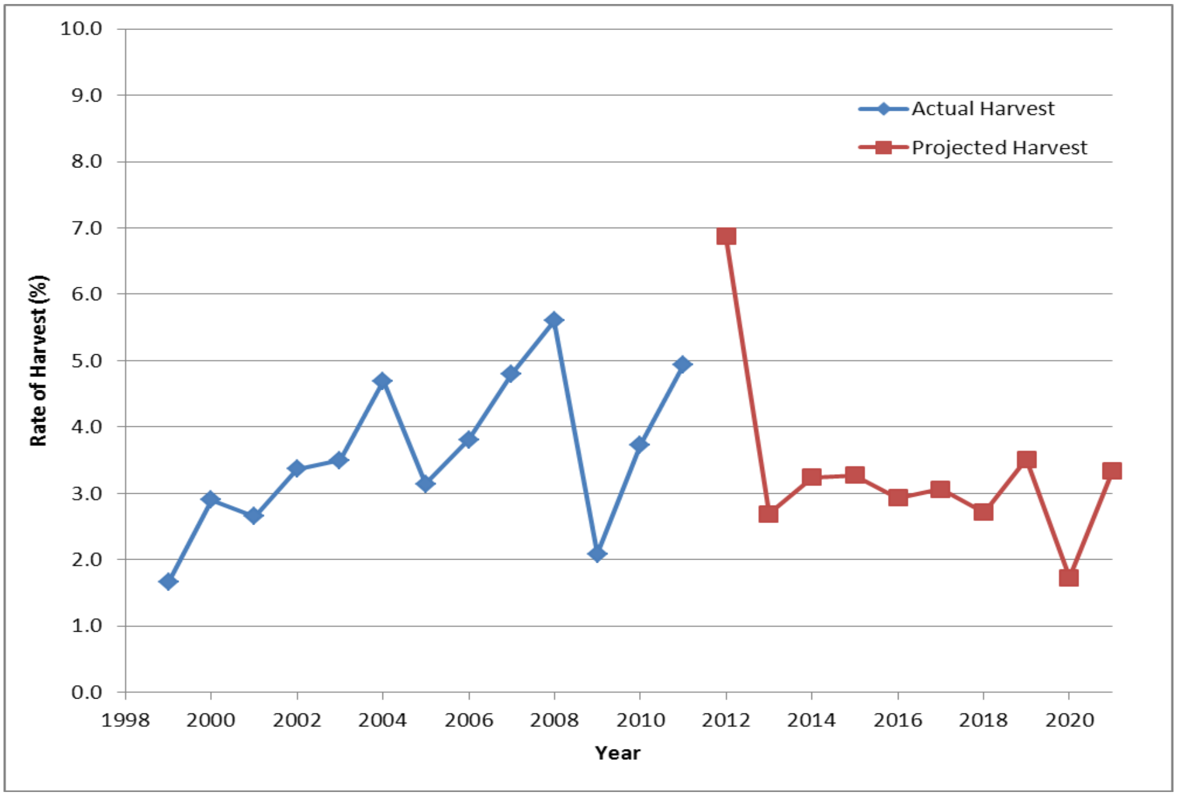

Figure 1. The actual and projected annual rate of harvest of Green Diamond's Maple Creek ownership from 1999 through 2021. The reported rates of harvest incorporate all harvesting methods from THPs including areas retained in RMZs and other partial or no harvest areas.

b) Riparian Management Measures

The riparian measures specify no salvage in the inner zone of Class I and II watercourses and salvage in outer zone if non-functional criteria are met. This conservation measure maintains in-channel LWD and allows for further recruitment of downed LWD from the RMZ which will increase overwintering habitat for juvenile salmonids. The increased pool habitat will help avoid displacement or minimize the effects of displacement of juvenile salmonids caused by peak flows. The LWD in headwater streams function primarily to create suitable riffle habitat through the storing and sorting of sediment and to dissipate hydraulic energy during peak flows.

The riparian conservation measures were also designed to increase LWD recruitment through enhanced widths and canopy retention standards. On Class I watercourses and the first 200 feet of a Class II watercourse where it enters a Class I watercourse, no trees that are judged likely to recruit are harvested. Over time, this conservation measure will increase the amount of LWD in streams, which will help sort and store sediment in streams and ultimately increase overwintering habitat for juvenile salmonids.

c) Slope Stability Measures

Most past road related failures on steep streamside slopes were generally attributed to perched road fill loosely sidecast on steep slopes or concentrated road runoff discharging onto the fill. The slope stability conservation measures for SSS zones avoid building new roads or substantial upgrading on these features without the evaluation of a registered geologist. Upgrading or decommissioning of roads on SSS's address areas with perched unstable fill and sites with concentrated road runoff on fill material.

A benefit of tree retention with regard to slope stability on deep-seated landslides, headwall swales, and SMZs is the maintenance of forest canopy, which preserves some measure of rainfall interception and evapotranspiration. Although these benefits of tree retention cannot be readily modeled across Green Diamond's ownership within the AHCP area, such maintenance of rainfall interception and evapotranspiration is expected to contribute to acceptable slope stability conditions in some locations through partially mitigating high pore water pressures that may be management related.

d) Road Management Measures

Through the road upgrading and decommissioning program, the Green Diamond road network is being progressively hydrologically disconnected from the watercourses. Inboard ditches collect surface runoff and intercept subsurface flows, then quickly route the water (and sediment) to streams, if hydrologically connected, thereby potentially producing higher and early peak flows. Through the use of decreased cross-drain and rolling dip spacing, and outsloping, as specified in the AHCP Road Management Plan, the amount of concentrated surface runoff at any point will decrease. The ditch water is dispersed onto the forest floor where it can infiltrate and reduce the effects of increased peak flow caused by the road network.

Both the road management and decommissioning measures in the AHCP, MATO and RMWDRs reduce the impacts of any operations-related altered hydrology by reducing the magnitude of peak flows and reducing the volume of sediment available for runoff during such events.

e) Harvest-related Ground Disturbance Measures

Timber harvest activities that compact or disturb the soil can reduce the infiltration capacity of soils and alter the process of subsurface water movement. Soil compaction can increase surface runoff and increase the rate which runoff reaches the watercourses as compared to subsurface flow. Site preparation measures are designed with seasonal operating limitations and minimized use of tractor-and-brushrake piling which can cause soil compaction during saturated soil conditions. There are also seasonal limitations for ground-based yarding operations with tractors, skidders, and forwarders which are intended to minimize soil compaction and risk of sediment delivery to watercourses. In addition, Green Diamond has also emphasized the use of shovel logging equipment which has very limited ground disturbance. There are many attributes of shovel logging equipment and the practice that minimizes impacts including:

- Do not have blades and do not require the construction of skid trails for the movement of logs.

- Are equipped with wide surface area – low ground pressure tracks.

- Have high undercarriages allowing them to work on top of the residual slash and stumps – thus providing for less potential for ground disturbance and soil displacement than conventional tractor logging.

- Limited to operating on topography averaging less than 35% in slope.

- Roads and landing areas associated with specific shovel harvesting areas are, by design, located on mild slopes requiring significantly less cutting and filling and often are designated as temporary. These temporary roads and landings are commonly drained and slash packed with the shovel equipment – nearly removing the footprint of the roadway.

- Landings associated with shovel logging are often not "constructed" but designated as areas along the temporary roadways where logs are decked (roadside decking) on top of the slash and existing mild topography – often eliminating the need for the actual construction of landings altogether.

The AHCP's harvest-related ground disturbance measures reduce the impacts of any operations-related to altered hydrology by minimizing soil compaction which can increase the magnitude of peak flows and the volume of sediment available for runoff during such events.

Altogether, these measures work to minimize impacts to aquatic resources that could result from harvest-related increases in runoff and peak flows. They reduce runoff, sediment transport and reduce the impacts of altered hydrology.

B. Forest Management Effects on the Sediment Inputs and Green Diamond's Conservation Strategies to Minimize, Mitigate or Avoid Those Impacts on Water Quality and Aquatic Species

1. Potential Forest Management Effects on Sediment Inputs

The frequency and magnitude of landslides is governed by a number of natural factors, including; hillslope gradient, level of soil saturation, composition of dominant soil and rock types, degree of weathering, and occurrence of climatic or geologic events. Landslides also have the potential to be substantially influenced by the type and level of management activities. Landslides are usually episodic events and tend to contribute significant quantities of course and fine sediments and organic debris to stream channels. Forest management practices can affect slope stability and increase the risk of landslides by changing vegetative cover, hillslope shape, and water flow above and below the ground surface. Different forest management operations have distinct effects on the factors that control slope stability. Roads, skid trails and harvesting trees are the major components of forest management operations that can influence slope stability. Roads and skid trails may result in unstable cut and fill slopes and divert or concentrate surface and subsurface flow. In addition, road and skid trail crossings can plug, causing fill washouts or gullies, if the flow is diverted down the road and adjacent hillslopes. Roads have long been identified as the dominant source of sediment inputs to watercourses caused by forest management activities. Harvesting trees can increase the rate of landsliding by reducing the root strength of the soil and increasing the pore water pressure by reducing interception of precipitation and evapotranspiration of soil water.

Deep-seated landslides also have the potential to produce large amounts of both coarse and fine sediments. Natural mechanisms that may trigger deep-seated landslides include intense rainfall, earthquake shaking, and erosion of landslide toes by streams. Forest management activities can potentially increase the occurrence or rate of movement of deep-seated landslides; however the accelerated rates of movement are very small (i.e. measured in millimeters).

In addition to the summary above, see Appendix A for a more detailed description of timber harvest impacts on sediment inputs and transport.

2. Green Diamond's Conservation Strategies for Sediment Input Reductions

The conservation measures that contribute to minimizing sediment input and associated reduction in impacts to water quality are Riparian Management Measures, Harvest-related Ground Disturbance Measures, Slope Stability Measures, and Road Management Measures.

a) Surface Erosion (non-road related)

Sediment production from surface erosion of hillslopes is assumed to be most important with regard to the sediment budget on slopes that are adjacent to watercourses, although erosion does occur higher on the hillslope within harvest units. Eroded sediment can be delivered to watercourses through gullies or rills or through sheet transport processes. The AHCP's riparian prescriptions and harvest-related ground disturbance prescriptions were designed to reduce non-road related surface erosion and contribute to decreased sediment delivery to the watercourses.

(1) Riparian Management Measures

The minimum width of RMZs on Class I (fish bearing) watercourses is 150 feet with 85% overstory canopy retention in the inner zone (50-70 feet depending on slope class) and 70% overstory retention in the remaining outer zone. Class II watercourses have a minimum RMZ width of 75-100 feet with 85% overstory canopy retention in the inner zone (30 feet) and 70% on the remaining outer zone. Modified Tier A, Class III watercourses (established in areas with highly erodible soils) have an EEZ width of 30 feet with 15 square feet of basal area of hardwoods, and all channel zone trees retained. Tier B, Class III watercourses have an EEZ width of 50 feet with 100% hardwood retention and one conifer per 50 feet of stream length. These retention standards, with the inherently associated understory retention, ensure that there is almost no loss in total forest canopy in the inner RMZ along Class I and II watercourses and greatly increased canopy along Class III watercourses relative to the CFPRs. This canopy coverage impedes surface erosion in these critical areas, where eroded sediment would have relatively short transport distances to reach watercourses.

In addition to the canopy requirements, general RMZ conservation measures such as the limitations on equipment in the RMZs (EEZs), seeding and mulching of areas of ground disturbance larger than 100 square feet in Class I and II RMZs, and limitations on site preparation in RMZs and EEZs also contribute to mitigating the effects of timber harvest on erosion processes on hillslopes that are adjacent to watercourses by preventing and remediating harvest related exposure of bare mineral surface soil.

Retention of trees that are judged to be critical to maintaining bank stability along Class I, II, III (Modified Tier A and Tier B) watercourses and retention of trees with roots that act as control points in Modified Tier A and Tier B Class III watercourses contribute to mitigating accelerated bank erosion and down-cutting by maintaining a live root network that increases total cohesion in the surface soil.

Other RMZ conservation measures, such as retention of trees that are likely to recruit and restrictions on salvage logging, may also contribute to mitigating the effects of management related increased sediment loads to the aquatic system to the extent that those trees and that downed wood do actually recruit to fish bearing watercourses.

(2) Harvest-related Ground Disturbance Measures

The AHCP's Harvest-Related Ground Disturbance measures are specifically designed to minimize management related surface erosion. In particular, there are time period restrictions on silvicultural and logging activities when operations conducted during those time periods have a greater risk of sediment delivery to watercourses. Harvesting activities generally result in some level of ground disturbance. The time period restrictions allow those harvest activities with relatively low ground disturbance (and associated low risk of surface erosion), such as shovel logging (not requiring constructed skid trails) and skyline and helicopter yarding, to be conducted during the winter period. Those harvest activities that can create more ground disturbance (e.g. skid trail construction, mechanized site preparation) are limited to the summer period only, with some activities (e.g. ground based yarding with tractors, skidders or forwarders) extending into the early spring or late fall, as well, if certain favorable climatic conditions occur. There are also specific areas (Salmon Creek and N.F. Elk River) with erodible soils where winter yarding is excluded.

Harvest related ground disturbances and exposure of bare mineral soil within harvest units are also minimized by way of carefully designed site preparation methods, limiting use of ground based yarding equipment that require constructed skid roads to slopes less than 45% (with some exceptions), preferential use of cable yarding systems versus ground based yarding systems, and water-barring of cable corridors where necessary. Evaluation of existing skid trails that have the potential to divert a watercourse and cause gully erosion or surface erosion are evaluated on a site-specific basis for repair during THP layout. All of these harvest related ground disturbance conservation measures contribute directly to minimizing management related surface erosion potential within harvest units by reducing harvest related ground disturbance and exposure of bare mineral soil.

b) Mass Wasting (non-road related)

Sediment production from mass wasting is most significant in riparian management zones (RMZs), steep streamside slopes (SSSs), headwall swales, and active deep-seated landslides. These areas, with the exception of RMZs, are collectively referred to as Mass Wasting Prescription Zones (MWPZs) and are subject to specific slope stability conservation measures that are intended to reduce landslide occurrences and sediment production from non-road related landslides. Most of the MWPZ's are applied in conjunction with the riparian prescriptions to provide additional protection to reduce management related landsliding.

(1) Slope Stability and Riparian Management Measures

The AHCP's Slope Stability Measures require tree retention in MWPZs, which are areas identified as having relatively high landslide-related sediment delivery rates and are sensitive to management activities. In Streamside Management Zones (SMZs), single tree selection harvest is the most intensive silvicultural prescription permissible without geologic review. The Riparian Streamside Management Zones (RSMZs) are no cut in the Blue Creek HPA. For the rest of the HPAs, the inner RSMZ band for Class I and Class II-2 is no cut and 85% canopy retention on the outer band. The total width of the SSS's, which includes the RSMZ and SMZ, varies depending on HPA location. SSSs along Class I watercourses are a maximum slope distance of 150 feet in the Smith River HPA, 425 feet in the Coastal Klamath HPA, and 200 feet in all other HPAs. SSSs along Class II-2 watercourses are a maximum slope distance of 100 feet in the Smith River HPA, 195 feet in the Coastal Klamath HPA and 200 feet in all other HPAs. SSSs along Class II-1 watercourses are a maximum slope distance of 135 feet in the Coastal Klamath HPA and 75 feet in all other HPAs. The initial default SSS prescriptions for slope gradients and slope distances are scheduled to be revised based on the results of further data collection. The initial default prescriptions for the Coastal Klamath HPA have been refined based on the results of the SSS delineation study for this HPA. Data collection is currently under way for the remaining HPAs.

EEZs along Tier B, Class III watercourses require retention of all hardwoods and an average of one conifer per 50 of stream length, plus all trees that are judged to be critical to bank and channel stability. EEZs along Tier A, Class III channels in areas with highly erodible soils receive Modified Tier B protections that require retention of 15 square feet of basal area of hardwood and all channel zone trees. In high-risk headwall swales that are field verified, selection harvest is the most intensive silvicultural prescription permissible. Active deep-seated landslides are prescribed limited operating areas of 100% tree retention above their scarps and on the lower portions of their toes. Also, road construction and reconstruction is limited in MWPZs.

