UCCE

Meeting Agricultural Water Needs in the Navarro River Watershed, Mendocino County, California

Final Report

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Executive Summary

The availability of water for all rural and urban water users in Mendocino County, and the Navarro River Watershed specifically, is an increasingly contentious and acute issue. Legislation such as California Assembly Bill 2121 and resulting policies are requiring evaluation of water allocation to meet environmental needs. Resulting regulations, such as the *Policy for Maintaining Instream Flows in Northern California Coastal Streams* by the State Water Resources Control Board (SWRCB), will result in specific directives designating the timing and amount of withdrawals for all users.

Potential regulatory constraints require all users to choose from alternative options to meet their respective water needs, including water conservation and use of alternative water sources. The goal of this study was to work with Navarro River Watershed agriculture to understand its current and future water demand and then evaluate the existing and potential options for meeting this need in order to mitigate competing pressures for water. The study was conducted by the University of California Cooperative Extension (UCCE) Mendocino County with financial assistance from the Mendocino County Water Agency (MCWA) and The Nature Conservancy (TNC).

This study was conducted in 2009 using historical data analysis, on-farm irrigation system evaluation, grower surveys, aerial photograph interpretation, Geographic Information System (GIS) analysis and modeling. Research effort focused on documenting historic, current and potential future irrigated agricultural acreage and water demand, along with opinions and attitudes towards water conservation and water management alternatives. Major study findings include:

- As of 2009, irrigated agriculture acreage in the Anderson Valley totaled 3,124 acres including, 2,790 acres of wine grapes, 66 acres of irrigated pasture, 218 acres of orchard crops (primarily apples) and another 50 acres planted to other horticultural crops.
- *Calculated* irrigation demand derived from standard agronomic equations and site specific spatial data ranged from 1683-2152 af/yr. This calculation does not include water used for frost protection.
- Based on grower surveys in 2009, we estimated that 1,825 acre-feet (af) were used, including approximately 678 af for frost protection. A total of 558 af were used for grapevine irrigation (consumptive use), 457 af for orchards, and 132 af for irrigated pasture. These results suggest growers are using effective water conservation techniques.
- In 2009, the *total* annual estimate of water needed for crop production was 1.4% of the 2009 *total* annual discharge of the Navarro River near Philo, California, which was measured as 106,971 acre feet.

- The amount of water that growers apply is based upon site specific conditions (*soil available water holding capacity, crop type and planting system*), crop specific cultural objectives (*yield and quality*), an understanding of the link between energy and water costs to deliver water to crops, and reliability of water resources to which growers have access.
- Growers have adopted and adapted improved irrigation technologies and methods over the last three decades, realizing significant water conservation. These include installing drip irrigation systems in grape vineyards and other perennial crops, and under canopy sprinkler systems in orchards.
- Average irrigation system distribution uniformity for grape vineyards (90%) and orchards (70%) were high values, indicating systems distributed water evenly and efficiently.
- Frost protection techniques varied on the 1,339 acres assessed in grower surveys. No frost protection was required during most seasons on 225 acres (25%).Conventional sprinklers were used on 947 acres (66%), micro-sprinklers on 67 acres (4%).70 acres (5%) were protected with wind machines.
- Growers participated in conservation programs including UC Water Quality Planning short courses, USDA Natural Resources Conservation Service's (NRCS) Environmental Quality Incentives Program (EQIP), and Fish Friendly Farming. Key reasons for this participation are stewardship values and reducing farming costs for both water and energy. Growers are eligible for cost share items including weather stations to improve frost prediction, valves to enable the system to be shut off in areas not in immediate danger of freezing in their vineyards to be shut off, and wind machines and other devices to conserve water.
- Of the 1,339 acres assessed in our survey of 14 growers, 44 acres (3%) were irrigated from wells (*ground water*); 202 acres (13%) were irrigated from *direct diversion of surface water*; and the remaining 1093 acres (84%) were irrigated from *off stream ponds*.
- As of 2009, the State Water Resources Control Board (SWRCB) had issued 264 licensed and permitted water rights with a total face value of 9,635 acre-feet (af) in the Navarro Watershed. There were 165 ponds and reservoirs with a combined surface area of approximately 140 acres and average pond surface area of 0.8 acres. Not all ponds were used for agriculture—some included springs for domestic use and ponds for wild life.
- The land suitability model developed for this study suggests that approximately 2,650 acres of non-forested land with slope <10% are suitable for potential new irrigated agriculture development. A slope threshold of <20% expands that potential to approximately 4,650 acres.

- At the use rates described herein, future annual agricultural water demand in the Anderson Valley could range from 1,326- 2,325 acre-feet if grapes are the dominant crop. If orchard crops regain popularity these values could range from 5,834-10,228 acre-feet.

Suggested next steps to continue better understanding (human) water use in the Navarro Watershed and improve measures growers have already taken to effectively manage water resources include:

- Establishing an **irrigation system evaluation service**. This will provide the insurance that properly functioning irrigation systems continue to operate well and that those requiring attention and improvements are identified and addressed;
- **Forming partnerships between agriculture and other water users** in the study area that have a shared interest in reviewing and providing input on local, state and federal water policy;
- Investigating **alternative water management strategies to reduce summer surface water diversions**, including small scale winter flow storage, improved water use monitoring, and water reuse opportunities;
- **Evaluating domestic and commercial water use** in the watershed.

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Introduction

The last inventory of water demand, including agricultural use, for the coastal watersheds of Mendocino County was conducted in 1992 (Sommarstrom 1992). To meet the need for an update in the context of current water availability and use, the Mendocino County Water Agency (MCWA) initiated an inventory in 2007 through a number of studies and partnerships to document the current and future water needs for all users, including agriculture, domestic, and commercial users in rural and urban areas of the County.

The availability of water for all rural and urban water users in Mendocino County is an increasingly important issue due to limited available water. Longer term statewide policies to regulate water allocations include Assembly Bill 2121, passed in 2004 (*stats.203, ch.943, §3*). This legislation added Water Code section 1259.4 and required the State Water Resources Control Board (SWRCB) to implement guidelines for maintaining in-stream flows in northern California coastal streams. In 2010, the SWRCB published the Policy for Maintaining In-stream Flows in Northern California Coastal Streams (*SWRCB 2010*). Such policies and actions were partially in response to critical habitat designation for Coho salmon and steelhead trout in the Navarro River and other North Coast watersheds by the National Marine Fisheries Service (*70 FR 52488*). Implementation of these regulatory requirements to reduce impacts to in-stream habitat requires all water users, including agricultural, to weigh a list of options and alternatives for meeting their respective water needs including water conservation and use of alternative water sources.

Besides concerns about instream flows, agricultural applications for water rights have been delayed, in some cases, for over a decade by the SWRCB Division of Water Rights (B. Wiley, personal communications). These delays result from concern that the basin is at least fully allocated, with no remaining water for pending applications. These new and pending policies and guidelines will direct the review and approval of water rights applications by regulating the timing and amounts of water withdrawal to meet stringent minimum by-pass flow requirements.

The best opportunity to relieve the pressure that competition for water is creating for all users is to work with Mendocino County agriculture to understand current and future water demand, and then evaluate existing and potential options for meeting these needs. University of California Cooperative Extension (UCCE) Mendocino County initiated this study to estimate agricultural water demand and use in the Navarro River Watershed (Figure 1) with funding provided in part by the MCWA and a generous grant from The Nature Conservancy (TNC).

Project goals were to:

- Improve understanding of agricultural water needs and uses within the Navarro River Watershed;
- Evaluate the efficiency of the irrigation practices used by growers in the watershed;
- Estimate the potential land suitability for future agricultural expansion in the watershed using the following land form features:
    - currently non-forested land
    - slopes <10% & <20%
    - excluding magnesium affected soils;
- Inform long term resource planning.

About the Navarro River Watershed

The Navarro River Watershed is located in southwestern Mendocino County (Figure 1). It is a place of great beauty dominated by a rural landscape of Douglas fir and redwood forests on north facing slopes and in deep canyons, and by oak woodland and grasslands on west facing and southern slopes. The area is sparsely populated (approximately 3,200 people), and the principle economic activities are agriculture (vineyards, orchards, livestock, small scale mixed horticultural enterprises and commercial softwood production), beverage production (wine and beer) and tourism.

The Navarro River Watershed is the largest coastal watershed in Mendocino County, covering approximately 200,000 acres (315 square miles). The Navarro River itself is rather short, only 26 miles from Philo to the Pacific Ocean. Most of the river flows through redwood forest along Highway 128. The median flow of the Navarro River is similar to the Russian River as it flows near Hopland, with a drainage area of approximately 231,680 acres (362 square miles) (Lewis et al, 2008). However, the Navarro River is much more prone to extremes in its high and low flows. Most rain falls between the months of October and May. It is a natural river with no dams or other obstructions on its main stem. Rainfall averages 40.6 inches per year compared to nearby Ukiah (headwaters of the Russian River) where average rainfall is 36.6 inches per year (B. Bearden, 1974). Peak flows can reach much higher rates along the Navarro River than the Russian River since more water falls on a smaller area. For instance, the last major storm and flood event in Mendocino County occurred on New Year's Day in 2006. The Navarro River was gauged at a flow of 62,000 cubic feet per second compared to a flow of 35,000 cubic feet per second for the Russian River at Hopland. Yet by summer, the flow of the Navarro River becomes a trickle, and it is easy to wade across many places without getting wet above the knees.

In an average year, the Navarro River Watershed intercepts almost 800,000 acre feet of water (by comparison, Lake Mendocino and Warm Springs Dam have a combined storage capacity of over 500,000 acre feet of water when completely full). Some water is stored in subsurface aquifers which tend to be limited in their volume and pumping capacity. There are not many large areas of porous geological formations in which water can accumulate (Schott, personal communications). Most wells produce much less than 10 gallons per minute, making them suitable mostly for domestic use. Some of these aquifers leak to the surface and form springs which are used for domestic use and drinking water for livestock and wild life.

