Hydrologic Analysis, Artesa Fairfax THP and Conversion

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Overview

Conversion of timberland to vineyard and vineyard development on existing pasture lands may affect hydrologic processes by two primary mechanisms. First, the removal of forest vegetation reduces interception of rainfall by forest canopy and would be expected to reduce annual consumption of water from the soil by vegetation (reduced evapotranspiration or ET).

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 base flow in streams
- total water yield (annual runoff) and
- peak and total storm runoff.

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

Second, development of vineyards is likely to alter soil conditions. Potential changes in soil conditions that could affect hydrologic function of soils include changes in cover on the soil surface, changes in root abundance and root channels, and changes in soil bulk density and permeability, all or some of which could affect the processes of infiltration and surface runoff.

Comprehensive monitoring or experimental data for vineyard conversion projects are not available to directly assess potential hydrologic effects. Applicable scientific literature from the region provides a basis for qualitative and semi-quantitative assessment of likely hydrologic effects of the project. The most useful of these studies is the watershed experiment conducted at Caspar Creek in coastal Mendocino County by the USDA Forest Service, PSW Research Station, Redwood Sciences Lab (RSL) in cooperation with the California Department of Forestry and Fire Protection, Jackson Demonstration State Forest.

The Caspar Creek experimental study of forest hydrology examined the impacts of forest harvest on runoff, comparing pre-treatment conditions (second growth redwood forest) to post-treatment conditions (clearcut harvest areas comprising various percentages of watershed area from about 50% to 95%). The breadth and depth of that study provides by far the best information available regarding impacts of vegetation management (timber harvest) on hydrologic processes in the region, and therefore warrants a thorough review to provide a starting point for supplemental assessment. Following the review and interpretation of the Caspar Creek study, additional relevant research is reviewed to identify likely effects of the project on critical hydrologic processes. Finally, a water balance is developed to assess likely project effects on hydrology in the project area.

Review of the Caspar Creek Study

Comparison of Project Site Conditions and Caspar Creek Conditions

The proximity and general similarity of the Caspar Creek watershed to the project site near Annapolis indicates that the experimental results at Caspar Creek would be generally applicable at the project site. The Caspar Creek watershed, located in Mendocino County a few miles from the coast about halfway between the communities of Ft. Bragg and Mendocino, has similar climate, soil and geologic conditions compared to the site near Annapolis. Annual rainfall at Caspar Creek is about 45 to 50 inches, compared to about 60 to 70 inches in Annapolis. There are some differences in geology, soils, topography and vegetation. Caspar Creek is underlain entirely by sandstone of the Coastal Belt Franciscan Formation; the project site is also underlain by this formation, but also includes a younger marine sandstone (the Ohlsen Ranch Formation) overlying the Franciscan over most of the project site.

Caspar Creek soils are "well drained clay loams" and are derived from parent materials of the Coastal Belt Franciscan, including sandstone and shale; they are 3 to 6 ft deep (Henry 1998, p2). They have "high hydraulic conductivity and subsurface stormflow is rapid, producing saturated areas only limited extent and duration". The Goldridge soils are "moderately well-drained fine sandy loams that have a sandy clay loam subsoil", and have available water capacity of 8 to 11 inches (Miller 1972). Goldridge soil dominates the project area, and is derived from parent material of the Ohlsen Ranch Formation. The remainder of the project site is mantled by Hugo soils, a common soil type found associated with Coastal Belt Franciscan parent material under redwood forest vegetation. Hugo soils are "well-drained very gravelly loams that have a gravelly sandy clay loam subsoil", generally greater than 3 ft thick, with a 4 to 8 inches available water capacity (Miller 1972).

The Patchett Creek watershed in which potential hydrologic impacts are concentrated, has a drainage area of about 1,130 acres. The sub-basin drainage areas of interest in the project area range in area from about 5 to 75 acres. 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 qualitative extrapolation of experimental results to the project site.

Caspar Creek Changes in Rainfall Interception and Runoff

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 1998)b. These early winter increases in storm runoff have been attributed to reduced evapotranspiration from forest vegetation during the growing season, resulting in

increased soil moisture. 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.

Interception and evaporation of rainfall by forest canopy is a significant hydrologic process in forest ecosystems. Previous studies found that interception losses in temperate forests average about 20% (Dunne and Leopold, 1978). Reid and Lewis (in press), found that about 25% of annual rainfall was intercepted by forest canopy in experimental plots located in 100 year-old stand of redwood and Douglas-fir at Caspar Creek. About a tenth of the intercepted rainfall reached the forest floor via stemflow, hence about 22% of the annual rainfall is evaporated. In larger storms (about 3 inches rainfall), interception losses were about 21%, somewhat less than the annual average. Interception losses are equivalent to about 8 to 9 inches of additional precipitation that would reach the soil surface annually.

At Caspar Creek, annual runoff increased an average of 15% (ranging from 6 to 29%) for monitoring periods of about 10 years following harvest (Keppeler 1998). These levels of flow increase were observed in the North Fork and South Fork of Caspar Creek in successive watershed experiments on fish-bearing perennial streams with drainage areas > 1000 ac. 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 annual increase was 75% and the largest was 287% over the period 1990-1997 (Table 1). 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).

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 and 16% for partially harvested watersheds. Percentage increases were higher when antecedent wetness was lower. Annual storm runoff volume for all storms increased 60% in clearcut watersheds and 23% in partially harvested watersheds. The depth of excess storm runoff was 0.37 ft in clearcut areas and 0.14 ft in partial harvest areas. The depth of excess

annual runoff for the entire North Fork watershed (~50% clearcut) was 0.20 ft, compared with mean annual runoff of about 1.3 to 1.7 ft.

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).

Table 1. North Fork Caspar Creek annual water yield 1963-1997 and minimum mean daily flow, ranked from lowest to highest annual yield. Bold face numerals represent 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	

(Lewis 1998) found that suspended sediment yield measured from the small harvested watersheds increased on the order of 200% (Table 2). Although the experiment did not determine the source of this increase in suspended sediment, it was suggested that a substantial portion was caused by accelerated channel or bank erosion associated with observed increases in stream flow. The Caspar Creek study (Lewis 1998) did not demonstrate that increases in suspended sediment yield in intermittent and ephemeral headwater streams (Class II and Class III channels) resulted in increased suspended sediment loads in Class I channels downstream. Three monitoring stations on the mainstem of the North Fork Caspar Creek (LAN, FLY and ARF) located downstream of tributary watersheds where large percentage increases in sediment yield were measured showed an increase in suspended sediment yield of 2% at LAN, and decreases of 2% (FLY) and 17% (ARF), an average decrease of about 6%.

Table 2. Data from Lewis (1998, Table 1, p. 62); the last 4 columns result from converting suspended sediment (SS) yield per unit watershed area to units of t/yr. This allows comparison of the absolute quantities of sediment yield from tributaries relative to mainstem stations. Bold face entries emphasize 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 station (DOL), located downstream of EAG in the same tributary.

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)	Pre-dicted Total SS Yield (t/yr)	Change Total SS Yield (t/yr)	Change SS Yield as % of Main-stem 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.