Tree retention in the MWPZs is expected to maintain a network of live roots that preserves total soil cohesion and contribute to acceptable slope stability conditions in these areas. Another benefit of tree retention with regard to slope stability is the maintenance of forest canopy, which preserves some measure of rainfall interception and evapotranspiration. Although these benefits of tree retention cannot be modeled in a simple and practical manner across Green Diamond's ownership within the AHCP area, such maintenance of rainfall interception and evapotranspiration is expected to contribute to acceptable slope stability conditions in some locations through partially mitigating high pore water pressures that may be management related.

The riparian and slope stability conservation measures for Class I and II watercourses that require 85%-100% canopy retention in the inner RMZ and prohibit harvesting of trees that are likely to recruit, as well as the conservation measures for Tier B Class-III watercourses that require retention of hardwood trees and trees that are judged to be critical to maintaining bank stability and that act as stream control points, ensures that removal of trees and reduction of root reinforcement of soil shear strength is minimized. In addition, Modified Tier A Class III protections, applied in areas with highly erodible soils, require retention of 15 square feet of basal area of hardwood and all channel zone trees. Collectively these riparian and slope stability measures provide root strength to mitigate management related sediment inputs associated with stream bank instabilities.

Limiting road construction and reconstruction in MWPZs is intended to avoid and reduce the undercutting and overburdening of sensitive hillslopes and also avoid unnatural concentration of storm runoff to these slopes. Additional benefits of road related conservation measures pertaining to road cut and road fill failures as well as watercourse crossing failures are discussed below.

The AHCP's Slope Stability Measures are intended to reduce management related landslide occurrences and contribute to decreased sediment delivery, which is intended to mitigate the possible effects of management related sediment input to watercourses and the impacts on water quality.

The default slope stability prescriptions in the AHCP are based on a presumption that: (a) harvest-related activities on any unstable features (as defined in the AHCP) poses a certain level of environmental risk (e.g., causing movement of the unstable area and delivery of sediment to watercourses); and (b) applying the default prescription to harvesting activities on that feature provides a sufficient level of risk avoidance or mitigation of such impacts on water quality. The AHCP also provides for the development of site-specific alternatives based upon unique site conditions that would minimize the risk of sediment delivery and provide a level of protection to water quality that equals or exceeds that provided by the default prescription. In other words, the alternatives would be designed to achieve the same conservation objective as the default. Therefore, applying the alternative will achieve protection and conservation benefits that are equal to or better than that provided by the default prescriptions.

c) Road Related Surface Erosion and Mass Wasting

Road related erosion and mass wasting is known to be a significant contributor to the sediment budget in most managed watersheds. Eroded sediment can be delivered to watercourses through gullies or rills or through sheet transport processes from roads or through mass wasting.

(1) Road Management Measures

There are two key components of the AHCP Road Management Plan: (1) the Road Implementation Plan and (2) the Road Maintenance and Inspection Program. The objective of the Road Implementation Plan (AHCP Section 6.2.3.2) is to carry out a systematic road upgrading and decommissioning program using the Plan's road assessment and prioritization system (AHCP Section 6.2.3.1). The strategy under the AHCP differs from the past approach of conducting road work, which was on a THP-by-THP basis. The AHCP approach compartmentalizes the Green Diamond ownership into Road Work Units, or groupings of sub-watersheds. These Road Work Units were prioritized for potential upgrading and decommissioning based on a priority ranking system of providing the greatest sediment reduction and conservation benefits to aquatic resources. The intent of the AHCP is to conduct scheduled road assessments and road treatments by prioritized Road Work Units, as well as THPs, as necessary to comply with State regulations.

The Road Maintenance and Inspection Program (AHCP Section 6.2.3.9) requires:
(1) annual inspections and maintenance of all mainline and appurtenant roads to THPs; and, (2) on a 3-year rotating schedule of secondary roads within Routine Maintenance Areas. The inspections are conducted in accordance with the process outlined in AHCP Section 6.2.3.9.5.

The objectives of the Road Maintenance and Inspection Program and their related responsibilities placed on Green Diamond are distinct from those of the road upgrading program (contained in the Road Implementation Plan). The objectives of the Road Maintenance and Inspection Program depend on whether or not the road being maintained and inspected has been upgraded under the AHCP. For all roads that have been upgraded under the Road Implementation Plan, the Road Maintenance and Inspection Program is designed to keep these upgraded roads in a "low risk" category.

In contrast, for roads that have not yet been upgraded or decommissioned under the Road Implementation Plan, the objectives of the Road Maintenance and Inspection Program are to minimize the risk of significant road failures and to control significant chronic sources of sediment discharges from these roads until the point at which the entire road can be upgraded or decommissioned according to the prioritization schedule in AHCP Section 6.2.3.1.1.

The AHCP was designed to manage Green Diamond's road network by systematically and efficiently upgrading, decommissioning and maintaining roads using a landscape-based approach. Green Diamond has agreed to spend $2.5 million per year (2002 dollars) for the first 15 years of the implementation of the AHCP to accelerate the repair of high- and moderate-priority road sites. The RMWDRs and MATO provide programmatic regulatory coverage for THP-related sites as well as for non-THP sites in a comprehensive approach that provide the greatest conservation benefits by: (1) fixing sites with the greatest potential sediment savings; and, (2) deferring improvements on those sites with low risk of failure until the road is upgraded, decommissioned or the risk of failure of the site is elevated.

The AHCP, RMWDRs and MATO contain a site identification, prioritization and rating system that is designed to determine which sites have the highest probability for risk of failure. The Agreement and RMWDRs provide the regulatory authorization for repair of all categories of road sites (upgrading, decommissioning, and maintenance) across the landscape through a proactive approach that provides significantly more environmental protection and biological benefits than is possible under the typical THP/1600/General WDR process. These authorizations greatly reduce the probability of catastrophic road crossing failures that would, in turn, cause significant sediment delivery to streams.

The AHCP, RMWDRs and MATO include performance and prescriptive measures required to protect fish and wildlife resources, as well as other public trust resources. These conservation measures address: crossing types; time of operation; permanent crossings; temporary crossings; fish passage; culvert crossings; fords; water drafting, flow bypass and drafting site maintenance; erosion and sediment control; bank stabilization; road decommissioning; obstruction and sediment removal; vegetation removal and control; deposition and disposal of materials; equipment use, petroleum and other pollution control; and geology.

In the respective sections below, we summarize ongoing monitoring data from the Maple Creek watershed (Figure 2) to evaluate the potential negative effects of the current rate of harvest in this basin where Green Diamond has been implementing contemporary management practices.

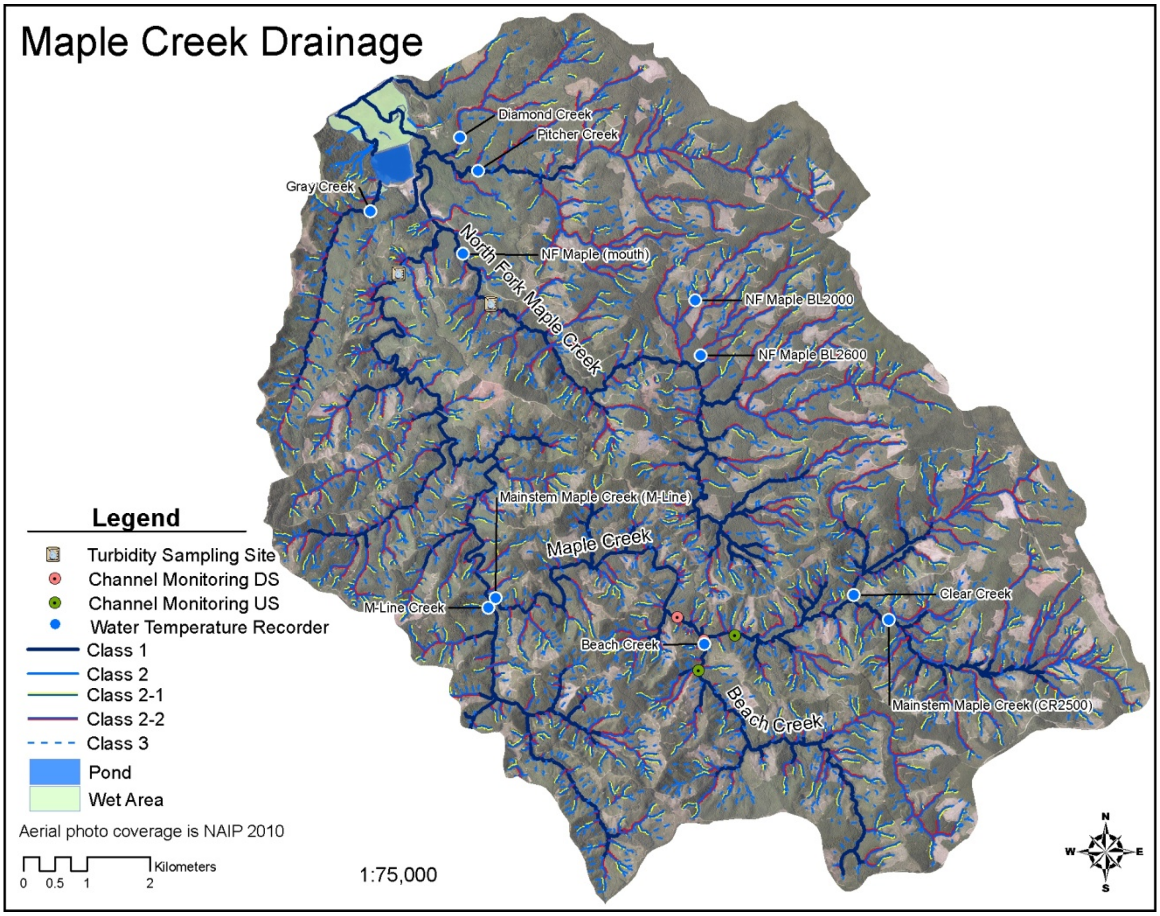

Figure 2. Map of the Maple Creek watershed and Green Diamond's turbidity monitoring, water temperature monitoring, and channel monitoring locations.

The Road Management Measures in the AHCP, RMWDRs and MATO reduce road related sediment production and delivery to watercourses. Turbidity threshold sampling (TTS) data collected from 2005-2012 at two sites in Maple Creek watershed (Figure 2) indicate that stream turbidity has generally decreased over time. This change is evident from assessment of the annual relationship between stage and turbidity (Figure 3). Assuming a constant slope, an increase in the y-intercept would suggest an increase in the overall turbidity levels in the watershed across all ranges of water depths (or stream flows), whereas, a decrease in the y-intercept would suggest a decrease in the overall turbidity levels in the watershed across all ranges of water depths (or stream flows). Assuming a constant y-intercept, an increase in the slope over time would suggest that turbidity levels are higher for a certain water depth (or stream flow), whereas, a decrease in slope would suggest that turbidity levels are lower for a certain water depth (or stream flow). Over the past seven years of monitoring, the slopes of these relationships have remained constant at mainstem Maple Creek (MSM linear regression: t-value = 0.9935, p = 0.3588, R^2 = 0.1423) and North Fork Maple Creek (NFM linear regression: t-value = 1.5226 , p = 0.1787, R^2 = 0.2787) but the y-intercepts of these relationships have decreased significantly at both sites (MSM linear regression: t-value = -2.7786, p = 0.0321, R^2 = 0.5627 and NFM linear regression: t-value = -2.6362 , p = 0.0387, R^2 = 0.5367). The constant slope suggests that road management has not negatively impacted turbidity. In fact, the change in the regression intercept translates into a decrease in turbidity across the range of stages (discharges) at each site. We evaluated the current rate of harvest above each turbidity station to assess the observed changes in turbidity (Figure 4). The rate of harvest was lagged by one year in an attempt to align the potential impact of harvesting with the expected response from the turbidity monitoring. The decrease in turbidity appears to be independent from the rate of harvest in each sub-basin. This decrease is likely attributable to the collective suite of sediment minimization measures described above and implemented by Green Diamond in conjunction with the AHCP.

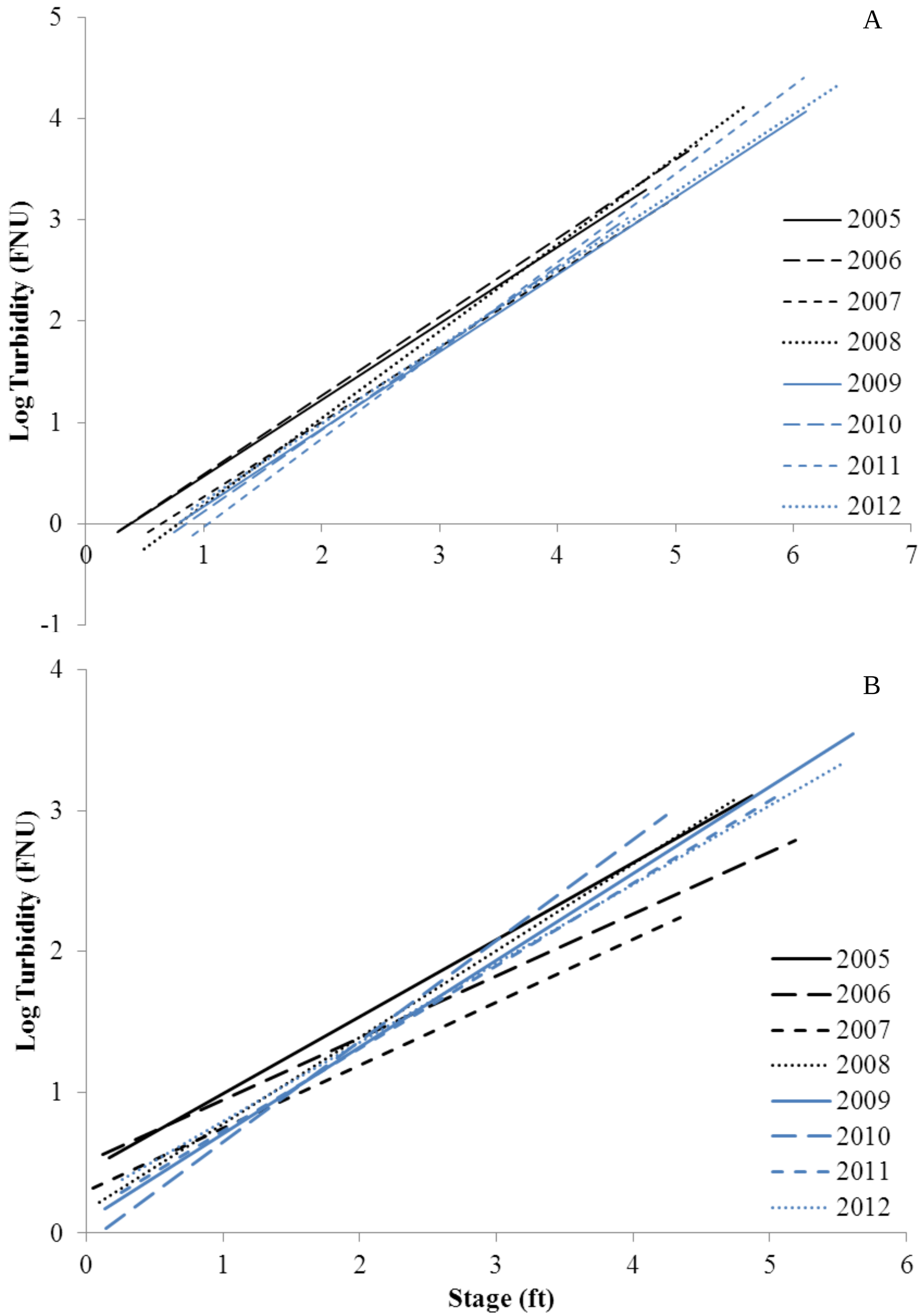

Figure 3. Comparison of stage-turbidity relationship from 2005-2012 in mainstem Maple Creek (A) and North Fork Maple Creek (B).