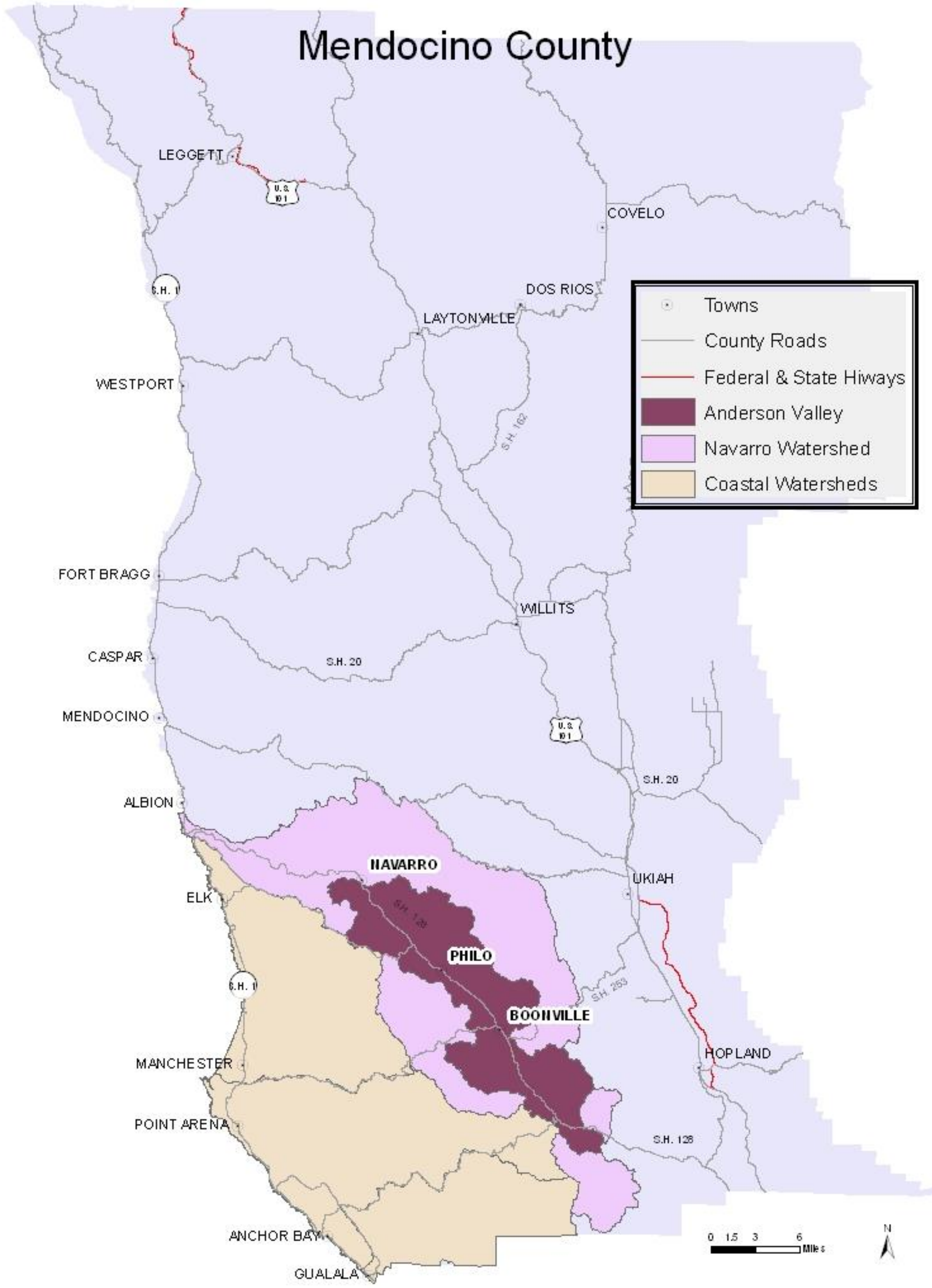

Figure 1: The Navarro River Watershed including the Anderson Valley, southern Mendocino County, California.

The climate of the Navarro River Watershed can be described as Mediterranean with most rainfall occurring in the winter months, followed by no rainfall from late May to late October most years. Because of the close proximity to the Pacific Ocean, there is a strong marine influence on the area, with fog occurring many late nights and mornings, and cooling westerly winds during the day. Much of the rain water is stored in soil and is utilized by plants through evapotranspiration. This amount of water varies seasonally, but overall, evapotranspiration rates are moderate compared to many agricultural areas in California (UC IPM On-Line).

Table 1. Average Evapo-transpiration (ET) in Philo, Anderson Valley and Hopland, Upper Russian River Valley, 2009-2012. Source: Roederer Estate US Adcon Data.

Year	2009	2010	2011	2012
Anderson Valley (*ET inches*)	32.1	31.1	31.2	32.3

How Agriculture Has Changed Over the Centuries

Agriculture in Anderson Valley began in the 1850s as the Anderson, Gschwend, Guntley and Gossmand families settled in the valley. Subsistence farming was the primary focus of agriculture, with families grazing cattle and sheep, growing grain and other produce. These small farms also supplied some of the groceries for the logging camps that were very active for most of the second half of the 19th century. Most of Mendocino County was fairly inaccessible except by "dog hole schooners" (small steam powered boats) that traveled up and down the Pacific Coast, mostly taking on board lumber to be delivered in San Francisco, and returning with manufactured goods as cargo. The first toll road out of the valley to Ukiah was built in 1868. Besides livestock, Anderson Valley began a tree fruit industry to sell dried fruit to the outside area as a cash crop. Apples were the primary orchard crop in planted acreage, followed by pears and peaches. There were even a few hop yards and some wine grapes. Most of the wine grapes were planted on the ridges above the valley and above the frequent fog line, where warmer temperatures and a longer growing season allowed the fruit to ripen. On the valley floor, it was considered too cool for vines to adequately ripen fruit. Spring and fall frosts, fall rains and a limited access to markets for fruit were also obstacles that kept the vineyard industry from developing until fairly recently.

Most of these farms were not irrigated, and instead relied on clean tillage to remove competition from weeds and conserve moisture by creating dust mulches on the surface of the soil. Erosion was a problem, as there is not very much level ground in Anderson Valley that doesn't slope and drain into a surface water way (Wiley 2009). Dry land farming was common for orchards and the few vineyards that were present in the valley until irrigation technology began in the mid-20th century (Bearden 1989). By the 1950s, apple acreage began to decline as the most accessible market was for juicing and canning. Older varieties typical of the valley were not in demand for fresh market, and the dried fruit industry was in steep decline for apples. Some growers with access to surface water were able to secure water rights and improve their yields. There also was a development of an organic apple juice business that also kept some dry land orchards in production longer than would have otherwise been economically feasible. However, by the 1980s, apple production was in serious decline and wine grapes began to replace apples as the dominant agricultural enterprise in the valley.

The Modern Vineyard Industry Arrives

By the early 1900s, there were about one hundred acres of wine grape vines planted along the ridges above Anderson Valley, primarily by Italian immigrants. Wine was made and sold mostly to local consumers in Mendocino County, especially along the coast where wine grapes couldn't be grown, but there were wine drinkers. Prohibition, along with a period of very cold weather, and fewer wine drinkers resulted in many vines being pulled, but a few older vineyards have survived to this day.

In the 1940s, Italian Swiss Colony made a large planting on flat ground near Boonville of Ugni blanc and French Columbard. Other independent growers signed contracts for varieties such as Golden Chasselas and Carignane which required long growing seasons to mature. The plantings were not economically viable due to frost and poor quality fruit (low sugar and high acidity), and were abandoned during the 1950s. Additionally, phylloxera (an insect that destroys grape vine roots) was also found to have infested some of the plantings, since most vines were not planted on resistant rootstock (Bearden 1989).

In the 1960s, Dr. Donald Edmeades started the modern wine industry when he planted 28 acres of mixed varieties for premium wine. Guided by UC Davis viticultural experts such as Dr. A.J. Winkler, the region was identified as being suitable for varieties that don't require long warm growing seasons, such as Pinot noir, Chardonnay and Gewurtztraminer. Tony and Gretchen Husch planted these varieties in the late 1960s, and soon both properties were producing wine. Brad Wiley planted Chardonnay in 1972 in a cool area almost near the town of Navarro. Soon more acreage was added by Ted Bennett and Deborah Cahn (Navarro Vineyards), Larry and Nicki Parsons (Pepperwood Springs) The B.J. Carney Company planted nearly 80 acres of vines near Boonville in 1974 and 1975. The Day Ranch, Valley Foothills and other small plantings were also planted in this era.

The development of Roederer Estate US vineyards and winery in the 1980s greatly expanded acreage and put Anderson Valley on the map as a significant production area for high quality cool climate wine grapes. Scharffenberger Cellars also was started about the same time. In the 1990s, Anderson Valley became very well known for its Pinot noir wines, and the arrival of Goldeneye resulted in the region becoming well known for its fruit. By the end of the 1990s, over 1000 new acres were planted. Even as the economy slowed after 2007, more vineyard acreage has been added to the Anderson Valley. The quality of the fruit has become well known in the winegrowing industry, and there is strong demand for what is being produced.

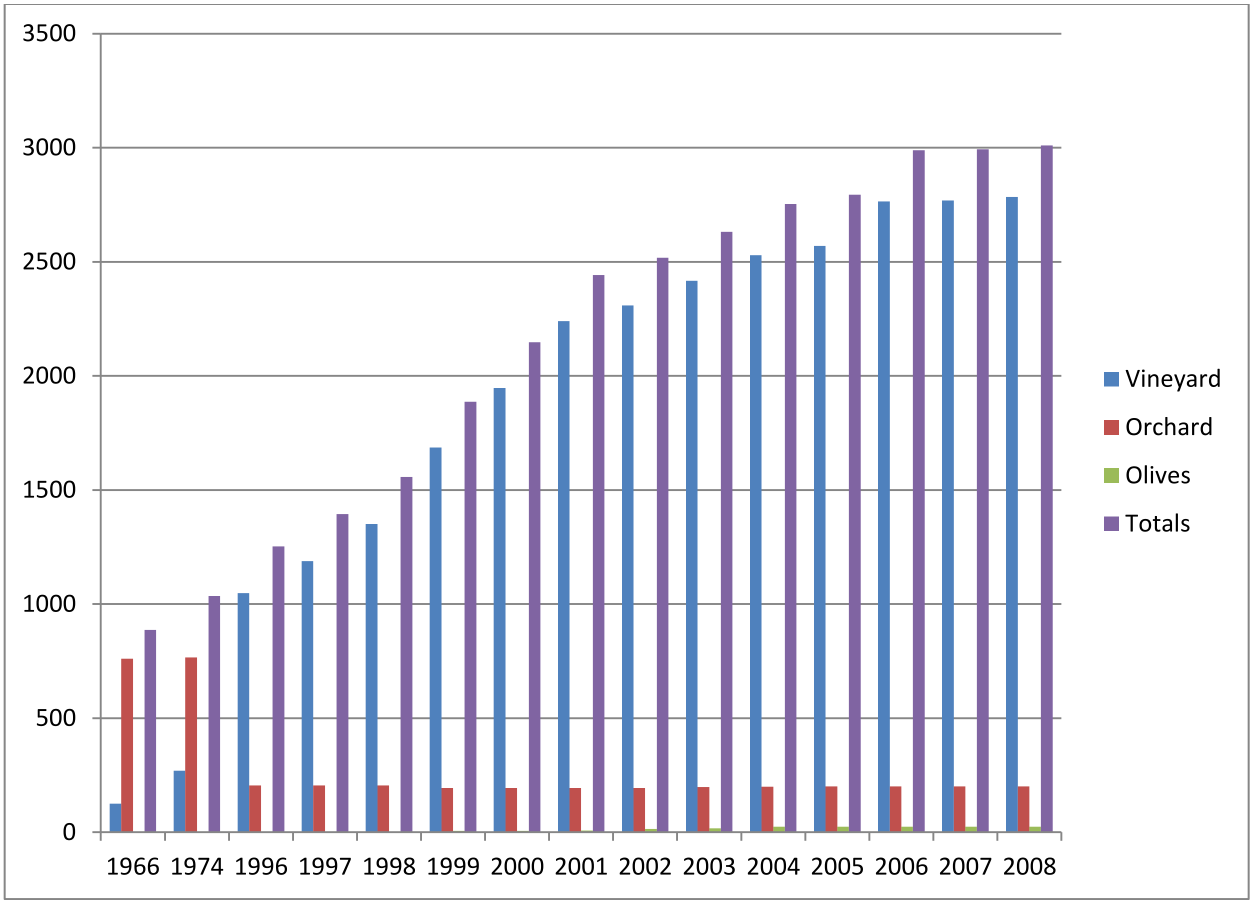

Figure 2: Anderson Valley Irrigated Agricultural Mix, 1966-2008. Source: Mendocino County Agricultural Statistics.

