September 29, 2009

TO: Marc Deprey, President
Manchester Ridge, LLC
321 South Main Street, #525
Sebastopol, CA 95472

State of California, Water Resources Control Board
Division of Water Rights
1001 I Street
P.O. Box 2000
Sacramento, CA 95812-2000

PROFESSIONAL GEOLOGIST ★ M.D. O'Connor No. 2449 CERTIFIED ENGINEERING GEOLOGIST ★ STATE OF CALIFORNIA

FROM:

Matthew O'Connor, PhD, CEG #2449
President, OEI

Subject: **Water Availability Evaluation for Alder Creek and Manchester Ridge Reservoir, T13N R6E, Sec. 16, NE ¼ of NE ¼ S**

This memorandum provides a brief hydrologic evaluation of water availability for an existing 17 ac-ft reservoir located on Adams Ridge in Mendocino County, and draining to Alder Creek thence the Pacific Ocean. The above mentioned reservoir is filled primarily by spring flow and surface sheetflow, but has been judged to be located in an "on-stream" position, and thus the availability of water for appropriation is of interest. I have prepared previous hydrologic analyses of this project area (attached), and have also prepared several Water Availability Assessment and Cumulative Flow Impairment Index studies for water rights applications in coastal watersheds in Mendocino and Sonoma County.

Alder Creek is not listed by the Division as a "fully appropriated" stream. Existing water rights located on Alder Creek were reviewed using eWRMIS. The two existing appropriations are located over two miles downstream on the coastal terraces. These are A016247 and A016592, with face value appropriations of 131 acre-feet per annum (afa) and 80.7 afa, respectively.

The drainage area of Alder Creek, measured at a point about halfway between the Adams Ridge reservoir site and the downstream appropriator's points of diversion, is about 24.6 square miles (15,750 acres). This point in the watershed is noted because it was defined as watershed node E in our prior analysis (pages 19-20), and is a convenient location for this evaluation of water availability. The prior evaluation estimated mean annual precipitation to be about 50 inches[1]. Assuming an average annual runoff ratio of 0.5 produces approximately 25 inches (about 2.1 ft) of runoff per unit drainage area. Thus, Alder Creek at node E produces approximately 33,075 afa of streamflow (15,750 acres x 2.1 ft/anum). Regional estimates of mean annual runoff produced by the US Geological Survey[2] provide even higher estimated runoff. The Garcia River watershed (98.5 square miles) had annual average precipitation of 56 inches and runoff of 43.7 inches. The South Fork Gualala River watershed (161 square miles) had precipitation of 51 inches and runoff of 31.9 inches. The annual runoff ratios for these watersheds were 0.78 and 0.62, respectively.

Existing appropriations total 211.7 afa. Based on the estimated runoff from Alder Creek of 33,075 afa, existing appropriations consume about 0.6 percent of total annual runoff. Adding 17 afa for the Adams Ridge reservoir brings existing appropriations to 228.7 afa, about 0.7 percent of total annual runoff from Alder Creek. Based on this analysis, there is a reasonable likelihood of available water in Alder Creek to support the 17 afa reservoir on Adams Ridge.

[1] http://www.wrh.noaa.gov/lox/climate/CA_NORTH.gif

[2] Mean Annual Runoff in the San Francisco Bay Region, California, 1931-1970, 1974, Miscellaneous Field Studies Map MF-613.

Assessment of Potential Hydrologic Effects, Manchester Ridge LLC Project Part Alder Creek and Brush Creek Watersheds, Mendocino County

Prepared for

Manchester Ridge, L.L.C.
321 South Main Street, #525
Sebastopol, California 95472

by

O'Connor Environmental, Inc.
P.O. Box 794
Healdsburg, CA 95448

January 12, 2004

Matt O'Connor, Ph.D., R.G. #6847
Brenda Rosser, MSc

Contents

Executive Summary

This assessment evaluates potential hydrologic and associated erosion and sedimentation effects associated with the Manchester Ridge LLC Timber Harvest Plan and Conversion, Alder Creek and Brush Creek Watersheds, Mendocino County, including areas of agricultural development located outside the northern boundary of the THP/Conversion areas. This larger area (about 250 acres) is referred to as "the assessment area" in this report. The spatial scope of this assessment is, consequently, much larger than the THP/Conversion (Project) area alone (108 acres). The expanded scope of this analysis is intended to fully address potential hydrologic cumulative effects associated with the THP/Conversion and adjacent agricultural development by Manchester Ridge LLC. Under the proposed THP/Conversion, most of the Conversion area and the larger assessment area would be converted to silvopasture vineyard and silvopasture silvopasture-orchard as described in the THP/Conversion report.

The assessment reviews previous research on watershed scale hydrologic processes conducted at Caspar Creek by the USDA Forest Service Redwood Sciences Laboratory (RSL) in cooperation with the Jackson Demonstration State Forest (JDSF) to help determine expected trends in water quantity and quality if the Project is implemented. The chief effects of clearcut timber harvest (excluding roads) on hydrologic processes are removal of existing vegetation and resultant changes in canopy interception and evapotranspiration. These changes are expected to increase water delivery to the soil, soil moisture, and runoff. Caspar Creek experimental results are particularly relevant to predicting the gross hydrologic effects of vegetation removal associated with timberland conversion to silvopasture-vineyard. Average annual runoff at Caspar Creek increased by about 15 %, minimum mean daily flows (i.e. summer low flows) increased by about 150 %, and peak storm runoff for the 2 year flood increased by about 25 %. Peak flow increases have the potential to accelerate channel and bank erosion under some circumstances.

The review of Caspar Creek experimental results leads to the conclusion that annual and seasonal stream flows are expected to increase as a result of the proposed conversion of timberland to silvopasture-vineyard. Agricultural development and cultivation could also cause changes in soil infiltration capacity and flow paths that might affect rates of transmission of water from the soil surface into the soil (infiltration), and from the soil into bedrock aquifers (percolation). Infiltration rates are not expected to change significantly, and could increase or decrease somewhat. Soil compaction that may occur is counteracted by cover crops and agricultural soil preparation that minimize velocity of surface runoff and promote infiltration.

To estimate the effects of silvopasture-vineyard conversion on peak runoff, the "rational method" was used to evaluate existing conditions and proposed Project conditions, including the larger assessment area. A time of concentration of 15 minutes was considered appropriate for the size of the sub-catchments involved in the assessment area (which range from about 1 to 40 acres. The estimated 2-year recurrence, 15-minute duration rainfall intensity was 0.44 in/hr. The equivalent rate for a one-hour period used in the rational runoff equation was 1.76 in/hr.

Drainage areas corresponding to different runoff nodes used for the runoff analysis were determined from assessment area topographic maps (2 ft contour interval) and from USGS topographic maps. Surface runoff from about 60 acres distributed in three sub-catchments will be collected in three storage reservoirs with a total capacity of about 140 ac-ft. Most of the assessment area area is in the Alder Creek watershed; the southeastern portion of the assessment area area drains to Brush Creek. Estimated peak flow increases for individual sub-catchments averages around 20%, and range from about 10 to 40%. Off-site and downstream flow increases diminish rapidly with increasing drainage area such that larger streams draining Adams Ridge are predicted to experience peak flow increases of 10% or less. In Alder Creek, flow increases are predicted to be < 1%.

Short-term hydrologic effects of conversion to agricultural uses are expected to be somewhat greater than long-term effects. The process of forest clearing and planting typically results in localized changes in runoff patterns and intensity owing to surface disturbance and temporary disruption of vegetative cover. As vineyard, orchard and cover crops mature, runoff patterns and infiltration processes will tend to stabilize. Hence, it is likely that greatest impacts are likely to occur in the first year or two during establishment of cover crops.

The most applicable research available strongly suggests that annual water yield and summer stream flows can be expected to <u>increase</u> owing to decreases in evapotranspiration processes associated with removal of forest vegetation. Soil and geologic conditions suggest that infiltration to the water table is not expected to decrease substantially, and may increase in some areas as a result of agricultural soil treatments. Peak flow increases are expected to occur in Class II channels draining some proposed silvopasture-vineyard areas; on-site peak flow increases are expected to increase erosion hazards locally, but can be mitigated using standard erosion control techniques. It is unlikely that significant changes in water quality or sedimentation would occur in Nye Creek, Alder Creek, or Brush Creek.

Introduction

The assessment area lies atop Adams Ridge overlooking Manchester Beach and Pt. Arena, and is approximately 1.5 miles long and 0.25 miles wide. Owing to its ridgetop position, the assessment area straddles the divide between Alder Creek to the north, Nye Creek (a tributary to Alder Creek) to the east, another unnamed Alder Creek tributary to the west, and Brush Creek to the south. Figure 1 shows these drainage boundaries overlaid on the Project base map. Note that the assessment area extends to the north and west relative to the Project area as shown in Figure 2. Potential hydrologic impacts are distributed across approximately 25 small catchments, some of which are drained by Class III channels. Most of the assessment area lies in the Alder Creek catchment. The Project would convert approximately 108 acres of timberland to agricultural use. More comprehensive descriptions of the site and the Project are provided in the THP/Conversion documents and are not repeated here except as necessary for the assessment of potential hydrologic effects.

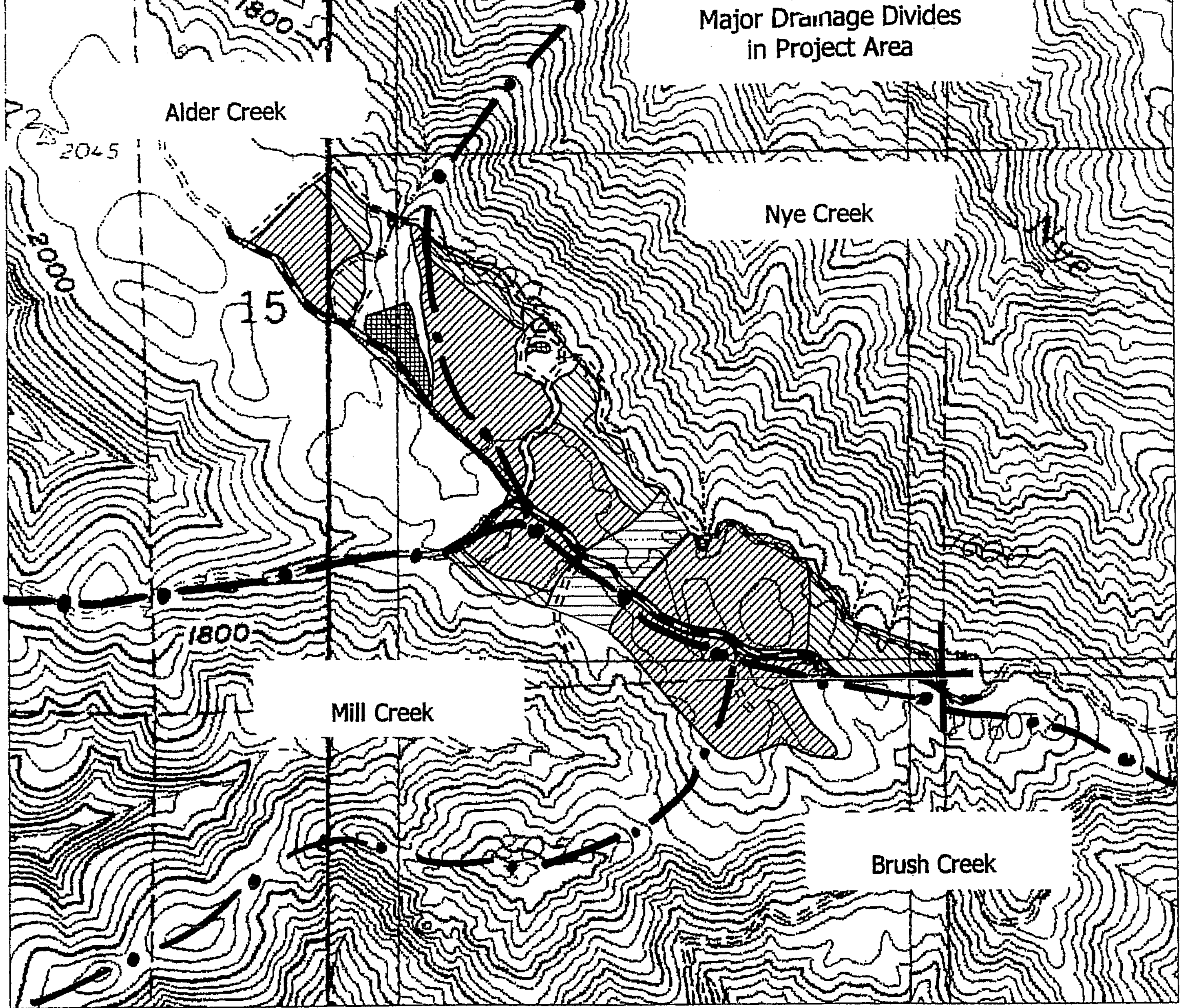
This assessment evaluates likely changes in

1. Annual water yield,
2. Dry season flows and dry year flows,
3. Groundwater,
4. Peak flows and channel erosion potential
5. Hydrologic cumulative effects.