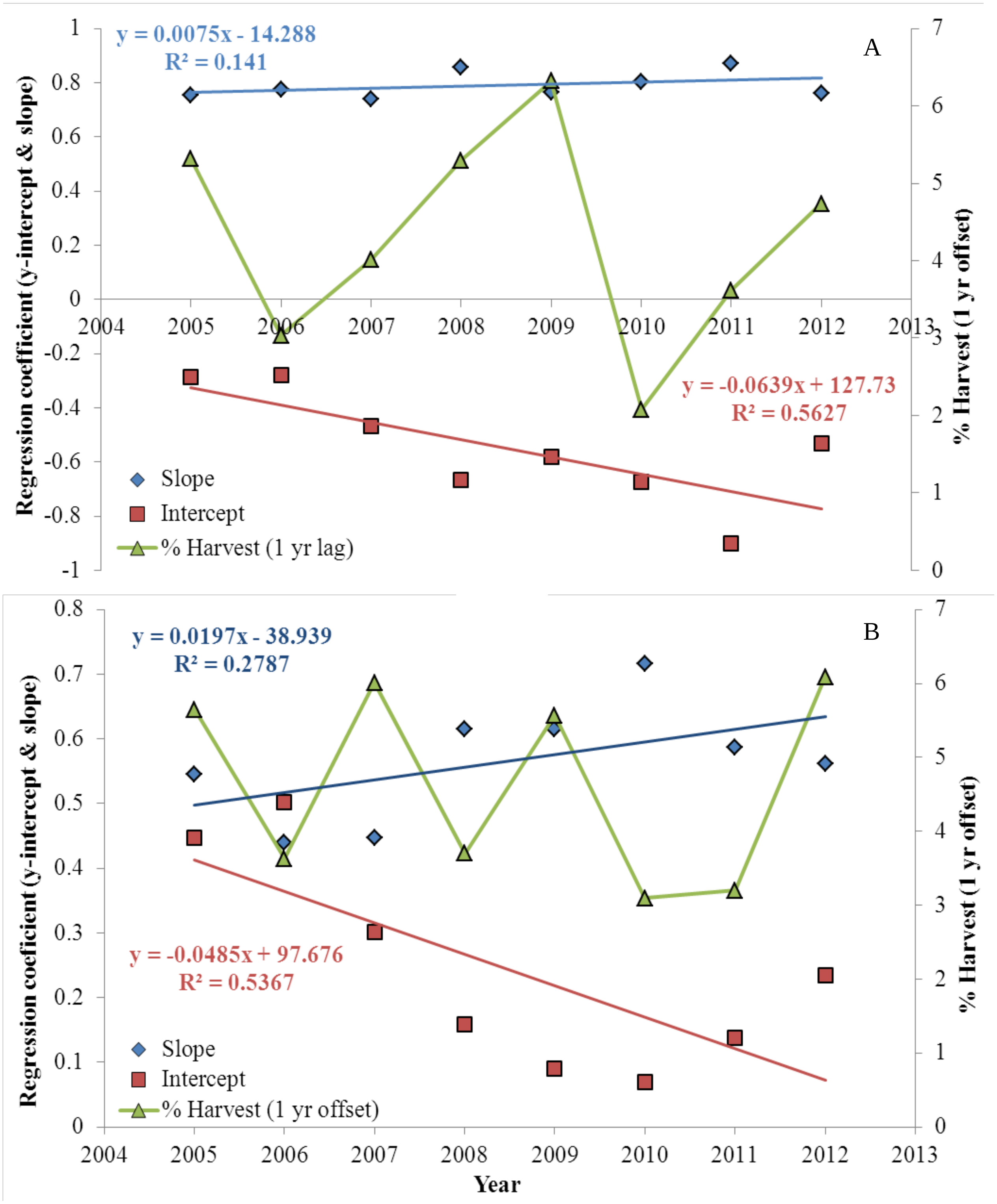

Figure 4. Relationships between stage-turbidity linear regression coefficients [slope = blue diamonds; y-intercept = red squares] and percent harvest [green triangles] from 2005-2012 in the mainstem Maple Creek (A) and North Fork Maple Creek (B). The rate of harvest was lagged by one year in an attempt to align the potential impact of harvesting with the expected response.

C. Forest Management Effects on the Altered Water Temperature and Green Diamond's Conservation Strategies to Minimize, Mitigate or Avoid Those Impacts on Water Quality and Aquatic Species

1. Potential Forest Management Effects on Altered Water Temperature

Stream temperature is controlled by multiple factors such as solar and thermal radiation, riparian shading, air temperature, wind velocity, relative humidity, tributary inflow, groundwater inflow, and hyporheic flow. Timber harvest can affect water temperature in streams in three principal ways: (1) increased incoming solar radiation and decreased incoming thermal radiation through the removal of canopy cover; (2) increased sediment inputs that results in wider and shallower channels; and (3) modification of hydrologic processes that regulate the timing and quantity of stream flow. Incoming solar radiation appears to be the dominant factor at the site level; however, modeling studies of the cumulative effects of large scale timber harvest emphasize that it is a complex set of factors, rather than a single factor such as shade, that governs stream temperature dynamics. Increases in water temperatures during summer can have negative impacts on the aquatic system. However increased light levels and increased autotrophic production can also have a positive effect through an increase in food production and higher growth rates if water temperature increases are not significant.

In addition to the summary above, see Appendix A for a more detailed description of timber harvest impacts on altered water temperature.

2. Green Diamond's Conservation Strategies for Minimization of Altered Water Temperature

The AHCP's Riparian Management and Slope Stability Measures minimize, mitigate and avoid the impacts of Green Diamond's operations associated with altered water temperature.

a) Riparian Management Measures

The minimum width of RMZs on Class I (fish bearing) watercourses is 150 feet with 85% overstory canopy retention in the inner zone (50-70 feet depending on slope class) and 70% overstory retention in the remaining outer zone. Class II watercourses have a minimum buffer width of 75-100 feet with 85% overstory canopy retention in the 30 foot inner zone and 70% on the remaining outer zone. These retention standards ensure that there is almost no loss in canopy in the critical inner zone. There is an immediate net reduction of canopy cover of approximately 15-20% following timber harvest in the outer zone, which will be replaced within 5-10 years by recovery of the remaining tree crowns.

As a result, there should be little or no measurable change in water temperature as a result of canopy reduction following timber harvest.

Although the sample size is still small, Green Diamond has direct experimental data to support the conclusion that the riparian conservation measures will prevent impacts to water temperature. A Before-After-Control-Impact (BACI) experimental design was used to assess the influence of clearcut timber harvest on water temperature in small Class II watercourses where the influence of reduction of canopy has the greatest potential to impact water temperature (see AHCP Appendix C, Class II Temperature Assessments). The riparian protection measures were based on past California FPRs and Green Diamond's NSO HCP guidelines, which included 50-75 foot buffers with 70% total (overstory and understory) canopy retention. Two of the treated streams showed minor (0.5-1.0 ºC) increases in water temperature within the limits of the harvest unit relative to the controls during the warmest time of day in the warmest 14-day period of the summer and two of the treated streams showed minor decreases (-1.3-1.4 ºC). The decreases in temperature were likely the result of increased ground water inputs following harvesting of the adjacent stand. Considering the small magnitude of change under the most extreme annual conditions, the opposite direction of the response, and the fact that riparian protection measures are substantially more restrictive under the AHCP than the time the study was conducted, Green Diamond believes there should be no measurable change in water temperature in Class I or larger Class II watercourses due to minor reductions in canopy following timber harvest. Even if there continues to be minor positive and negative changes in water temperature in the smaller Class II watercourses, the limited time and area of the impacts should result in no biological effects.

Temperature data collected in the Maple Creek watershed were also analyzed to determine if changes have occurred in response to the current rate of harvest in this basin. Eleven monitoring sites were evaluated; eight sites located in Class I watercourses and three in Class II watercourses (Figure 2). To determine if water temperatures changed over time, the maximum seven-day moving average (M7DMA) water temperature was calculated each year for each monitoring site and linear regressions were used to assess the direction and significance of changes to M7DMA water temperatures at each site. Two sites showed a significant decrease in M7DMA water temperature and the other nine sites (82%) showed no significant change (Table 1). However, many of these sites demonstrated a slight decrease or generally had consistent water temperatures over time. Diamond Creek and Gray Creek were the two sites where M7DMA water temperatures decreased (Figure 5A). These decreases in water temperature were likely due to the close proximity of these sites to the coast. The persistent coastal fog in this area likely reduces the potential for heating from solar radiation. The lack of any increase to M7DMA water temperatures in the Maple Creek watershed provides evidence to relieve concerns about altered water temperatures related to past and planned rates of harvest.

Several sites (e.g., Beach Creek, Clear Creek, Mainstem Maple Creek [M-line], Mainstem Maple Creek [CR2500], NF Maple Creek [BL2000], and NF Maple Creek [mouth]) experienced a warming period from 2003-2006. The potential influence of harvest rate and air temperature during this time was assessed by plotting these two variables against time and looking for associations with annual changes in water temperature (Figure 5). Maximum August air temperature appears to be partially associated with the observed water temperatures and harvest rate showed minimal and seeming coincidental associations at only two sites. For example, the highest M7DMA water temperature at Clear Creek in 2006 coincided with an increased harvest rate; however, there was no response from the higher rate of harvest that occurred in 2010. These results further suggest that harvest rate is not significantly associated with the observed changes in water temperatures in Maple Creek.

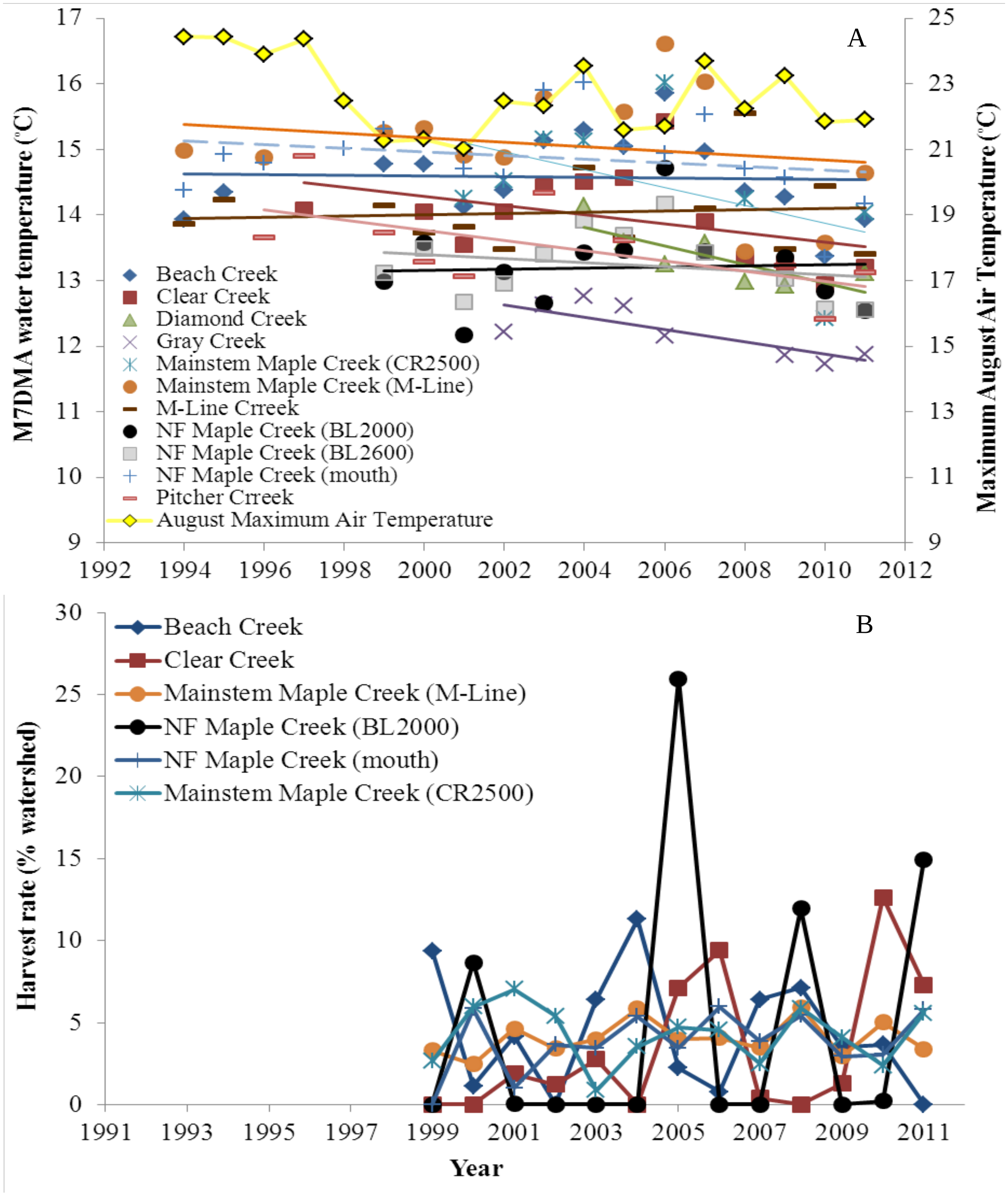

Figure 5. Change in maximum seven-day moving average (M7DMA) water temperatures [primary y-axis] at sites monitored in the Maple Creek watershed and maximum August air temperature [secondary y-axis] from the midpoint of the basin from 1994-2011 (A) and harvest rate history at a subset of these sites from 1999-2011 (B). For purposes of comparing water temperature and rate of harvest, the x-axis for the harvest rate was advanced by one year to align the potential impact of harvesting with the expected response from the water temperature monitoring.

Table 1. Summary of linear regression results assessing the change in maximum seven-day moving average (M7DMA) water temperatures over time.

SiteName	N	Slope	R-squared	t-value	P-value
Beach Creek	15	-0.0056	0.002	-0.1629	0.8731
Clear Creek	13	-0.0695	0.1764	-1.5351	0.153
Diamond Creek	7	-0.14	0.6207	-2.8605	0.0354
Gray Creek	8	-0.0944	0.63	-3.1959	0.0187
Mainstem Maple Creek (CR2500)	8	-0.1367	0.2339	-1.3536	0.2246
Mainstem Maple Creek (M-Line)	13	-0.0347	0.0424	-0.6975	0.4999
NF Maple (mouth)	17	-0.0278	0.0542	-0.9271	0.3685
NF Maple BL2000	12	0.0083	0.0026	0.1602	0.8759
NF Maple BL2600	12	-0.0311	0.0556	-0.767	0.4608
M-Line Creek	13	0.0098	0.0082	0.3014	0.7687
Pitcher Creek	10	-0.0784	0.3768	-2.1995	0.059

b) Slope Stability and Road Management Measures

Green Diamond's qualitative assessment (review of past air photographs and identifying physical indicators of past conditions such as historical terraces and location of riparian vegetation) of Class I watercourses indicate that streams generally reached peaks in aggradation during the 1960's and 1970's. Since that time, most channels have dramatically downcut and narrowed. More recently, changes in channel morphology has been more subtle, and it is expected that this trend will continue with periodic adjustments due to the severity of winter storms. With the slope stability and road management measures that are designed to minimize management related sediment inputs, Green Diamond believes that sediment inputs will be reduced relative to past practices. Given that water temperatures are generally favorable throughout Green Diamond's ownership even with past sediment inputs, Green Diamond believes that future sediment minimization measures described in the AHCP, RMWDRs and MATO will further reduce the likelihood that aggradation of channels will result in elevated water temperatures.