Study Methodology

Our field work was conducted in the 2009 growing season. Grower surveys, field surveys, GIS mapping using air photos, and spatial modeling were combined to complete this study. This section describes the methods used to accomplish each study component. The focus study area was the portion of the Navarro River Watershed where the majority of the irrigated agriculture acreage exists. The study area was divided into sub- watersheds to better understand differences in irrigated agriculture water use between these portions of the watershed (Figure 3).

Hydrology

Long-term measurements of stream discharge by the United States Geological Survey (USGS) provided a historical record and context for 2009 and were utilized for this study. Specifically, data from the USGS stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County were compiled and analyzed.

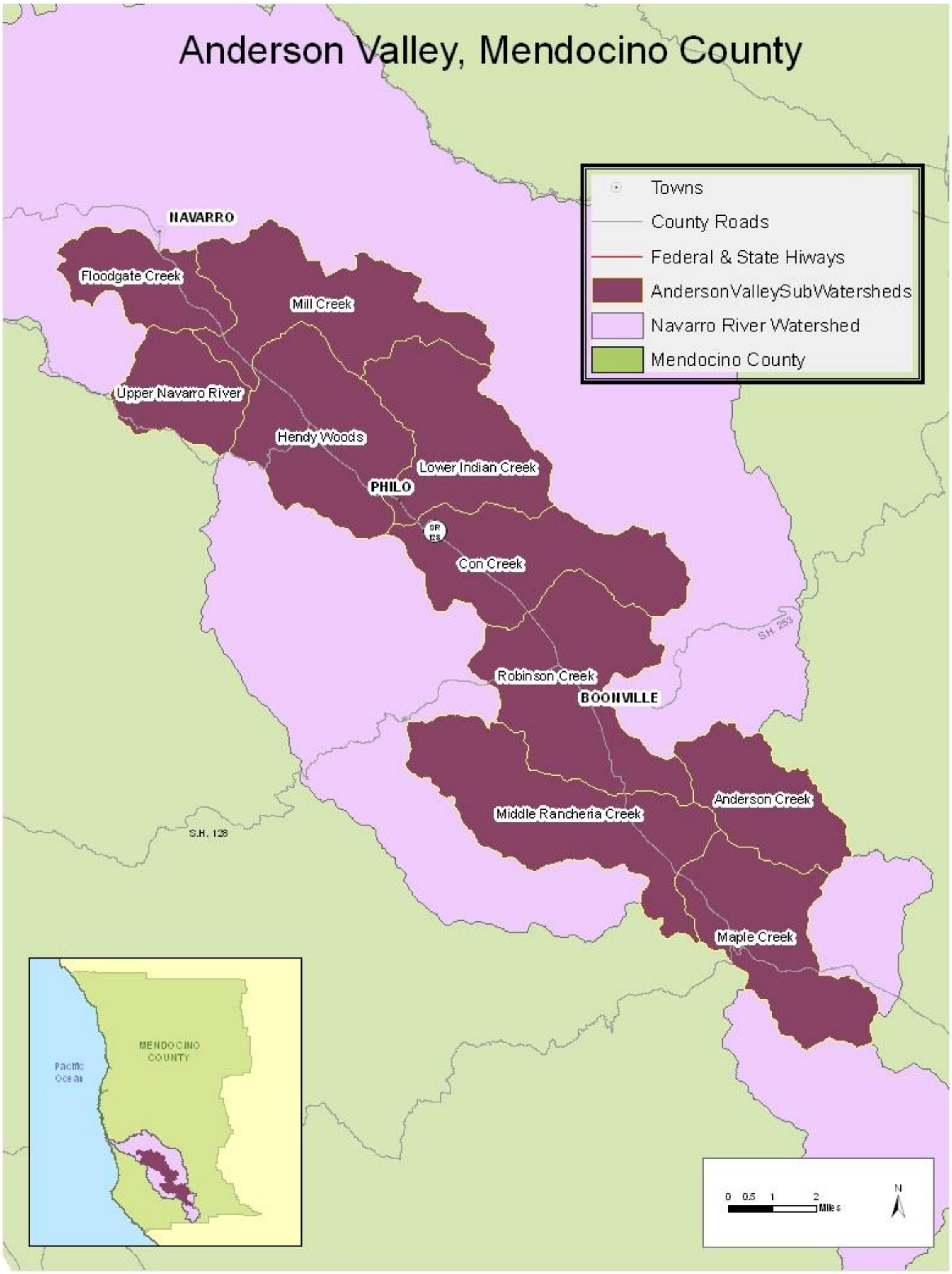

Figure 3: Sub Watersheds of the Navarro Watershed, southern Mendocino County, California.
Source: Calwater 2.0 Watershed Boundaries

Historical and Existing Irrigated Agricultural Acreage

Agricultural acreage statistics were obtained from Mendocino County Department of Agriculture annual crop reports (Linegar 2008), California Department of Water Resources (DWR 1964, 1979, 1989), and California Department of Food & Agriculture (CDFA 1968, 1976, 2006, 2009). Additionally, the current spatial extent of irrigated agricultural land was mapped in a Geographic Information System (GIS) using current air photos (NAIP 2009). Data were then summarized to provide a picture of the historical and current extent of irrigated agriculture in the study area. While the Navarro River flows beyond the study area, it was decided to constrain our efforts to the portions of Navarro River Watershed with active agricultural operations (Figure 3).

Grower Surveys

Surveys designed to understand water use patterns for a majority of wine grape and fruit tree growers in the Anderson Valley were adapted from a prior effort focused on the Russian River Watershed (Lewis et al. 2008). These surveys were sent to the Anderson Valley grower's community with support from the Anderson Valley Winegrowers Association. Orchardists were also solicited to participate in the study. The 25 questions in the survey were developed to gather information on the history of water resource management that included frost and heat protection, changes in irrigation system technology, participation in conservation programs, and opinions on alternative water sources. Fourteen growers participated representing a broad range of operational size in vineyard and orchard crops. All survey respondents completed appropriate human subjects releases required of the University of California, Davis Office of Research and Internal Research Board.

Irrigation System Evaluation

Irrigation (Consumptive Use) and Distribution Uniformity

Project team members conducted field evaluation and measurements of existing irrigation systems on 26 vineyards and three orchards to understand consumptive water use and system distribution uniformity using previously described methods (Prichard et al. (2007), Schwankl (2007), and Schwankl and Smith (2004)). Evaluations included field measurements of applied water rates and irrigation system distribution uniformity. Additionally, guided interviews were conducted with individual cooperating growers for each respective farm evaluated to document the duration of the irrigation season and number and duration of each irrigation event during the season. The measured application rate and grower interview information were combined to estimate the total amount of water applied for frost protection and irrigation (consumptive use).

To calculate potential crop consumptive use and net irrigation requirement in order to compare to actual applied water, values for reference evapotranspiration (ET_o) (*or reference rate at which water evaporates from the soil and transpires*) were obtained for the 2009 season from an AdCon (AdCon Telemetry, Austria) weather station located at Roederer Estate US in Philo. Total ET_0 for the 2009 growing season from April through October was summarized to produce a seasonal ET value (ET_s). Available water holding capacity data for the dominant soil types occurring within irrigated agricultural lands were obtained from the Soil Survey of Mendocino County, California, Western Part (Rittiman and Thorson 1993).

Water use and crop coefficients (K_c) are known to be highly correlated (Williams and Ayers 2005). The Paso Panel technique (Battany 2012) was used to directly measure canopy shaded area on representative sites and trellis designs in the Anderson Valley. Field data were then used to calculate grapevine crop coefficients according to the methods outlined by Battany. Field measurements of vine canopies were made at Roederer Estate US Vineyards in Philo on September 28 and October 2, 2012. Vine canopies were healthy, green and fully expanded. A total of four sites planted to Pinot Noir and Chardonnay were selected based on trellis type, vine vigor and row orientation. Measurements were made between 1200-1300 hours (solar noon). A total of 40 observations were recorded from each site. Crop coefficients were calculated using the algorithm provided by Battany (2012). These values were used to produce an average K_c.

Frost Protection and Other Irrigation Practices

Frost protection equipment and patterns of use information was gathered during grower surveys. Frost protection systems are almost always designed to apply 0.1 inches of water per hour to protect vines from freezing. This is considered the most effective amount to transfer adequate latent heat of water with the minimal amount of water use. The following calculation was used to estimate total frost water use:

Equation 1: Equation for calculating frost water application volume

$$\mathbf{TW = Tfp * Afp * C}$$

Where:

TW = total volume of water applied to a site (acre-feet)
Tfp = total hours of frost protection
Afp = total area frost protected (acres)
C = rate constant for frost protection irrigation systems (0.1 inches/hr)

Only three growers surveyed indicated that they used postharvest irrigations or heat protection with sprinklers. Since Anderson Valley is cooler due to its proximity to the Pacific Ocean, high temperature events (*air temperature > 100 degrees F*) are less common compared to the Russian River Valley area of interior Mendocino County. Also, growers often have limited water supplies, so they save available water exclusively for irrigation. Additionally, since water availability is limited in the fall, many growers do not make postharvest irrigations to their vineyards (Gibson 2009).

Mapping Spatial Extent of Existing Agricultural Acreage

The existing spatial extent of irrigated agriculture was mapped in a Geographic Information System (GIS) using current aerial photographs of the Navarro River watershed. Mapping with a 0.5 acre minimum mapping unit was completed by the UC Cooperative Extension Mendocino County Agricultural Technologist using 2009 National Agricultural Imagery Program (NAIP) aerial imagery for Mendocino County. The NAIP collects land cover imagery annually across much of the United States) which is intended for use in evaluating agricultural and natural resources (NAIP 2009).