Scientific Background and Overview of Approach

This assessment utilizes previous research on watershed scale hydrologic processes conducted at Caspar Creek by the USDA Forest Service Redwood Sciences Laboratory (RSL) in cooperation with the Jackson Demonstration State Forest (JDSF) to help determine expected trends in water quantity and quality if the Project is implemented. Watershed research at Caspar Creek is relevant because the hydrologic effects of conversion of forest stands to silvopasture-vineyards are comparable to the primary effects of clearcut forest harvest.

The chief effects of clearcut timber harvest (excluding roads) on hydrologic processes are removal of existing vegetation and resultant changes in canopy interception and evapotranspiration. These changes are expected to increase water delivery to the soil, soil moisture, and runoff. Caspar Creek experimental results are particularly relevant to predicting the gross hydrologic effects of vegetation removal associated with timberland conversion to silvopasture-vineyard.



Plotted Scale = 1 : 12,000
1 inch = 1,000 feet

1000 0 1000 2000 Feet

Manchester Ridge, LLC
Conversion

Sec. 9, 15, 16, & 22, T13N, R16W, MDB&M
Point Arena & Eureka Hill 7.5' U.S.G.S. Quads.

APN 132-260-03

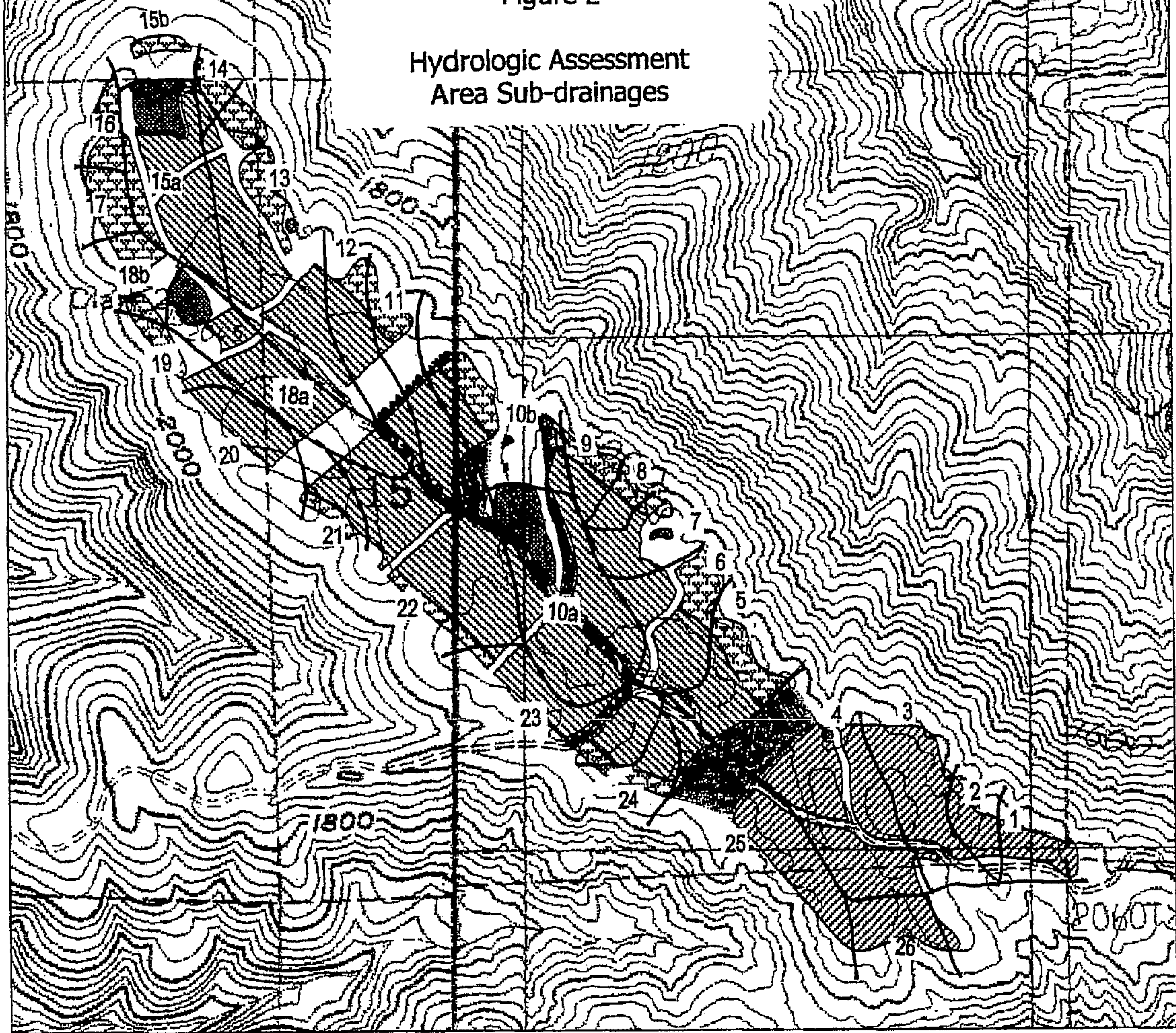
Legend:

- SILVOPASTURE - ORCHARD
- CLASS IV WATERS
- SILVOPASTURE - VINEYARD
- SILVOPASTURE - ORCHARD UNFENCED WILDLIFE CORRIDOR
- WILDLIFE HABITAT RESERVE NO OPERATIONS
- CLASS II WATERCOURSE
- CLASS III WATERCOURSE
- PERMANENT ROAD
- PROPOSED ROAD
- SEASONAL ROAD

N

NCRM

December 5, 2003
Version 1.2



Plotted Scale = 1 : 12,000
1 inch = 1,000 feet

1000 0 1000 2000 Feet

Adams Ridge
Vineyard & Orchard Project

Sec. 9, 15, 16, & 22, T13N, R16W, MDB&M
Point Arena & Eureka Hill 7.5' U.S.G.S. Quads.

APN 132-260-03

Legend:

PONDS

ORCHARDS

VINEYARD-PHASE3

VINEYARDS

PROJECT BOUNDARY

ADDED ORCHARD

NCRM

N

In addition to the effects of changed forest canopy, the project under consideration includes collection of surface runoff from a portion of the area in three reservoirs (one of which is within the Project area), storage of a portion of the surface runoff for irrigation, several shallow wells, and potential changes in soil hydrologic properties including infiltration capacity, associated with agricultural site preparation and cultivation. Each of these potential effects will be addressed in this assessment.

The proximity and general similarity of the Caspar Creek watershed to the assessment area at Adams Ridge reasonably ensures that the experimental results at Caspar Creek are generally applicable. The Caspar Creek watershed, located in Mendocino County a few miles inland from the coast about halfway between the communities of Ft. Bragg and Mendocino, has generally similar climate, vegetation, and geologic conditions as the assessment area. Annual rainfall is similar at Caspar Creek (about 50 inches), however there are some differences in soils and topography at the assessment area, where soils are deeper and terrain is relatively level to gently sloping. Sub-watershed areas investigated on the assessment area range from < 1 ac to about 40 ac. Peak stream flow changes are estimated for larger watershed areas to evaluate potential offsite Project impacts. These larger areas include Alder Creek (drainage area of about 15,750 ac), Brush Creek (drainage area of about 10,950 ac), Nye Creek (749 ac) and an unnamed tributary to Nye Creek (69 ac). The North Fork Caspar Creek watershed is about 1,170 acres, and experimental sub-basins range in size from about 25 to 70 acres. These similarities in watershed size allow reasonable extrapolation of experimental results to the assessment area.

Limitations

Some aspects of the THP/Conversion Project description were modified after the quantitative aspects of this analysis were completed. While these changes are not large, they are noted because they create minor inconsistencies in the hydrologic assessment when compared to the THP/Conversion Project as described in the Project documents. These minor modifications are displayed in Figure 2. In addition, the proposed silvopasture management for orchards and vineyards in the Project area, as well as the larger area assessed in this report, was not specified when the hydrologic assessment was conducted. Although silvopasture management is not specifically assessed, we believe that the runoff coefficients used in the rational runoff calculations are conservative and the incorporation of silvopasture management in the assessment would not produce significantly different results.

Anticipated Changes in Rainfall Interception and Runoff

The majority of proposed Project acreage was under forest cover in various stages of maturity until 2002. The assessment area outside the Project area was primarily grassland with scattered trees. Historic land uses` over the preceding decades include timber harvest and grazing. Removal of forest canopy, which includes components of redwood, Douglas-fir, hardwoods and shrub understory, and replacement by silvopasture-vineyard and silvopasture-orchard, will affect interception and evapotranspiration processes. It should be noted that 1963 aerial photography of the site shows the Project area converted largely to grassland.

The conversion of forest vegetation to agricultural use (silvopasture-vineyards and silvopasture-orchards) will reduce the interception and evaporation of rainfall by forest canopy. Silvopasture-orchard areas will behave similarly in the short-term, however, interception rates in silvopasture-orchard areas will gradually increase as the silvopasture-orchards mature. Experimental data indicate that forest canopy intercepts and evaporates approximately 20% of storm precipitation in temperate coniferous forests (Dunne and Leopold 1978, pp. 87-88). Removal of the forest canopy therefore is expected to increase the quantity of precipitation reaching the ground surface, potentially causing increases in

- infiltration of water to the soil and percolation to groundwater aquifers
- summer streamflow
- storm runoff.

These potential effects are discussed below in the context of regional scientific studies of redwood forest watershed hydrology.

Watershed experiments regarding the effects of harvesting redwood forests on streamflow and water quality have been conducted in the region for over 30 years at Caspar Creek (Ziemer, 1998a). As found in other watershed studies in the Pacific Northwest, increases in storm runoff during the first few rainstorms of the season may be large (Ziemer, 1981), however, "[t]hese first rains and consequent streamflow in the fall are usually small and geomorphically inconsequential in the Pacific Northwest" (Ziemer, 1998b). These early winter increases in storm runoff have been attributed to reduced evapotranspiration from forest vegetation during the growing season, which causes a higher level of soil moisture and summer stream flow. In other words, following harvest, forest vegetation draws less water from the soil via its root system and more of the rain water that enters the soil during the wet season remains in the soil or moves by gravity into surface or sub-surface channels, or percolates to groundwater aquifers.

The change in evapotranspiration and/or canopy interception caused by forest harvest has been found to result in significant increases in both total annual runoff and minimum summer stream flow. At Caspar Creek, annual runoff increased an average of 15% for monitoring periods of about 10 years following harvest (Keppeler, 1998). These levels of flow increase were recorded in two different watershed experiments at gauge sites on Class I perennial streams with drainage areas > 1000 ac. Maximum annual increases were about 30%. Minimum mean daily summer flows increased an average of 148% following clearcut harvesting of about 50% of the watershed of North Fork Caspar Creek (Keppeler, 1998). The smallest increase was 75% and the largest was 287% over the period 1990-1997 (Table 1).