A preliminary assessment of channel monitoring data collected in the Maple Creek watershed (Figure 2) support the effectiveness of current management measures to minimize sediment inputs and reduce the likelihood of elevated water temperatures. A comparison of channel monitoring long-profile data collected from 2002-2011 along two reaches in the Maple Creek watershed were conducted. To determine if the longitudinal profiles of these streams changed over time, profiles were analyzed using linear regression to calculate regression coefficients (i.e. slope and y-intercept) and these coefficients were subsequently regressed to assess the direction and significance of changes to the long profiles over time. An increase in the y-intercept would suggest aggradation (i.e. increased sediment inputs over time), whereas, a decrease in the y-intercept would suggest channel down cutting. Interpretation of channel morphology changes with respect to the slope depend on whether the changes occur at the upstream or downstream end of the long profile. A decrease in slope at the downstream end of the channel would suggest downstream channel aggradation is occurring, whereas, a decrease in slope at the upstream end of the channel would suggest upstream channel down cutting is occurring.

No significant change in slope occurred at either Maple Creek (linear regression: t-value = -1.231, p = 0.258, R^2 = 0.178) or Beach Creek (linear regression: t-value = 2.66, p = 0.057, R^2 = 0.639) (Figure 6). A significant decrease in the y-intercept was found at Maple Creek (linear regression: t-value = -6.185, p = 0.0005, R^2 = 0.845) but no change occurred at Beach Creek (linear regression: t-value = -1.58, p = 0.189, R^2 = 0.385). The significant decrease in y-intercept along Maple Creek suggests that sediment inputs have reduced sufficiently to allow for the channel to down cut. The slight increase in slope at Beach Creek that occurred in 2007 was likely influenced by the enlargement of the large wood debris accumulation (Figure 6), especially considering that the change was only apparent upstream from the debris accumulation. This wood accumulation likely reduced the movement of sediments downstream and caused the upper portion of the monitoring reach to aggrade but has since remained constant. Overall, there is no apparent influence from the current rate of harvest (% area harvested) on the observed changes to channel profiles in these two basins (Figure 7).

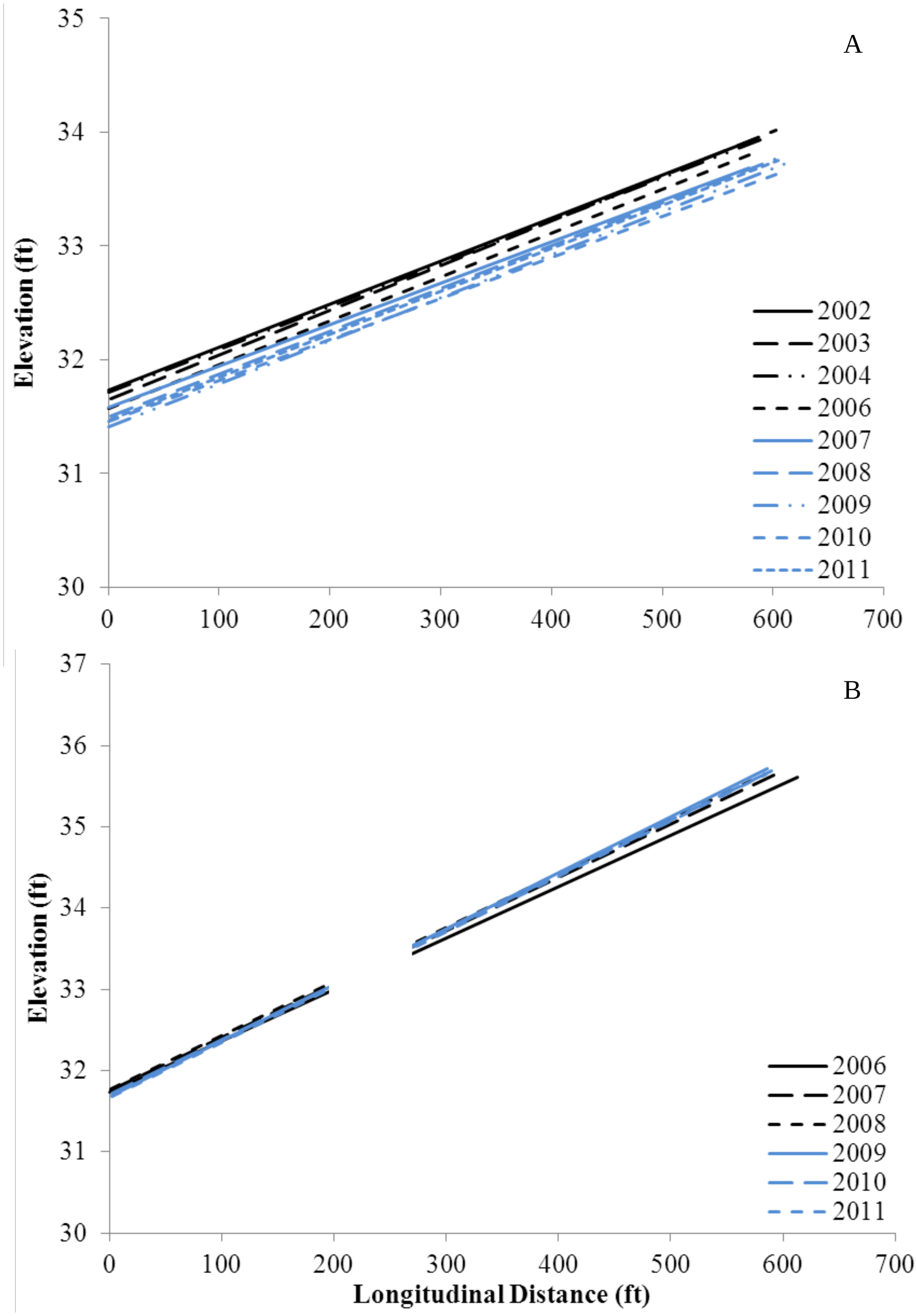

Figure 6. Comparison of channel monitoring long-profile trend lines collected at Maple Creek (A) and Beach Creek (B) from 2002-2011 by Green Diamond. Gap in the data for Beach Creek (from 210-280 ft.) resulted from a segment that could not be effectively measured due to a large woody debris accumulation.

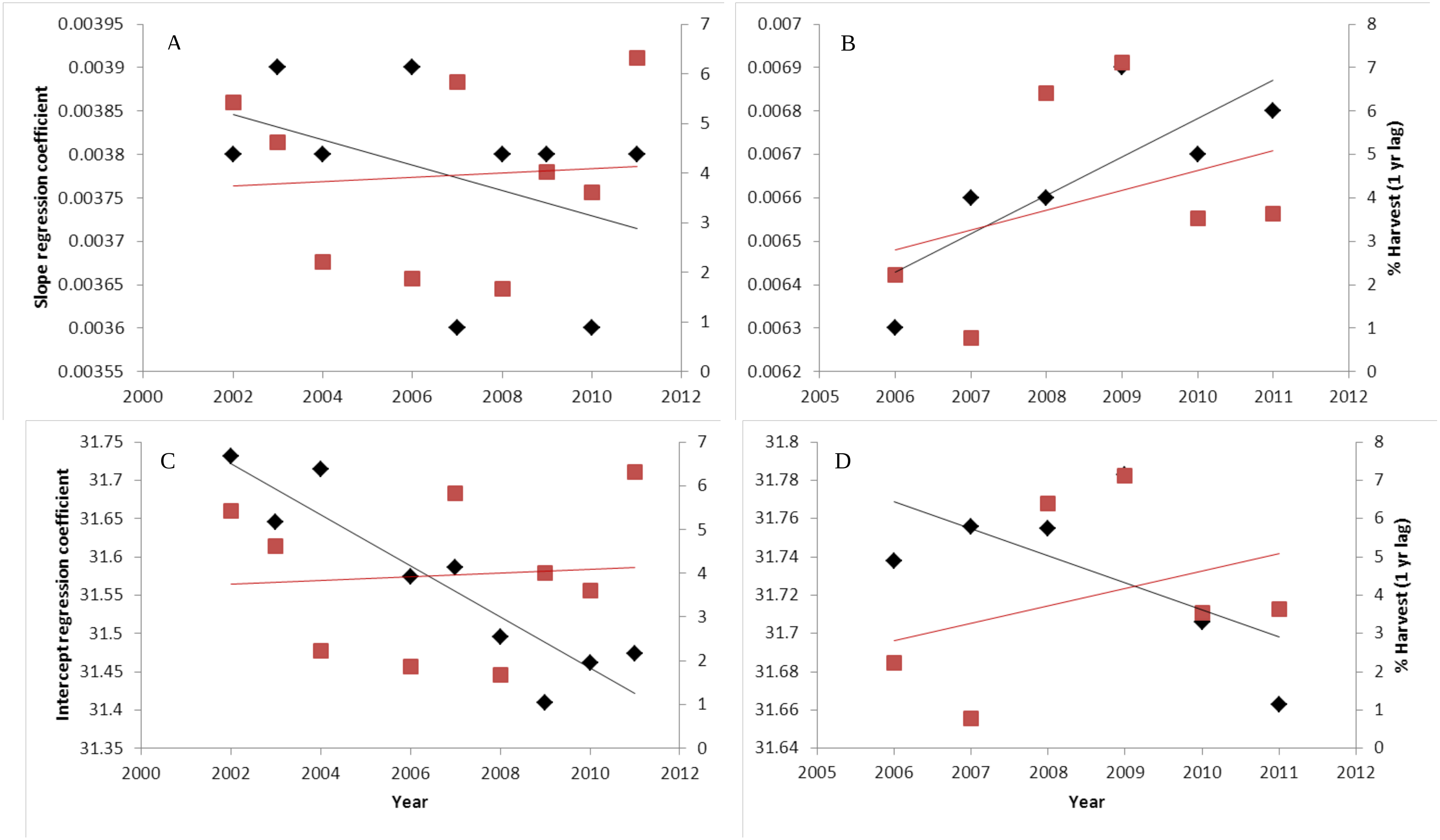

Figure 7. Change in long profile linear regression coefficients (i.e. y-intercept and slope) over time for Maple Creek (A & C) and Beach Creek (B & D). Regression coefficient trends (black lines), with annual data points (black diamonds), and harvest rate trends (red-lines), with annual data points (red squares), are shown. The rate of harvest was lagged by one year in an attempt to align the potential impact of harvesting with the expected response.

D. Forest Management Effects on Large Woody Debris Recruitment and Green Diamond's Conservation Strategies to Minimize, Mitigate or Avoid Those Impacts on Water Quality and Aquatic Species

1. Potential Forest Management Effects on Large Woody Debris Recruitment

Large woody debris (LWD) influences stream channel morphology and is an important component to forming pools and instream cover. Historical practices such as splash damming, stream cleaning, and intensive logging in watercourses and riparian zones resulted in extensive removal of LWD and potential recruitable LWD from watercourses. These historical practices have resulted in the loss of important habitat features and impacted aquatic species. Timber harvesting and the presence of, or the construction of roads in riparian areas may result in a decline in the recruitment of LWD and a resulting reduction of in-channel LWD. Timber harvest in riparian zones removes trees that could potentially become in-channel LWD. Roads in riparian zones may reduce potential LWD by the presence of the road surface eliminating tree production and also by intercepting trees that fall toward the channel.

In addition to the summary above, see Appendix A for a more detailed description of timber harvest impacts on large woody debris recruitment.

2. Green Diamond's Conservation Strategies for Large Woody Debris Recruitment

The AHCP's Riparian Management measures and certain Slope Stability measures minimize and mitigate impacts associated with loss of LWD. Maintenance of riparian management zones (RMZs) provides several biological and watershed functions. In addition to functions such as maintaining the riparian microclimate and providing nutrient inputs, one of the most important functions of the RMZs is to provide for the recruitment of LWD.

a) Riparian Management Measures

The minimum width of RMZs on Class I (fish bearing) watercourses is 150 feet with 85% overstory canopy retention in the inner zone (50-70 feet depending on slope class) and 70% overstory retention in the remaining outer zone. However, probably the most important measure relative to the potential recruitment of LWD is that no trees are harvested that are judged likely to recruit. There are a variety of criteria used to make this judgment including, but not restricted to, distance from the stream, direction of the lean, intercepting trees and potential for being undercut by the stream.

Most of the trees that are harvested from RMZs are those on the outer edge of the riparian buffer. These same trees also have the lowest potential to be functional in the stream since only the upper portion of the tree would reach the stream. Excluding geologic processes, the riparian conservation measures ensure that all the trees with the greatest potential for significant LWD function (e.g. LWD recruited by fluvial processes, windthrow or tree mortality with sufficient size and proximity to the stream that it can influence fluvial processes and provide cover for fish) are retained. The small proportion (<10%) of trees that are harvested within the RMZs not only have a very low probability of contributing significant LWD to the stream, but by removing some trees, the surrounding trees will have increased growth with even greater potential functionality in larger Class I watercourses. Therefore, Green Diamond concludes that the riparian conservation measures for Class I watercourses will provide for fully functional LWD recruitment rates and may actually enhance LWD recruitment compared to natural rates from no cut buffers.

LWD performs many similar functions in Class II watercourses, but also has some unique functions in Class II watercourses, particularly in the smaller headwater streams. The piece size that is functional tends to decrease as the stream and associated hydraulic energy of the stream decreases. In addition, pool habitat is more likely to be formed by bedrock and boulders in small confined channels. Finally, there is little evidence for a reduction of LWD in most Class II watercourses in Green Diamond's ownership . Instead, past logging practices may have resulted in an overabundance of LWD in many of these smaller streams. As a result, LWD recruitment is less of a conservation priority in these streams and much of the benefit of the Class II RMZ is thought to be for the maintenance of microclimate and bank stability. Even so, it is still important that there are adequate sources of LWD for these channels into the future with the Class II protections. The minimum width of RMZs on Class II watercourses is 75-100 feet with 85% overstory canopy retention in the 30 foot inner zone and 70% overstory retention in the remaining outer zone.

As part of the riparian conservation measures, there is only a single entry into RMZs to harvest trees during the term of the AHCP for both Class I and II watercourses. Only a small proportion of the trees within RMZs are harvested (85% retention in inner zone and 70% in the outer), and those remaining will continue to age and grow larger following removal of the adjacent stands. Based on the age of RMZs at the time the AHCP was being developed, over one third of the stands comprising the RMZs will be greater than 100 years old and the remainder will be between 51-100 years by the end of the permit period. At age 100 in a typical RMZ in the redwood zone, there will be approximately 120 trees per acre, with 12% of the trees > 36" DBH. A few trees will exceed 48" DBH and the tallest trees in the stand will be about 170 feet tall. Under exceptional conditions (little competition, very good soils, abundant light, water and nutrients) a 100 year old redwood can exceed 5 - 6 feet in diameter. In the more interior Douglas-fir/hardwood zone, diameter growth will not be quite as rapid, but there will be approximately 130 trees per acre, with 6% of the trees > 36" DBH. An occasional tree will exceed 48" DBH and the tallest trees in the stand will be about 180 feet tall.

b) Slope Stability Measures

Most of the Slope Stability Measures are designed to minimize management induced sediment inputs into Plan Area watercourses; however, geologic processes can be important mechanisms to provide LWD into streams, and in some situations, it may be the predominate mechanism by which LWD reaches streams. In particular, shallow rapid landslides have the potential to deliver large amounts of LWD when they form in steep streamside slopes or inner gorges. In addition, debris torrents from small headwater Class II and III watercourses can be an important source of LWD when they empty directly into Class I or large Class II watercourses. This latter phenomenon has not been frequently observed within most of the Green Diamond's ownership, but there are isolated areas where debris torrents are sufficiently common to be a potential important source of LWD.

The slope stability management zones (SMZs) occur outside of RMZs in areas (inner gorges and steep streamside slopes, headwall swales and toes of deep-seated landslides) that have been determined to be prone to shallow rapid landslides. As noted above, the primary objective of the SMZ is to minimize the likelihood of management-induced landslides. However, landslides do occur in these areas with or without management activities, and the SMZ conservation measures ensure that when a landslide does occur, it has the potential to deliver large amounts of LWD to the stream.