Potential Future Agricultural Land Suitability Model

Modeling alternative agricultural futures is a useful tool for informing public policy and developing conservation and land management strategies (Santelmann 2007). Previous efforts to evaluate potential vineyard expansion in Sonoma County demonstrated the utility of spatial modeling to inform alternative futures and long range planning (Heaton & Merenlender 2000). The goal of this effort was to inform the current discussion on water use within a rational framework of geographic data and known assumptions. This work left out explicit consideration of local land use policies, ownership patterns, and access to infrastructure, all of which would be expected to have a significant impact on any actual future land use change.

Aerial imagery from the 2009 USDA NAIP aerial mapping program was used to develop a land cover classification for the Anderson Valley watershed. Sample points from forest and non-forest land cover types were identified in the 2009 aerial images and used to inform an image classification procedure. Maximum Likelihood Classification (ESRI Web Resource) was used to generate the land cover classes with a 10m pixel resolution.

National Elevation Data (NED) at 10m resolution was used to derive topographic slope for the Anderson Valley. The NED provides uniform topographic data across the US and allows for explicit consideration of topography in geographic analysis and modeling (USGS Web Resource). Slope classes of <10% and <20% were created to discriminate vineyard potential under different slope thresholds. In general, steeper slopes are more difficult and costly to farm. Vineyard land cover identified during air photo mapping was used to extract existing vineyard land cover from the model.

The Squawrock-Witherall-Yorkville-Hopland soil series, known to be high in magnesium (Rittiman and Thorson 1993), were excluded from our final analysis due to their known impacts on vineyard performance including potassium deficiencies, potential toxicity from nickel, poor surface stability and high erosion potential. While there are some vineyards planted on these soils, low yields, soil instability when saturated, and high erosion make them difficult to manage. Generally, these sites are not recommended for agricultural enterprises.

All analysis was conducted using ArcGIS Spatial Analyst (ESRI, Redlands, CA) using the raster (GRID) data format. The raster data format is optimal for evaluating phenomena that change across a continuous area including topography and land cover.

Water Demand Calculation

Water demand was calculated for the majority of soil series within study area vineyard boundaries using known relationships between evapotranspiration, soil water holding capacity and the crop co-efficient.

Equation 2: Equation for calculating irrigation demand

$$ID = ET_o \times K_c - AWC$$

Where:

ID = Irrigation Demand
ET_o = Reference Evapotranspiration
K_c = Crop Coefficient
AWC = Available Water Holding Capacity

Soil series data (Rittiman and Thorson 1993) were intersected with the vineyards layer to generate new data describing the soil series within all currently known vineyards. These results were summarized to determine the percent contribution of each soil series to the total vineyard area in the valley.

Average crop co-efficient (K_c) generated using the Paso Panel technique was used to determine the crop consumptive use requirements for the growing season. This is the amount of water needed to meet the complete ET needs of the crop, irrespective of specific management strategies such as Regulated Deficit Irrigation (RDI).

Finally, the available water capacity (AWC) (or moisture stored in the soil) for each soil series was subtracted (Equation 2) from the consumptive use requirements to determine the amount of remaining water that would need to be applied through irrigation. Total potential water demand for the vineyards in Anderson Valley was then calculated yielding a set of possible water demand scenarios. Rooting depth was assumed to be 4 feet for the purpose of our calculations. In reality, many vineyard blocks are planted on soils that are both deeper and shallower than this depth. It is beyond the reach of our study to generate more accurate rooting depth information for individual vineyards.

Results

The Historical Record of the Navarro River Flow

California's Mediterranean climate is characterized by extreme variability and seasonality in precipitation and stream flow (Lewis et al. 2000). For example, mean daily stream discharge in the Navarro River can vary annually from below 20 cfs to above 45,100 cfs (Figure 4). Flood events such as those that occurred in 1955, 1964, 1974, and 2005 are complemented by low flow years such as 1976, 1977, 1987, 1990, and 1994. The variability in flow is further confirmed by the juxtaposition of high and low flow years like 1955 and 1956 or 1986 and 1987.

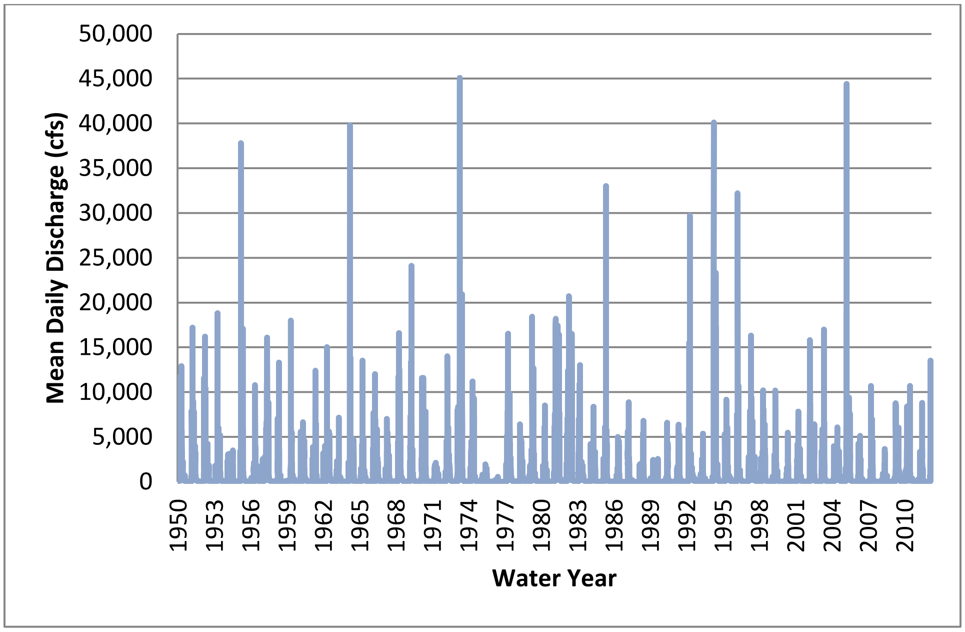

Figure 4. Mean daily discharge (cfs) for water years 1951 to 2012 at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County.

Of critical relevance to this study is the *seasonality* of instream flows and agricultural water demand. The bulk of high stream flows occur during the late fall, winter, and early spring months (Figure 5). Historically, agricultural water use in the Navarro River watershed occurs during the early spring frost season (March-May), as well as the late summer dry season (July-Oct). It is important that any management strategies account for this coincidence of supply and demand (Figures 5 & 6) in order to effectively meet biological and agricultural water demand.

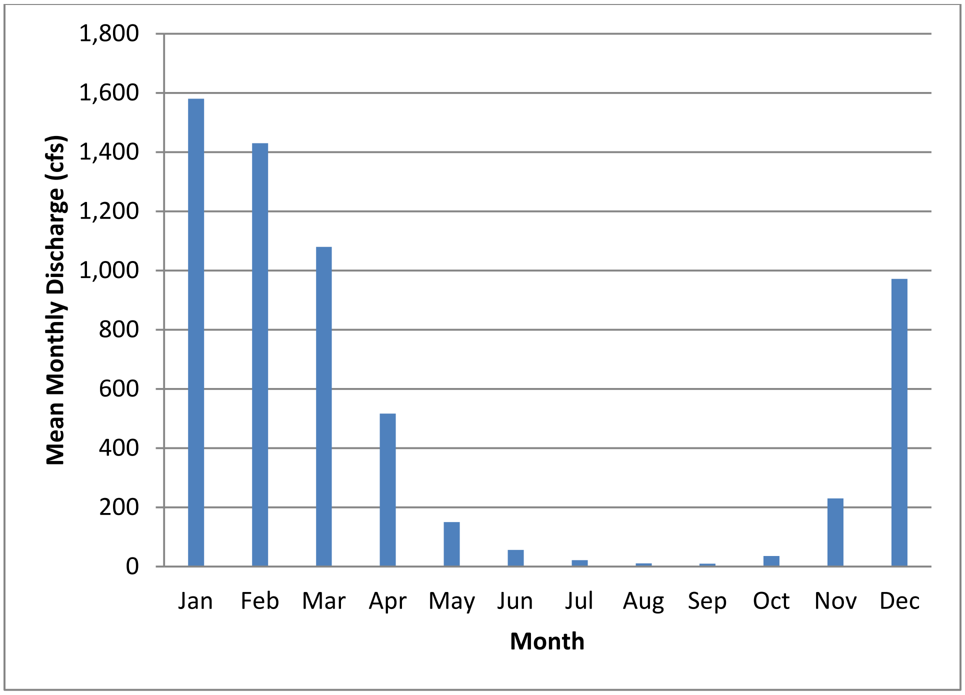

Figure 5. Mean monthly discharge (cfs) water years 1951 to 2012 at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County.

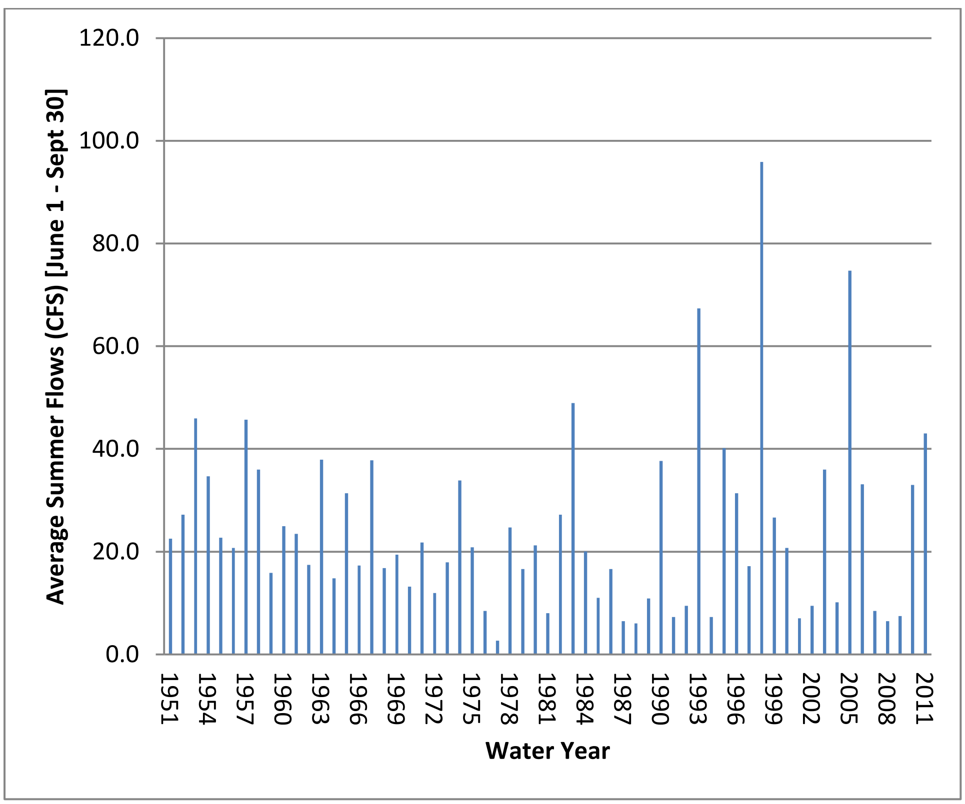

Figure 6. Mean daily discharge (cfs) during the summer months (June 1 – Sept 30) for water years 1951 to 2012 at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County.