The Caspar Creek experiments also found increases in peak storm runoff following clear cut harvest of 50% of the North Fork watershed. Streams draining >95% clearcut harvested watersheds ranging in size from 25 to 67 ac in North Fork Caspar Creek were gauged for streamflow and compared to unlogged control watersheds (Ziemer, 1998b). For storms with a recurrence interval of about 2 years, which generate peak runoff greater than about 0.11 cfs per acre of watershed area, there was a mean peak flow increase of 27% in the five clearcut tributaries. For the entire North Fork watershed (1,170 ac), the instantaneous peak flow increase for a 2-yr recurrence interval was 9% for an area that was 50% harvested. "As the size of the watershed increases and the proportion of the watershed logged decreases, the post-logging and pre-logging observations become more similar"(Ziemer, 1998b, p.18).

Increases in total storm runoff were similar to those for peak runoff. Under the wettest antecedent conditions, total storm runoff volume increased 27% for clearcuts. Percentage increases were higher when antecedent wetness was lower. Annual storm runoff volume for all storms increased 60% in clearcut watersheds.

Statistical analyses of the runoff data that were designed to determine factors that significantly affect runoff rates found that only logged area and antecedent wetness were important. "No variables related to roads, skid trails, landings, firelines, burning, or herbicide application were found to improve the fit of the linear least squares model that includes logged area and its interaction with antecedent wetness" (Ziemer, 1998b, p.19).

Lewis (1998) found that suspended sediment yield measured from the small watersheds increased on the order of 200% (a three-fold increase after harvest). Although the source of this increase in suspended sediment was not determined, it was suggested that a substantial portion was caused by accelerated channel or bank erosion associated with observed increases in stream flow.

Anticipated Hydrologic Effects

Dry Season Flows and Annual Water Yield

The experimental results from Caspar Creek indicate that the Project will result in higher soil moisture levels in the assessment area and higher rates of streamflow in watersheds affected by conversion of forest vegetation to silvopasture-vineyards and silvopasture-orchards. Increased minimum flows in the dry season at Caspar Creek resulted in "increased habitat volumes, and...lengthened the flowing channel network along logged reaches (Keppeler, 1998, p. 43). Hence, it can be stated with relatively high certainty that the proposed Project is not likely to reduce dry season flows. Furthermore, the Caspar Creek data indicate that this effect is likely to persist in relatively dry years.

As can be seen in Table 1, the post-logging period included the three years of lowest runoff (excluding 1977 and adjusting for the estimated increase in flow attributed to harvest effects), and a representative range of water yield compared to the pre-logging record. These data demonstrate that even in relatively dry years, it is expected that both minimum summer flows and annual yields will increase relative to existing conditions in the assessment area.

Summary of Anticipated Hydrologic Effects Based on Experimental Watershed Data

In summary, watershed experiments at Caspar Creek indicate substantial increases in annual water yield, summer minimum flows, and storm runoff following clearcut harvest in the North Fork Caspar Creek. In addition, suspended sediment yield for small watersheds (about 25 to 70 ac) increased substantially. Increased annual water yield is due largely to increased storm runoff which results from decreased canopy interception of rainfall and increased soil moisture;

Table 1. North Fork Caspar Creek annual water yield 1963-1997 and minimum mean daily flow, ranked from lowest to highest annual yield. Figures in bold faces are post-logging data; water yields for these years were adjusted to the level predicted from pre-logging data after (Keppeler, 1998) Table 1. Minimum mean daily flows were not adjusted. Post-harvest flow increases are given in columns 3 and 5. No data were reported for the drought year 1977 in the source reference.

Water Year	Water Yield (m^3/ha/yr)	% Change Post-harvest Water Yield	Minimum Mean Daily Flow (L/s/km^2)	% Change Post-harvest Minimum Mean Daily Flow
1991	**1447**	**21**	**0.46**	**256**
1994	**2190**	**29**	**0.46**	**166**
1992	**2539**	**27**	**0.59**	**287**
1981	2754		0.28	
1976	3337		0.36	
1987	3337		0.23	
1964	3541		0.17	
1988	3560		0.26	
1985	3646		0.23	
1990	**3687**	**6**	**0.41**	**75**
1972	3730		0.34	
1968	3747		0.22	
1979	4111		0.64	
1989	4239		0.46	
1966	4943		0.22	
1963	5283		0.72	
1986	6265		0.49	
1980	6289		0.54	
1984	6782		0.28	
1996	**6800**	**13**	**0.80**	**75**
1997	**6801**	**15**	**1.19**	**129**
1978	6898		0.43	
1967	6929		0.40	
1970	6986		0.16	
1965	7210		0.29	
1971	7447		0.46	
1993	**7833**	**6**	**1.28**	**107**
1975	7932		0.55	
1973	8093		0.37	
1969	8184		0.26	
1995	**9566**	**7**	**0.72**	**89**
1982	9812		n.a.	
1974	13054		0.43	
1983	13919		0.74	

increased summer flows are significant, but represent a smaller proportion of the increased annual yield. Increased summer minimum flows result primarily from reduced growing-season evapotranspiration and higher soil moisture. The increasing trend in these parameters and the approximate magnitude of change is likely to be similar for conversion of forest to silvopasture-vineyard and silvopasture-orchard at the Project site on Adams Ridge.

Anticipated Effects on Groundwater Quantity

Experimental results from Caspar Creek indicate that the Project will likely result in more percolation to groundwater from the soil. Given the greater delivery of precipitation to the soil surface (as much as 20% based on Dunne and Leopold (1978), or as little as 10 to 15 % for North Fork Caspar Creek (Keppeler, 1998, p 40)) and reduced evapotranspiration, there would be more water available in the soil for percolation to groundwater. In watersheds with topographic relief and fractured Franciscan bedrock such as Caspar Creek, and most of Alder and Brush Creeks, it is likely that flow from groundwater aquifers sustain a portion of the summer baseflow in local stream channels. The velocity of groundwater may be sufficiently slow in Franciscan bedrock that increases in percolation rates may not be reflected in streamflow for a period of years. The Caspar Creek data include minimum flow increases that may be related to increased percolation rates to bedrock aquifers, however, the study was not designed to examine groundwater conditions.

Conclusions Based on Experimental Data and Scope of Further Analyses

The preceding review and discussion of Caspar Creek experimental results leads to the conclusion that annual and seasonal stream flows are expected to increase as a result of the proposed conversion of timberland to agricultural uses. Peak flow rates in stream channels are also expected to increase, and this creates potential for increased channel and bank erosion. Based on the evidence from Caspar Creek, additional analyses pertaining to potential peak flow increases and stream channel erosion potential are warranted and are presented below. The effect of storage of surface runoff in reservoirs must also be considered.

Agricultural development and cultivation could also cause changes in soil infiltration capacity that might affect rates of transmission of water from the soil surface into the soil (infiltration), and from the soil into bedrock aquifers (percolation). The conclusions drawn above do not explicitly account for such potential changes in soil hydrologic characteristics. These potential changes and their potential significance with respect to both surface runoff and groundwater are discussed in the following section.

Hydrogeologic Conditions

Agricultural development may affect soil hydrologic characteristics through several mechanisms. These include potential changes in water infiltration rates and changes in topography and drainage that affect surface runoff paths. No significant topographic changes are planned at the Project site (aside from reservoir construction), hence there are no significant changes in flow paths that might affect the distribution of surface runoff. Hence, the primary potential effect of the Project on soils would be to change soil infiltration rates. The following discussion of geology, hydrogeology and soils at the Project site provides necessary background information. In this section, the role of soil and bedrock geology are assessed to evaluate groundwater conditions at the Project site. Likely Project impacts on infiltration and percolation processes and groundwater withdrawal are also evaluated.

Soils

Carl Rittiman and Associates (2001) prepared a report pertaining to soils of the assessment area, a copy of which is provided with the Project document. Soil data summarized here is derived from that report and the Soil Survey of Mendocino County, Western Part, prepared by the Natural Resources Conservation Service, U.S. Department of Agriculture. The gently-sloping to level top of Adams Ridge has developed unusually deep soils. The soils are classified as Ornbaun – Zeni complex, 9 to 30 percent slopes (Map Unit 187). Most of the assessment area has slopes of < 9%, which is consistent with the mapping criteria for inclusions of different slope class used in the soil survey. Drainage and hydrologic characteristics are typical of the Ornbaun soils. Soils are characterized as well drained clay loam, and the permeability of the soil profile is moderate (0.6 –2.0 inches per hour). Available water capacity ranges from 0.14-0.18 inches per inch. Typical soil depths are > 6 ft, based on observations of 18 soil pits.

With respect to hydrologic processes, the soils on the project site are expected to generate relatively little surface runoff. The deep soils with infiltration rates of > 0.6 in/hr are capable of absorbing all but the most intense rainfall rates. The gentle topography of the site further encourages infiltration of incident rainfall. Assuming a total average soil depth of a minimum of 6 ft, and average water storage capacity of 0.16 in/in, the soil column may store about 11.5 in of water, considerably less than annual rainfall. Consequently, the soil profile is expected to provide conditions that are quite favorable for recharging the underlying water table aquifer.

Geology

The gently sloping topography of the assessment area is underlain by marine sedimentary rocks mapped as the Ohlson Ranch Formation by Wagner and Bortungo (1982). Based on previous experience in the region and prior hydrogeologic investigations (DWR, 1975), Ohlson Ranch sedimentary rocks are relatively thin (< 200 ft), horizontal beds of sandstone composed of well sorted sand that comprise a relatively permeable aquifer material. Field observations by OEI and by RGH Geotechnical and Environmental Consultants (1999; letter attached in Appendix B) indicate that the bedrock is not typical of the Ohslon Ranch Formation. RGH described these rocks as observed in exploratory trenches as "firm, friable meta-sedimentary bedrock". OEI's observations were limited to the drainage trench below the proposed reservoir site, but are consistent with those of RGH. The distinction between the typical Ohlson Ranch Formation and the geologic materials on Adams Ridge is of limited significance; the critical characteristic is that the materials are sedimentary, granular and friable (i.e. loosely cemented), which makes them relatively permeable with respect to groundwater infiltration. The hydraulic conductivity of rock fitting this general description ranges from 0.0001 to 1 ft per day (Heath, 1998, p.13), equivalent to a minimum of about 0.00005 in/hr, ranging up to 0.5 in/hr.

relatively simple to calculate the required rate of recharge to match a withdrawal rate of 48 ac-ft per year. First, we assume that the average duration of the aquifer recharge season is 120 days (e.g. December through March). Then it can be stated that the product of drainage area (56.1 ac), the number of days of recharge per year (120), and the recharge rate R in units of ft/day is equal to 48 ac-ft/yr: 56.1 ac x 120 days x R ft/day = 48 ac-ft. Solving for R gives the required recharge rate to be about 0.007 ft/day. This rate of recharge is near the center of the possible range of recharge rates (i.e. hydraulic conductivity), but lies in the lower half of the range. Field observations and pre-Project aerial photography indicate that ephemeral Class III channels typically begin near the break in slope where the relatively level ridge top gives way to steeper slopes on Franciscan rocks. This suggests that infiltration and percolation processes operate at relatively high rates, otherwise stream channels would form more readily in the gentle swales that typify the topography because exfiltration and/or saturation overland flow would occur more frequently. Considering these factors, it is reasonable to suggest that the aquifer recharge occurs relatively efficiently, and the projected groundwater withdrawal rate is less than or equal to the recharge rate.

Although it is reasonable to assume that withdrawal and recharge are likely to be in approximate balance, there is substantial uncertainty in the estimate of recharge. It is possible that withdrawal could exceed recharge. Should this prove to be the case, it is nevertheless unlikely to result in significant off-site effects. There are no other wells on Adams Ridge that could be affected. In addition, given the anticipated increase in precipitation delivered to the soil surface of 10 to 20%, and assuming that aquifer recharge increases if more water infiltrates the soil and percolates to groundwater, a substantial quantity of additional groundwater recharge could result from the Project, offsetting groundwater withdrawal.