II. Cumulative Watershed Effects and Rate of Harvest

The ability to make generalizations about the effects of forest harvest on aquatic systems is difficult because there are a number of confounding issues that have generated a wide variety of responses. Issues such as the timing and magnitude of peak flow generating events, watershed characteristics, the type and condition of roads, forest species composition, types of harvest systems, forest practices, and time since harvest can influence the observed responses reported in the literature. Separating harvest effects from road effects is similarly problematic since those activities studied in paired watersheds typically occurred coincidently or were closely coupled.

The ability to make inferences from the various paired watershed studies to Green Diamond's ownership is another limitation at multiple levels. First, how applicable are the results observed from different watershed studies to a particular watershed or ownership of interest, such as Green Diamond's ownership within the AHCP area? The answer is that the results are probably applicable for certain metrics such as water temperature where the different variables are more readily predicted and modeled, but less applicable for metrics such as sediment input which is strongly influenced by local geology, topography and storm history. The second and probably most important question on the limitation of inference is whether the findings from the historical paired watershed studies are germane when evaluating the effects, including cumulative effects of contemporary forest practices? Given the substantial changes in every aspect of contemporary forest management, attempting to draw inferences from paired watershed studies that included substantial areas of historical logging is clearly inappropriate.

Historical logging practices involved harvesting all merchantable trees across entire ownerships and watersheds over a very short period of time with little or no constraints resulting in more roads built than necessary, roads built in poor locations, tractor logging on steep slopes, construction of tree falling layouts, vast skid trail networks, hot and intense broadcast burning, inadequate or no protection or retention of riparian zones, and little or no concern for proper design and location of stream crossings. These practices were utilized on Green Diamond's property primarily in the 1950's through early 1970's when contemporary environmental protections were non-existent or inadequate. Due to the lack of a consistent approach to landscape planning and regulation, large watersheds were roaded and harvested over a relatively short period of time which exposed large areas to soil compaction, erosion and longer term environmental legacy impacts.

It wasn't until the Z'berg-Nejedly Forest Practice Act of 1973 was established that a system for regulating timber harvest activities in California began. Although the California Forest Practice Rules (FPRs) have many different objectives, a primary one has always been to minimize and avoid significant adverse impacts on aquatic resources. Over time the FPRs have been altered to provide additional protections for aquatic species such as Federal and State listed fish species based on the increasing knowledge made available in the literature regarding impacts of harvesting activities on aquatic systems as described above. The net effect of these various studies has been the establishment of management practices with a central focus on streams that includes riparian buffers along fish bearing watercourses (Class I) and non-fish bearing watercourse that support other aquatic life (Class II) and the establishment of equipment exclusion zones on watercourses that do not support aquatic life (Class III). In addition to providing buffers and equipment exclusion zones on watercourses, the general provisions that have evolved to be associated with forest Best Management Practices (BMP), in virtually every state, include properly designing, locating and maintaining roads and watercourse crossings; minimizing soil compaction and soil disturbance; and avoiding or providing buffers on unstable topography. Although the specific measures vary between states, the mitigation principles are the same; to protect aquatic resources.

In California, there has been a significant paradigm shift as to the classification and the protections provided for Class I and Class II watercourses. In 1990 many streams, both Class I and Class II watercourses, qualified for shade exemptions where no overstory canopy retention was required during timber harvest operations. The exemptions were authorized in coastal climates where water temperature increases were not expected to be significant. The exemptions focused solely on water temperature effects and did not consider the many other benefits that riparian zones provide. In 1992, Green Diamond (then Simpson Timber Co.) began operating under the NSO HCP. This HCP established higher canopy retention standards than the CFPRs for Class I and II watercourses. In 1994 when the southern torrent salamander was petitioned to be listed under CESA, there was a significant California forest industry-wide upslope migration of Class II riparian retention along watercourses that would otherwise had been designated as Class IIIs with equipment exclusions zones. During this time period there were amphibian training programs for foresters to help them recognize the specific habitats that these salamanders occupied so appropriate classifications would be made and protections provided to the watercourses. Also beginning in 2000, the specific criteria of what qualifies a particular stream as a Class II watercourse evolved significantly in addition to the riparian buffer width and retention requirements. Before this time period watercourses were designated as Class II when either salamanders were detected or the gravel substrate that provided habitat for the animals were present. The criteria that were developed and are currently utilized by Green Diamond today include the presence of perennial flow, aquatic obligate plants, aquatic obligate amphibians, aquatic macro-invertebrates, season of classification and drainage area.

The most recent enhancement to Class II watercourses on Green Diamond's ownership occurred in 2007 with the implementation of the Aquatic HCP. The buffer width and overstory retention standards were again increased relative to the CFPRs and Green Diamond's NSO HCP. These changes in Class II watercourse classification and riparian retentions standards have resulted in significant additional watercourse buffers across the landscape, extending retention in many cases to ridge tops.

Historical paired watershed studies were extremely valuable in understanding the fundamental effects of timber harvest on water quality, water quantity and watershed processes and were instrumental in guiding the development of current forest practices and protections to avoid, minimize and mitigate forest management impacts. However the use of these studies to evaluate the effects of present day forest practices on aquatic resources is inappropriate. A majority of the existing research was conducted in the 1970s, 1980s, and early 1990s during a time when forest practices were non-existent or vastly different from current practices. In addition, the harvesting practices used historically not only varied with time locally, but even regionally. This is still a very important consideration when evaluating and comparing contemporary watershed studies because specific protection measures such as watercourse buffers still widely vary from state to state. Also the types of equipment utilized to yard and transport logs during initial harvest entries were much larger than the equipment needed and used today. Significant advances in yarding and road construction techniques and technology have minimized soil compaction, ground disturbance, surface runoff and sediment delivery to watercourses.

An example of the advances in management practices can be found in Williams et al. (2000), who conducted a retrospective study of harvesting impacts where BMPs were applied and compared those results to a study by Hewlett (1979) where no BMPs were applied in the B.F. Grant Memorial Forest in the Piedmont. Hewlett (1979) reported that the majority of the sediment increases observed originated from roads and channel disturbances. Williams et al. (2000) similarly monitored sediment and other water quality parameters following timber harvesting operations that utilized state BMPs. They estimated that the BMPs reduced sediment yield increases tenfold compared to those that utilized no BMPs.

There have been other recent retrospective studies that have evaluated the impacts of harvesting that utilize more contemporary harvesting practices. For example Litschert and MacDonald (2009) evaluated the frequency and stream connectivity of sediment rills and plums originating from harvest units that ranged in age from 2 to 18 years old in the Sierra Nevada and southern Cascades. After assessing approximately 200 harvest units, they found 19 erosional features within the harvest units but only 6 were connected to watercourses. Sixteen out of the 19 erosional features that were found and 5 out of the 6 features that were connected to watercourses originated from skid trails. They concluded that new harvest practices rarely initiated large amounts of runoff and surface erosion but suggested that sediment delivery from timber harvest can be further reduced by proper construction and post-harvest treatment of skid trails.

CalFire et al. (2011) conducted a rapid assessment of sediment delivery sources from recent clearcut timber harvesting activities in the Battle Creek Watershed in the Sierra Nevada's. They evaluated 135 sites that had a high risk of potential sediment delivery to watercourses and observed no significant direct water quality impacts related to clearcutting. They found that the riparian buffers were effective in filtering sediment from adjacent clearcut areas; however, there was one instance where less than 1 cubic yard of sediment delivered to a watercourse due to an encroachment of a tractor into an equipment exclusion zone resulting in a violation of the FPRs. They noted that road crossings, tractor crossings and roads and landings adjacent to watercourses had the greatest probability of sediment delivery but could be further minimized with proper implementation of mitigation measures.

It has been well documented that forest roads can cause significant increases in erosion rates within a watershed (Haupt 1959, Gibbons and Salo 1973, Beschta 1978, Rice et al. 1979, Cederholm et al. 1980, Reid and Dunne 1984, Furniss et al. 1991, Sidle et al. 1985; Montgomery 1994; Veldhuisen and Russell 1999; Sidle and Wu 2001; Brardinoni et al. 2002). Gibbons and Salo (1973) concluded that the sediment contribution per unit area from forest roads is usually greater than that contributed from all other timber harvesting activities combined. MacDonald et al. (2004) found that erosion rates from roads can be one or more orders of magnitude higher than erosion rates from skid trials and non-compacted areas in harvest units.

Although roads have been shown to play a significant role in affecting water quality, Klein et al. (2012) found that roads did not significantly influence observed turbidity levels in managed watersheds. Their results indicated that harvest rate and drainage area explained much of the observed variation. However their analysis and conclusions were potentially flawed in a variety of critical ways.

1. Their analysis included only a single year of turbidity data (WY 2005) so they were not able to evaluate the inherent annual variability of turbidity within and between watersheds.
2. They used an equivalent clearcut area disturbance index based on "high' and "low" harvest using three, 5-year increments and found that the years 1990-1994 preceding the turbidity data record explained most of the turbidity differences between sites. They assert that this result substantiates a rate of harvest impact; however, Green Diamond believes the authors are associating impacts of historical practices to the impacts of contemporary practices.

3. They also speculate that the link to the period 10-15 years preceding the WY2005 turbidity record was due to a lag effect for root decay and subsequent harvest-related landslide occurrences; however, there was no landslide inventory information presented for their study watersheds to substantiate this claim. They only reference a study (e.g. Reid, 2012) that evaluated harvest-related landslide rates from harvest practices that occurred in the late 1980s and early 1990s (which included clearcutting, broadcast burning and later treatment with herbicides) to support this assumption.

Klein et al. (2012) also assert that there are no regulations in place to control rates of harvest. This statement is simply not true in California. As described above there are several provisions in the CFPRs that control the timing, location and intensity of timber harvest (See 14 CCR 913.1(a)(1), (a)(3), and (4)(a)). In addition the combined application of Green Diamond's management measures will result in approximately 25% of a watershed in RMZs and other partial harvest retention areas that will consist of older forests with high basal area and dense canopy cover.

While harvesting practices that are used today still can cause significant adverse impacts to aquatic resources if poorly implemented, there are rules and regulations in place to avoid, minimize and mitigate the impacts and to ensure the measures are implemented. The California FPRs are among the most restrictive in the United States. Beyond that, Green Diamond has been operating under HCPs that have consistently provided more protections that the standard CFPRs. The most recent being the Aquatic HCP, beginning in 2007, that requires additional mitigation measures and provides further aquatic resource protections. The measures in the Plan were developed for Green Diamond's ownership taking into account existing habitat and watershed conditions and were designed to address the specific activities that Green Diamond employs to conduct its management while minimizing and mitigate the impacts of those activities on aquatic species and their habitats and to protect water quality.

Green Diamond also considers and analyzes cumulative watershed effects (CWEs) when designing and conducting its timber harvest operations. In general, CWEs can be categorized as incremental changes that induce changes in watershed processes that alone are not overwhelming, yet if combined, the impacts on stream channels and habitat for aquatic species are detrimental. The assessment of CWE's is problematic because many resources can be affected, the resources can be affected in many different ways, and various spatial and temporal scales can be used in the analysis (MacDonald 2000). In addition, identification of CWEs is difficult due to both the technical complexities of designing statistically valid field studies, and because few research efforts have been sustained for extended time periods which have considered the significant changes in forest practices over time.

Current methods for evaluating CWE's range from low cost, simple and qualitative checklists to high cost, complex, quantitative, and physical based models (MacDonald 2000). Whichever method is utilized they each have positive and negative aspects. For example the checklist approach works well to: 1) identify which issues should be investigated, 2) ensure the range of issues are considered, and 3) provide a simple method to address the issue of cumulative watershed effects (MacDonald 2000). However the checklist approach typically only includes a qualitative approach to the assessments, lacks repeatability, and contains limited documentation. The model based approach provides a mechanism to: 1) include causal actions, 2) include external factors, 3) estimate on-site changes, 4) route the changes spatially and temporally, and 5) evaluate the impact on the resource of concern at different locations (MacDonald 2000). A disadvantage of the model based approach is it often uses a single watershed scale disturbance index to represent the aggregate impacts from multiple sources. Examples of the single disturbance index include the equivalent clearcut area and equivalent roaded area. It is highly unlikely that any method which relies on a single metric can adequately assess multiple, unrelated impact mechanisms over different spatial and temporal scales. Additionally, the models generally lack validation and typically do not relate the predicated physical changes to a biological impact or other designated beneficial use (MacDonald 2000).

The complexities and uncertainties involved in conducting a CWE analysis do not obviate the need to perform the analysis to meet CEQA requirements. CalFire utilizes the checklist approach to guide RPFs in conducting a cumulative effects assessment when developing a THP. Green Diamond similarly utilizes this process when developing THPs; however, there are additional actions that Green Diamond has taken to manage and assess CWEs; and these are by, 1) minimizing on-site impacts through implementation of state-of-the-art management practices so that off-site impacts are effectively eliminated and, 2) monitoring and adaptive management. A specific activity typically has the largest effect at the local scale and the impact can more easily be detected at that same scale (MacDonald 2000). Similarly if the local impacts can be minimized, then the potential for CWEs at a larger scale should also be reduced. The measures that Green Diamond implements through its existing landscape management plans (e.g. NSO HCP, AHCP, RMWDRs, MATO) and those plans that are currently in development (e.g. FMWDRs and Forest HCP) collectively minimize the adverse effects of its operations at the local scale as well as the watershed scale.

Although decades have passed since the historical landscape impacts occurred and the majority of the sites are no longer sediment producing sources, there still remain legacy road sites, stream crossing sites and stream diversions on the landscape that need to be identified and repaired to ensure they no longer produce sediment. Green Diamond has observed that the majority of current sediment producing sites across the ownership are associated with roads. This fact was the driving force in developing the AHCP and obtaining the RMWDS and MATO that specifically target sediment sources associated with road construction, road upgrading and road decommissioning, and road maintenance on a landscape basis. The AHCP similarly addresses other non-road related legacy features such as diverted skid trails which if left unmitigated could add to sediment production across the landscape.

While there has been a rapid succession of enhanced environmental protections within the last 10-15 years, the realization and expression of the benefits from these landscape plans will require time. Green Diamond has also acknowledged that over time there still may be better ways to manage watersheds that may further benefit aquatic species and their habitats and has developed mechanisms to incorporate this new information into practice as it becomes available. This process was built into the AHCP by way of the Effectiveness Monitoring and Adaptive Management Programs.

Monitoring and adaptive management are used to evaluate the overall effectiveness of the AHCP and to fine-tune specific measures as needed. The effectiveness monitoring program measures the success of the conservation measures in relation to the AHCP's biological goals and objectives. The monitoring projects and programs in the AHCP fall into four categories: Rapid Response Monitoring, Response Monitoring, Long-term Trend Monitoring and Research, and Experimental Watersheds Program. The first three categories are based on the minimum time frame over which feedback for adaptive management is likely to occur. The time scales are a product of the specific variables or processes being measured as well as the available monitoring protocols currently used. The last category provides a unique spatial scale for individual experimental projects and for the development of new or refined monitoring or research approaches.

The Rapid Response and Response Monitoring projects form the backbone of the adaptive management process. Each project has (or will establish) measurable thresholds which, when exceeded, initiate a series of steps for identifying appropriate management responses. To provide the ability to respond rapidly to early signs of potential problems while providing assurances that negative monitoring results will be adequately addressed, a two-stage "yellow light, red light" process is employed. The yellow light threshold serves as an early warning system to identify and rapidly address a potential problem. As such, the yellow light thresholds can typically be exceeded by a single negative monitoring result (i.e., summer water temperatures). The red light threshold is usually triggered by multiple negative monitoring responses (a series of yellow light triggers) and indicates a more serious condition than the yellow light threshold. The intent is to provide a timely review of monitoring data to allow for corrective actions to occur, if necessary, prior to the next season.