Similar to the variability in the pattern of flow or discharge is the variability in volume of annual discharge. The greatest amount of discharge at USGS Navarro stream gauging station was 949,954 acre- feet in the 1983 water year (Oct 1, 1982 to Sept 30, 1983) and least was 18,520 acre-feet in the 1977 water year (Figure 7). It is interesting to point out that years with higher or lower mean daily discharge rates do not always correspond with high or low total annual discharge (Figures 4 & 7). Contrary to intuition, years with extreme high daily discharge flows like 1956 do not have corresponding total annual discharge values higher than the majority of other years. Even more confounding is the observation that notorious flood years like 1964 can actually have relatively *lower* total annual discharge values. Conversely, 1983 was a year in which mean daily discharge rates were moderate but more consistent relative to other years, resulting in the maximum total annual discharge value of record (Figure 7).

These observations point to the importance of precipitation *timing*, *duration*, and *intensity* and the annual cumulative precipitation delivered in each annual storm season in terms of generating stream and river flow. This study was conducted in the 2009 water year (Figure 8); total annual discharge at USGS Station #11462500 was 106,971 acre-feet (Figure 7). This was a relatively low flow year compared with the record and was preceded in 2006 by a relatively high flow year with a total annual discharge of 759,989 acre-feet. By rank, 2009 was 46th in total annual discharge. Approximately 92% of the years in the record had total annual discharge values greater than that in 2009 (Figure 9).

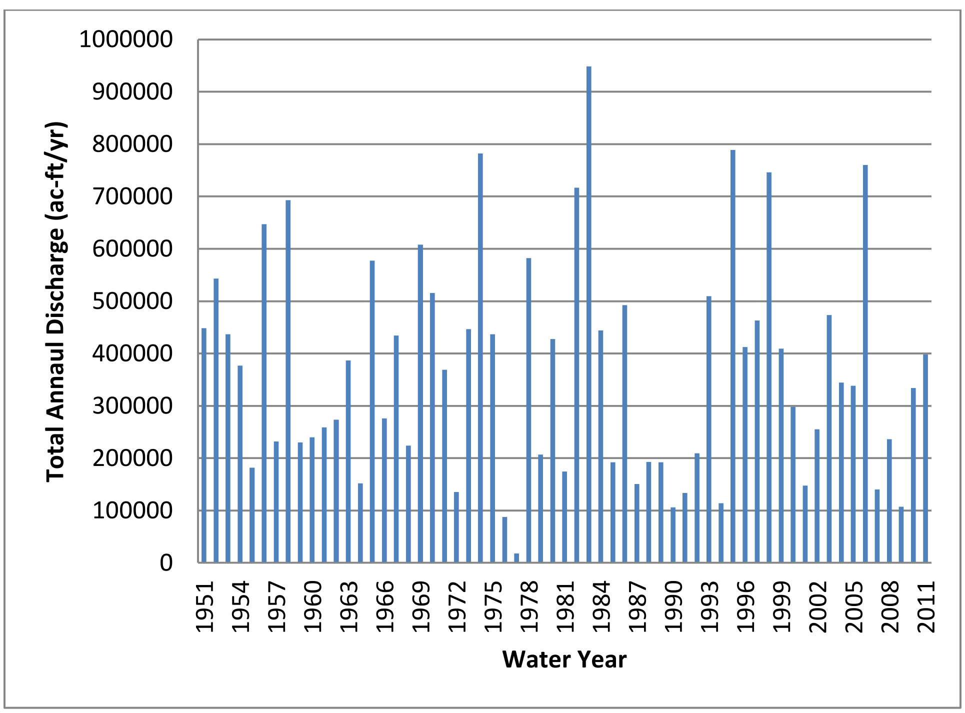

Figure 7. Total annual discharge (acre-ft) for water years 1951 to 2012 at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County, California.

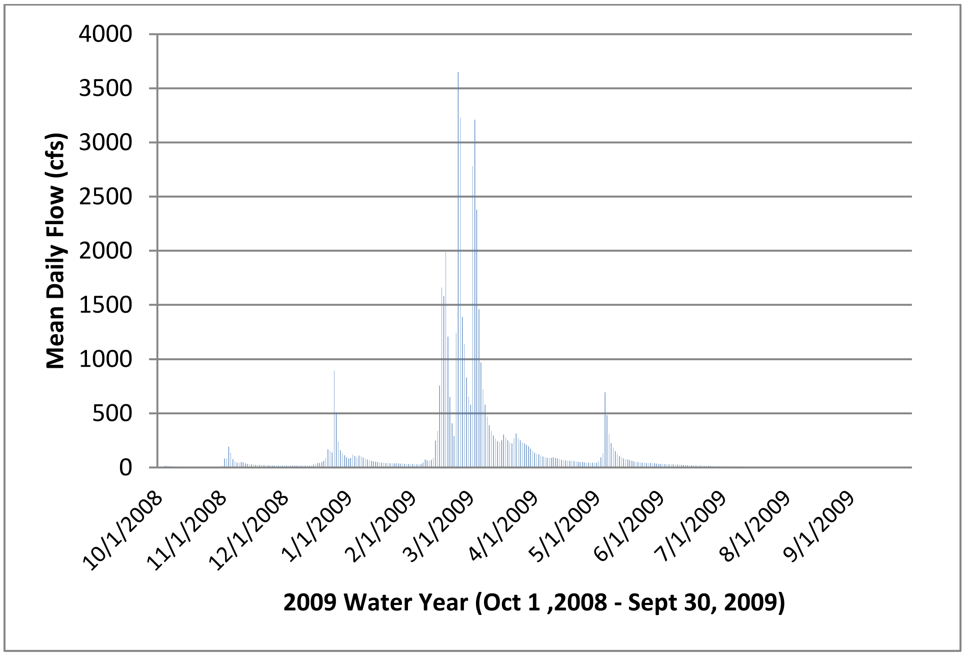

Figure 8. Annual hydrograph for the 2009 water year (Oct 1, 2008 – Sept 30, 2009) at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County, California.

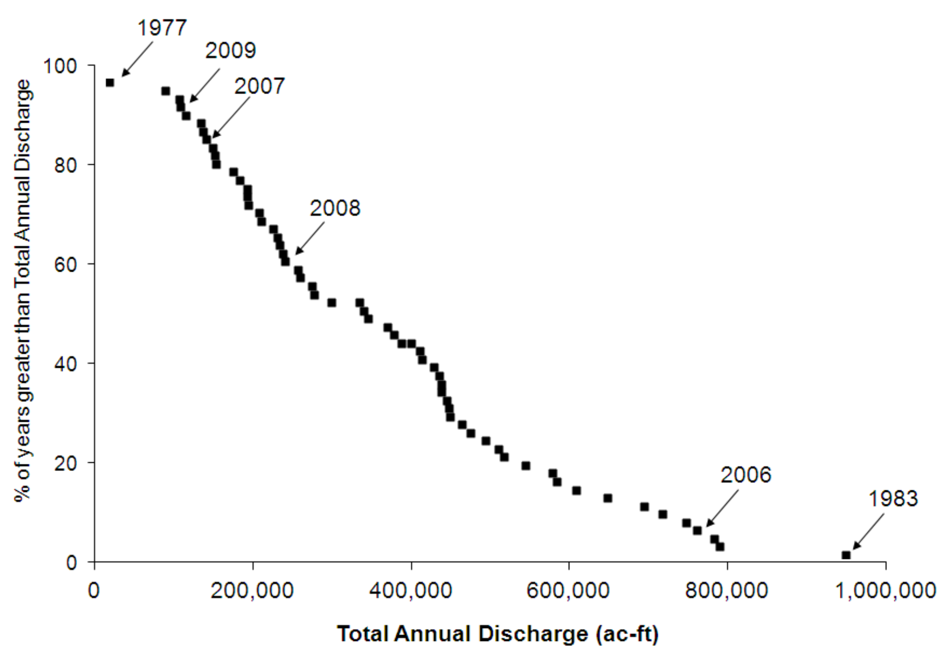

Figure 9. Frequency distribution of total annual discharge for water years 1951 to 2011 at United States Geological Survey stream gauging station 11468000 on the Navarro River near Navarro, Mendocino County, California.

Evaluation of Acreage and Crop Designations

Overall, irrigated agriculture in the Navarro River watershed within the study area totals 3,124 acres (Table 3). Of that area, wine grape vineyards make up about 90%, orchards 7%, pastures 2%, and all other irrigated crops 1%. There has been a major transformation of crop types from orchards to vineyards in the Anderson Valley from mid-1960's to the present time (Figure 10). These changes reflect the dynamic nature of the agricultural marketplace, and also have significant impacts on the agricultural demand for irrigation water.

Table 3. Crop types and area from 2008 in the Anderson Valley, Navarro River watershed, Mendocino County, CA. Source: Mendocino County Agricultural Statistics (Linegar 2008)

Crop Type	Acres	% of Total
Grapes	2790	90%
Orchard	218	7%
Pasture	66	2%
Other	50	1%
Totals	**3124**	**100%**

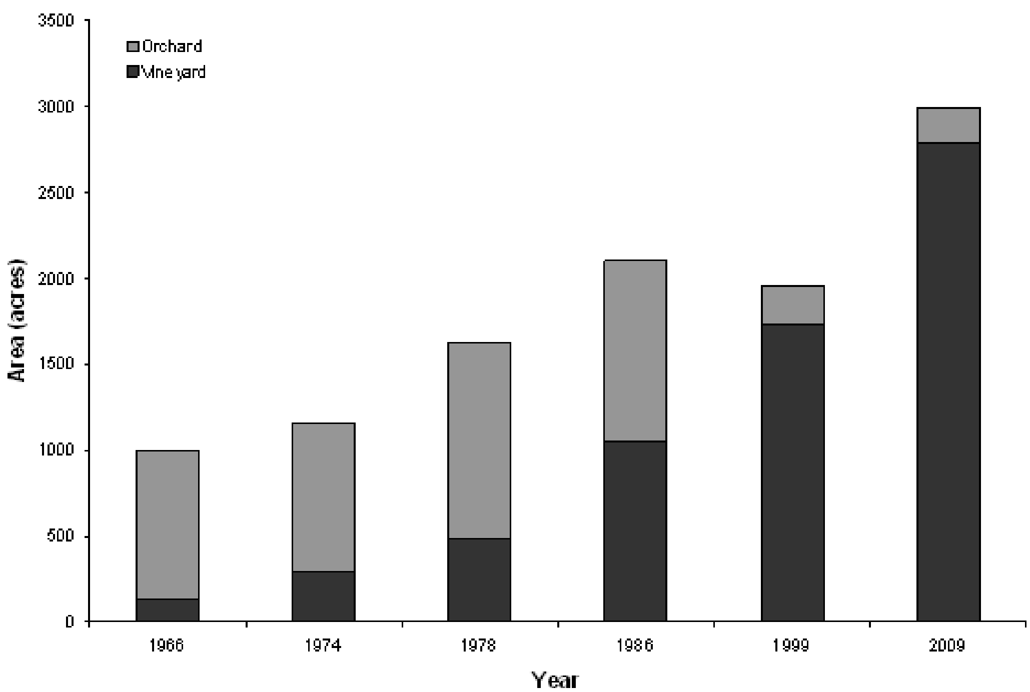

Figure 10: Comparison of orchard and vineyard acreage from 1966-2009 in District 5 Reporting Region (Garcia, Navarro, and some portion of the Gualala River Watersheds). Sources: California Department of Food & Agriculture (CDFA), 1966, 1974, 2008; California Department of Water Resources (CDWR), 1979, 1989.

