PILOT STUDY OF GROUNDWATER CONDITIONS IN THE JOY ROAD, MARK WEST SPRINGS, AND BENNETT VALLEY AREAS OF SONOMA COUNTY, CALIFORNIA

September 17, 2003

A Report Prepared for:

Sonoma County Permit Resource Management Department
2550 Ventura Avenue
Santa Rosa, California 95403

SUMMARY OF FINDINGS
WATER RESOURCES MANAGEMENT
DATA ASSESSMENT
SONOMA COUNTY, CALIFORNIA

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1. INTRODUCTION

1.1 BACKGROUND

Large areas of Sonoma County are identified as water scarce. Although the amount of annual rainfall in the County is fairly generous, the availability of groundwater in the water scarce areas is limited, primarily by geology and topography. As the County's population, industry and agriculture have grown, more development has taken place in these water scarce areas. Consequently, there has been an increasing demand for groundwater. In recent years citizens have reported that groundwater conditions are changing and that further development may adversely affect groundwater availability.

In response to these concerns, the County of Sonoma has sought a greater understanding of groundwater conditions in the water scarce areas. The County retained Kleinfelder to conduct pilot studies of groundwater conditions in three special study areas. These areas were chosen based on the findings of Kleinfelder's previous study. In that study Kleinfelder plotted the location of building permits issued in the past five years for new wells or other projects dependent on the availability of groundwater. The plot revealed several locations within the water scarce areas of the county where there has been a concentration of building and well construction. These were identified as *Areas Experiencing Development Pressure*. The Joy Road, Mark West Springs, and Bennett Valley areas were selected for further study because they have had the densest concentrations of water dependent building.

1.2 PROJECT OVERVIEW

This study used existing data to explore the factors affecting the availability of groundwater in the three special Study areas. The data were used to characterize the geohydrologic setting, land use, and water demands in each study area and describe apparent constraints on groundwater availability. A statistical analysis of data from driller's boring logs was used to evaluate trends in the depth to water and completion depth of new wells over time. Finally, conclusions based on review of this work were used to identify questions for further study and to develop recommendations to address them. It is important to keep in mind that this study was limited by the availability of existing data and did not include fieldwork.

The study began with the establishment of study area boundaries. The boundaries were set to meet the objective of the study, which, basically, is to understand how changes in one component of a natural system affect other components within that system. In this case the change is increased pumping, the natural system is the water cycle, and the affected component is the occurrence and availability of groundwater. To be efficient each study area had to be large enough to include the causes and effects of change but no larger. Setting larger boundaries would waste investigative effort studying unaffected parts of the system. The smallest functioning unit in the water cycle is a watershed, an area bounded by a divide and draining inwardly to one outflow point. Many factors within a watershed can significantly affect groundwater but conditions in adjacent watersheds generally have little effect. Ideally, the Study Area boundaries would be limited to the smallest single watershed the completely encloses the *Area Experiencing Development Pressure*. This was ideal was achieved for the Bennett Valley Study area but had to be compromised in the Joy Road or Mark West Study areas. In the Joy Road Study Area the *Area Experiencing Development Pressure* is situated along a series of ridges that separate five small watersheds. In the Mark West Study Area, Mark West Springs Creek carries water from upstream watersheds through the Study Area. USGS 7.5 minute topographic maps were used as a base for delineating the boundaries and as the primary reference for place and feature names. The Study Area boundaries for the Joy Road Study Area are shown on Plates 1, and 2, for Mark West on Plates 9, and 10, and for Bennett Valley on Plates 17, and 18.

Once the boundaries were established Kleinfelder researched existing data to develop a better understanding of the conditions affecting the availability of groundwater in the special study areas. Kleinfelder's research focused on factors that are key to understanding groundwater conditions including:

- Geology
- Climate
- Land use patterns
- Development history

Geology is considered the most important factor because it is the medium in which groundwater occurs. Geologic conditions vary from place to place and some geologic materials hold a great deal of water and others do not. Geology also affects the depth, distribution, and quality of groundwater. Where and how much of that groundwater is used are functions of land use. Residential, agricultural, and other uses all have widely different demands on groundwater resources. Discussions of the factors affecting the availability of groundwater in each of the study areas are included in Sections 2, 3, and 4.

Kleinfelder prepared GIS maps and databases to represent and analyze the collected data. GIS shape files and data tables were created in ArcView 8.3 format using orthophotography, parcel maps, street maps and elevation contours from PRMD's GIS database. Copies of Kleinfelder's maps and data are included with this report on a compact disc.

Kleinfelder also evaluated historical groundwater information. Ideally, we would look at historic records of conditions in existing wells to see if water levels and well yields are changing with time. However, there are no Department of Water Resources monitoring wells near the study areas and monitoring of private wells is not required in Sonoma County so, unfortunately, no such data is available. Another way is to look at the depth to water and completion depth of new wells over time. Are drillers digging deeper and deeper with time? A statistical evaluation of well log data is included in Section 5.

Review of the collected data and maps has led to a number of conclusions that are presented in Section 6. Although these conclusions provide new insight, there remain a number of unanswered questions. Chief among them are "How are conditions changing in individual wells?" and "How much water can be sustainably supplied?" Answers to these questions would require a more complete understanding of groundwater conditions based on field observations and aquifer testing. Kleinfelder's suggestions for further study, including fieldwork, are included in Section 7.