Hence, there was little or no change in suspended sediment yield in fish-bearing Class I channels downstream, despite large (three-fold) increases in tributary watersheds. This can be explained by the fact that erosion rates in the headwater channels are 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 as a whole. The overall increase in suspended sediment yield for the North Fork Caspar Creek (89%) is 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 (this topic is discussed in greater detail in Appendix A). Hence, the risk to downstream habitat and water quality implied by potential increases in channel erosion or surface erosion associated with anticipated peak flow increases at the project site 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 of Hydrologic Effects of Timber Harvest

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. Increased summer flows are significant, but storm runoff is a larger proportion of the increased annual yield. Peak flow increases for storms with 2 yr recurrence intervals are about 25 to 30% for watershed areas that were >95% clearcut. Reduced evapotranspiration and canopy interception is the likely cause of increases in both total annual runoff and minimum summer stream flow. In addition, suspended sediment yield for small watersheds (about 25 to 70 ac) increased substantially, but this effect diminished downstream such that watersheds > 370 ac showed a mean decrease in suspended sediment yield.

Anticipated Hydrologic Effects of Proposed Vineyard Development

Owing to the fundamental similarity of hydrologic processes in clearcuts and vineyard conversion areas relative to a forest stands, the increasing trends in runoff parameters and the approximate magnitude of change observed at Caspar Creek should be expected for conversion of forest to vineyard at the project site near Annapolis. Observations from Caspar Creek suggest that the project will result in higher soil moisture levels at the project site owing to reduced evapotranspiration and higher annual streamflow and higher summer baseflow in watersheds affected by conversion of forest vegetation to vineyards. Qualitatively, it is very likely that the conversion process is likely to create additional runoff and soil moisture. On a quantitative basis, and in the absence of data specific to second-growth forest to vineyard conversion, the likely maximum increase in runoff should be expected to be comparable to that observed at Caspar Creek.

The Caspar Creek data indicate that increases in summer baseflow and annual runoff is likely to persist in 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 at the project site.

Water yield data suggest that groundwater quantity would tend to increase, and be unlikely to decrease, as a result of the project. Increased summer baseflow observed at Caspar Creek can be attributed to increased infiltration of precipitation to the soil and increased percolation of soil water to groundwater. In watersheds with topographic relief and fractured Franciscan bedrock such as Caspar Creek and much of Patchett Creek, 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 may include minimum flow increases related to increased percolation rates, however, that study was not designed to examine groundwater conditions.

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 vineyard. Greater quantities of water reaching the soil may be expected to increase groundwater percolation rates. Peak flow rates in stream channels are also expected to increase, and this creates potential for increased channel and bank erosion Inferred project effects based on the Caspar Creek research are evaluated by means of a water balance analysis presented below. Limited further analysis of potential project effects on groundwater quantity is also warranted; the Caspar Creek experimental data do not directly measure percolation rates or effects on groundwater, despite strong implications of increased quantity. Potential effects on groundwater are assessed in the following section.

It should be noted that vineyard 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). The conclusions drawn above do not explicitly account for such potential changes in soil hydrologic characteristics. These potential changes and their potential significance are discussed below.

Groundwater Aquifer Characteristics

Published Descriptions

As shown in Figure 1, there are two distinct geologic formations underlying the project site and the surrounding area, each with distinctive hydrogeologic characteristics (DWR 1975). The gently-sloping ridgetops, mantled with Goldridge soils, are underlain by the Ohlson Ranch Formation, which is similar to the more widely-distributed Merced Formation in western Sonoma County. This formation consists of flat-lying beds of marine sandstone, siltstone and conglomerate up to 160 ft thick. These bed lie unconformably atop steeply dipping beds of the Franciscan Formation, which includes a wide variety of fractured rocks.

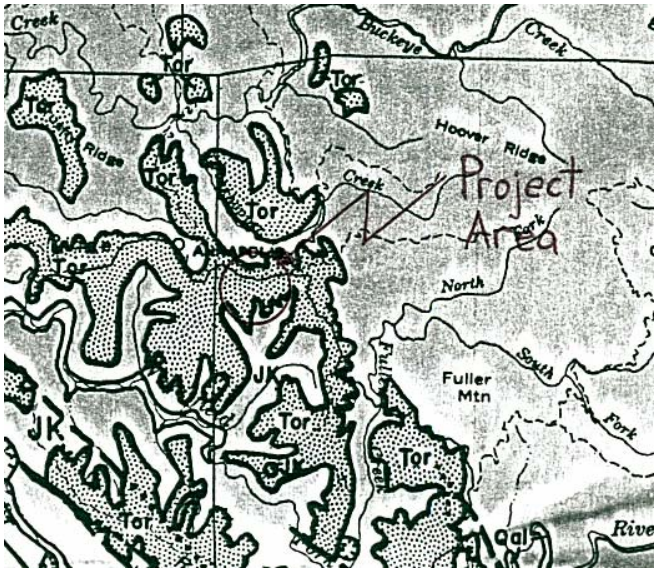


Figure 1. Surficial geology of project area (DWR 1975). "Tor" is the Ohlson Ranch Formation and "JK" is the Franciscan Formation. North is the top of the image. Approximate scale is 1"=2 miles. This map is effectively identical in its rendering of bedrock geology to Figure 1 in Erosion Analysis.

Yields from wells in the Franciscan are typically small, and are generally < 3 gpm (DWR 1975). In contrast, the Ohlson Ranch Formation has yields of 2 to 36 gpm in five wells in the Annapolis area. Yields in the Franciscan are low because water is transmitted and stored primarily in fractures in the rock, whereas in the Ohlson Ranch Formation (assumed similar to the Merced Formation), the well-sorted sand produces numerous pores in the structure of the rock and a high specific yield of 10 to 20%. Specific information regarding depths and yields of wells in the vicinity of the project site are not available, however, based on the characteristics described above, the Ohlson Ranch Formation is the more productive aquifer.

Reports by well owners in the Ohlson Ranch Formation indicated that "water levels decline markedly during the summer months and many wells go dry by early fall (DWR 1975, p. 157)". It was estimated that the Ohlson Ranch Formation has a maximum storage capacity of about 3.1 ac-ft/ac (DWR 1975, p. 157), and that this total capacity is likely to be significantly less when water levels decline in late summer.

Locations of Wells and Surface Water Diversions

North Coast Resources Management (NCRM) received from the County of Sonoma Permit and Resource Management Department a listing of wells and surface water diversions within a 1,000 ft radius of the project site. Additional information on wells and water supplies in the vicinity was solicited from nearby residents by NCRM. These wells and diversions were plotted on a topographic map to help evaluate potential impacts of the project. The wells, diversions, and water supply systems are listed in Table 3. The approximate locations of the parcels and systems are shown in Figure 2.

Most of the wells are located west or northwest of the project area, with one County of Sonoma well (located at the Transfer Station) located to the southeast.

Table 3. Known domestic water supplies and small water systems.