Grower Surveys

A total of 14 growers representing 1576 acres completed a guided survey on water resources and irrigation management in the study area. Acreage included 1333 acres of grapes, 218 acres of orchards, 3 acres of irrigated pasture, and 22 acres in other crops, or approximately 50% of the irrigated agriculture acreage identified in the study area (Table 4). Individual grower experience with irrigated agriculture in the study area ranges from 10 to 70 years. Respondents' irrigation practices encompassed those employed by other growers within the same area, hence their input may be assumed to represent the irrigation practices in the Anderson Valley and the Navarro River Watershed, and provides for a robust sample rate.

Table 4. Surveyed grower's farmed acreage as % of total irrigated agricultural acreage in the Navarro River Watershed, Mendocino County, California. 2009.

	Vineyard	Orchard	Pasture	Other	Totals
Acreage Farmed by Survey Respondents	1333 (48%)	218 (100%)	3 (5%)	22 (44%)	1576 (50%)
Total Irrigated Agricultural Acreage in Study Area	2790	218	66	50	3124

Nearly 96% of the acreage farmed by the 14 respondents was irrigated (Table 5). Responses provide an anecdotal description of the history of water resource management during the last four decades. Growers consistently identified 1976, 1977, 2000, 2008 and 2009 as years in which meeting crop consumptive use was difficult. Low rainfall years and low pond levels were the two most frequently identified conditions that contribute to this problem. Eight of the 14 survey respondents had changed their irrigation systems, citing multiple reasons for these conversions (Figure 11). The most commonly cited reason was water conservation and the least identified reason was to increase yield.

Responses indicate that growers use a diversity of information sources to make irrigation decisions, and 12 of the participants and respondents had participated in one or more conservation programs, including the Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP), UCCE Water Quality Planning, and Fish Friendly Farming. Respondents cited natural resource stewardship, lower farm costs for energy and water, and personal values and beliefs as "very important" reasons to participate (Figure 12). Providing water for urban growth and development had the most "not important" responses.

It was noteworthy that 98.6% of the vineyard acreage farmed by survey respondents is irrigated and only 1.4% is non-irrigated (Table 5). While these results suggest the strong reliance on irrigation to farm in the Anderson Valley, they may also suggest that growers who rely on irrigation are more motivated to participate in studies of this kind. It is also noteworthy that 50% of the surveyed growers indicated not making changes to their irrigation systems (Figure 11). This is most likely because the system was originally installed as a high efficiency drip system when the vineyard was initially installed, since so much acreage was planted relatively recently.

Table 5. Percent of irrigated vs dry farmed acreage for 14 grower survey respondents in the Navarro River Watershed, Mendocino County. 2009.

	Vineyard		Orchard		Other		Pasture		All Ag	
Irrigated Acreage	1328	98.60%	146	76.40%	21.5	100%	3	100%	1499	95.90%
Dry-farmed Acreage	19	1.40%	45	23.60%	0	0%	0	0%	64	4.10%
Total Surveyed Acreage	1347.5		191		21.5		3		1563	100%

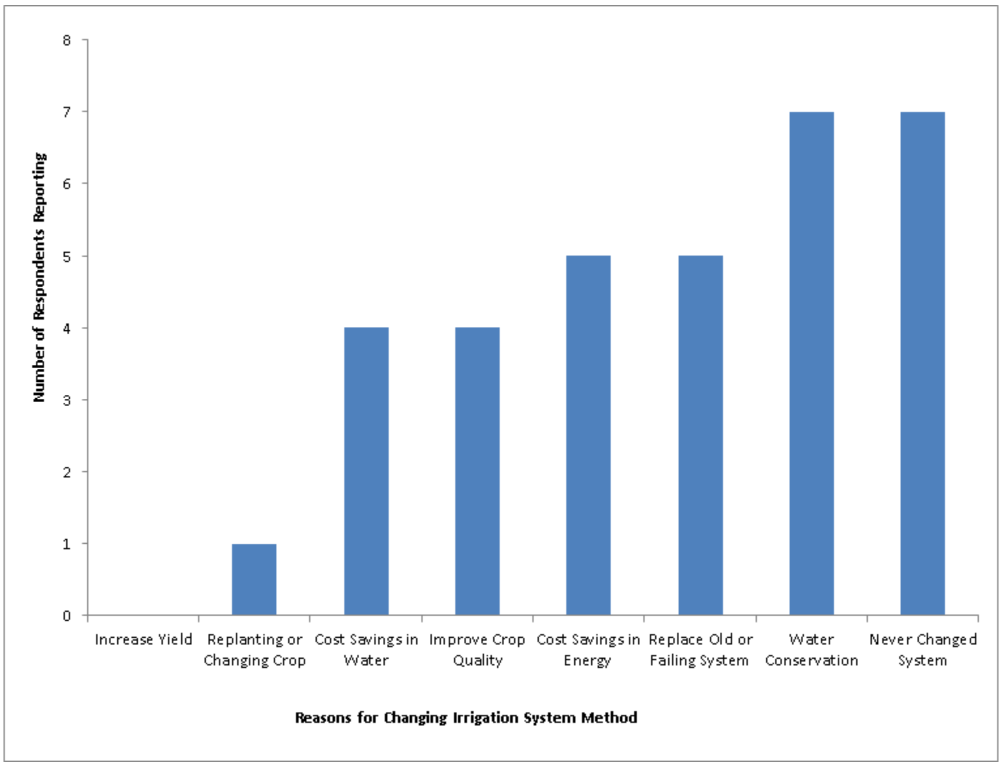

Figure 11. Summary of 14 survey respondents to question about motivation for changing agricultural irrigation systems in the Navarro River Watershed, Mendocino County (2009).

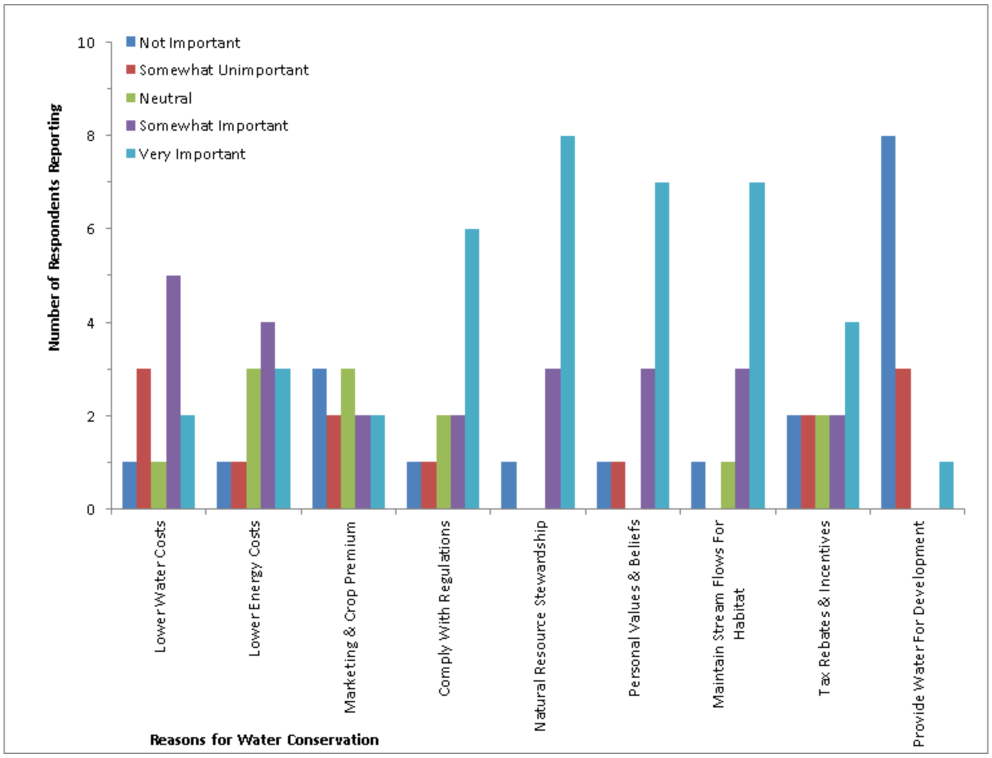

Figure 12: Indication of importance of reasons growers would participate in on-farm water conservation in the Navarro River Watershed, Mendocino County, California (2009).

Irrigation System Evaluations

Survey cooperators were identified to 1) maximize the acreage of irrigated agriculture that could be represented by the study and 2) represent as many of the sub-watersheds as possible within the study area (7 of 8). 26 blocks or fields totaling 116 acres, and representing all 14 respondents, were enlisted in the irrigation system evaluations. A block or field was defined as representing a farm segment that is planted and managed similarly. Blocks are established by being planted with the same variety and on the same planting date. They also are generally managed within the same irrigation system and rarely larger than 20 acres in size.

Distribution Uniformity

System uniformity measured in wine grape vineyards was very good, averaging 90%. Orchard sprinkler uniformity was much lower at 72% (Table 6). System uniformity was not measured for pastures.

Table 6. Distribution uniformity at 26 vineyard sites and 3 orchards in the Anderson Valley, Mendocino County, California (2009).

Crop	Sample Size	Mean	Std Dev	Min	Max
Grapes	26	90%	6.60%	68.70%	96%
Orchards	3	72%	41.40%	41.40%	88%

Available Water Capacity, Crop Co-efficient & Reference ET

Our results show average Available Water Capacity (AWC) in irrigated agricultural lands of the Navarro River Watershed to range from 0.13 – 0.19 (ac-in/in) (Appendix 1). Based on the previously described equation (Equation 2) we calculated irrigation demand to range from 1683-2152 af/yr. This does not include water use for frost protection.

Table 7. Calculated irrigation demand for agricultural lands of the Navarro River Watershed, Mendocino County, California.