The Rapid Response Monitoring projects and programs provide the early warning signals necessary to ensure that the biological goals and objectives of the AHCP will be met. The current Rapid Response Monitoring projects include: 1) annual property-wide water temperature monitoring in Class I and Class II watercourses; 2) paired water temperature monitoring in sites on Class II watercourse; 3) tailed frog monitoring; 4) southern torrent salamander monitoring; 5) implementation and effectiveness monitoring of the Road Management Measures; and 6) road maintenance assessments. While trends which occur over longer time scales will also be monitored through these projects, they are distinguished from the response and trend monitoring projects by their potential to provide rapid feedback for adaptive management. The yellow light threshold for these projects can typically be triggered in less than one year, although the annual analysis of results will be necessary to identify the yellow light condition. The red light threshold will generally take two to three years to be triggered. See Figures 8 and 9 for the spatial distribution of the Rapid Response Monitoring projects.

The Response Monitoring projects, like the Rapid Response projects, monitor the effectiveness of the conservation measures in achieving specific biological goals and objectives of the AHCP. These monitoring projects are distinguished from the Rapid Response projects by the greater lag time required for feedback to the adaptive management process. The Response Monitoring projects are focused on the effects of cumulative sediment inputs on stream channels. The current Response Monitoring projects include: 1) Class I channel monitoring; and 2) Class III sediment monitoring. Natural variability in stream channel dimensions, combined with the potential time lag between sediment inputs and changes in the response variables of these projects, make it difficult to determine appropriate thresholds for adaptive management at this time. When yellow and/or red light thresholds are determined, they are expected to require more than three years of results to be triggered in most cases. See Figure 8 for the spatial distribution of the Response Monitoring projects.

The Long-term Trend Monitoring/Research projects are those monitoring projects for which no thresholds for adaptive management are set. For some projects, this reflects the multitude of factors which affect the response variables, in others, the long time scales required to distinguish the ‘noise’ from the underlying relationships. Research projects are designed to reveal relationships between habitat conditions and long-term persistence of the AHCP’s Covered Species. Each of these projects has the potential to provide feedback for adaptive management, but in some circumstances, decades may be required before that can occur. The current Long-term Trend Monitoring projects include: 1) steep streamside slope delineation study; 2) steep streamside slope assessment; 3) mass wasting assessment; 4) long-term habitat assessments; 5) LWD monitoring; 6) summer juvenile population estimates; 7) outmigrant trapping; and 8) turbidity threshold sampling. See Figure 10 for the spatial distribution of the Long-term Trend Monitoring projects.

While the majority of the AHCP’s monitoring projects are conducted throughout the AHCP Area, four experimental watersheds judged to be representative of the different geologic and physiographic provinces across the AHCP Area were specifically designated where additional monitoring and research on the interactions between forestry management and riparian and aquatic ecosystems will be conducted. Those watersheds are the Little River (Little River HPA), South Fork Winchuck River (Smith River HPA), Ryan Creek (Humboldt Bay HPA), and Ah Pah Creek (Coastal Klamath HPA).

The AHCP’s monitoring program is intended to increase the understanding of watershed processes and the effects of forest management activities on the habitats and populations of the Plan’s Covered Species, and adapt the AHCP’s conservation measures in response to this new information. The adaptive management measures become applicable through the triggering of a “Yellow or Red Light” condition determined through on-going monitoring, the slope stability monitoring, or through the outcome of a designed experiment in one or more of the Experimental Watersheds.

The overall benefits of the monitoring and adaptive management program are to: 1) continuously validate that the habitat and populations of the fish and amphibian species are in good condition where they currently exist; 2) document the trend in recovery in areas that have been impacted from past management activities or natural disturbances; 3) modify or augment existing conservation measures where fine-tuning is necessary; and 4) re-allocate resources to make the conservation measures more efficient and effective.

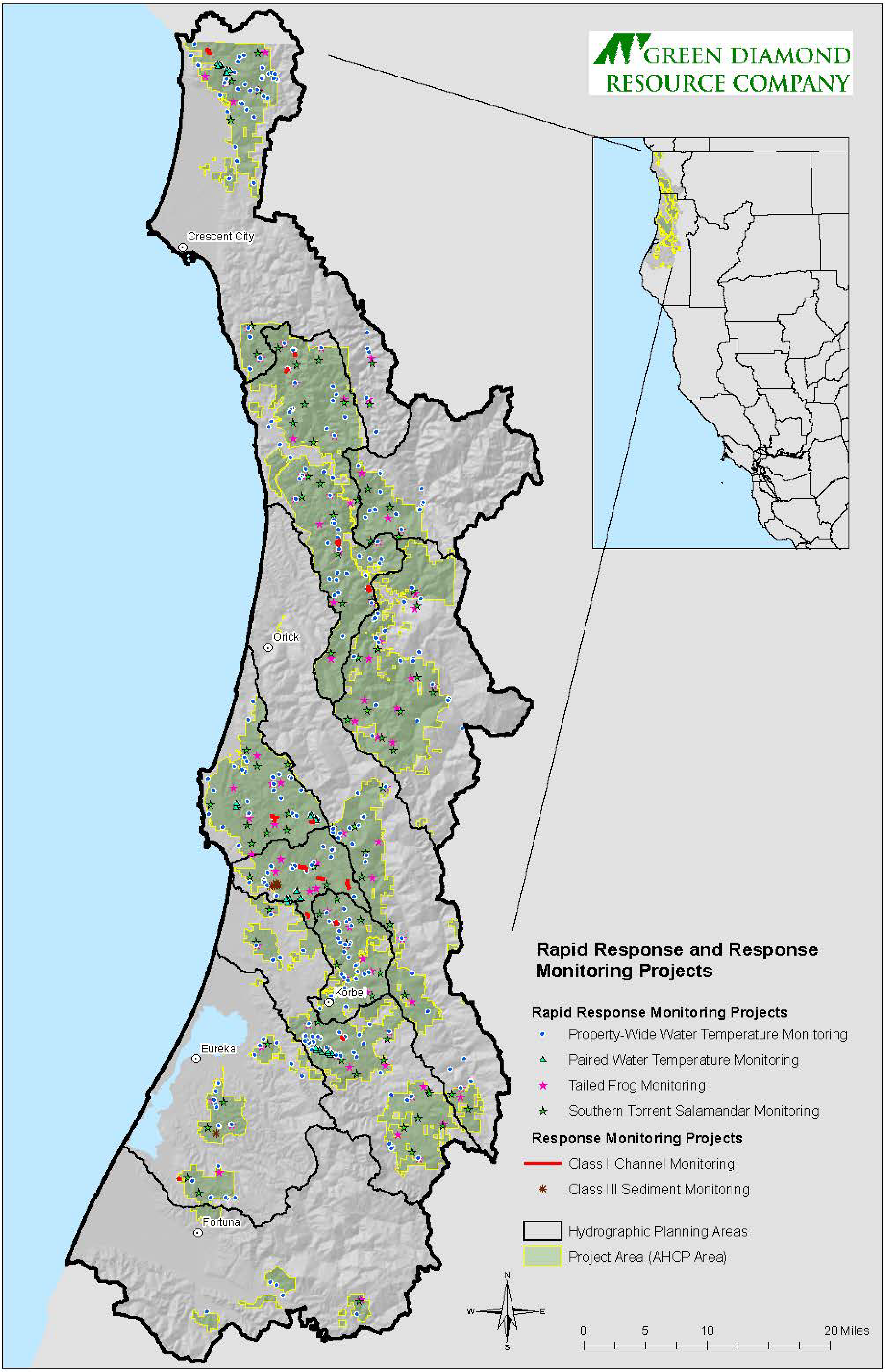

Figure 8. Map showing the locations of rapid response and response monitoring conducted by Green Diamond in the AHCP area.

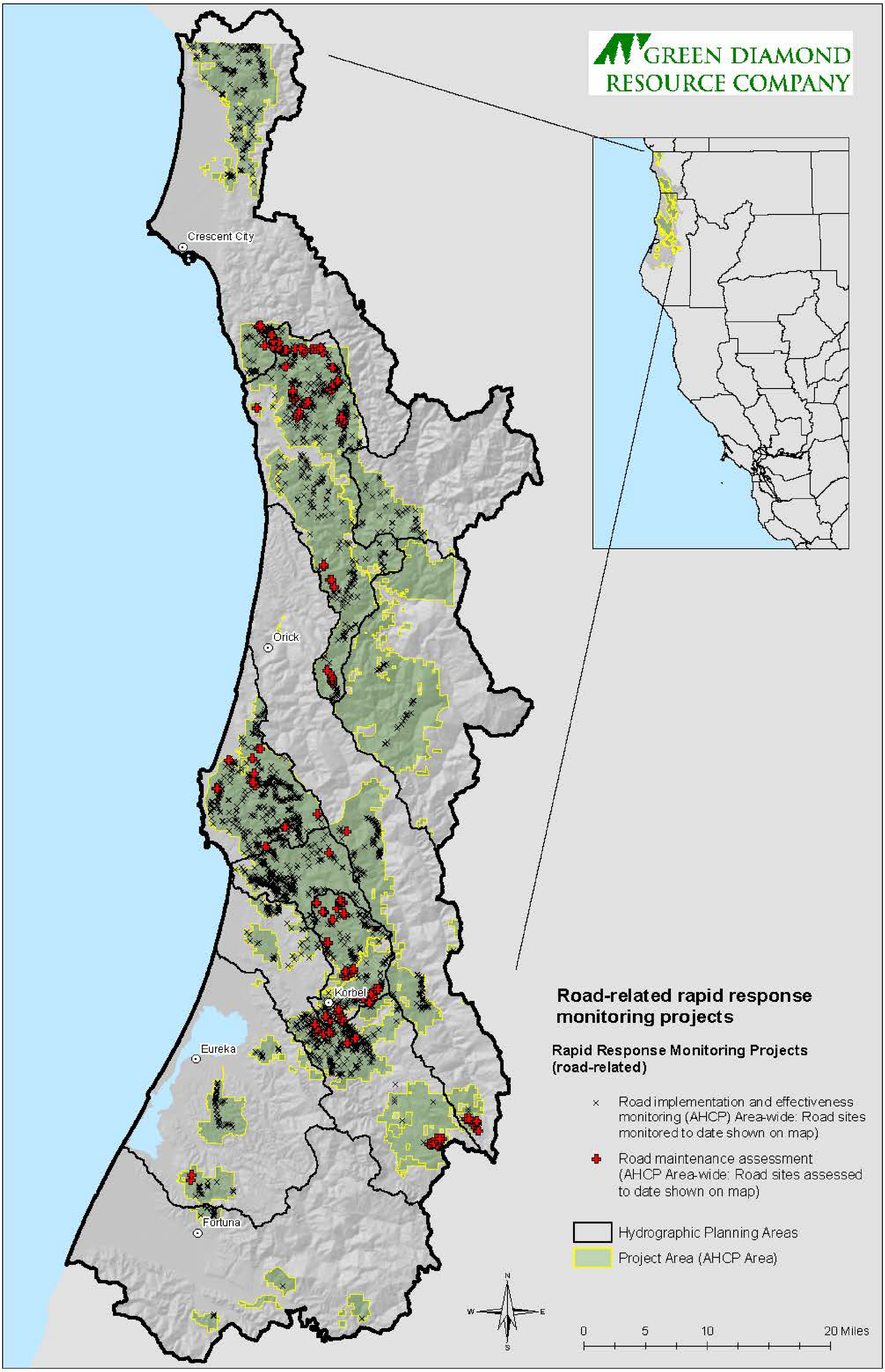

Figure 9. Map showing the locations of road-related rapid response monitoring projects conducted by Green Diamond in the AHCP area.

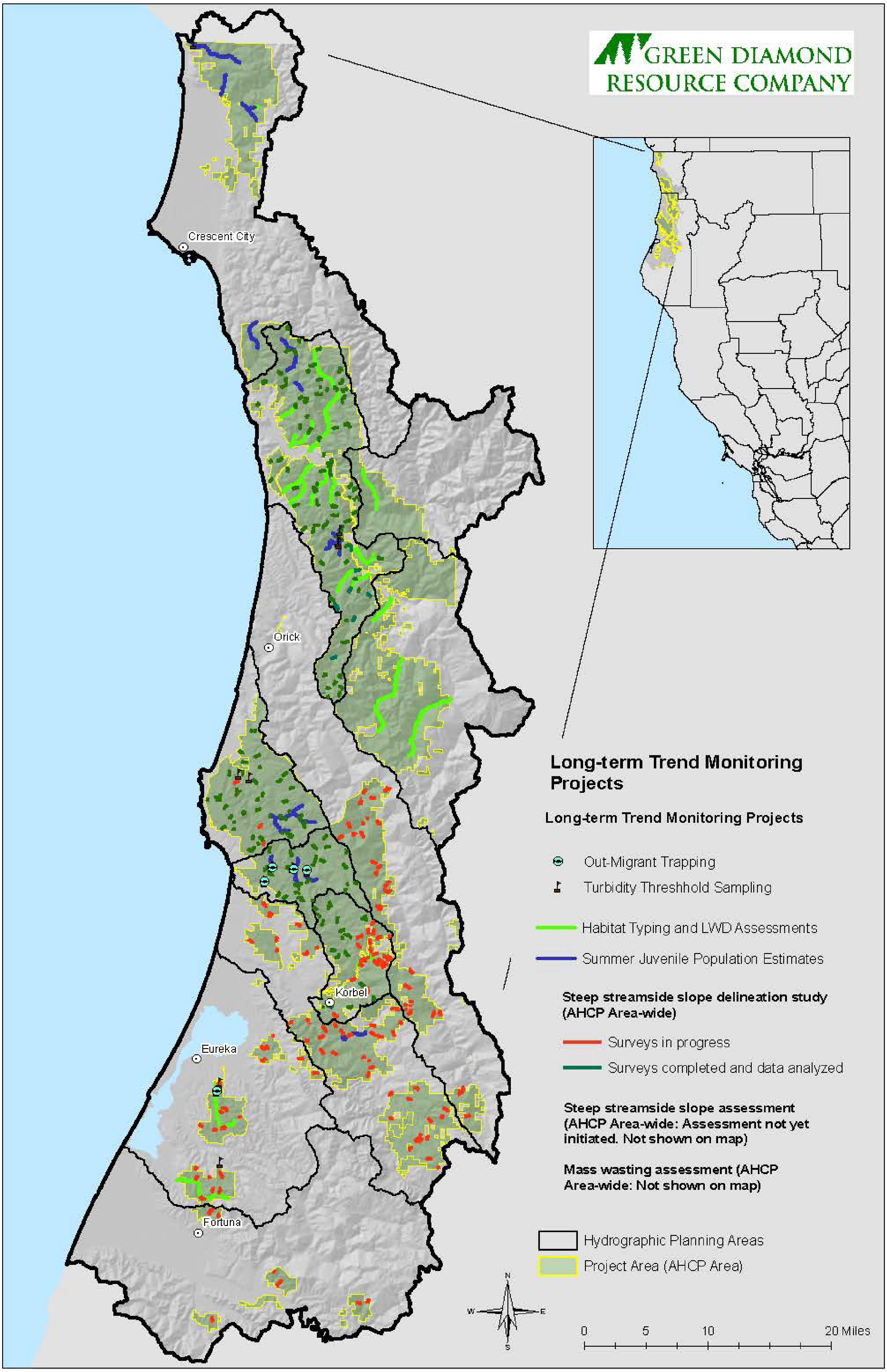

Figure 10. Map showing the locations of long-term trend monitoring projects conducted by Green Diamond in the AHCP area.