Assessor's Parcel #	Type	Owner	Address
122-100-008	Well	Burbach	35158 Annapolis Rd.
122-110-012	Well	Nichols	35411 Annapolis Rd.
122-110-016	Well	Veregge	35369 Annapolis Rd.
123-010-011	Creek Diversion	Campbell	35180 Annapolis Rd.
123-030-004	Well	County of Sonoma	33551 Annapolis Rd.
123-040-011	Well	Beck	35401 Annapolis Rd.
122-140-006	Small Water System	Horicon School	35555 Annapolis Rd.
123-040-10	2 Wells	Spacek	35405 Annapolis Rd
123-040-017	2 Wells	Taeuffer/Anderson	34175 Annapolis Rd
123-040-037	Well	Breidenthal	33700 Annapolis Rd
123-040-033	3 Wells	Starcross Community	34500 Annapolis Rd
123-040-023	3 Wells and creek diversion[1]	Wellman	PO Box 6 Annapolis
123-040-180	Spring	Hall	34910 Annapolis Rd
123-040-013	Well	Duncan	n.a.
122-110-006	Well and creek diversion	Dew	35337 Annapolis Rd

[1] "Red Fern Creek" may have several wells in its drainage

Site Hydrogeology

Field observations of outcrops of the Franciscan Formation at the site (Figure 2), in combination with hydrogeologic maps and descriptions (DWR 1975), reveal the general hydrogeologic character of the site. The geologic cross-section in Figure 3 defines the approximate boundaries of the aquifer and the likely groundwater gradient underlying the project site. The Ohlson Ranch Formation is probably < 50 ft thick under the project area. The pattern and elevation of outcrops of Franciscan Formation bedrock (Figure 2 and Figure 6) indicate that the geologic contact between the Ohlson Ranch Formation and the underlying Franciscan Formation dips gently but distinctly to the east. Owing to the high specific capacity of the Ohlson Ranch Formation and the low permeability of the underlying Franciscan Formation, a perched water table is formed in the Ohlson Ranch Formation. The groundwater gradient most likely parallels the slope of the geologic contact, which is in turn generally parallel to the surface topography. Most of the project area is underlain by this sloping shallow aquifer. The dominant hydraulic gradient of groundwater under most of the project area is expected to move groundwater from west-northwest to east-southeast, toward Patchett Creek as shown in Figure 3. Some groundwater moves from south to north perpendicular to Annapolis Road, following the topography in the northern portion of the project area.

The geometry of the aquifer and the location of the contact between the Franciscan and the Ohlson Ranch Formation to the west is uncertain (Figure 3). It is possible that the Ohlson Ranch Formation thickens to the west, depending on the configuration of the underlying Franciscan Formation. The topography of the small

drainage in the northwest corner of the project area that flows to the west suggests a hydraulic gradient that would move groundwater in this area to the west.

Figure 2. Site map showing features pertaining to hydrogeology.

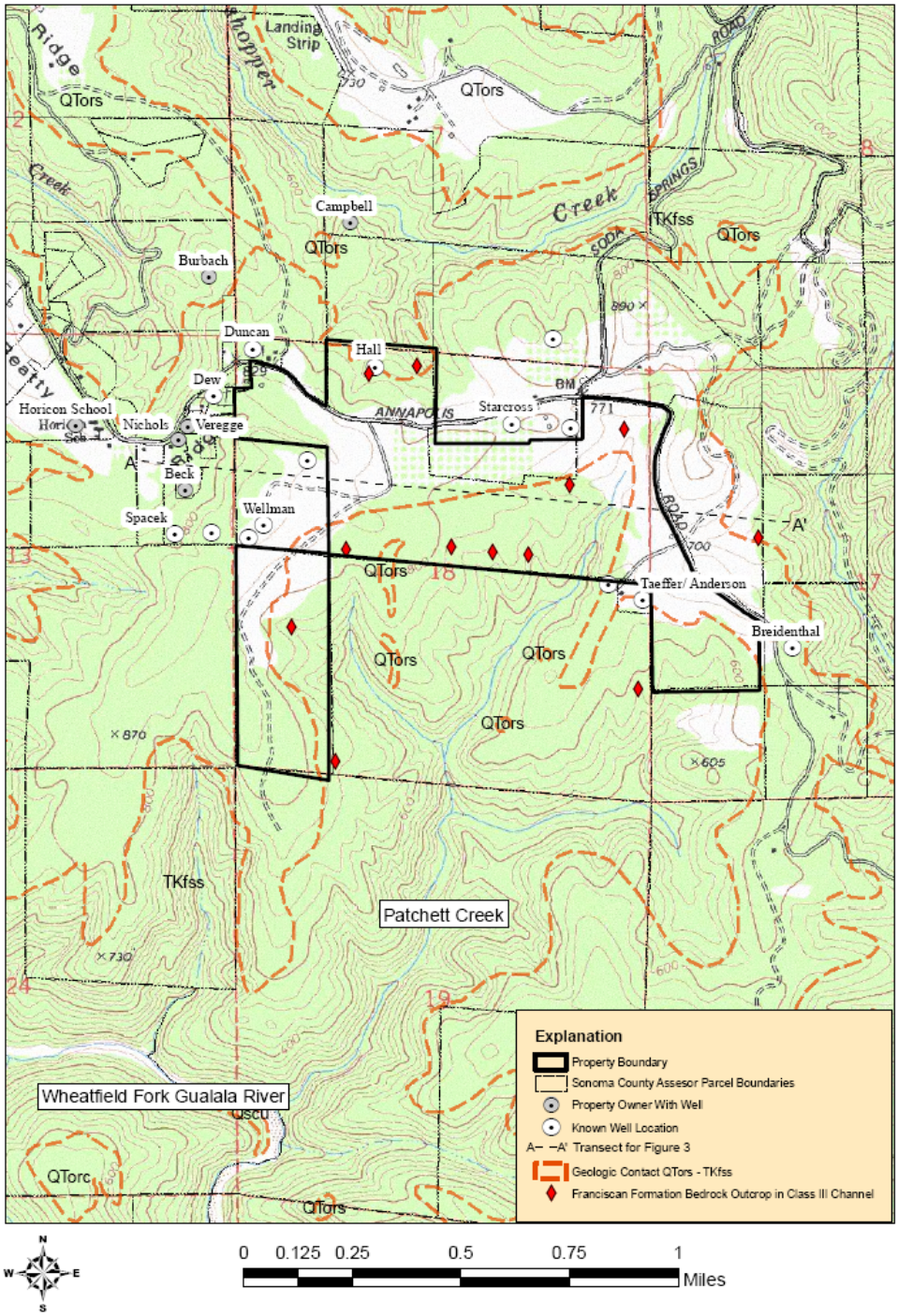
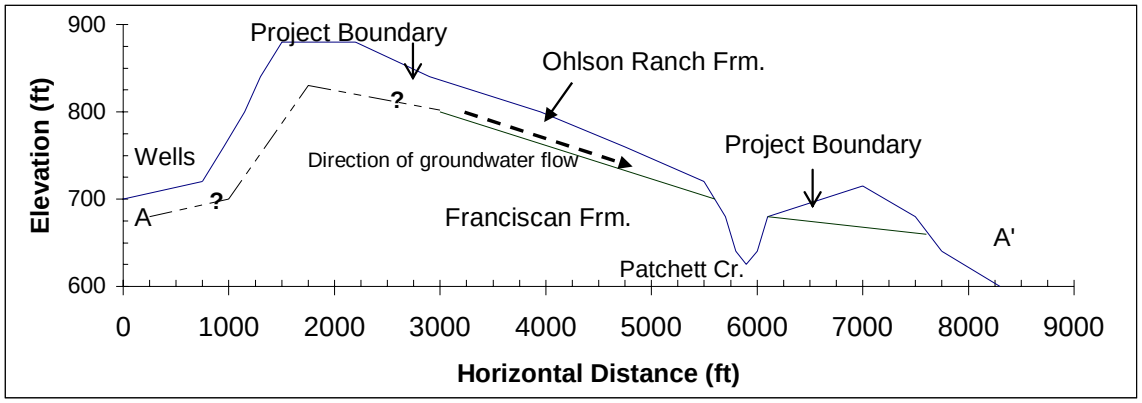


Figure 3. Geologic cross-section A-A' (see Figure 2 for location). Contact between the Franciscan Formation basement rocks and the overlying Ohlson Ranch Formation is dashed with "?" where uncertain, solid where inferred from mapped outcrops. See text for discussion.