			Calculated Irrigation Demand	
Sum of MU (acres)	% of Total (n=3126)	Map Unit (MU) Name	*Low soil H20 contribution (af/yr)*	*High soil H20 contribution high (af/yr)*
647.1	20.7%	Pinole loam, 2-9% slopes	650	521
378.5	12.1%	Boontling loam, 2-9% slopes	411	305
377.8	12.1%	Bearwallow-Wolfey complex, 5-15% slopes	395	319
190.4	6.1%	Feliz loam, 0-5% slopes	184	153
135.6	4.3%	Cole loam, 0-5% slopes	147	115
127.4	4.1%	Ornbaun-Zeni complex, 9-30% slopes	128	108
92.6	3.0%	Perrygulch loam, 0-9% slopes	115	78
90.3	2.9%	Pinole loam, 9-15% slopes	91	73
2039.6	65.2%	Total	2152	1683

Paso Panel measurements yielded crop co-efficient (K_c) values for wine grapes that ranged from 0.49-0.68 (Table 8). These results are consistent with measurements taken by other researchers in coastal California (R.H. Smith & M. Battany Pers. Comm., 2012). For the purposes of this study we are using the average value of K_c=0.59.

Table 8. Paso Panel measurements at 4 locations at Roederer Estate US, Philo, California. 2012.

Date	9/28/2012	9/28/2012	9/28/2012	10/2/2012
Vineyard Name	Roederer 1	Roederer 2	Roederer 3	Roederer 4
Block	PC-T3-PN	PC-TZ-CH	NA	NA
Trellis Type[1]	VSP	DCL	DCL	CS
Row Spacing (ft)	7	8	8	8
Row Orientation	NW-SE	NW-SE	N-S	NW-SE
Full Sun Panel Reading (amps)	1.17	1.2	1.25	1.18
Panel % Shaded	44	57	49	40
Field % Shaded	36	41	35	29
K_c	0.6	0.68	0.59	0.49

[1]Trellis Types: VSP= Vertical Shoot Positioned; DCL=Divided Canopy Lyre; CS=California Sprawl

Cumulative weekly reference evapotranspiration (ET_o) ranged from 0.02 to 0.23 inches with a mean of 0.15 inches during the 2009 growing season (Figure 13). Total ET_o for the 2009 growing season at Roederer Estate US was 32.3 inches.

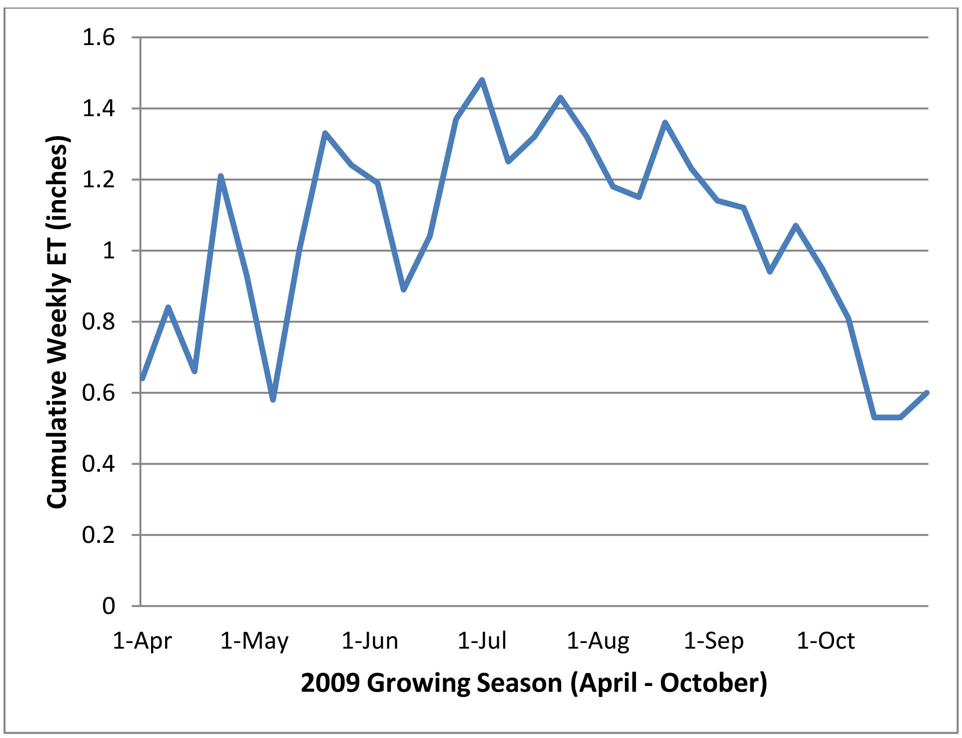

Figure 13. Cumulative weekly ET_o (inches) recorded during the 2009 growing season (April 1 – Oct 30) at Roederer Estate US, Philo, California

Consumptive Use

Calculated values for water applied to meet annual crop consumptive use differed by crop type (Table 9). It was calculated that wine grapes received less than 0.2 acre-feet/acre (afa) on average while orchards received 2.2 afa. This is 33% of the 0.61 afa for wine grapes and 95% of the 2.31 afa for orchards previously measured in the Russian River Watershed (Lewis et al. 2008). This difference may be attributed to lower evapotranspiration rates and smaller canopy sizes in most vineyards in Anderson Valley compared to the Russian River Valley, as well as yearly variability.

Table 9. Calculated water use for irrigated agriculture by crop and use type in the Navarro River Watershed, Mendocino County, California (2009).

Crop Type	Total Acreage	Water Use Type	Volume (af/acre)
Grapes	2790	Consumptive Use	558
		Frost Protection	678
		Total	1236
Orchards	206	Consumptive Use	457
		Frost Protection	0
		Total	457
Pasture	66	Total	132
		Cumulative Water Use	1825

It is important to realize that wine grape growers differed greatly in the amount of water that they applied to their vineyards due to many factors, including variety and trellis system; soil type and depth; irrigation thresholds if they are using Regulated Deficit Irrigation (RDI), and the total amount of available soil moisture. Our grower survey results show the range of water use in vineyards in the Navarro River watershed ranged from 0 (*no applied water*) to 0.7 acre feet (af) during the 2009 growing season (Figure 14). Based on our surveys growers irrigated on average 60 hours per year, mainly between late July and October. Orchards received more water per acre due to larger canopy sizes (higher ET). We took a conservative approach in calculating total water demand by retaining the breadth of water use patterns reported in grower surveys.

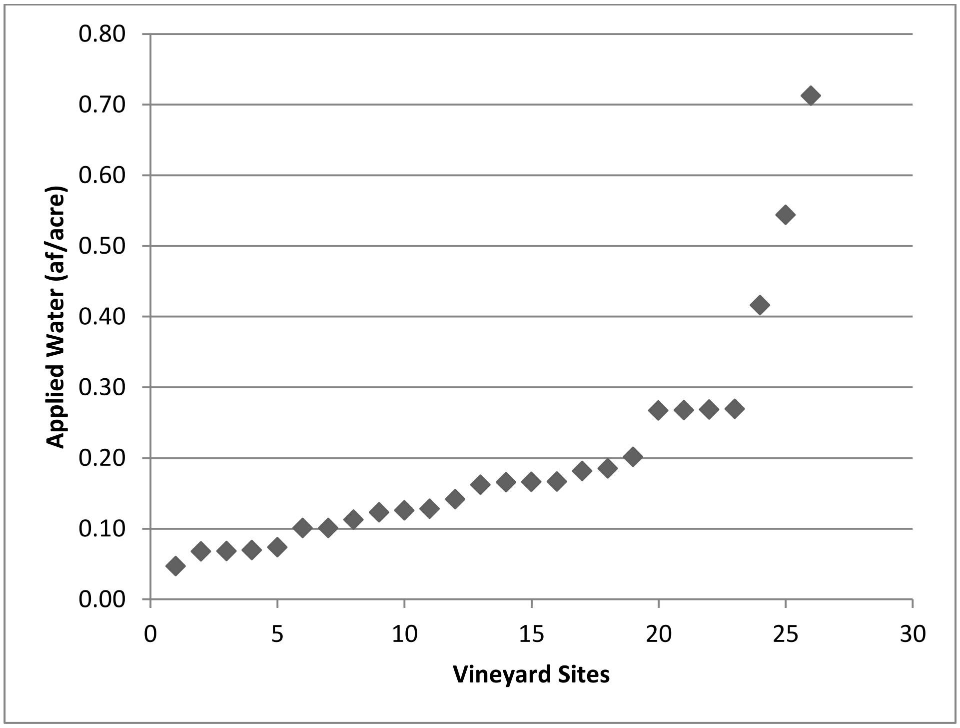

Figure 14. Scatter plot of actual water use reported by managers of 26 vineyard sites in the Navarro River Watershed, Mendocino County, California (2009).

Frost Protection

It is important to note that most (81%) vineyards in our study had an active frost protection system in place due to the high risk of frost in the Navarro River Watershed (Table 10). By comparison, only 42% of orchards had active frost protection. Most vineyards without frost protection are located in higher elevation sites where cold air, likely to cause freezing, does not settle during the typical spring inversions that happen in radiant freezes. Fans and micro-sprinklers are used in sites where there is limited water availability for site protection from freezing.

Table 10: Frost Protection Methods and Practices among 14 Surveyed Growers in the Anderson Valley, Mendocino County, California (2009)

	Vineyard		Orchard		Other	
Frost Protection Method	*Acreage*	*% of total*	*Acreage*	*% of total*	*Acreage*	*% of total*
No Protection	255	19%	111	58%	19.5	91%
Overhead Sprinkler	947	71%	80	42%	2	9%
Fan	70	5%	0	0%	0	0%
Micro-sprinkler	67	5%	0	0%	0	0%
Totals	1339	100%	191	100%	21.5	100%

According to our survey results, 91% of frost protected vineyard acreage is covered by water from off-stream storage (Table 11). The remaining 9% of acreage is frost protected from direct diversion sources. In 2009, growers averaged about 40 hours of frost protection during 5 events which is considered somewhat average. In the past decade, there have been some years with no frost events, and in some sites in 2008, there were over 20 frost events.

Table 11. Summary of grower responses regarding sources for agricultural water use in the Navarro River Watershed, Mendocino County, California (2009)

	Farmed Acreage	% of Total
Direct Diversion	136	9%
Off-stream Storage	1331	91%
Total	1467	100

It is important to understand that the water applied during frost season is also utilized by vines for meeting evapotranspiration demands early in the season, and in frosty years, the vineyards often start the growing season near field capacity (*the soil is completely filled with all the water that it can hold against gravity*). It other cases, some vineyards have subsurface drains in which leached (*excess*) water is recovered through sumps equipped with pumps that return the water to the irrigation pond.

Irrigation Water Sources

Growers have recognized the problems with direct diversions from surface waters of the Navarro watershed associated with endangered species and dewatering fish habitat. Many have developed ponds and other water storage to eliminate direct diversions (Table 12). It is also noteworthy that many of the survey respondents reported employing multiple types of water capture and storage systems to meet their irrigation needs. This approach diversifies the growers' dependence on any one particular system and suggests a willingness to try different solutions.