In summary, infiltration rates probably will not decrease, and could increase, but the changes are not expected to result in significant decreases in groundwater recharge. Consequently, peak flow increases are expected to be attributable to changes in vegetation cover and interception and evaporation of precipitation, and changes in soil characteristics are expected to be negligible. Peak flow increases have the potential to accelerate channel and bank erosion. The remainder of this assessment addresses the likely magnitude of peak flow increases and associated erosion hazards.

Peak Flow Changes

As discussed in the review of the research at Caspar Creek, removal of forest vegetation is expected to increase runoff rates owing to reduced evapotranspiration and canopy interception. Watershed experiments at Caspar Creek found that the peak instantaneous stream flow associated with a 2-year recurrence interval storm (probability of occurrence in any year = 50%) after clearcut harvest was about 27% greater than expected under pre-harvest conditions for small watersheds (about 25 to 70 ac). This portion of the analysis describes the method used to quantify the magnitude and location of potential peak flow increases in the assessment area.

Application of the Rational Runoff Method

There are a variety of techniques that could be employed to quantify expected runoff rates. Owing to the small size of the drainage areas involved, modest data requirements, and relative simplicity of the technique, the "rational runoff method" was selected (Leopold and Dunne, 1978, pp. 298-305; Pacific Watershed Associates, 1994, Appendix A). This technique is often used in developing flow estimates for culvert sizing and other hydraulic design problems. The rational method utilizes a simple formula, Q = C I A, where instantaneous stream discharge, Q (cfs) is the product of a coefficient pertaining to the character of the watershed C, the precipitation rate I (in/hr), and the drainage area A (ac).

The coefficient C is determined from tables relating to land use characteristics of the watershed area (e.g. Dunne and Leopold, 1978, p.300). Relevant values of C for loam soils under cultivated and woodland conditions are 0.4 and 0.3 respectively.

To estimate the effects of silvopasture-vineyard conversion on peak runoff, the rational method was evaluated under existing conditions and Project conditions. For the existing condition (pre-Project), portions of the assessment area that are currently forested are evaluated for C=0.3. These areas are evaluated with C=0.4 for cultivated areas under the post-Project scenario. Pre-Project forest cover is effectively 100% in all Project areas. Roads were evaluated using C=0.85; road lengths were measured on aerial photographs to determine pre-Project conditions, and the large-scale assessment area topographic maps were used to determine final road lengths. These lengths were multiplied using a standard road width of 15 ft.

The precipitation rate (I) used was determined by the approximate time of concentration of flow in the sub-drainages in the Assessment areas and the magnitude and/or frequency of the design storm. The frequency (return period or recurrence interval) selected for evaluation was 2 years. Runoff increases for larger, less frequent rain storms are expected to diminish (Ziemer, 1998b). For smaller, more frequent rain storms, percentage changes in runoff rates are expected to be larger (e.g. Jones and Grant...), but of little geomorphic significance. The 1.5 year to 2 year recurrence interval flows are believed to be the most influential in determining channel form, and represent the magnitude of flows that do the most geomorphic work (Wolman and Miller, 1960). Considering the geomorphic significance of the 2-year flow, and considering that the most significant effect of peak flow increases are hypothesized to be channel and bank erosion, the 2-year recurrence interval flow is particularly appropriate for this analysis.

As stated above, the Caspar Creek experiment found peak flow increases after logging of about 27% for 2-year recurrence flows. Using the rational runoff method, and holding all other factors equal, the conversion of woodland (C=0.3) to silvopasture-vineyard (C=0.4) would yield peak flow increases of 33% ([0.4-0.3]/0.3). Hence, using a 2-year design flow for the analysis produces runoff predictions that are in general agreement with and somewhat larger than the Caspar Creek experimental data pertaining to changes in peak flow following timber harvest . Therefore, the application of the rational method for this analysis has the advantage of relative simplicity along with empirical support from regional watershed experiments.

The rational runoff technique requires determination of time of concentration; calculations indicate that 15 minutes is a reasonable estimate for the small sub-catchments in the assessment area. Hence, for calculations of peak instantaneous runoff (Appendix A), the duration of the storm to be evaluated is about 15 minutes. Estimates of precipitation for 15-minute storm duration can also be calculated using existing data (NOAA, 1973). For Adams Ridge, the estimated 2-year recurrence, 15-minute duration rainfall intensity was 0.44 in/hr. The equivalent rate for a one-hour period used in the rational runoff equation is 1.76 in/hr. It is assumed in application of the rational runoff method that this rainfall intensity is sufficient to generate surface runoff. This assumption is conservative with respect to assessing potential Project effects in that the soil infiltration rate is > 0.6 in/hr. In other words, there is reason to believe that the design storm rainfall intensity may not exceed soil infiltration rate, and therefore not produce surface runoff at all, let alone the quantities estimated. Hence, the analysis of surface runoff should be considered to be a maximum estimate of potential Project effects.

Drainage areas corresponding to different runoff nodes used for the runoff analysis were determined from large scale, 2-ft contour interval topographic map of the Assessment area and from USGS topographic maps. The approximate boundaries of these sub-drainages are shown in Figure 2 on a preliminary version of the Project base map available when the analysis was conducted. Note that the topography shown in Figure 2 is not always consistent with the large scale topographic map (1 in = 200 ft) used to delineate the sub-drainages. The 2-ft contour interval for this large scale topographic map establishes a drainage pattern somewhat different from USGS topographic maps used for the Project base map. The large scale topographic base map was developed by Sandine & Associates. Inc. for an Erosion Control Plan. The size of these maps prevents their inclusion in this report owing to requirements that all THP documents fit a standard page size. Drainage from areas contributing to runoff nodes 1 through 9 (Figure 2), drain to Nye Creek (a tributary to Alder Creek), runoff from sub-catchments 10 through 23 drain directly to Alder Creek, and drainage areas 24 to 26 drain to Brush Creek.

Three reservoirs are either currently in use or contemplated. Two currently exist outside the Project area (sub-catchments 15 and 18). A third reservoir is being considered for development in the Project area (sub-catchment 10). The runoff analysis pre-Project scenario assumes that no reservoirs are present. In the analysis, it is assumed that the 2-year storm event occurs when the reservoirs are at storage capacity, meaning that the reservoirs will begin to spill when surface runoff begins. Owing to the discharge regime of controlled release from the reservoirs through outlet structures, a stormwater detention effect occurs and the peak flow through the reservoir attenuates the peak rate of discharge. The peak outflow from each of the reservoirs for the 2 year 15 minute design storm was calculated using the flow indication curve method (Bedient and Huber, 1992, pp 412-415).

*Table 2. Summary of predicted peak flow changes using the rational runoff method. A complete set of acreage of land use types and flow changes pre- and post-Project is provided in Appendix A. * indicates sub-catchments with estimated reservoir detention effects; ** indicates sub-catchments where expected reservoir detention effects were not modeled in the analysis; <u>these areas have predicted peak flow increases that significantly over-predict peak flow increases.</u> Bold face indicates sub-basin wholly within conversion area; bold italics indicates sub-basin partially in conversion area. Sub-basin drainage units 13-22 are wholly outside conversion area.*

Drainage Unit	Total Area (ac)	Pre Project 2-yr Peak Runoff (cfs)	Post Project 2-yr Peak Runoff (cfs)	Change in Peak Flow (%)
1	**1.4**	**0.8**	**1.0**	**30%**
2	**2.1**	**1.2**	**1.5**	**30%**
3	**9.2**	**5.2**	**6.6**	**28%**
4**	**23.5**	**13.3**	**16.8**	**26%****
5	**5.5**	**2.9**	**4.0**	**37%**
6	**11.5**	**6.5**	**8.5**	**31%**
7**	**9.9**	**5.2**	**7.5**	**44%****
8	**2.8**	**1.5**	**2.0**	**39%**
9	**3.0**	**1.6**	**2.3**	**44%**
10*	***40.9***	***23.0***	***13.2***	***-43%****
11	***20.7***	***12.4***	***15.1***	***21%***
12	***8.7***	***5.3***	***6.2***	***17%***
13**	14.8	9.2	11.2	21%**
14	6.1	4.1	4.5	9%
15*	21.6	13.9	7.0	-50%*
16	2.1	1.4	1.6	18%
17	4.6	3.0	3.4	14%
18*	14.7	9.1	4.8	-48%*
19	5.3	3.4	3.9	16%
20	6.0	3.9	4.4	11%
21	4.6	2.9	3.1	10%
22	6.4	3.8	4.7	25%
23	***11.0***	***6.3***	***8.4***	***33%***
24	**1.4**	**0.7**	**1.1**	**54%**
25	**10.4**	**5.8**	**7.6**	**30%**
26	**0.9**	**0.5**	**0.6**	**25%**
TOTAL	249.1	146.9	151.3	3%
			Sub-basin Mean =	18%

Subtotals

In Conversion	**1-9, 24-26**	**81.4**	**45.2**	**59.7**	**24%**
Partially In	***10-12, 23***	***81.4***	***47.0***	***43.0***	***-9%***
Outside Conv.	13-22	86.2	54.7	48.6	-12%

It should be noted that during many storms of this magnitude, the reservoir will not be full and a large component of runoff from the site will be collected in the drainage system and stored. In those cases, peak flow increases predicted for those portions of the channel network that recharge the reservoirs would not occur. Determination of the frequency of events that occur with the reservoir full requires a complex analysis that provides probabilistic results, and was considered unnecessary for this analysis. For simplicity, this analysis assumes conservative runoff conditions (i.e. reservoir water surface at spillway elevation) for the design storm, biasing the analysis toward a larger effect on peak runoff rather than a smaller effect.

The limitations of estimating peak flows using any method, including the rational runoff method, are substantial. Hydrologic systems are complex, many of the variables are difficult to quantify, and models rarely produce precise results. The method employed for this analysis is expected to give peak flow estimates that are of the proper order of magnitude, but of undetermined accuracy. Of greater importance is generating an estimate of relative change for pre- and post-Project conditions, and the technique used provides repeatable estimates of relative change using accepted methods and data inputs of a level of detail consistent with available data.

Results: Predicted Pre- and Post-Project Peak Flow

The runoff analysis estimated the magnitude of peak flows pre- and post-Project for each of 26 sub-catchments (#10, 15 and 18 are divided into upper and lower sub-catchments to model reservoir development). Hence, for all sub-catchments, an estimate of peak flow change at the assessment area boundary was calculated (Table 2 and Appendix A). Peak flow increases for individual sub-catchments range from about 10% to greater than 40%, and average 27%, excluding sub-catchments with reservoir detention effects. The significance of these increases are discussed in the following section. In sub-catchments with reservoirs, however, the detention effect significantly reduces peak flows by a factor of about 40 to 50%. Considering the net effect on predicted peak flows from the assessment area, the large detention effects that occur in a few sub-catchments largely compensate for the moderate increases predicted for most sub-catchments, resulting in a net predicted peak flow increase of 3% (about 4 cfs).

Detention effects from small ponds in sub-catchments 4, 7 and 13 are not estimated, however they can be expected to substantially reduce estimated increases in peak flow for these catchments. This is another aspect of this assessment that overstates the likely extent of peak flows increases.

The predicted peak flow changes are displayed graphically as a function of sub-catchment area in Figure 3 below. This graph emphasized the average magnitude of predicted peak flow increase in most sub-catchments as well as the large decreases in predicted peak flow where reservoir detention effects occur.