Anticipated Effects of Project on Existing Wells

As shown in Figures 2 and 3, most existing wells are located to the west and north of the project area, and most groundwater in the project area flows away from these areas. Project areas on the north side of the project area that drain to Grasshopper Creek and Little Creek are located upgradient from some wells shown in Figure 2 and listed in Table 3. Flow from portions of the project area to the west is also likely to be upgradient from wells west of the project area. The wells of Taueffer-Anderson, located near the southeastern corner of the project area, are also likely to be downgradient from the project area. The County of Sonoma well is located southeast of the project site, but a canyon interrupts the continuity of the Ohlson Ranch formation, and groundwater flow beneath the canyon is unlikely.

The Ohlson Ranch Formation is a relatively thin, perched aquifer that is relatively permeable. The elevation of the water table in this aquifer declines seasonally as water drains to stream channels and is extracted from well. The aquifer is recharged seasonally during the winter. As described in following water balance analysis, the project is not expected to diminish groundwater supplies, and may increase water delivery to the soil through conversion of forest vegetation, creating potential for increased groundwater recharge. Irrigation water will be obtained from surface runoff.

Wells to the west of the project area likely to be down gradient of potential aquifer recharge areas within the project area have the greatest potential to be affected by the project, however, this impact is unlikely to be significant. First, the majority of the likely recharge area for these wells is not within the project area, substantially reducing potential impacts. Second, the dominant recharge zone in the project area that could affect these wells consists of a relatively flat valley bottom extending about 2,000 ft into the project area. Vineyard development is set back from the stream and wetlands in this valley by an average distance of about 100 ft, thereby preserving the hydrologic function of this area. Potential increases in runoff from conversion areas reaching this valley

bottom would have a high potential of recharging the water table in this area. Finally, the water balance analysis indicates increased soil water availability in conversion areas, which has the potential to increase groundwater recharge.

The surface drainage areas of the project that lie within the likely recharge area for the Taueffer-Anderson wells in the southeast portion of the project area include a wetland mitigation area that would tend to increase groundwater recharge. In addition, increased soil water in conversion areas has the potential to increase groundwater recharge.

In summary, it is unlikely that the project would significantly reduce groundwater availability. Increased soil water availability expected to result from forest conversion could potentially increase groundwater recharge. Although some soil compaction could occur, this will be counteracted by site preparation (limited ripping of soils), and overall higher water delivery to the soil owing to reduced canopy interception is likely to further compensate for potential soil compaction. Existing compacted soils in historic pasture areas may actually have higher infiltration rates following vineyard development. Cover crops and elongated flow paths in v-swales will reduce sheet flow velocity and encourage infiltration. Groundwater flow gradients in most of the project area are toward Patchett Creek (east-southeast), away from know domestic wells. Considering and weighing these factors, the project is not expected to reduce groundwater percolation or affect domestic wells and water supplies.

Water Balance Analysis

The fundamental conceptual basis for a water balance is described by Dunne and Leopold (1978) as follows:

> *[t]he water balance of a small drainage basin underlain by impervious rock at depth can be represented by [the] figure [4] below and expressed in the following equation:*
>
> $$P = I + AET + OF + \Delta SM + \Delta GWS + GWR$$
>
> *where the symbols, expressed as equivalent depths of water for some time interval, represent precipitation, interception, evapotranspiration [AET], overland flow, change of soil moisture storage, change of groundwater storage, and groundwater runoff.*

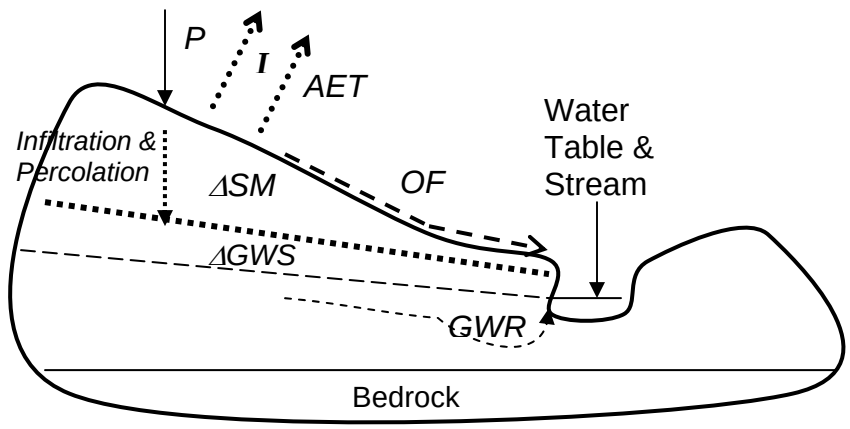


Figure 4. Simplified diagram of water balance components in an upland watershed.

The process of infiltration of water to the soil surface leads to an increase in soil moisture storage; evapotranspiration represents a decrease in soil moisture as plants utilize water from the soil for respiration. The process of percolation leads to an increase in groundwater storage; groundwater runoff occurs as streamflow and removes groundwater from storage. Where streamflow records are available, annual water yield represents the sum of *OF* and *GWR.*

In this section, elements of the water balance for both North Fork Caspar Creek and for the proposed project are quantified in an effort to analytically verify the qualitative expectations of increased runoff and groundwater. Growing season evapotranspiration rates for forests, vineyards and grassland vegetation from a variety of sources are presented to assess likely changes in the local water balance that could occur as a result of the project.

North Fork Caspar Creek Water Balance

The Thornthwaite technique (Dunne and Leopold, 1978, p. 236-250) for estimating evapotranspiration was applied to data from Caspar Creek by Redwood Sciences Lab for the period 1990-1995 (www.fs.fed.us/psw/topics/water/caspar/Thornthwaite.shtml). Figure 5 below graphically portrays mean monthly precipitation (P) and potential evapotranspiration (PET) from the RSL analysis. Evapotranspiration implicitly includes interception losses. Potential evaporation is generally distinguished from actual evapotranspiration, however, in the moist coastal climate at Caspar Creek, sufficient soil moisture is likely to be available for plant use and actual and potential evapotranspiration probably have similar values. When P-PET (the difference between precipitation and potential evapotranspiration) is negative (as shown in Figure 5 by bars extending downward on the graph from the zero value of the y-axis), evapotranspiration exceeds precipitation, and plants utilize stored soil moisture. This condition exists during the period June through September.