III. Summary

There have been more than 2000 articles published on watershed-scale studies since 1970 (Ice and Stednick, 2004). Despite the immense body of literature, much of the work was conducted during a period when forest practices were unregulated or had minimal mitigation measures. However invaluable lessons were learned from this rich history of watershed research. They have increased our understanding of how streams and forest ecosystems function and how to improve forest management practices to minimize their impacts to the aquatic system. As described above, the scale and magnitude of these environmental effects depend on the extent and intensity of the harvest, logging methods, geology, topography, watershed size, and the timing and magnitude of large, infrequent storm events. Green Diamond also acknowledges that some effects of timber management are unavoidable even when using the most cautious harvesting and road management techniques. However, based on an assessment of current aquatic habitat conditions across Green Diamond's ownership within the AHCP area and an understanding of the potential effects of forest management, Green Diamond has developed and employs a suite of state-of-the-art aquatic conservation measures to minimize individual impacts of our operations on the aquatic system. These management practices are regulated by the CFPRs, Green Diamond's AHCP approved by the NMFS and USFWS, the Consistency Determination and the MATO approved by CDFG, the RMWDRs approved by the Regional Water Board and the FMWDRs pending approval by the Regional Water Board. Green Diamond also has monitoring and adaptive management provisions in place to validate that the prescriptions are working and provides a mechanism to modify the measures to improve their effectiveness. The potential environmental effects of Green Diamond's timber harvesting operations at the harvest levels reflected in Green Diamond's Maximum Sustained Production Plan were taken into account in the FEIS and IS/MND for the AHCP/CCAA, MATO and RMWDRs and those documents concluded that Green Diamond's operations at these levels will not result in significant environmental impacts as such impacts are avoided or minimized or mitigated to a level of insignificance. In this paper, Green Diamond has confirmed that the implementation of the management practices and the current provisions in place that control the rate of Green Diamond's timber harvesting operations avoid, minimize and mitigate the impacts of Green Diamond's operations on the aquatic system and protects water quality. "New" watershed studies are underway for Caspar Creek in California, Hinkle Creek in Oregon, Trask Watershed in Washington, Mica Creek in Idaho and the Alto Watersheds in Texas that are evaluating the effects, including cumulative effects, of contemporary timber harvest practices on the aquatic system. These and Green Diamond's ongoing monitoring will invariably continue to shape Green Diamond's science-based adaptive approach to landscape management.

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Appendix A

Potential Effects of Forest Management on Water Quality and Aquatic Species

I. Potential Forest Management Effects on the Hydrologic Cycle

The basic components of the hydrologic cycle are precipitation, infiltration, evaporation, transpiration, storage and runoff. In the Pacific Northwest, where annual precipitation is highly seasonal, the timing, quantity and quality of rain and snowfall have great influence on water quality. Timber harvest temporarily reduces or eliminates leaves and stems at a stand and catchment level. The surface area of this vegetation normally intercepts precipitation for short-term storage that is either evaporated or released as drip. The loss of forest vegetation also reduces the amount of water extracted from the soil by root systems via evapotranspiration and increases soil moisture and pieziometric head. This was demonstrated by Keppeler and Brown (1998) after harvest of second growth redwood forest. The effect of any reduction in evapotranspiration is typically short lived (3-5 years), as rapid regrowth of vegetation may consume more water than pre-timber harvest amounts (Harr 1977). This is likely to be true in redwood forests as well, in part owing to the stump-sprouting habit of redwood. The commercial timberlands within Green Diamond's ownership within the AHCP area are rain-dominated. However, some watersheds in this area have upper sections within the transition zone between rain and snow. Along these hillslopes the forest canopy intercepts snowfall, redistributes the snow, shades the snowpack and acts as a windbreak. In these transient areas the snow is generally wet and sticks to the forest canopy longer than colder, drier snow. In transitional areas snow usually reaches the ground in clumps under trees or as snow melt so that snow pack in forested areas tends to vary in distribution and depth compared to logged hillslopes (Berris and Harr 1987).

Snow melt from hillslopes in coastal watersheds is usually the result of warmer rainfall or latent heat in air moisture rather than from solar radiation. Snow packs in transitional areas may accumulate and melt several times during the wet season. When the forest canopy has been removed more of the snow pack is directly exposed to rainfall, warm air and direct sunlight.

A. Surface Water Hydrology

The primary effects of timber harvest on surface water hydrology pertain to annual water yield, low flows, and peak flows.

Paired watershed experiments to measure changes in flow following timber harvest have been conducted in Oregon and Northern California. Annual water yield generally increases following timber harvest (Bosch and Hewlett 1982, Harr 1983, Stednick 1996). The magnitude of the increase depends on the climate regime, forest type, harvest type, and amount of harvest (Bosch and Hewlett 1982, Stednick 1996). Clearcutting and patch-cutting increased annual water yields up to 6 mm for each percentage of basin harvested in rain dominated catchments, while selective cutting increased annual water yields up to 3 mm for each percentage of basal area removed (Moore and Wondzell 2005). Increases in water yield are not detectible by measuring streamflow when less than 20% of the catchment is harvested (Bosch and Hewlett 1982, Stednick 1996). In studies that evaluated seasonal variation in water yields, most of the increased yields (by volume) occurred in the wetter fall-winter period (Harr, 1983, Keppeler and Ziemer 1990) whereas the larger proportional change occurred in the dryer summer period. Increases in water yield tend to diminish with forest regrowth over time (Harr et al. 1979, Hibbert 1967, Keppeler and Ziemer 1990).

Summer low flows in rain-dominated watersheds were typically augmented following logging. At Caspar Creek in northern California, the low flow increases were greatest in the first year after harvest and diminished irregularly thereafter (Keppeler and Ziemer 1990). At the Alsea Watershed in the Coast Range of Oregon, summer low flows slightly increased (though not statistically significant) for the first 5 years after harvest in Needle Branch, then slightly decreased for the next 3 years; however, low flows in Flynn Creek were reduced for the full three years post-logging (Harr 1977).

An exception to the low flow increases occurred at the Bull Run Municipal Watershed in the northern Oregon Cascades, where patch-cutting 25% of the catchment area initially increased the number of annual low flow days in two of the catchments (Harr 1982). Harr hypothesized that the reduced number of low flow days was caused by the reduced inception of fog drip following harvest. About 5 years after harvest the summer flow increases were detected by Ingwersen (1985).

The effects of harvesting on peak flows have been extensively studied (e.g. Beschta et al. 2000, Harr 1980, Jones and Grant 1996, Lewis 1997, Moore and Wondzell 2005, Reid and Lewis 2007, Ziemer and Lisle 1998). The hydrologic processes affecting peak flows include evaportransportation, interception, fog drip, snow accumulation and melt rates, and soil compaction (Grant et al. 2008).

In relatively small watersheds (about 150 to 1200 ac), peak flow magnitude following harvest tends to increase, with the largest increases occurring in smaller runoff events (less than one-year) (Beschta et al. 2000, Ziemer 1998). For one-year recurrence interval events, peak flow magnitude increased 13-16%; these increases were 6-9% for five-year recurrence interval events (Beschta et al. 2000). At Caspar Creek in northern California, increases in peak flow magnitude were about 27% for two-year storm recurrence interval events in 100% clearcut tributaries (Ziemer 1998). The effect of timber harvest on peak flows generally diminishes with increasing watershed size, increasing time since harvest and with increasing flow magnitude (Beschta et al. 2000, Thomas and Megahan 1998, Ziemer 1998).

Timber harvest activities that compact or disturb the soil can reduce the infiltration capacity of soils and alter the process of subsurface water movement. Compacted soils found on roads and landings are relatively impermeable and water runs off them quickly. Inboard ditches along truck roads not only collect and concentrate surface runoff, but also intercept subsurface flow and bring it to the surface (Furniss et al. 1991). Reduced evapotranspiration, reduced soil infiltration capacity, and the interception of surface flow may lead to increases in surface runoff, peak stream flows, and sediment inputs to watercourses.

Water and sediment from roads can enter stream channels by many mechanisms (Furniss et. al. 2000):

- Inboard ditches that deliver road drainage to stream channels at truck road watercourse crossings,
- Inboard ditches that deliver flow to culverts, road drainage dips or water bars with sufficient discharge to create a gully or generate a sediment plume that extends to a stream channel,
- Improperly spaced or located road drainage structures that discharge sufficient water to create a gully or generate a sediment plume that extends to a stream channel, and
- Roads located close enough to a stream that fill slope erosion or fill failures result in sediment discharge into the stream channel.

Research conducted at the plot and reach scale have shown evidence of the effects of roads on peak flows (Luce 2002, Wemple et al. 1996). However research conducted at the watershed scale have examined the effects of roads on peak flows when coupled with timber harvesting. Some paired watershed studies have shown that roads did not have a significant effect on peak flows (Lewis et al. 2001, Ziemer 1981). While other have shown a significant increase in peak flow when roads occupy at least 12% of a watershed (Harr et al. 1975). Because of the difficulty in decoupling the effects of roads with harvesting at the watershed scale in paired watershed studies, modeling efforts have been used to predict changes in peak flows due to roads. A modeling effort in Washington suggests that the increase in peak flow is approximately equal to that of forest harvest however the magnitude of the change is very different on a per unit area basis (Bowling and Lettenmaier 2001). Roads increased the magnitude of the mean annual flood 11-12% per 2% of the area disturbed, whereas forest harvest increased the magnitude 8-15% per 35-66% area disturbed; however, both of these increases in peak flows decreased with increasing return interval (Bowling and Lettenmaier 2001).

The effects of timber harvest on annual water yield, peak flow magnitude and timing, and summer low flows on aquatic species and habitat characteristics are difficult to assess. The life-cycles of salmonid species have adapted to temporal variations in flow conditions by timing the phases of their life cycles to take advantage of seasonal discharge characteristics (Sullivan et. al. 1987). Increased runoff in the early part of the rainy season may, in some cases, benefit salmonids by reducing water temperatures, improving water quality, and providing more flow for immigrating adult spawners. However, a harvest-related increase in peak flows may increase the number of times that channel substrates are mobilized by storm events and potentially damage developing eggs and alevins in redds (Hicks et al. 1991). Channel forming flows may occur more frequently as a result of an increase in peaks flows; however, the effects should be confined to channels with gradients that are less than approximately 0.02 and with streambed and banks that are composed of gravel and finer material (Grant et al. 2008). Increased peak flows may also affect the survival of over-wintering juvenile salmonids by displacing them out of preferred habitats. These flow increases could also have beneficial effects by increasing available aquatic habitat. Short-term increases in summer low flows may improve survival of juveniles (Hicks et. al. 1991) and increase the amount of aquatic habitat. However, these hydrologic effects are temporary and diminish with regrowth of forest vegetation.

II. Potential Forest Management Effects on the Sediment Inputs and Transport

Timber harvest and the associated construction and use of the road system have the potential to increase sediment inputs. Increased sediment inputs from such activities can impair water quality through increased turbidity levels.

Hillslope erosion, sediment delivery to streams, and sediment transport and sorting within streams are natural dynamic processes. Steep, geologically young, coastal mountains are especially prone to high natural rates of erosion. However, excessive inputs of sediment (both coarse and fine) from a combination of anthropogenic and natural sources can overload a stream's ability to store and transport sediment which can be detrimental to water quality.

A. Sediment Sources and Erosional Processes

Sediment of varying size from the smallest fines to large boulders can be generated from a variety of different sources involving different erosion processes. One such process, surface erosion, tends to generate smaller particles sizes, and is a two-part process in which particles are first detached and then transported downslope. The two hydrologic processes that transport surface erosion are channelized erosion by constricted flows (rilling and gullying) and sheet erosion in which soil movement is non-channelized (rolling and sliding) (Swanston 1991). Increases in channelized and non-channelized erosion occur when the infiltration capacities of soils are reduced by management activities, large storm events or fires. Chamberlin et al. (1991) reported that the potential for surface erosion is directly related to the amount of bare soil exposed to rainfall and runoff. A study in Redwood National Park indicated that higher erosion rates tended to occur where rill erosion was more common, which was associated with tractor-harvest, and to a lesser extent, cable yarding, on schist soils (Marron et al. 1995).

In general, surface erosion does not account for a large portion of the total sediment budget in a watershed. Hagans and Weaver (1987) analyzed the data used by Marron et al. (1995), as well as data on percent bare soil following harvest and data on sediment delivery to streams from surface erosion processes on logged areas, including skid trails, for the lower Redwood Creek basin for the period c. 1954-1980, and concluded that only 4% of erosion was caused by sheet and rill erosion. Rice and Datzman (1981) conducted detailed surveys in northern California of 102 harvested plots averaging about 11 acres in size over a range of geologic and slope conditions. In aggregate, they found that two-thirds of the observed erosion was associated with roads, landings or skid trails. Surface erosion in the form of rills and gullies not associated with roads, landings or skid trails (i.e. harvested areas) accounted for about five percent of total erosion.

Mass wasting is another process that has the potential to produce large amounts of both coarse and fine sediment. In steep mountainous terrain, mass soil movement is a major type of hillslope erosion and sediment source in watersheds (Sidle and Ochiai 2006, Swanston 1991). The frequency and magnitude of mass soil movements is governed by a number of factors, including; hillslope gradient, level of soil saturation, composition of dominant soil and rock types, degree of weathering, type and level of management activities, and occurrence of climatic or geologic events.

Mass soil movements are usually episodic events and tend to contribute significant quantities of sediment and organic debris to stream channels over time intervals ranging from minutes to decades (Swanston 1991). The resultant sediment and organic debris may have a profound effect on a stream channel including large increases in coarse and fine sediments, shifts of existing bed-load, and increases in woody debris that can lead to partial or complete stream blockages.

Forest management practices can affect slope stability and increase the risk of mass wasting by changing vegetative cover, hillslope shape, and water flow above and below the ground surface. Different forest management operations have distinct effects on the factors that control slope stability. For two of the major components of forest management operations—road construction (and to a lesser extent skid trail construction) and harvesting trees—the potential consequences with respect to shallow landslide processes and slope stability are relatively well known. Road and skid trail construction may:

1. Create cut slopes and fill slopes too steep to be stable,
2. Result in deposition of sidecast material (spoils) that overburdens and/or oversteepens slopes, and
3. Divert and/or concentrate both surface and subsurface runoff.

While dominate factors affecting slope stability due to harvesting trees include:

1. Root strength deterioration: reducing effective soil cohesion by disrupting networks of interlocking roots from living trees in the “window” of reduced root reinforcement between 3 and 15 years after harvesting (Sidle and Ochiai 2006), and
2. Increase pore water pressure by reducing interception of precipitation and evapotranspiration of soil water. This is significant because greater soil moisture reduces the amount of precipitation from a given storm event required to cause soil moisture levels to reach a critical level.

The actual influence of specific forest management activities on slope stability, however, depends on the design and construction of the road network, density of residual trees and under-story vegetation, rate and type of revegetation, topography, material strengths, patterns of surface and subsurface flow, and patterns of water inflow (Sidle and Ochiai 2006, Yoshinori and Osamu 1984). Landslide rates associated with roads are generally much greater than landslide rates associated with timber harvest alone (Sidle and Ochiai 2006). However, separating the effects of timber harvest activities from the associated yarding, construction, maintenance and use of skid roads and the forest road system may be difficult. Further, the results vary between watersheds. Most studies indicate that the sediment inputs from timber harvesting alone are less than those of the associated road network (Sidle and Ochiai 2006, Raines and Kelsey 1991, Best et al. 1995).

Deep-seated landslides also have the potential to produce large amounts of both coarse and fine sediments. Natural mechanisms that may trigger deep-seated landslides include intense rainfall, earthquake shaking, and erosion of landslide toes by streams. It is generally acknowledged that deep-seated landslides (earthflows and rockslides) may be destabilized by undercutting of the landslide toe (e.g. by streambank erosion or excavation of road cuts), by adding significant mass to the landslide body (e.g. disposing of spoils from grading or excavation projects), or by significantly altering the groundwater conditions in a landslide (e.g. clearcutting, road building, diversion of road drainage into head scarps or lateral scarps) (Keaton and Beckwith 1996, Swanston 1981). However the effect of hydrologic changes associated with reduced evapotranspiration, reduced canopy interception, and elevated pore pressure on deep-seated landslides is not well understood. Elevated pore pressures as a result of timber harvesting may result in accelerated movement of deep-seated landslides due to prolonged exposure to such pore pressures (Sidle and Ochiai 2006). However, pore pressures appear to be affected only during moderate rain storms preceded by dry conditions (Sidle 2005).