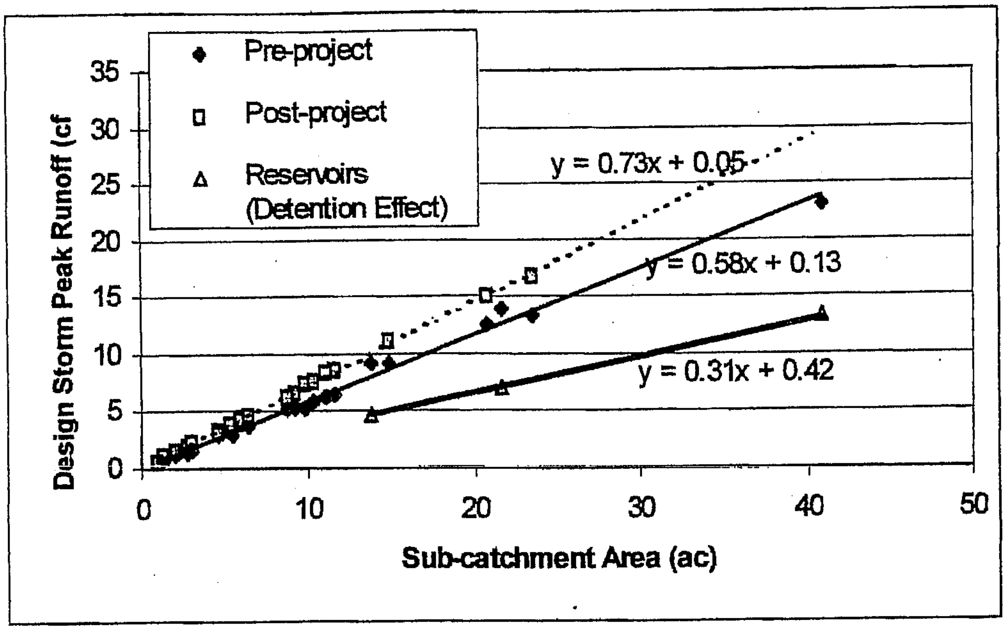


Figure 3. Pre-Project and post-Project peak flow predictions using the rational runoff method. Reservoir detention effects induce large predicted decreases in peak flow where they occur.

Cumulative Effects: Peak Flow Changes

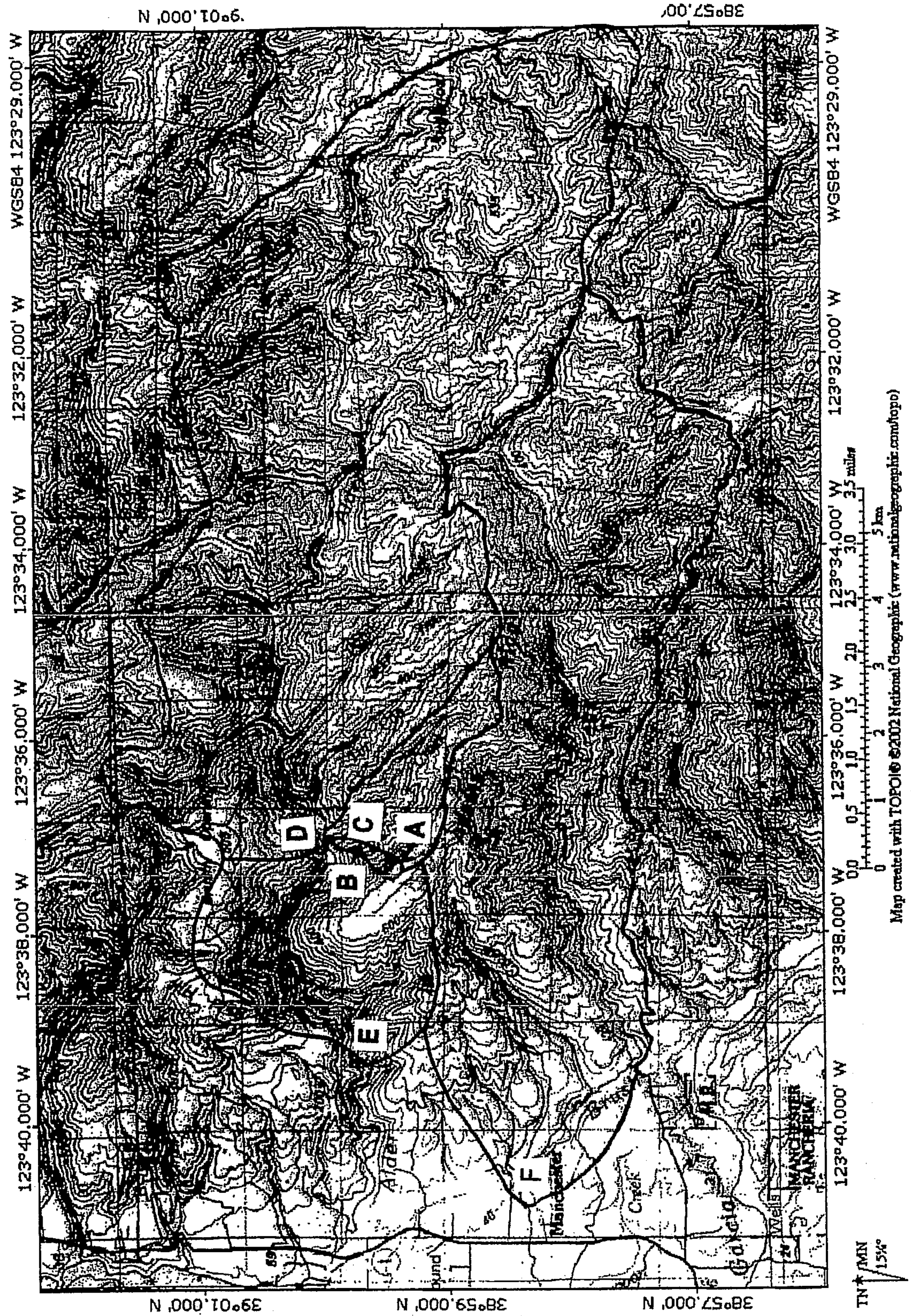
To assess potential downstream cumulative effects in terms of peak flow changes, calculations were made to estimate assessment area and Project effects during a 2-year recurrence interval flow event for a representative series of progressively larger catchments beginning at Project sub-catchments at the headwaters of Nye Creek, a tributary to Nye Creek, Nye Creek and Alder Creek (Figure 4). For the larger drainage basin scales, 2 year-peak flows were estimated using the U.S. Geological Survey National Flood Frequency software (USGS 2003), which calculates peak flows using regional flood frequency regressions. The necessary data for these calculations are minimal and readily available, and include drainage area at the point of interest, watershed mean annual precipitation, and watershed mean elevation. Peak flow increases predicted using the rational runoff method were calculated as a percentage of peak flow estimated from the NFF program to provide a quantitative basis of comparison for assessing potential magnitude of peak flow changes. This comparison necessarily utilizes data from the rational runoff method, and compares it with peak flows estimated from regional flood frequency relationships developed from USGS stream gage data. Comparison of predictions from different techniques should be regarded with appropriate caution, especially given the relatively wide confidence intervals associated with NFF predictions. However, given the magnitudes of peak discharge from large watersheds such as Alder Creek and the relatively small increases in peak discharge predicted from the assessment area and Project, the methodological issue is of relatively little significance. For example, if the peak flows from the NFF over-predict by 100%, the effect would remain < 2%. Drainage areas and runoff pre- and post-Project for these larger watershed areas are summarized in Table 3.

Predicted flow increases are very small for Nye, Alder and Brush Creek. The largest flow increases affect channels draining proposed Project areas in sub-catchments 7, 8 and 9 at the Project boundary, collectively considered runoff node A in Table 3. For node A, a 44 % increase in discharge is predicted, from 8.2 to 11.8 cfs. However, as this flow is mixed with runoff from a larger sub-watershed tributary to Nye Creek (node B, Table 3), the same 3.6 cfs increase in post-Project peak flow represents only about a 10% peak flow increase. At node C, which includes all peak flow increases predicted from the Project that reach Nye Creek, predicted peak flow increases total 16 cfs, but in the larger Nye Creek watershed, this represents a 4% peak flow increase. At the confluence of Alder Creek and Nye Creek, this flow increase represents an increase of < 1% as runoff from Nye Creek mixes with runoff from the much larger Alder Creek watershed. The significance of these predicted (and possibly over-stated) peak flow increases is discussed in the following section.

*Table 3. **Summary of results of the runoff analysis for individual runoff nodes (see Figure 3) for a 2-year recurrence interval, 15-minute duration rainstorm of 0.44 inches (equivalent to 1.76 in/hr for calculation of runoff). Flow estimates for smaller watershed areas (up to about 1 mile square; Nye Creek) utilize only the rational runoff predictions. For larger watersheds (Alder and Brush Creeks), the rational runöff predictions are compared with peak flow predictions from regional flood frequency analyses (see text for additional discussion). "MAP" is mean annual precipitation; "na" indicates not applicable.***

Watershed	Node	Area		Rainfall (in/hr)	Flow estimates (cfs)					
		(ac)	(mi^2)	2 yr	Rational Method - 2 yr R.I.				Δ cfs/2yr flow	NFF
				15min	before	after	Δ cfs	% change	(%)	2 yr
Nye sub-project	A	15.6	0.02	1.76	8.2	11.8	3.6	44	na	na
Nye sub-basin	B	68.6	0.11	1.76	36	40	3.6	9.9	na	na
Nye (all)	C	749	1.17	1.76	395	412	16.1	4.1	na	na
Alder below Nye	D	13958	21.8	na	na	na	16.1	na	0.9	1830
Alder below Assessment Area	E	15749	24.6	na	na	na	17	na	0.8	2040
Brush below Assessment Area	F	10947	17.1	na	na	na	2.3	na	0.2	1350
Assessment Area		249	0.41	1.76	147	151	4.3	2.7	na	na
				MAP=50"						

Peak Flow Cumulative Effects
Sub-drainages and Watersheds



Assessment of Erosion Hazards Related to Predicted Peak Flow Increases

The analysis of runoff for the 2-yr design storm predicted that most sub-catchments would experience peak flow increases ranging from about 10 to 40%. The analysis is conservative in that it is more likely to overestimate than underestimate Project effects on peak runoff, hence these estimated increases in peak flow should be regarded with appropriate caution. Field observations of swales and stream channels along the entire perimeter of assessment area site in 2002 and 2003 revealed that stream channel heads, where present, are typically located near the break in slope along the edge of Adams Ridge. The high intensity rainfall in late 2001 apparently caused concentrated surface runoff in some areas along the northeast side of Adams Ridge in sub-catchments 10, 11 and 12. This concentrated runoff mobilized and transported some sand and gravel as evidenced by localized deposits near the assessment area perimeter road. Although of minor extent, there is some evidence of channel erosion or rill and gully development during the most intense rainstorms. It is likely that the rainfall in November and December 2001 that caused the observed erosion processes exceeded the intensity of the 2-year design storm, hence it probably does not represent typical hydrologic response to winter rains. Nevertheless, the predicted peak flow increases should be considered potentially capable of causing at least some erosion at or near channel heads where surface runoff is naturally concentrated. Hence, there are potential erosion hazards that may warrant erosion control mitigation.

Potential Mitigation and Erosion Control

Surface runoff appeared to be limited to convergent and low-lying topography near and in existing channels and locally on old skid trails. In these areas, site-appropriate erosion control measures should be employed as necessary to prevent the development of rills or gullies, and to limit potential accelerated erosion of existing channels. The length of channel or swale that may require erosion control treatments is generally short (e.g. 100-200 ft) because the concentration of surface flow occurs near the assessment area boundary. Beyond the assessment area boundary, stream channels become much steeper owing to different geologic materials and are generally armored by bedrock, boulders and cobbles and are not particularly vulnerable to erosion by peak flow increases. In addition, because the Project, including the assessment area, maintains natural drainage paths and does not generally include piped subsurface drainage systems, increased runoff is not generally delivered to a discharge point in the form of concentrated accelerated runoff. Consequently, erosion hazards are not particularly concentrated or severe. Erosion control treatments are not proposed in detail in this report. However, the standard erosion control treatments for such circumstances include placement of straw logs, rip-rap aprons or grassy waterways in swales, and rip-rap placement or check dams in channels or swales (e.g. Goldman et al. 1986). These types of treatments are currently proposed in some locations as per the Erosion Control Plan developed by Sandine & Associates.