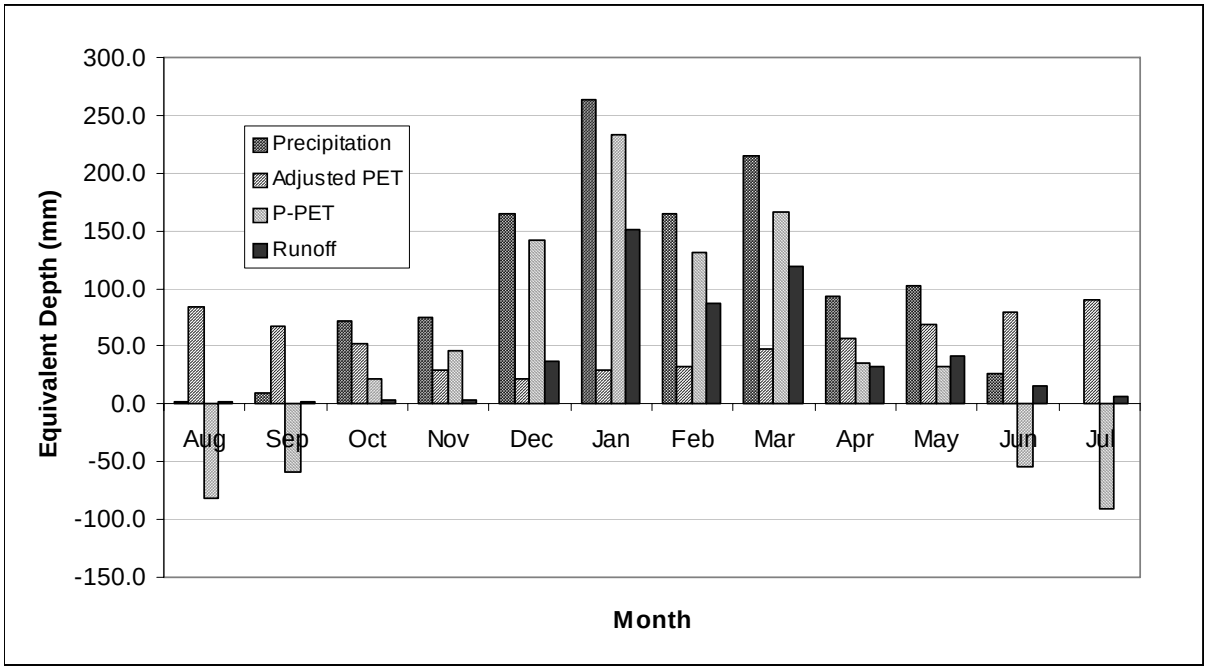


Figure 5. Water balance for North Fork Caspar Creek 1990-95 based on data published by RSL.

The difference between precipitation and evapotranspiration (P-PET) represents water available for runoff and infiltration. The RSL water balance for North Fork Caspar Creek showed that annual P-PET was 528 mm and that measured streamflow was 503 mm. The mean annual water balance for North Fork Caspar Creek above indicates 56% of annual precipitation leaves the watershed by evapotranspiration, and about 42% leaves the watershed as runoff. The annual calculation suggests that the water balance is relatively accurate based on the agreement between P-PET and runoff, however, it does not provide perspective on infiltration and groundwater components of the water budget.

We used daily runoff data from North Fork Caspar Creek to compute mean monthly runoff as shown in Figure 5. The difference between P-PET and runoff provides an estimate of infiltration. During the winter months November through March, P-PET exceeds runoff by about 50 to 100 mm per month, and indicates the likely magnitude of infiltration and percolation. This demonstrates that during the rainy season in the California Coast Range, when the effects of canopy interception losses would be realized as increased water delivery to the soil surface, infiltration and groundwater recharge occurs. This evidence tends to confirm that project effects are likely to include increased infiltration of rainfall to the soil with likely increases in groundwater recharge.

Growing Season Evapotranspiration

During the growing season, vineyard evapotranspiration is expected to be less than evapotranspiration that would occur from the existing vegetation. Limited data are available for actual evapotranspiration from forests in a Mediterranean climate. (Unsworth, Phillips et al. 2004) measured evapotranspiration from different components of an old-growth Douglas-fir—Western Hemlock stand at Wind River, Washington in the interior Cascade Range near the Columbia River. For the months of June and July 1999, they measured mean daily evapotranspiration of about 2.3 mm with a standard deviation of 0.6 to 0.7 mm. They also found evidence indicating that the forest vegetation is capable of drawing soil moisture into the root zone from greater depth in the soil. For comparison, the North Fork Caspar Creek water balance estimated evapotranspiration for the months of June through September to be 2.7 mm (June), 3.0 mm (July), 2.8 mm (August) and 2.2 mm (September), an average of about 2.7 mm/day. This value is similar to that measured in the Cascades. Finally, an estimate based on professional opinion was developed in response to our inquiry regarding redwood forest evapotranspiration rates by Oregon State University Professor Emeritus Dick Waring (personal communication, February 2005). He estimated average transpiration during the summer of about 3 mm/day, or about 90 mm/month for a 50-80 year old forest with a leaf area index of between 5 and 10. Maximum mean daily potential evapotranspiration was about 3 mm/day at North Fork Caspar Creek in the month of July.

Actual evapotranspiration for various locations in Sonoma County has been estimated by (Elford 1964), based on an assumed 4 inches of plant available soil moisture. Goldridge soils on gentle slopes have up to 3.9 inches of available water in the upper 28 inches of soil profile given available water capacity of 0.14 inches/inch. Goldridge soils on steeper slopes would have less available water, and would be predicted to have proportionately lower actual evapotranspiration. The project site lies between the Point Arena and Cloverdale climate stations, and Elford (1964) estimated actual growing season evapotranspiration to be 16.9 and 12.3 inches (429 and 312 mm), respectively at these locations. For reference, North Fork Caspar Creek evapotranspiration was estimated to be about 450 mm for the period May through September. Grassland evapotranspiration would be expected to be less than in forests, but no explicit estimate for grassland vegetation is offered.

Growing season evapotranspiration for grapevines and irrigation requirements for vineyards have been measured in California by (Williams 2001). He calculated that in a Paso Robles (Central Coast region) vineyard during a 126 day irrigation season in 2000 growing season that average water use was about 2.3 mm/day, with a maximum of 3.3 mm/day. Total water use was equivalent to 11.2 inches. Williams (2001) also found that the yield of grapes declined relatively little when irrigation rates were reduced below plant evapotranspiration rates. For example, when irrigation was reduced to half of calculated evapotranspiration, harvest yields from four vineyards and two cultivars ranged from 70 to 96% of yield (mean = 84%) compared to vines irrigated at 100% of the evapotranspiration rate. At irrigation rates of one-fourth calculated evapotranspiration, harvest yields ranged from 61 to 92% with a mean of 74% compared to fully-irrigated vines. These findings demonstrate that vines cultivated with modest applications of water produce viable crops; many viticulturists have found that vines that are stressed in their growing environment produce high quality wines.

The proposed vineyard project has been planned with irrigation applications of about 0.3 ft, equivalent to 3.5 inches or about 90 mm (Erickson Engineering, 2002). Given the likely soil moisture available and the findings regarding vineyard irrigation by Williams (2001), the proposed vineyards would likely use substantially less water than the existing vegetation. Consequently, based on likely water use by native vegetation and vineyards, the proposed project would tend to increase soil moisture and ground water percolation.

Summary of Water Balance Analysis

Comparisons between existing forest vegetation and anticipated vineyards with respect to hydrologic effects of vegetation indicates decreased evapotranspiration is likely under project conditions, both in the growing season and the rainy season. During the rainy season, reduced interception losses are expected to be about 10% to 20%, which represents a net gain to water delivered to the soil surface for infiltration and percolation.

Vineyard Development and Potential Changes in Soil Hydrologic Characteristics

Vineyard 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.

Soil Characteristics

There are two soils on the project site where vineyards are proposed (Miller 1972). These are the Goldridge fine sandy loam, 15-30% slope (map unit GdE) and the Hugo very gravelly loam, 30 to 50% slopes (map unit HkF). Table 4 provides a summary of relevant information about these soils. These characteristics indicate that the Goldridge soil has a shallow subsurface horizon that can impede infiltration and generate surface runoff under rainfall rates of about 0.2 to 0.6 in/hr once the relatively thin surface horizon is saturated. In contrast, Hugo soils are deeper and more porous, and would only be expected to generate surface runoff under rainfall rates > 0.6 in/hr or more, which rarely occur in this area.

Field observations in early 2002 are consistent with these data. The Goldridge soils were observed to have a shallow water table and showed clear evidence of significant surface runoff, including rill and gully formation, particularly on the lower portions of hillslopes. The Hugo soils did not appear to generate surface runoff except in Class III stream channels mapped on the project site.

Table 4. Selected soil characteristics at the project site. Based on soil descriptions and Estimated Engineering Properties in the Sonoma County Soil Survey (USDA 1972).