Table 12. Summary of grower responses regarding sources of agricultural water for those growers using off-stream storage in the Navarro River Watershed, Mendocino County, California (2009)

Reservoir Water Source	Storage Volume (af)
Surface Water Diversion	134
Sub-surface Drainage	274
Captured rainfall & sheet flow	411

Air photo mapping and GIS analysis of the Navarro River watershed indicated 165 ponds with a total surface area of 140 acres and average individual pond surface area of 0.8 acres in 2009. Some are used for wildlife, livestock and aesthetics rather than irrigation. These systems are usually shallow perforated plastic pipe that empty into cisterns from which water is pumped into lined ponds. Since soil profiles reach saturation most years in Anderson Valley (Rittiman and Thorson 1993; Schott 2012), this is a legal and viable way to create an irrigation water source as long as the water is not being drained from a surface water course (O'Hagen 2013). At this point, these systems are considered ground water, and are not regulated by the SWRCB. They do require a Mendocino County Grading Permit and engineered plans prior to construction.

Potential Future Irrigated Agricultural Land

Table 13 shows the possible extent of future irrigated agricultural land use in the Navarro River Watershed based on the land suitability model described above. Considering the simple inputs of *current land cover, slope and soil suitability,* the model suggests there are ~2650 acres of land suitable for irrigated agriculture development at <10% slope threshold, and ~4650 acres at <20% slope threshold. Variation from acreage totals reported earlier result from data derived from aerial mapping versus those reported in county agricultural statistics and should be considered within a reasonable range of variability.

Table 13. Current existing & potential future irrigated agricultural acreage (at <10% & <20% slope thresholds) in the Navarro River Watershed, Mendocino County, California (2009)

Sub-Watershed Name	Total Acres	Total Existing Vineyard Acres	Total Potential *Additional* Agricultural Acres (<10% slope threshold)	Total Potential *Additional* Agricultural Acres (<20% slope threshold)
Mill Creek	7740	267	173	374
Floodgate Creek	3836	253	145	374
Hendy Woods	7774	847	477	856
Upper Navarro River	3759	43	84	192
Lower Indian Creek	6946	131	193	335
Con Creek	7462	283	460	885
Robinson Creek	8960	622	904	1153
Middle Rancheria Creek	9316	0	81	284
Anderson Creek	4867	21	8	23
Maple Creek	6986	63	129	173
Totals	67646	2531	2652	4649

Water Demand

Based on all surveys and data gathered total agricultural water use was estimated to have been approximately 1825 af in 2009 in the Navarro River Watershed. This averages approximately 0.5 afa of wine grapes, 2.3 afa of orchard and 2.2 afa per acre of irrigated pasture. Potential future land suitability results along with grower reported water use results were used to calculate potential future agricultural demand for water (Table 14). If all potential land is converted to vineyard cumulative water demand could be expected to increase an additional 1,326-2,325 af/yr depending on development patterns. Potential future water demand could be significantly different depending on many factors including crop selection, local land use policy, and ownership patterns among others.

It is an unlikely scenario to expect all the potentially suitable land to be developed to irrigated agriculture. The spatial model and extrapolation results provide a mechanism for explicit quantitative consideration of potential future land use patterns. These results allow us to identify possible minimum and maximum land use changes and use them to inform our policy discussions.

Table 14. Potential future additional water needs to support new agricultural development (vineyards or orchards) in the Navarro River Watershed, Mendocino County, California (2009)

		<10% slope threshold		<20% slope threshold	
Crop	Current Water Use Rates (afa)	New Acres	Water Needed (af/yr)	New Acres	Water Needed (af/yr)
Vineyard	0.5	2,652	1,326	4,649	2,325
Orchard	2.2	2,652	5,834	4,649	10,228

Water Rights

There are 264 licensed and permitted water rights in the Navarro River Watershed as of 2012 with a cumulative annual face value of 9635 acre feet (af) of water (SWRCB 2012). *Face value* of a water right represents the maximum possible diversion amount for a given right (SWRCB 2013). This is considerably more than is presently being used to irrigate agricultural crops. Many of these rights are probably for springs and other diversions including livestock, domestic, some industrial and public uses.

In 2009 there were 88 licensed, permitted, or pending water rights for irrigation use in the Navarro River watershed. These water rights had a combined face value of 3645.6 af, with 1789 af to direct diversion mostly between March 1 and November 1 of each year and 1856.6 af going to storage ponds mostly between November 1 and June 1. It was not in the scope of this study to evaluate and categorize all of the uses, but certainly there has been a fairly large volume of water licensed and permitted by the SWRCB in the Navarro River Watershed.

Though a water right may be licensed, water may not always be available for use. In some years flow rates are low or nonexistent. While there may be opportunities for further water rights, especially for small ponds and storage of water during high winter flows (O'Hagen 2013), many creeks and streams are fully appropriated already so any new water rights in those locations are unlikely. Finally, there are already restrictions on diversion rates based on date and flow (Table 14).

Table 14. Maximum diversion rates and average river flows (at the Navarro River gauge) at different times of the year for known water rights in the Navarro River Watershed, Mendocino County, California (SWRCB 1998).

	November-March	April-May	June-October
Authorized Rate (CFS)	21.7	32	6.1
Average River Flow (CFS)	1,080	312	27

It is important to recognize that stream flows in the Navarro River are highly variable. As a result, some years there may be ample water available for both agricultural needs and fish habitats. In other years seasonal rainfall variability may result in stream channel dewatering during certain parts of the year. Close monitoring and management of water levels in the watershed, including main stem and tributaries, is necessary to ensure optimal allocation of resources.

Riparian water rights are based on proximity to water ways. Water can only be diverted under a riparian right when that water is used on land that drains back to the lake, river, stream, or creek from which the water was taken. Only the natural flow of water can be diverted under a riparian right. A riparian right exists on the smallest piece of land that touches a water source. Until recently, riparian water users did not have to report their water use. This is now changing, and self-reporting is required (SWRCB 2013). Although not in the purview of this effort, further studies are needed to assess the impact of riparian rights and water use on the Navarro River Watershed.

Discussion

Agriculture is an important part of the social and economic makeup of the Navarro Watershed. The total water use during 2009 for all irrigated agriculture was estimated to be 1,530 acre-feet (af). In the same year, total annual discharge measured at the Navarro River USGS Gauge was 107,000 af. On that basis, agricultural water use in the Navarro River water shed was equivalent to 1.4% of the water that flowed out of the water shed. 2009 was considered a low river flow year, and in years such as 2006 when peak flow reached around 760,000 af, agricultural water use of 1,825 af would represent only 0.2% of the Navarro River's flow. Based on these figures, agriculture uses a modest amount of the water that falls into the

Navarro watershed. However, this view is a little simplistic in that the timing of irrigation can have dramatic effects on the watershed.

There is concern that water is being used for agriculture at a time during the year when surface water flows are very low. In 1975, the Navarro River reached a record low of 0.5 cubic feet per second (cfs). At such low flows, any diversions could easily have a negative impact on fisheries by causing dewatering and loss of habitat for the various salmonid life stages and other organisms dependent on surface waters. Most wine grape growers have addressed this concern by developing alternatives to direct diversions from surface waters during the growing season, and have focused on developing off stream ponds that are filled by surface (rain fall) or subsurface flow (drain tile and sumps), or wells.

Additionally, growers have taken steps to conserve water by improving their frost protection practices (closely monitoring dewpoints and temperatures, valving so that only the blocks that need frost protection are turned on), and implementing Regulated Deficit Irrigation to control vine and fruit growth to optimize wine quality while saving water. Further evidence of growers' interest in water conservation is shown in the responses to grower surveys. In Figure 11, a large percentage of growers changed irrigation systems to conserve water. In Figure 12, the three top reasons rated as "very important" for participating in water conservation programs included natural resource stewardship; personal values and beliefs; and maintain stream flows for habitat. These results suggest that respondents are sensitive to conserving water as an important part of maintaining a healthy watershed.

It is likely that additional agricultural acreage will be added to the Navarro Watershed to accommodate favorable economic demand for wine grapes and wine. The most likely places where growth will be seen are in the Hendy Woods and Robinson Creek sub watersheds. These areas are already the most densely planted areas, and infrastructure exists for some operations to expand including roads, nearby processing facilities, access to properties and zoning. However, water development would remain an issue as it is unlikely that very much new water could be appropriated from surface waterways. The most viable approach would be to have subsurface water collection, sumps and lined ponds to collect rain and excess water. This would be expensive in most cases, but would still be feasible. The amount of water that would have to be developed for orchards makes future plantings less likely.

Conservation and Alternatives

Meeting the agricultural, residential and environmental water needs within the study area will require a combination of solutions and options for conserving and securing additional sources of water. These will include continuing on-farm conservation and water-use efficiency, water harvesting and storage, more ponds and water impoundment at peak flows from surface water, and other potential policy changes and more novel programs to afford winter storage when precipitation and watershed flows are at their peak. Vineyard design may also change, with growers utilizing more drought tolerant rootstocks, higher fruit wires in the trellis system (making the vines less prone to freezing by as much as 1 degree F), valving to isolate the coldest part of the vineyard so that the entire vineyard isn't frost protected all at once, and better monitoring for frost incidence by having more remote sensing for temperature and dew point.

Policy changes will be necessary if increasing winter storage is going to be one of the viable alternatives, including changes to the pending Policy for Maintaining In-stream Flows in Northern California Coastal Streams (SWRCB, 2007) which discourages private ponds to capture winter flows. There are also creative programs in other agricultural areas of California in which the underlying approach is to provide storage infrastructure and appropriative water rights in place of riparian rights and summer diversions. These approaches could be replicated in the study area to provide growers with alternative sources of water.

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Appendices

Appendix 1. Available Water capacity for dominant soil types in irrigated agricultural lands of the Navarro River Watershed, Mendocino County, California.

Sum of MU (acres)	% of Total (n=3126)	Map Unit (MU) Name	Available Water Capacity	
			low (ac-in/in)	*high (ac-in/in)*
647.1	20.7%	Pinole loam, 2-9% slopes	0.14	0.19
378.5	12.1%	Boontling loam, 2-9% slopes	0.12	0.19
377.8	12.1%	Bearwallow-Wolfey complex, 5-15% slopes	0.13	0.18
190.4	6.1%	Feliz loam, 0-5% slopes	0.15	0.19
135.6	4.3%	Cole loam, 0-5% slopes	0.12	0.18
127.4	4.1%	Ornbaun-Zeni complex, 9-30% slopes	0.14	0.18
92.6	3.0%	Perrygulch loam, 0-9% slopes	0.08	0.18
90.3	2.9%	Pinole loam, 9-15% slopes	0.14	0.19
2039.6	65.2%	Averages	0.13	0.19