Potential Downstream Impacts of Channel Erosion Hazards

In the preceding assessment of erosion potential, potential channel and/or bank erosion is not quantified. The potential significance of hypothesized channel erosion derives in large part from the Caspar Creek study (Lewis 1998), which suggested that channel erosion could be a significant component of observed increases (200% or more) in suspended sediment yield from small watersheds.

Increased sediment yield from channel erosion in the assessment area is unlikely to affect downstream aquatic habitat in Alder Creek and Brush Creek. The Caspar Creek study (Lewis 1998) demonstrated that increases in suspended sediment yield in headwater streams (Class II and Class III channels) attributed to channel erosion did not result in increased suspended sediment loads in Class I channels downstream. Three monitoring stations on the mainstem of the North Fork Caspar Creek showed an increase of 2% at one station, and <u>decreases</u> of 2% and 17% at two other stations. These data document that there was little or no change in suspended sediment yield in fish-bearing Class I channels downstream, despite large percentage increases in tributary channels. This interpretation of the Caspar Creek experiment is discussed in greater detail in Appendix C.

This can be explained by the fact that erosion rates in the headwater channels are very low, and that when those rates are increased by a factor of two or more, the absolute erosion rate remains small relative to erosion rates in the watershed and mainstem channel as a whole. This would be particularly true in Brush Creek and Alder Creek in relation to likely minor increases in erosion from the Project area owing to the relatively large size of these watersheds and the existing sediment sources in these steep forested watersheds.

The overall increase in suspended sediment yield for the North Fork Caspar Creek was attributed to a single landslide that occurred near the end of the study period (Lewis 1998), and not to increased erosion rates in headwater channels. Hence, the risk to downstream habitat and water quality implied by potential increases in channel erosion associated with anticipated peak flow increases at the assessment area probably would not be significant. These considerations should temper assessment of the significance of the erosion hazards as well as the efficacy and cost of proposed mitigation measures.

Summary

The most applicable research available strongly suggests that annual water yield and summer stream flows can be expected to <u>increase</u> owing to decreases in evapotranspiration processes associated with removal of forest vegetation. Soil and geologic conditions suggest that infiltration to the water table is not expected to decrease substantially, and that percolation to groundwater might increase. Small peak flow increases (about 10 percent or less) are expected to occur in some off-site channels draining Adams Ridge. Potential erosion in swales and channels on the Project site should be treated using standard erosion control techniques. The degree of erosion hazard is small, and it is unlikely that significant changes in water quality or sedimentation would occur in Class I reaches of Alder Creek or Brush Creek located downstream. In our opinion, the potential impacts of erosion and sedimentation to water quality are not significant, but warrant appropriate mitigation and/or monitoring on-site to prevent erosion by potential peak flow increases.

References Cited

Bedient, P.B, Huber, W.C. (1992) Hydrology and Floodplain Analysis, Addison-Wesley Publishing Company, 692p.

Department of Water Resources (1975) Evaluation of ground water resources: Sonoma County. State of California, The Resources Agency, Department of Water Resources in cooperation with County of Sonoma, Bulletin No. 118-4. December, 1975.

Dunne, T. and Leopold, L.B. (1978) Water in Environmental Planning. W. H. Freeman and Company, 818 p.

Goldman, S.J., Jackson, K.J., Bursztynsky, T.A. (1986) Erosion and sediment control handbook. McGraw-Hill, Inc, 453 p.

Keppeler, E.T., 1998. The summer flow and water yield response to timber harvest. PSW-GTR-168, Pacific Southwest Research Station.

Pacific Watershed Associates (1994) Handbook for forest and ranch roads. Prepared for Mendocino County Resource Conservation District. 161 p.

Wolman, M.G. and Miller, J.P. (1960) Magnitude and frequency of forces in geomorphic processes. Journal of Geology, 68(1):54-74.

United States Department of Agriculture Soil Conservation Service (1972) Soil Survey, Sonoma County, California.

United States Geological Survey (2003) National Flood Frequency Program. NFF Version 3.2, 2003/04/30. http://water.usgs.gov/software/NFF.

Ziemer, R.R., 1981. Storm flow response to road building and partial cutting in small streams of northern California. Water Resources Research, 17: 907-917.

Ziemer, R.R. (1998a) (Technical Coordinator) Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, USDA Forest Service Pacific Southwest Research Station, General Technical Report, PSW-GTR-168, 149 p.

Ziemer, R.R. (1998b) Flooding and stormflows. IN Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, USDA Forest Service Pacific Southwest Research Station, General Technical Report, PSW-GTR-168, pp. 15-24.

Appendix A

APPENDIX A: MANCHESTER RIDGE ASSESSMENT AREA

Rational runoff calculations

2-yr 15-min. Intensity (in/hr)	Runoff Coefficients					
	Service C1	Pond C2	Woodland C3	Road C4	Grass C5	Vineyard C6
1.76	0.65	1	0.3	0.85	0.35	0.4

Vineyard Drainage Unit	Total Area (ac)	Pre-project								
		Area (Ac)				Peak Runoff for 2-yr RI (cfs)				
		Forest	Grass	Road	Pond	Forest	Grass	Road	Pond	Total
1	1.4	1.3	0.0	0.0	0.0	0.7	0.0	0.1	0.0	0.8
2	2.1	1.9	0.0	0.1	0.0	1.0	0.0	0.1	0.0	1.2
3	9.2	7.2	1.8	0.2	0.0	3.8	1.1	0.3	0.0	5.2
4	23.5	17.1	5.7	0.5	0.1	9.0	3.5	0.7	0.2	13.3
5	5.5	5.5	0.1	0.0	0.0	2.9	0.0	0.0	0.0	2.9
6	11.5	11.1	0.0	0.4	0.0	5.8	0.0	0.7	0.0	6.5
7	9.9	9.2	0.0	0.2	0.5	4.8	0.0	0.4	0.8	5.2
8	2.8	2.8	0.0	0.0	0.0	1.5	0.0	0.0	0.0	1.5
9	3.0	3.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	1.6
10 tot	40.9	37.7	2.0	1.2	0.0	19.9	1.2	1.8	0.0	23.0
10a res. outflow	23.4									
10b d/s	17.5									
10a + 10b										23.0
11	20.7	13.8	5.9	1.0	0.0	7.3	3.6	1.5	0.0	12.4
12	8.7	2.9	5.6	0.2	0.0	1.5	3.5	0.3	0.0	5.3
13	14.8	4.1	9.9	0.6	0.1	2.2	6.1	1.0	0.3	9.2
14	6.1	0.2	5.5	0.4	0.0	0.1	3.4	0.6	0.0	4.1
15a (u/s)	12.9	0.5	12.0	0.4	0.0	0.2	7.4	0.7	0.0	8.3
15a res. outflow										
15b (d/s)	8.7	0.0	8.4	0.3	0.0	0.0	5.2	0.4	0.0	5.6
15a + 15b										13.9
16	2.1	0.1	1.9	0.1	0.0	0.0	1.2	0.2	0.0	1.4
17	4.6	0.1	4.3	0.2	0.0	0.0	2.7	0.3	0.0	3.0
18a (u/s)	8.5	0.6	7.7	0.1	0.0	0.3	4.7	0.2	0.0	5.3
18a res. outflow										
18b (d/s)	6.2	0.2	6.0	0.1	0.0	0.1	3.7	0.1	0.0	3.9
18a + 18b										9.1
19	5.3	0.8	4.3	0.2	0.0	0.4	2.7	0.3	0.0	3.4
20	6.0	0.9	4.7	0.4	0.0	0.5	2.9	0.6	0.0	3.9
21	4.6	0.9	3.5	0.1	0.0	0.5	2.2	0.2	0.0	2.9
22	6.4	3.8	2.4	0.2	0.0	2.0	1.5	0.3	0.0	3.8
23	11.0	10.1	0.5	0.4	0.0	5.3	0.3	0.6	0.0	6.3
24	1.4	1.3	0.1	0.0	0.0	0.7	0.1	0.0	0.0	0.7
25	10.4	10.0	0.0	0.4	0.0	5.3	0.0	0.5	0.0	5.8
26	0.9	0.6	0.4	0.0	0.0	0.3	0.2	0.0	0.0	0.5
TOTAL	249.1									146.9

O'Connor Environmental, Inc.
Watershed Geomorphology & Hydrology
California Registered Geologist

P.O. Box 794, Healdsburg, CA 95448
Office: (707) 431-2810 Fax: (707) 473-9050
www.oe-i.com

Appendix A (continued)

Vineyard Drainage Unit	Post-Project									Change in Peak Flow (%)
	Area (Ac)				Peak Runoff for 2-yr RI (cfs)					
	Road	Forest	Vineyard	Pond	Forest	Road	Pond	Vineyard	Total	
1	0.0	0.0	1.3	0.0	0.0	0.1	0.0	0.9	1.0	30%
2	0.1	0.0	2.0	0.0	0.0	0.1	0.0	1.4	1.5	30%
3	0.2	0.0	9.0	0.0	0.0	0.3	0.0	6.3	6.6	28%
4	0.9	3.5	19.0	0.1	1.9	1.4	0.2	13.4	16.8	26%
5	0.1	0.0	5.4	0.0	0.0	0.2	0.0	3.8	4.0	37%
6	0.6	0.0	10.9	0.0	0.0	0.8	0.0	7.7	8.5	31%
7	0.6	2.4	6.5	0.5	1.3	0.9	0.8	4.6	7.5	44%
8	0.1	0.0	2.7	0.0	0.0	0.2	0.0	1.9	2.0	39%
9	0.2	0.0	2.8	0.0	0.0	0.3	0.0	2.0	2.3	44%
10 tot	2.0	5.7	30.4	3.1	3.0	2.9	5.5	21.4	32.8	43%
10a res. outflow									1.0	
10b d/s	0.9	5.7	11.2	0.0	3.0	1.4	0.0	7.9	12.2	
10a + 10b									13.2	-43%
11	1.5	3.6	15.6	0.0	1.9	2.2	0.0	11.0	15.1	21%
12	0.4	1.5	6.8	0.0	0.8	0.6	0.0	4.8	6.2	17%
13	1.0	1.3	12.4	0.1	0.7	1.5	0.2	8.7	11.2	21%
14	0.2	0.0	5.8	0.0	0.0	0.4	0.0	4.1	4.5	9%
15a (u/s)	0.9	0.0	9.6	2.4	0.0	1.3	4.2	6.8	12.3	48%
15a res. outflow									0.4	
15b (d/s)	0.6	0.0	8.1	0.0	0.0	0.9	0.0	5.7	6.6	18%
15a + 15b									7.0	-50%
16	0.2	0.0	1.8	0.0	0.0	0.4	0.0	1.3	1.6	18%
17	0.2	0.0	4.4	0.0	0.0	0.3	0.0	3.1	3.4	14%
18a (u/s)	0.3	0.3	6.4	1.5	0.2	0.4	2.6	4.5	7.8	47%
18a res. outflow									0.4	
18b (d/s)	0.1	0.2	5.9	0.0	0.1	0.1	0.0	4.2	4.4	14%
18a + 18b									4.8	-48%
19	0.3	0.4	4.5	0.0	0.2	0.5	0.0	3.2	3.9	16%
20	0.5	1.3	4.2	0.0	0.7	0.7	0.0	3.0	4.4	11%
21	0.2	1.3	3.1	0.0	0.7	0.3	0.0	2.2	3.1	10%
22	0.3	0.2	5.9	0.0	0.1	0.5	0.0	4.2	4.7	25%
23	0.8	0.0	10.2	0.0	0.0	1.2	0.0	7.2	8.4	33%
24	0.2	0.0	1.2	0.0	0.0	0.3	0.0	0.8	1.1	54%
25	0.4	0.0	10.0	0.0	0.0	0.6	0.0	7.0	7.6	30%
26	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.6	0.6	25%
										18%
TOTAL									151.3	3%

Appendix B

Letter to Chris Stone dated July 29, 1999, from RGH Geotechnical and Environmental Consultants, 2 pages.