Soil Parameter	**Goldridge 15-30% slope**	**Hugo 30-50% slope**
Surface Horizon Texture	Fine sandy loam	Gravelly loam
Surface Horizon Depth (in)	16	48
Surface Horizon Infiltration Rate (in/hr)	0.63-2.0	0.63-2.0
Subsurface Horizon Infiltration Rate (in/hr)	0.2-0.63	n.a.
Typical % Gravel	0	35
Typical % Sand	50	23
Typical % Silt & Clay	50	42

Infiltration Processes and Rates

Changes in infiltration rates associated with vineyard development at the project site could be either positive or negative. Decreased infiltration rates are generally expected when converting forested areas to agricultural fields owing to reduced root mass and soil compaction from agricultural practices. Pasture areas would also be expected to have lower infiltration rates than forest soils, but probably greater than agricultural fields.

These potential decreases in infiltration rates for the project area might be counteracted by the deep tillage of soil prior to vineyard planting. Tillage would be expected to have the greatest effect on the Goldridge soils, which were observed in the field to have a high winter water table, and are to be tilled to a depth of about 2 ft. In addition, vineyard cover crops (annual grasses) will provide significant root mass and surface roughness to slow the flow of surface water, promoting infiltration. Consequently, infiltration and percolation rates for vineyard conditions are not expected to decrease significantly relative to pre-project conditions.

The foregoing assessment was echoed by A.T. O'Green, PhD, a soil scientist in the Cooperative Extension program at University of California, Davis, in an e-mail response in February 2005 to an inquiry regarding impacts of vineyard development on deep percolation of water in the Goldridge soil. The text of the e-mail is reproduced below.

> *Deep tillage of this soil is probably unnecessary. It is moderately well drained soil and any evidence of poor drainage appears to be a result of a seasonally high ground water table rather than a hydraulically restrictive soil horizon. Thus there will always be a direct but seasonal connection between the soil and groundwater no matter how the land is used*
>
> *If a clay layer is perching or slowing water infiltration the type of tillage has important implications on the persistence of a clay pan. Ripping a clay-rich*

> *soil is not an effective strategy to improve infiltration. Over the course of one or two seasons the clay layer will restore itself. Complete mixing with upper horizons to the base of the clay layer is needed to improve water penetration.*
>
> *The natural state of this soil is capable of handling a huge amount of infiltrating water and deep percolation. In my opinion, any form of soil disturbance would probably temporarily reduce infiltration rates by destroying the natural aggregates that have developed over time, particularly at or near the soil surface. Once the vineyard is established and cover crops planted I would expect that the natural aggregation would restore itself.*

Experiments on runoff and erosion processes on vineyard soils in Napa County provide evidence regarding infiltration capacity of vineyard soils. Battany and Grismer (2000) used an artificial rainfall generator to measure runoff, infiltration, and soil moisture changes in response to simulated rainstorms in February and March 1997 on six year old vineyards with relatively low vegetative cover and tilled soils. Rainfall simulators are best used to provide a relative index of infiltration, soil erodibility, or treatment effectiveness. There is lower confidence in extrapolation of absolute infiltration rates in inches per hour to behavior in actual storms or in other locations.

Artificial rainstorms had an intensity of 1.6 in/hr and 40 minute duration. These simulated rainstorms provided 8.5% greater energy and 55% greater depth than natural 100 yr recurrence interval 40 minute rainstorm ((Battany and Grismer 2000) p. 1292). Thirty study plots with mean slope of about 10% (range 2 to 17%) and mean cover of about 35% (range 2 to 67%) on clay loam soils of the Fagan soil series were studied. These soils have an infiltration rate of 0.2-0.6 in/hr in the upper 16 in and 0.06-0.2 in/hr at 16-28 in depth, substantially lower than those at the project site (Table 4).

Runoff and infiltration rates observed in the experiment were consistent, with mean runoff of 18% of rainfall and mean infiltration of 82%. Infiltration ranged from 75 to 89% of delivered rainfall, equivalent to about 1.3 inches of rainfall in a 40 minute period. This infiltration rate was about three times the maximum typical infiltration rate for this soil type (0.6 in/hr or 0.4 in per 40 minute period). Soil moisture in the upper 4 inches of soil increased 14%, equivalent to about 0.6 inches of water, nearly half of infiltrated volume. The remaining balance of infiltrated water was probably distributed to depths > 4 inches; the experiment did not measure soil moisture below 4 inches in the soil column.

Extrapolating the hydrologic behavior of the Fagan soils in Napa vineyards to the proposed vineyards at the project site should be cautious, however, given the observations in Napa, qualitative conclusions can be made with considerable confidence. Under unusually intense simulated precipitation, water infiltration to the soil occurred at very high rates on soils that are less permeable and generate more rapid runoff than the Goldridge and Hugo soils on the project site near Annapolis. The Fagan soils at the experimental site in Napa are classified by USDA soil survey criteria in hydrologic group C (slow infiltration rate when thoroughly wet). Soils near the project site in Annapolis are classified in hydrologic group B (moderate infiltration rate when thoroughly wet).

Overall, it appears that vineyard soils should be expected to be capable of relatively high infiltration of rainfall.

Changes in topography and runoff management in the vineyard are expected to change surface flow paths relative to existing site conditions. Erickson Engineering, Inc., has performed a detailed runoff analysis to calculating 100 yr recurrence interval flows from proposed vineyard areas on the site to verify the design capacity of the proposed reservoir and associated facilities as per requirements of Sonoma County. One component of this runoff analysis was calculation of the time of concentration (the time required for all points of a watershed to contribute flow to the mouth of the watershed). The analysis found that the time of concentration for two representative sub-drainages of about 5 ac each was about 18 minutes under existing conditions and under proposed vineyard conditions. Time of concentration is maintained at pre-project levels because "[t]he post-construction combination of short run of sheet flow, low-slope vee ditching at one-half to one-third existing runoff slopes, and longer more serpentine drainage pathways tend to balance presence of higher velocities in drainage pipes" (Erickson 2001).

Although the time of concentration is unchanged, increased length of flow paths in the vineyards would tend to enhance infiltration processes. As noted above, the shorter flow lengths and more gentle slopes in the system of v-swales compensate for relatively high velocity in drainage pipes. Surface runoff velocity prior to entering drainage pipes is actually slower than under existing conditions, thereby promoting infiltration relative to existing conditions. This effect would be accentuated by the presence of cover crops on the vineyard soil surface.

Summary of Likely Effects on Hydrologic Character of Soils

In summary, significant decreases in infiltration rates and percolation rates are not expected under post-project conditions. Potential changes in soil hydrologic characteristics are unlikely to reduce the quantity of groundwater recharge from the project, however, it is possible that there could be an increase in groundwater recharge.

Slope Stability

Potential increases in soil moisture in the vicinity of the project area are not expected to significantly increase potential slope instability in the vicinity of the project. Slope stability hazards are generally low or very low in the project conversion area, with some areas of moderate hazard, and no landslides have been observed in the project conversion area in our field studies or in previous landslide surveys of the area[1]. In addition, local slopes along the perimeter of conversion areas are not sufficiently steep (e.g. approximately 60% gradient or greater) to be generally susceptible to debris slide processes, and the extent and density of woody vegetation (trees and shrubs) that will remain in these areas provide significant additional reinforcement to the soil (Schmidt, Roering et al. 2001), reducing the potential for slope failure in the future.

[1] See Erosion Analysis, Figure 2.