The relatively few regional empirical landslide studies have produced varying conclusions on the effect of timber harvesting on earthflow stability (i.e. deep-seeded landslides). Short-term increases in ground displacement following clearcutting have been documented on several active earthflows in the Coast Range and Cascades of Oregon (Pyles et al. 1987; Swanson et al. 1988; Swanston 1981). In contrast, work by Pyles et al. (1987) on the Lookout Creek earthflow in central Oregon concluded that timber harvesting was unlikely to induce a large increase in movement, primarily because the slide was well drained. In either case, accelerated movement due to timber harvesting was not significant (i.e. measured in millimeters). Ongoing studies by Green Diamond indicate that movement of large deep-seated landslides may be influenced by timber harvest activities in some cases. However, overall average rates of movement are typically very slow (0.5 to 1.9 feet per year) making the accelerated movement due to harvest activities nearly imperceptible.

In summary, previous studies suggest that forest management activities can potentially increase the occurrence or rate of movement of deep-seated landslides. Recognition of active landslides and avoidance of management practices that are known to increase risks of movement can reduce the overall risk of erosion associated with deep landslides. Site-specific conditions pertaining to individual slides will always be important in development of site-specific forest management plans; nevertheless, substantial uncertainty is likely to remain regarding predicted effects of management on slide activity. Deep-seated landslides are relatively common, naturally occurring geologic features in northern California that will continue to generate substantial quantities of sediment delivered to streams, regardless of management influences.

The preceding discussion indicates that erosion from roads, including landslides (mass wasting), gullying caused by improper drainage, and rainsplash and sheetwash erosion on road and cutslope surfaces, are generally the most significant component of erosion related to forest harvest activities. Timber harvesting operations have historically relied on an extensive network of unpaved roads and necessitated building new roads to access portions of timberlands being harvested. Roads are recognized as a significant source of sediment inputs to watersheds (as described above; see also Gibbons and Salo 1973, Weaver and Hagans 1994). Sediment input from roads can occur through both surface erosion and mass wasting.

Research has shown that road construction for timber harvesting can cause significant increases in erosion rates within a watershed (Haupt 1959, Gibbons and Salo 1973, Beschta 1978, Rice et al. 1979, Cederholm et al. 1980, Reid and Dunne 1984, Furniss et al. 1991). Roads can affect watersheds by modifying natural drainage patterns and by accelerating erosion and sedimentation, potentially altering channel stability and morphology. If proper construction techniques and maintenance practices are not followed, sediment increases following road construction can be severe and long lasting. Gibbons and Salo (1973) concluded that the sediment contribution per unit area from forest roads is usually greater than that contributed from all other timber harvesting activities combined.

Forest road systems and their associated stream crossings in steep coastal watersheds have the potential to be a major cause of mass soil movements (e.g. Best et. al. 1995, Sidle et al. 1985). Road inventories conducted in the Pacific Northwest have reported that erosion from older roads may contribute 40 to 70 percent of the total sediment delivered to the system (Best et al. 1995, Durgin et al. 1988, McCashion and Rice 1983, Raines and Kelsey 1991, Rice and Lewis 1991, Swanson and Dryness 1975).

The actual increases in hillslope failures due to roads that are observed in any given watershed are affected by variables such as hillslope gradient, soil type, soil saturation, bedrock type and structure, management levels (usage) and road placement, design, and construction. The literature suggests that road placement is the single most important factor, because it affects how much the other variables will contribute to slope failures (Anderson 1971, Larse 1971, Swanston 1971, Swanston and Swanson 1976, Weaver and Hagans 1994).

B. Sediment Transport Processes

There are three modes of sediment transport in stream channels: bedload, intermittent suspended load, and suspended load. Although each of these processes corresponds to a generally consistent size range of sediment, the processes occur over a physical continuum, and there is substantial overlap among these modes of sediment transport. Depending on the intensity (i.e. velocity) of stream flow, the sediment transported in one mode may be transported in another mode. Many textbooks provide a description of sediment transport mechanics (e.g. Richards 1982, Raudkivi 1990, and Yang 1996).

The typical size of material transported primarily as bedload in upland streams is gravel (2 mm to 64 mm diameter) and cobble (64 mm to 256 mm diameter). Larger material (boulders) are also transported as bedload, however, sediment particles of this size move relatively slowly and are more likely to form nodes of stability in stream channels (i.e. boulder steps or transverse bars, Grant et al. 1990).

Bedload is transported by sliding, rolling, or skipping along the streambed. Bedload particles are rarely found in the water column far above the bed. Bedload sediment is typically routed through mountain channel systems slowly, with average annual transport distances from tracer studies of about 300 ft., ranging from about 60 to 1500 ft. (NCASI 1999). The volume of bedload sediment deposits is typically large in comparison with the annual transport rate.

Bedload sediment is broken and abraded as it collides with other sediment clasts on the bed or in transport; this gradual process of breakage and declining size is known as attrition. The attrition process converts a portion of the bedload to suspended load as larger sediment clasts produce smaller sediment particles. The attrition rate is usually estimated as a function of transport distance in the channel network. The magnitude of attrition varies, but as much as half of bedload material may be converted to suspended sediment over transport distances of about 20 km (Collins and Dunne 1989). Where bedrock is extremely weak (e.g. Wildcat Group rocks near Humboldt Bay), however, the attrition rate may be much higher, and where bedrock is relatively strong, the attrition rate much lower.

Intermittent suspended load (also called “saltation load” by Raudkivi (1990)) is typically comprised of fine gravel and coarse sand. It is transported partly in contact with streambed, and partly in suspension, depending on flow intensity and local channel morphology. These sediment sizes are often found in sorted deposits in the lee of channel obstructions or in pools, and are typically finer than typical median grain size on the surface of point bars and alternate bars. Intermittent suspended load is transported through channel systems more quickly, provided it is not deposited underneath coarse armor layers of bed and bar deposits. The typical annual velocity of intermittent suspended load is between that of bedload and suspended load, and is on the order of 1000’s of feet to miles.

Sand, silt and clay sizes (< 2 mm diameter) comprise the suspended sediment load in most upland stream systems. The sand fraction (> 0.06 mm and < 2 mm) is often a major constituent of the intermittent suspended load and a substantial constituent of the bedload. In many low-gradient rivers, sand is the dominant component of the bedload. Such conditions are found at the mouths of several coastal watersheds in northern California.

Suspended load is transported in suspension in the water column in relatively low-intensity flows. It typically is transported through the channel system rapidly; sediment velocity for suspended load is nearly equal to water velocity. If suspended sediment is present in or on the margins of channels it will be entrained rapidly with increasing stream discharge. This suspended sediment can be subsequently deposited in low-velocity areas downstream as stream discharge declines. Sediment of this type is rarely deposited in large quantities within the streambed in upland channel networks except in low-velocity environments such as unusually low gradient or hydraulically rough reaches, channel margins, side channels, and behind flow obstructions.

Suspended load transport in many northern California streams (e.g. Caspar Creek, Lewis 1998) is correlated with turbidity (an optical characteristic of water quantifying its clarity or cloudiness). Hence, the supply of suspended load sediment size fractions is the chief control on stream turbidity, a measure of water quality used by the California Regional Water Quality Control Board in its Basin Plan for northern coastal California. The silt and clay fraction in the suspended load strongly influences turbidity; hence control of sediment sources rich in silt and clay will provide the greatest reduction in turbidity.

The relationship between sediment inputs to a channel network and sediment transport capacity of the channel network will have a strong influence on channel sedimentation status (e.g. Buffington and Montgomery 1999, Montgomery and Buffington 1993,). For example, channel systems that are said to be “transport-limited” have a high sediment supply such that supply is greater than the streams sediment transport capacity. The channel bed in transport-limited channels is expected to be relatively fine, typically composed of finer gravel and sand with little armoring of the bed surface. Transport-limited channels may be found where there are abundant sediment inputs (e.g. recent concentrated inputs from landslides) or where channel slope declines rapidly (e.g. where a relatively steep confined channel reaches a broad valley with lower channel gradient). In contrast “supply-limited” systems have a high sediment transport capacity relative to sediment supply. The channel bed of supply-limited systems is expected to be relatively coarse, with frequent armoring of bed deposits and frequent bedrock exposures. Although conditions are variable, depending on channel and valley morphology and watershed erosion history, many of the smaller, steeper upland streams important for anadromous fish would be expected to be supply-limited. This expectation is conditioned largely on the high degree of confinement, moderately high slopes, and moderate to intense storm runoff typical of such streams (i.e. factors suggestive of high sediment transport capacity).

The timing and frequency of coarse sediment inputs into stream channels tend to be dominated by mass wasting processes. With the exception of channel erosion, bank erosion and soil creep, mass wasting processes typically generate sediment inputs that are relatively concentrated near the point of entry to the channel network. Landslide deposits in channels typically include abundant coarse and fine sediment and LWD. Deposits may fill existing channels and induce erosion along stream banks. The transport and downstream routing of such coarse sediment budgets have been investigated both in model and field studies of upland rivers (Benda and Dunne 1997a, 1997b, Lisle et al. 1997 and Lisle et al. 2001). While it is generally agreed that the local effect is greatest at the point of entry, consistent theoretical statements regarding the magnitude and timing of effects downstream and the governing processes are elusive. Regardless of the specific mechanism, the greatest short-term effects with respect to coarse sediment are localized, with only gradual (over a period of years to decades) translocation of effects (typically increased depth of gravel deposits and changes in size distribution of bed material).

III. Potential Forest Management Effects on Altered Water Temperature

Stream temperature is controlled by multiple factors such as solar and thermal radiation, riparian shading, air temperature, wind velocity, relative humidity, tributary inflow, groundwater inflow, and hyporheic flow. Removal of the riparian canopy can result in elevated summer water temperatures, often in direct proportion to the increase in incident solar radiation that reaches the water surface (Chamberlin et al. 1991). For a given exposure from solar radiation, water temperature increases directly proportional to the surface area of the stream and inversely proportional to stream discharge (Sullivan et al. 1990). Exposed channels will also radiate heat more rapidly at night. In addition, increased sediment inputs that results in aggradation will result in a wider and shallower channel that gains and loses heat more rapidly. Therefore, reduction of riparian vegetation and aggradation of a channel act synergistically to cause greater daily and seasonal fluctuations in water temperatures.

While the increases in summer water temperatures can be large after removal of riparian vegetation, the changes in winter water temperatures are usually less dramatic. Generally, the removal of riparian vegetation resulted in increases of winter water temperatures in low elevation coastal watersheds due to increases of solar energy (Beschta et al. 1987). Conversely, in northern latitudes and at higher elevations decreases in winter water temperatures may occur due to the loss of insulation from riparian vegetation, leading to an increase in radiative cooling from the watershed.

Changes in water temperatures from the removal of riparian vegetation may benefit or negatively impact salmonid populations. Among the potential benefits of canopy removal is an increase in primary and secondary production that would increase the amount of available food. Studies have reported increases in biomass and production of salmonid populations after riparian harvest (e.g. Hawkins et al. 1983, Johnson et al 1986, and Wilzbach et al. 2005). Increased water temperatures during winter months are usually less dramatic than summer increases; however these slight increases may have a great effect on salmonids. Studies conducted on Carnation Creek in British Columbia revealed that slight increases in winter water temperatures resulted in accelerated development of coho embryos, thus an earlier emergence of juveniles (Hartman et al. 1987, Holtby 1988). The earlier emergence resulted in a longer growing season for the juvenile coho salmon, but also increased their risk to downstream displacement during late-winter storms.

Increased water temperatures can also have negative impacts on the salmonids (Beschta et al. 1987). Potential impacts to salmonids from increased stream temperatures include (Hallock et al. 1970, Hughes and Davis 1986, Reeves et al. 1987, Spence et. al. 1996):

- reduction in growth efficiency,
- increased disease susceptibility,
- changes in age of smotification,
- loss of rearing habitat, and
- shifts in the competitive advantage of salmonids over non-salmonid species.

There is a potential secondary negative impact of increased water temperatures that is related to levels of dissolved oxygen in the water. During summer months, low flows and increased water temperatures accelerate respiration and reduce the solubility of oxygen. The reduction of available oxygen may reduce growth rates of individual fish and may limit the production capability of an entire watershed.

Incoming solar radiation appears to be the dominant factor at the site level (Johnson 2004), however modeling studies of the cumulative effects of large scale timber harvest emphasize that it is a complex set of factors, rather than a single factor such as shade, that governs stream temperature dynamics (Bartholow 2000, Sridhar et al. 2004).

IV. Potential Forest Management Effects on Large Woody Debris Recruitment

Historically, the mainstems of watersheds were utilized to transport logs downstream to processing mills. Thus, extensive clearing of debris jams occurred on most coastal watersheds (Sedell and Froggatt 1984). Splash damming was another management technique to transport logs downstream that tended to dislodge established large woody debris (LWD) from stream channels. These channel clearing activities directly removed salmonid habitat from watersheds and also reduced the probability of additional LWD retention within the channel.

In-channel salvage logging and the clearing of LWD from streams in the Pacific Northwest began shortly after the 1964 Flood. Much of this activity was sponsored by the federal government as a measure to protect bridges and to reduce cases of property liability in court (Maser and Sedell 1994). Removal of LWD from stream channels also occurred during the 1970s and 1980s when state and federal agencies spent over six million dollars annually in efforts to remove debris jams and improve fish habitat (Maser and Sedell 1994). Many of the large debris jams were probably barriers to fish migration and required modification. However, these stream clearing programs often went too far and now fisheries managers have spent the past 20 years reintroducing LWD to streams along the Pacific Northwest. Currently, some fisheries biologists consider the placement of LWD restoration structures in streams as an interim, short-term measure until large conifers are reestablished in riparian zones to provide a source of LWD.

Decades of timber harvesting in the riparian zone has altered the species composition and age classes of trees along stream channels. The removal of valuable conifer species has led to the predominance of early successional species such as alders and willows. Short-rotation harvesting has decreased the numbers of large trees available as potential LWD. Woody debris from second-growth forests has a shorter residence time in stream channels than debris from uncut watersheds (Grette 1985). Managed riparian zones of predominately red alder may have a greater input rate of wood to the stream channel than conifers in an uncut riparian zone, but the reduced longevity of alder debris results in reduced cover and fewer pools than in uncut watersheds (Grette 1985).

In-channel LWD is recognized as a vital component of stream habitats. The physical processes associated with LWD include sediment sorting and storage, retention of organic debris, and modification of water quality (Bisson et al. 1987). In headwater streams, LWD is also known to dissipate hydraulic energy, store and sort sediment, and create habitat complexity (Chesney 2000, Gomi and Sidle 2003, May and Gresswell 2003, O'Connor and Harr 1994). The biological functions associated with LWD structures include important rearing habitats, protective cover from predators and elevated stream flow, retention of gravels for salmonid redds, and regulation of organic material for the instream community of aquatic invertebrates (Bisson et al. 1987, Murphy et al. 1986). Decreased supply of LWD can result in (Hicks et. al. 1991):

- reduction of cover,
- loss of pool habitats,
- loss of high velocity refugia,
- reduction of gravel storage, and
- loss of hydraulic complexity.

These changes in salmonid habitat quality can lead to increased predator vulnerability, reduction of winter survival, reduction in carrying capacity, lower spawning habitat availability, reduction in food productivity and loss of species diversity.

Current timber harvesting and the presence of or construction of roads in riparian areas may result in a decline in the recruitment of LWD and a resulting reduction of in-channel LWD. Timber harvest in riparian zones removes trees that could potentially become in-channel LWD. Roads in riparian zones may reduce potential LWD by the presence of the road surface eliminating tree production and also by intercepting trees that fall toward the channel. The decline of recruitment of potential LWD from riparian zones can be expected to reduce LWD recruitment to streams for decades following timber harvest of riparian areas. High in the watershed, the potential impacts would be primarily localized, but in larger streams lower in the watershed, LWD can be transported during higher flow events and the impacts may be cumulative. A decline in pool density, pool depth, instream cover, gravel retention, and sediment sorting are likely to result if LWD recruitment is reduced. These habitat changes may reduce the growth, survival, and total production of aquatic species (Murphy et al. 1986, Steele and Stacy 1994).

V. Appendix A References

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