GEOTECHNICAL and
ENVIRONMENTAL
CONSULTANTS

Gary W. Russey
Keith S. Gregory
Juan B. Hidalgo

July 29, 1999

Mr. Chris Stone
P.O. Box 458
Healdsburg, CA 95448

RE: Geotechnical Evaluation
Adams Ridge Property
Piper Ranch
Manchester, California

Project Number: 1144.08.00.1

This letter presents the results of our geotechnical evaluation of two potential reservoir sites located on the northerly end of Adams Ridge on the Piper Ranch in Manchester, California. The property (Adams Ridge) consists of an approximately 2000 foot wide by 7000 foot long northwesterly trending ridge. The portion of the ridge proposed for development is grassland and has historically been used for grazing livestock. The gently rolling ridge top is at an elevation of just over 2000 feet.

The purpose of our evaluation was to determine the feasibility of constructing one reservoir at two alternative locations. One alternative site is located in a gently sloping westerly trending swale adjacent to a 2045 foot benchmark. Alternative two site is located in a gently sloping northerly trending swale at the northern end of Adams Ridge.

Division of Mines and Geology maps (open file Report 84-46; 1984) indicate the sites are underlain by Tertiary-Cretaceous age Coastal Belt Franciscan bedrock. This unit consists of well consolidated, hard sandstone interbedded with small amounts of siltstone, mudstone and conglomerate. The unit is said to be pervasively sheared, commonly highly weathered, and tends to easily desegregate. The unit typically develops debris slides along creeks and road cuts. No landsliding is shown in the two alternative reservoir areas. A spring is shown near the upper end of Alternative two site. The ridge is located about 2 miles east of the active San Andrea fault.

On July 1, 1999, our principal geologist performed a geologic reconnaissance of the site and explored subsurface conditions by observing the excavation of twelve test pits across the two sites.

Alternative one site contains an old embankment and small reservoir near the center of the site. Our investigation indicates the remainder of site is underlain by 10 to 15 feet

707-544-1072 *468 Yolanda Avenue · Suite #204 · Santa Rosa, California 95404* FAX: 707-544-1082

of stiff or dense clay, silt, and sand surface soils. The surface soils are underlain by firm, friable, meta-sedimentary bedrock.

Alternative two site at the northern end of the property is underlain by 2½ to 9 feet of stiff silt and clay surface soils overlying firm, friable, meta sedimentary bedrock.

Based on our geotechnical evaluation, we judge it is feasible to construct reservoirs at either alternative site. The major geotechnical concerns for constructing the reservoirs are the surface and subsurface erosion potential of the site surface soils and the strong ground shaking expected to affect the site during the design life of the reservoirs.

To mitigate these concerns, the reservoir embankments will have to be bottomed below the surface soils and into the meta-sedimentary bedrock. The embankments can then be constructed as an engineered buttress fill with the silty clay on-site soils. Depending on materials exposed after grading the reservoir bottom, a clayey soil liner may be required.

We trust this provides the information you require at this time. If you have questions or wish to discuss this further, please call.

Very truly yours,

RGH Geotechnical and
Environmental Consultants

Registered Geologist
Gary W. Russey
No. 5283
Exp. 3/31/02
State of California

Gary W. Russey
Principal

Juan B. Hidalgo
Principal

Registered Professional Engineer
Juan B. Hidalgo
GE 398
Exp. 3/31/01
Geotechnical
State of California

GWR:JBH:tr(1144801.Ltr)

Appendix C

RE-INTERPRETATION OF EFFECTS OF TIMBER HARVEST ON EROSION AND SEDIMENTATION, NORTH FORK CASPAR CREEK

Matt O'Connor, Ph.D., R.G., O'Connor Environmental, Inc.

Overview

Assessment of runoff and sediment yield changes resulting from timber harvest on small watersheds in the Coast Ranges of northern California can by guided by experimental studies at Caspar Creek (Lewis 1998). That study measured changes in runoff and suspended sediment load in the North Fork of Caspar Creek, located in the Jackson Demonstration State Forest in coastal Mendocino County. The study documented increases in suspended sediment yields in small catchments (25 to 70 ac) of about 200%. It was hypothesized (Lewis 1998) that the source of observed increases of suspended sediment load in some tributary streams (primarily California Department of Forestry Class II channels) was channel beds and banks, and that the agent of erosion was documented increases in peak runoff rates of about 25% for small clear-cut catchments during 2-year recurrence interval rain storms (Ziemer and Keppeler 1998). Surface erosion was not considered a likely source of increased sediment yield. Although there are no data presented to document this hypothesized source of erosion, it appears to be the most likely erosion mechanism given the timber harvest practices in the watershed and analyses of experimental data.

The large percentage increases observed in the small tributary catchments were not observed at monitoring stations in the mainstem of North Fork Caspar Creek over the seven-year post-treatment monitoring period. It has been suggested that "...much of the sediment measured in the tributaries has been trapped behind woody debris or otherwise stored in the channels, so that much of it has not yet been measured downstream" (Lewis 1998, p.65). This hypothesis may explain the absence of a measurable downstream increase in suspended sediment yield, however, there are other plausible explanations. As discussed below, an analysis of hydraulic conditions and sediment transport mechanics reveals that suspended sediment transported through the tributary streams in North Fork Caspar Creek would not tend to be deposited in the mainstem of the North Fork. The absence of observed increases in suspended sediment yield at monitoring stations in mainstem North Fork Caspar Creek, despite large increases in tributary watersheds, may also result from the low sediment yield of the tributary watersheds relative to the larger watershed as measured at mainstem monitoring stations. The large percentage increase in tributary yield actually represents a small absolute increase in sediment yield in the watershed, and hence is not detected at the larger watershed scale.

Suspended Sediment Transport Mechanics

In gravel-bed streams such as Caspar Creek, stream energy as measured by bed shear stress is sufficiently high that the finer fraction (silt and clay; < 0.075 mm diameter) of sediment inputs are carried in suspension through the system with minimal deposition in stream channels. This fraction of sediment is sometimes referred to as the wash load (Reid and Dunne, 1996); it typically travels at a velocity equal to the water velocity.

Using grain size data for channel deposits in the mainstem of North Fork Caspar Creek (Napolitano 1996), I calculated the approximate grain diameter thresholds that separate three regimes of sediment transport: wash load (constant suspension), intermittent suspended load, and bed load (Table 1). Sediment finer than about 0.1 mm is expected to be transported in suspension during periods of flow capable of mobilizing bed load material (these typically occur about twice or more each year). Sediment in the sand size range (about 0.1 to 1+ mm) would be transported in intermittent suspension. Coarser material would be transported as bed load. During periods of more intense flow, these grain diameter thresholds would be larger, and coarser material would be transported in suspension in the water column. Perspective on typical rates of transport for sediment of varying sizes in mountain streams based on a recent extensive literature review (NCASI 1999) is provided in Table 2.

Median surface grain diameter (d50 mm)	Threshold Bed Shear Stress (dy/cm^2)	Shear Velocity (cm/s)	Settling Velocity for Maximum Diameter Wash Load (cm/s)	Settling Velocity for Maximum Diameter Intermittent Suspended Load (cm/s)	Maximum Grain Diameter for Wash Load (mm)	Maximum Grain Diameter for Intermittent Suspended Load (mm)
11 (debris jam deposits)	84	9.1	0.91	9.1	~ 0.1	~ 1
36 (streambed deposits)	374	16.5	1.65	16.5	~ 0.1	~ 1.5

Table 1. *Summary of calculated grain size thresholds for wash load and intermittent suspended load. Threshold bed shear stress is calculated using Shield's relationship and a critical Shields stress of 0.047 and represents the shear stress necessary to entrain the bed material represented by the median surface grain diameter. Shear velocity is proportional to the square root of bed shear stress. The settling velocity is calculated using standard shape and roughness parameters (Dietrich 1982). Grain size thresholds for wash load and suspended load are a function of the ratio of settling velocity to shear velocity; the ratio is taken as 0.1 for wash load and 1.0 for intermittent suspended load, consistent with Reid and Dunne (1996). Corresponding grain diameters can be read from a curve or calculated given the shear velocity and the appropriate ratio.*

Particle Size and Stream Type	Range (km/yr)	Mean (km/yr)
Suspended sediment in mountain streams	2-20	10
Sand as the predominant bedload	0.5-5	2
Pebbles and cobbles in mountain streams	0.02-0.5	0.1

Table 2. *Typical annual velocity of sediment in streams after NCASI (1999), p. 299. The suspended sediment case is a reasonable representation of wash load the slowest washload and the fastest intermittent suspended load. The sand case is representative of slower intermittent suspended load. Pebbles and cobbles represent bedload.*

Based on the data in Tables 1 and 2, it is apparent that silt and clay inputs to Caspar Creek will be routed through the mainstem of North Fork Caspar Creek as wash load. Very little of this sediment would be deposited. This is confirmed by sediment analyses by (Napolitano 1996), which showed that sediment finer than sand (i.e. silt and clay) was never more than 0.25% by weight of the bed material. In other words, silt and clay is selectively removed from the mainstem of North Fork Caspar Creek by normal fluvial processes.

Given the general textural description of soils in the Caspar Creek watershed (clay loam, (Henry 1998)), at minimum, 55% of the soil column would be silt and clay; it is more likely that about two-thirds of the soil column is silt and clay. Hence, at least half and probably two-thrids of the sediment inputs measured at the mouths of logged tributary sub-basins are routed through the mainstem of North Fork Caspar Creek with minimal deposition. The remaining portion of suspended sediment inputs, primarily sand, may travel more slowly. Nevertheless, even sand is easily capable of being transported through the 3 km mainstem reach of North Fork Caspar Creek during the 6-year period of experimental observations (Table 2). Moreover, there were 2 peak flows with recurrence intervals of 5 years or greater in the post-treatment period (January 20, 1993 and March 14, 1995), with recurrence intervals of 8 and 5 years respectively (Cafferata and Spittler 1998). Finally, Lisle and Napolitano (1998) assessed the effects of logging on the mainstem of North Fork Caspar Creek and reported no remarkable evidence of channel aggradation by fine sediment. Therefore, the explanation that the increased suspended sediment load from tributaries was not observed in the mainstem stations because it was deposited is very unlikely. In fact, most of the suspended sediment delivered by tributaries is easily capable of being transported through mainstem North Fork Caspar Creek in the course of the 6-year monitoring period.

Alternate Interpretation of North Fork Caspar Creek Data

There is another plausible explanation as to why the increased suspended sediment is not detected in the mainstem. Presentation of data in terms of percentage change after logging masks the actual magnitude of the increases. Considering percentage changes in tributary sediment yield alone greatly inflates the expectation of corresponding downstream increases in sediment yield because a large percentage increase in a small quantity of sediment amounts to a small quantity of sediment. This conclusion is substantiated in the discussion below.

Table 3 summarizes the North Fork Caspar Creek sediment yield data (Lewis 1998). The data require some spatial interpretation; a map of the North Fork Caspar Creek watershed is shown in Figure 1 below.

Station	Years Post Harvest	Area (ha)	Percent Harvest	Percent Change in SS	Observed SS Yield (kg/ha/yr)	Predicted SS Yield (kg/ha/yr)	Change SS Yield (kg/ha/yr)	Observed Total SS Yield (t/yr)	Predicted Total SS Yield (t/yr)	Change Total SS Yield (t/yr)	Change SS Yield as % of Mainstem SS Yield
Tributary stations (drainage area < 80 ha)											
KJE	5	15	97	-40	821	1371	-550	12.3	20.6	-8.3	-13
JOH	5	55	30	-23	667	865	-198	36.7	47.6	-10.9	-17
GIB	4	20	99	**200**	358	119	239	7.2	2.4	4.8	**4**
DOL	5	77	36	**269**	1130	306	824	87.0	23.6	63.4	**33**
CAR	5	26	96	**123**	240	108	132	6.2	2.8	3.4	**2**
BAN	4	10	95	**203**	85	28	57	0.9	0.3	0.6	**0.3**
Mainstem stations (drainage area > 150 ha)											
LAN	5	156	32	5	420	400	20	65.5	62.4	3.1	2
FLY	5	217	45	-3	536	555	-19	116.3	120.4	-4.1	-2
ARF	4	384	46	-15	505	591	-86	193.9	226.9	-33.0	-17
NFC	6	473	50	89	465	246	219	219.9	116.4	103.6	n.a.