Potential increases in pore water pressure or short term increases in the elevation of a perched water table lying above the geologic contact between the overlying Ohlson Ranch Formation and the underlying Franciscan Formation is a mechanism that could hypothetically translate increased soil moisture from hydrologic change into increased risk of debris slides or debris torrents. There is no evidence of such landslides in the historic aerial photo record analyzed by the California Geological Survey in the NCWAP Gualala report;there is one area of "high" potential for landslides within the watershed described by Drainage Node 33[2].

This area of high potential was observed in the field to have evidence of one debris slide originating on steep slopes in past decades. Vineyard drainage for Node 33 will be largely controlled by sedimentation basins (Figure 8), mitigating the potential for increased soil moisture on down-gradient slopes. Existing woody vegetation is to be retained in this area, and as noted above, the maintenance of root strength in this area is expected to provide significant reinforcement of slopes. Project hydrologic impacts are not expected to significantly increase landslide hazards in the project area, either within or adjacent to project conversion areas.

Expected Hydrologic Effects

Increases in winter peak flows could occur, and this issue is analyzed further. The magnitude of peak flow change is estimated and its potential effect on channel erosion processes is assessed in the following section. The rational runoff method is used to estimate peak flow changes. The resulting maximum magnitude of changes using the rational method is consistent with the results of the Caspar Creek study, providing supporting evidence that this relatively simple empirical approach can be expected to provide reasonably accurate estimates of the likely magnitude of peak flow change. Locations where potential runoff increases were predicted were evaluated for their sensitivity to peak flow increase (i.e. potential for accelerated bed and bank erosion), based on field survey data characterizing existing conditions of channel development and channel substrate.

Potential peak flow increases would only have potentially significant effects on small intermittent and ephemeral drainage channels on and near the project site. Channels further downstream are not sensitive to potential peak flow changes because of the small potential magnitude of peak flow increase at a larger watershed scale[3] and the degree of erosion resistance in the steep channels draining the project area. Downstream channels have historically experience peak flows that are very large in relation to potential peak flow changes, and channel substrates typically include bedrock, boulders, cobbles and other fluvial materials. The degree of natural channel armoring that inherently exists in Patchett Creek is sufficient to prevent significant channel response to project effects on peak flow. Moreover, the Caspar Creek experiment found no increases in sediment load in fish-bearing (CDF Class I) portions of North Fork Caspar Creek, despite observed increases in sediment yield from small tributaries of North Fork Caspar Creek that were hypothesized to have been affected by erosion associated with observed increases in peak

[2] See Erosion Analysis, Figure 2.
[3] See hydrologic analysis by West Yost & Associates.

flow. Peak flow increases are therefore not expected to cause significant changes in downstream fish habitat.

Potential increases in annual water yield and summer base flow could occur as a result of timber harvest and conversion. 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). This could benefit aquatic habitat by increasing the extent and duration of flow and the habitat area available to aquatic organisms.

Collection of runoff from a portion of the proposed vineyard area for storage in an onsite, off-stream reservoir for irrigation is not expected to have a significant adverse effect on annual yield or peak runoff. Surface runoff from approximately 47 acres of the project area, including 9 acres comprising the reservoir and sump footprint, will be routed to the reservoir. Subsurface flow, including groundwater discharge to surface flow that comprises the baseflow, is not expected to be significantly reduced by the project; it is likely to increase as previously described.

Reductions in peak runoff are not expected to have deleterious effects. The magnitude of decrease in peak flow owing to the reservoir as it affects Patchett Creek has been estimated as described in the following section. Briefly, the drainage area of Patchett Creek at the project boundary (Drainage Node 50)[4] is about 152 acres. Peak surface runoff for the 15 minute, 2-yr design storm at this point is expected to decrease about 10% under proposed project conditions where about one-third of the drainage area is affected by reservoir collection. At the point in the Patchett Creek watershed where all portions of the project area are contributing runoff (about one-half mile downstream from Drainage Node 50), the total drainage area is about 1.27 mi^2 (813 acres). At that point in the watershed, about 3.6% of the drainage area drains to the proposed reservoir, and expected peak flow changes are negligible.

Given the expected increases in soil moisture and annual runoff, particularly summer baseflow, and soil moisture associated with forest conversion in the remaining portions of the project area, and the small percentage of drainage area contributing to the reservoir, there is no reason to expect that runoff or streamflow in Patchett Creek will be adversely affected by the reservoir. The reservoir collection system mitigates potential peak runoff increases from portions of the project area by intercepting runoff and attenuating peak runoff rates. Given the expectation that the conversion project will increase soil moisture and runoff, the development and use of the reservoir tends to offset those increases. Nevertheless, only a portion of the project area is designed to drain to the reservoir, and the project as a whole is expected to increase peak runoff and yield.

The following analysis assesses potential peak flow increases and potential channel sensitivity to peak flow increases. As described above and in Appendix A, research at Caspar Creek showed that despite significant local increases in erosion and runoff in tributaries, mainstem habitat water quality (as expressed by annual suspended sediment

[4] See Figure 6.

yield) did not decline. The lack of detectable impact in fish-bearing reaches of North Fork Caspar Creek is probably attributable to the relatively small magnitude of additional erosion relative to total watershed sediment supply. Hence, large percentage increases in small erosion volumes spread out over the watershed proved to be undetectable against the background of other erosion processes that are spatially concentrated along the banks of larger streams. This subject is discussed in detail in Appendix A.

Magnitude and Location of Potential Peak Flow Increases

As discussed above, removal of forest vegetation is expected to increase runoff rates. Watershed experiments at Caspar Creek found that the rate of 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 pre-harvest for small watersheds (about 25 to 70 ac). This portion of the analysis describes the method used to quantify the magnitude and location of expected peak flow increases at the project site.

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 (Dunne and Leopold, 1978, pp. 298-305: PWA, 1994). 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 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.

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 cultivation or pasture may range from 0.35 to 0.45, depending on conditions. Woodlands may have C ranging from 0.25 to 0.35, depending on conditions. To estimate the effects of vineyard conversion on peak runoff, the rational method is evaluated under existing conditions and proposed project conditions. Grassland and cultivated areas are represented by C = 0.4, while woodland is represented by C = 0.3. Areas converted from woodland to vineyard therefore are represented by a one-third increase in the runoff coefficient.

As previously discussed, 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 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 would yield runoff predictions that are in general agreement with the Caspar Creek experimental data pertaining to changes in peak flow following vegetation removal.

The precipitation rate (I) used is determined by the time of concentration of flow in the watershed and the magnitude and/or frequency of the design storm. The frequency (return period or recurrence interval) selected for evaluation is 2 years. Runoff increases for larger, less frequent rain storms are expected to diminish. For smaller, more frequent rain storms, percentage changes in runoff rates are expected to be larger, 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 (Richards 1982) p.141-2). 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 noted earlier, EEI determined the time of concentration for representative watersheds in the project area to be about 18 minutes under both vineyard and existing conditions. Hence, the duration of the storm to be evaluated is about 15 minutes. Since higher rainfall amounts would be produced for a shorter storm duration, the use of 15 minutes instead of 18 minutes for time of concentration is conservative in that it would tend to overestimate runoff. Estimates of precipitation for 15 minute storm duration can also be calculated using existing data (Miller, Frederick et al. 1973). For Annapolis, 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.

GIS Methods for Rational Runoff Analysis

Hydrologic change analysis utilized GIS data and tools to compute pre- and post-project conditions. Much of the GIS analysis also contributed directly to an application of the USDA Revised Universal Soil Loss Equation 2 (RUSLE2) to analyze potential changes in rates of surface erosion associated with vineyard development. The results of the surface erosion analysis are incorporated in a sediment budget for the Patchett Creek watershed (also know as Annapolis Falls Creek) presented in the following section.

Geographic Information System (GIS) tools were used for both of these analyses to calculate watershed drainage areas for different portions of the project area and adjacent portions of the landscape. This required creating a series of attributes for areas within the analysis including existing vegetation type (grassland, woodland, or existing cultivated crops), future cover and land use type (new proposed vineyard areas), local slope gradient of the land surface, and existing and future drainage characteristics (natural sub-watersheds and future drainage routed through proposed sedimentation basins). The GIS was also used to produce maps illustrating critical components of the hydrologic and erosion analyses.

We used ESRI's ArcGIS 9.2 and data from a variety of sources. All data sources that were created were generated as "feature classes" in a "personal geodatabase". The benefit of creating a feature class is that perimeter and area values are automatically generated in the attribute table for each polygon. The project area, including adjacent upstream drainage areas, was sub-divided into 18 sub-watersheds terminating in small stream channels at drainage nodes at or near the project boundary. The drainage areas contributing to drainage nodes formed polygons that were digitized in an onscreen editing session utilizing topographic data from Erickson Engineering. The average contributing drainage area to these 18 drainage nodes is 23.8 acres. The average node drainage area is 18.7 acres when the largest node, (N50-111 acres), is excluded.

Two adjacent drainage nodes on the northern edge of the project area contribute flow to Grasshopper Creek. Another two other nodes on the western edge of the project area contribute flow to two unnamed tributaries of the Wheatfield Fork west of Patchett Creek. The remaining 14 drainage nodes contribute flow to Patchett Creek.

The area covered by grassland was digitized onscreen from NAIP 2006 aerial photography available online from the USDA. The remaining area was assumed to be in a forested condition for this analysis. Grassland area was digitized conservatively in that small areas of grassland vegetation and areas of mixed vegetation types were classified as forest. Two other GIS layers were created from CAD files that Erickson Engineering created: proposed vineyard areas to be drained by a system of surface collectors and drop inlet pipes to sedimentation basins, and the proposed vineyard boundaries. In order to transform the CAD data to line up with other data, the technique described in this online article in ESRI's web-based Support Center for the topic "Transform CAD data in ArcMap to line up with other data" (http://support.esri.com/index.cfm?fa=knowledgebase.techArticles.articleShow&d=29039) was used. The proposed vineyard boundaries were broken into two subsets, one layer represented the interior vineyard boundary and the other incorporated the unplanted area of vineyard perimeter avenues.

Table 5. Summary of layers used for hydrologic analysis.

Layer	Method
Sub-watershed drainage boundaries (drainage nodes)	Onscreen digitizing using topography from Erickson Engineering
Grassland	Onscreen digitizing using 2006 airphoto; areas not in grassland were assigned forest for existing vegetation
Drainage area to sedimentation basins	Imported CAD coverage from Erickson Engineering
Proposed vineyards	Imported CAD coverage from Erickson Engineering

The above layers were merged into one feature class. The attribute table was exported into Microsoft Excel where pivot tables were used to generated summed acreages.

Results: Predicted Pre- and Post-Project Peak Flow

The runoff analysis estimates the magnitude of peak flows pre- and post-project at several points around the project site where concentrated and/or dispersed runoff would

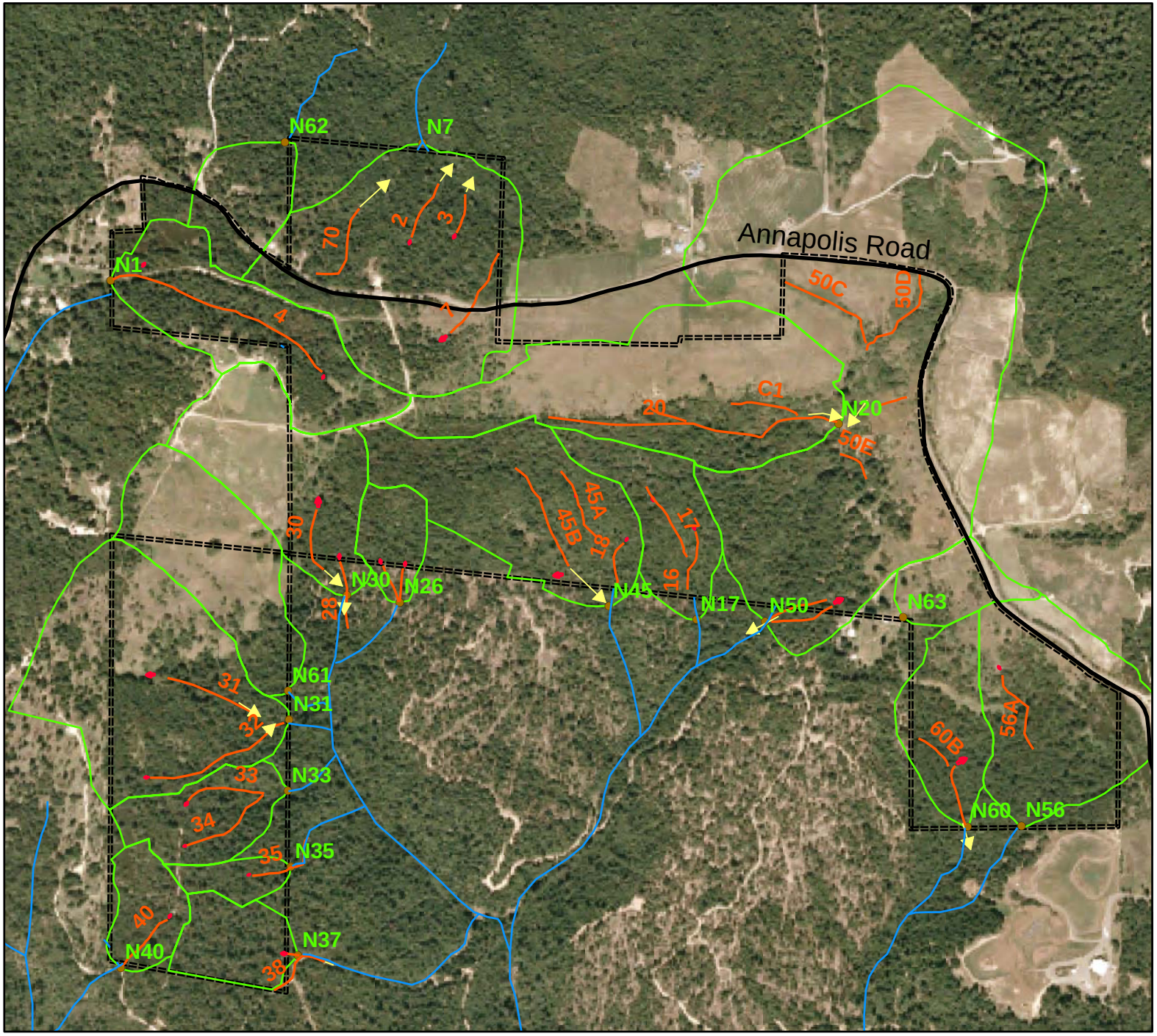


Figure 6.
2007 Field Surveyed Streams

Proposed Artesa
Fairfax Vineyard
Annapolis, Sonoma County

Legend

- Annapolis Road
- Continous bedrock
- Surveyed Streams
- Streams
- Proposed sediment basins

O'Connor Environmental, Inc.
www-oe-i.com
March 2007

2006 imagery courtesy USDA Farm Service Agency, Aerial Photgraphy Field Office, National Agricultural Imagery Program via ArcIMS Server