Table 3. *Data from Lewis (1998, Table 1, p. 62); the last 4 columns reflect conversion of suspended sediment (SS) yield to units of t/yr. This units conversion allows comparison of the absolute quantities of sediment yield from tributaries relative to mainstem stations. Bold face emphasizes the comparison of percentage increases in logged tributaries and percentage increases relative to the nearest downstream mainstem station. KJE and JOH are compared to LAN, GIB is compared to FLY, and DOL, CAR and BAN are compared to ARF. Mainstem stations are compared to ARF. Station EAG is not presented; its effect is represented by the downstream station (DOL) in the same tributary.*

Table 3 above shows that for mainstem stations with greater than 150 ha drainage area (LAN, FLY and ARF), suspended sediment load *decreased* 15% on average. For station NFC at the mouth of the North Fork Caspar Creek watershed, the increase of 89% is attributed to a single landslide in 1995 immediately above the NFC station in the last year of the study (see Lewis 1998, pp. 55 & 60). Hence, the data show that there is *no increase* in suspended sediment in Class I (mainstem) channels, despite large percentage increases in tributary streams. I have previously discussed the physical aspects of sediment transport that strongly suggest that this suspended sediment, particularly the wash load, would be transported to the measurement stations and would therefore be detectable.

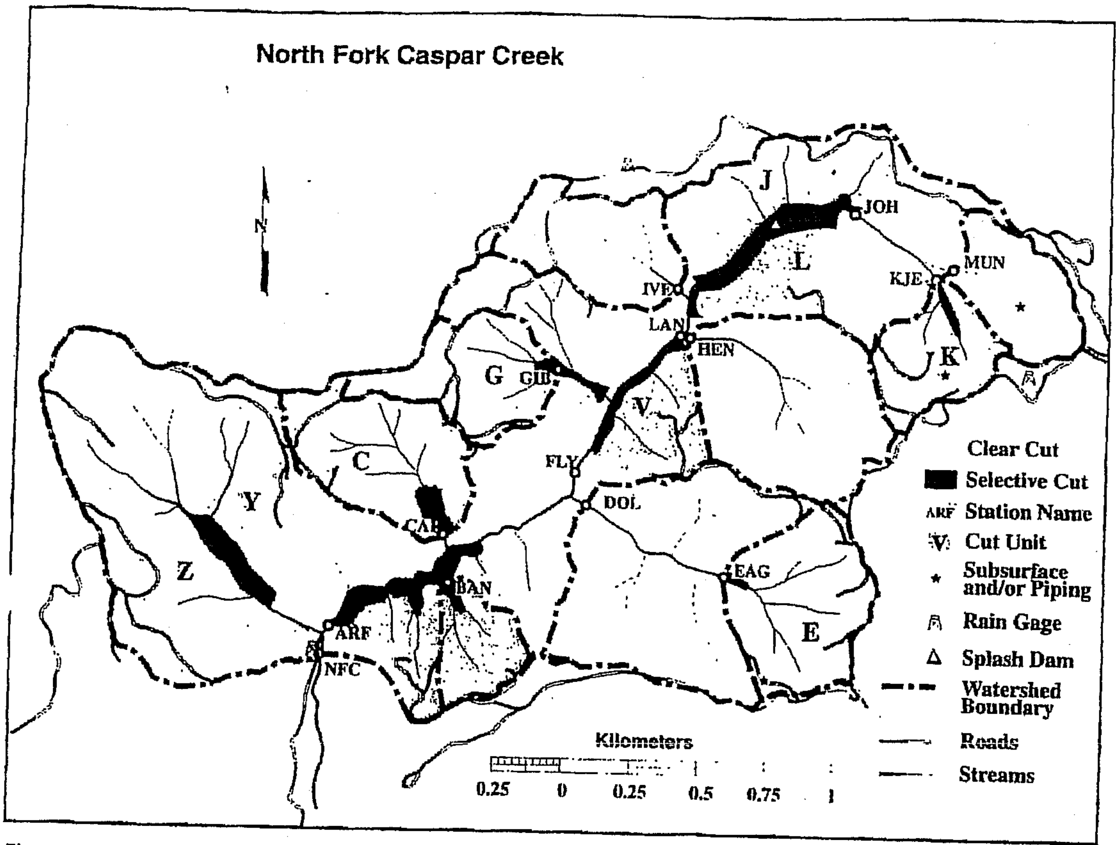


Figure 2 — North Fork Caspar Creek watershed.

iv

USDA Forest Service Gen. Tech. Rep. PSW-GTR-168. 1998.

Figure 1. *North Fork Caspar Creek watershed.*

Considerable effort was taken (Lewis 1998) to explain why station KJE showed a 40% decline in suspended sediment load (e.g. high pre-treatment sediment load due to previous logging, increased sediment deposition owing to dense regrowth of vegetation near channels and excessive blow down of trees in riparian buffer zones). However, there was little effort to explain why station DOL, which was only 1/3 clearcut, showed anomalously high increases in suspended sediment. As can be seen in Table 3 (last column), the increases in observed sediment yield in logged tributaries compared to observed sediment yield in the nearest downstream mainstem station is on average less than 2 percent. Only in the anomalous case of DOL (33% increase) do the data suggest that substantial increases in suspended sediment are realized. The mainstem monitoring station downstream of DOL is ARF, where suspended sediment yield decreased 17%, suggesting no detectable effect in the mainstem reach affected by DOL. This interpretation of the data also finds no consistent evidence of significant increases in mainstem suspended sediment yields following logging.

The magnitude of downstream effects is graphically demonstrated in Figure 2 below. These data highlight the magnitude of the increase in sediment yield at DOL and at station NFC. In the latter case, the 89% increase in suspended yield is attributed to a single debris flow that entered via a tributary below station ARF, and that increase is attributed to a single year of record (1995). DOL is the only other station with such a significant increase, and given the relatively low proportion of harvest, I believe that more effort should have been made to explain this result. It seems to me that such a large increase might *not* be attributable to hydrologically-induced channel erosion, but rather to a discrete, large scale sediment source (i.e. as for station ARF).

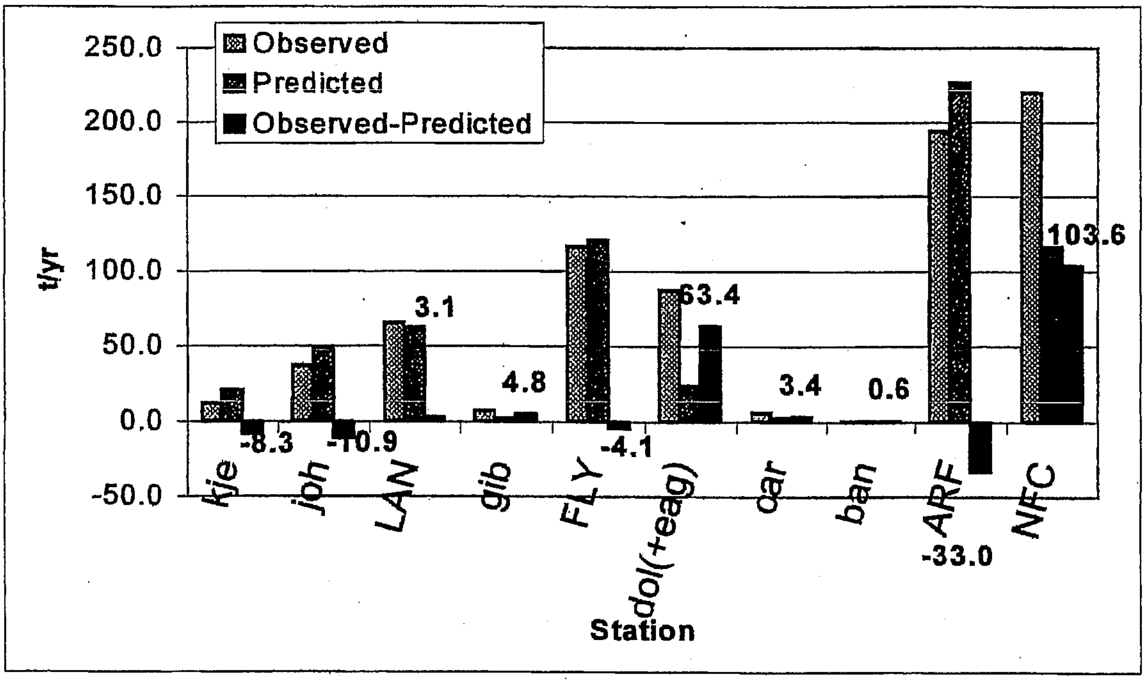


Figure 2. *Caspar Creek experimental results expressed as average annual sediment yield at each station. The values shown in the figure are the change in suspended sediment yield (observed – predicted) in units of metric tons per year following the experiment. Mainstem stations as per the classification in Table 3 are emphasized in CAPITAL letters*

Summary – Sediment Input Associated With Hydrologic Change

Based on the foregoing discussion, the experimental data from North Fork Caspar Creek demonstrating that hydrologic change attributable to timber harvest (e.g. peak flow increase of about 25% for 2-year recurrence interval storms for small drainages with nearly 100% clearcut area), do not reveal commensurate increases in suspended sediment yield in the mainstem of North Fork Caspar Creek where anadromous fish habitat is located. The large percentage increases in sediment yield from small tributaries that were clearcut may have resulted from increased channel erosion. These large percentage, small magnitude increases in sediment yield were not detected in the fish-bearing mainstem reaches either because the sediment entered into storage along the channel network, and/or the quantity of excess sediment generated in the tributaries was small compared to the sediment yield in the mainstem, preventing its detection at monitoring stations. In either case, there is no evidence that surface erosion processes associated with clearcutting of about 50% of the watershed caused detectable increases in sediment yield in mainstem monitoring stations.

References Cited

Cafferata, P. and T. Spittler (1998). Logging impacts of the 1970's vs. the 1990's in the Caspar Creek Watershed. Proceedings of the conference on coastal watersheds: The Caspar Creek Story, Ukiah, California, USDA Forest Service.

Dietrich, W. E. (1982). "Settling velocity of natural particles." Water Resources Research 18(6): 1615-1626.

Henry, N. (1998). Overview of the Caspar Creek Watershed Study. Proceedings of the conference on coastal watersheds: The Caspar Creek Story, Ukiah, California, USDA Forest Service.

Lewis, J. (1998). Evaluating the impacts of logging activities on erosion and suspended sediment transport in the Caspar Creek watershed. Proceedings of the conference on coastal watersheds: The Caspar Creek Story, Ukiah, California, USDA Forest Service.

Lewis, J. (1998). Evaluating the impacts of logging activities on erosion and suspended sediment transport in the Caspar Creek watersheds, Pacific Southwest Research Station: 55-70.

Lisle, T. and M. Napolitano (1998). Effects of recent logging on the main channel of North Fork Caspar Creek. Proceedings of the conference on coastal watersheds: The Caspar Creek Story, Ukiah, California, USDA Forest Service.

Napolitano, M. B. (1996). Sediment transport and storage in North Fork Caspar Creek, Mendocino County, California: Water years 1980-1988. Geology. Arcata, Humboldt State University: 148.

NCASI (1999). Scale considerations and the detectability of sedimentary cumulative watershed effects. Research Triangle Park, NC, National Council of the Paper Industry for Air and Stream Improvement: 327.

Reid, L. M. and T. Dunne (1996). "Rapid evaluation of sediment budgets." Catena Verlag GMBH: 24.

Ziemer, R. and J. L. Keppeler (1998). Streamflow and sediment response to logging, California, USA. Environmental Forest Science, Kyoto, Japan.