2. JOY ROAD STUDY AREA

2.1 STUDY AREA BOUNDARIES

The Joy Road Study Area is about 4 miles long and 3 miles wide and covers about 9 square miles. The boundaries and principal features of the Study Area are shown on Plate 1. Because development pressures in the Joy Road area are occurring along the ridge tops, the boundaries of the Study Area had to include more than a single watershed to envelope the developing areas. The western boundary of the Study Area roughly follows Fitzpatrick Lane along the ridge between Coleman Valley and Fay Creek. The southern boundary crosses Fay, Thurston, and Nolan creeks at the base of the hills just north of Bodega Highway. The eastern boundary follows the ridge top east of Nolan Creek to the highpoint and then down a ridge southeast of Bittner Road almost to the town of Occidental. The northern boundary generally follows Coleman Valley Road from Occidental to its intersection with Joy Road.

2.2 TOPOGRAPHY

The topography of the Joy Road area is characterized by broadly arching ridges dissected by steep-sided creek bottoms. The ridges run predominantly from north to south but run in an easterly direction toward Occidental in the northeastern section of the Study Area around the headwaters of Salmon Creek. The topographic features of the Study Area are illustrated on Plates 1 and 2. The Maximum elevation in the Study Area is about 1100 feet above mean sea level, and minimum elevation is about 100.

2.3 DRAINAGE

Fay, Thurston, Nolan and many smaller unnamed creeks drain the Joy Road Study Area. All of these streams are tributaries of Salmon Creek, which begins near the intersection of Joy and Bittner Roads and flows to the northeast toward Occidental. It turns just short of the town and flows away from the Study Area to the southeast past Freestone and then west along the Bodega

Highway. It runs along the southern boundary of the Study Area for a short distance near the mouth of Fay Creek.

2.4 GEOLOGY

The bedrock of the Joy Road Study Area consists of the Franciscan and the Merced Formations and a relatively small outcropping of the Great Valley Sequence. A map showing the generalized geology of the Study Area is shown on Plate 3.

2.4.1 Franciscan Formation

The Franciscan Formation is composed of marine sediments and volcanic rocks. These rocks are intensely sheared, folded and faulted. Near the center of the Study Area just east of Joy Road, the Franciscan Formation outcrops with members of the Great Valley Sequence, which consists of sandstone, shale, siltstone, and conglomerate.

The Franciscan Formation is mostly a tight, non-porous rock unit and groundwater occurs only in secondary openings such as joints, fractures, and shear zones. As a result, well yield is typically low, 1 to 3 gallons per minute (gpm), although wells with yields as high as 68 gpm are recorded (Ford, 1975).

2.4.2 Merced Formation

The Merced Formation is composed of fine to very fine-grained sandstone with many fossiliferous zones. These sediments were deposited on top of the eroded surface of the Franciscan Formation in a calm inland sea. The Merced is exposed on about 54 percent of the Study Area. About 42 percent occurs on the ridges, the rest is at lower elevations in the southeastern portion of the Study Area east of Bodega and is not accessible by wells on the ridges. Along the ridges, the thickness of the Merced Formation ranges from tens of feet to more than two hundred feet. Its thickness is likely much greater in the valley and along the base of the hills north of the Bodega Highway.

U.S. Department of Agriculture data (1950) indicates that the Merced Formation in the area southwest of Sebastopol has an infiltration rate of 0.7 acre-feet per acre per day. This is a relatively rapid rate and it suggests that efforts to enhance recharge could be very productive.

In the rocks of the Merced Formation, spaces between the grains of sand store a great amount of water that flows easily into wells. The formation produces large amounts of good quality water. Yields range from 20 to 1,000 gpm with minimal draw-down (Ford, 1975).

2.4.3 Alluvium

Sediments eroded from the surrounding hills have been deposited in unconsolidated deposits along Salmon, Fay, and Thurston, Creeks where the grade is shallow. These sediments are highly variable in composition and may be as thick as 150 feet.

According to Ford (1975) well yields are highly variable in the alluvium. He reports yields ranging from 10 to 140 gpm. Water quality from alluvial sediments is generally of good quality.

2.5 PRECIPITATION

Rainfall in the Joy Road area has been recorded by a number of residents including some who collect data for the National Oceanic and Atmospheric Administration (NOAA) and other government agencies. The data collectors willingly supplied copies of these records to Kleinfelder. The data are summarized in Appendix A along with data from NOAA stations in Occidental and Graton. There is a considerable variation in annual rainfall from station to station suggesting the presence of a number of microclimates within the Study Area. In some years rainfall totals vary by as much as 30-inches between stations. The average of annual precipitation recorded at all stations is about 55-inches per year and varies from less than 20 (1976) to 91 (1982) inches per year.

The total volume of water that rains on the Joy Road Study Area in an average year is about 26,750 acre-feet (8.7 billion gallons). The input ranges from about 10,049 acre-feet (3.2 billion gallons) in the driest year to 43,546 acre-feet (14.1 billion gallons) in the wettest.

2.6 RUN-OFF

Stream flow data is available from a stream gauge in Salmon Creek about a half mile northwest of Bodega. Daily mean stream flow values, in cubic-feet per-second were collected from August 1, 1962 to October 1, 1975. The drainage area above the gauge is 15.7 square miles, including the 8.9 acres of the Study Area. The Study Area accounts for about 60 percent of the total drainage area. The stream flow data is included in Appendix B.

2.7 EVAPOTRANSPORATION

Evapotransporation (Et) data are not available specifically for the Joy Road Area. However, the California Irrigation Information System produces data representing conditions in the north coast valleys. The data is collected from stations in Healdsburg, Santa Rosa, Windsor, Petaluma, Bennett Valley, and Valley of the Moon as well as several stations in Mendocino Counties. The evapotransporation, precipitation, and other relevant data from the Sonoma County stations are summarized in Appendix A.

2.8 LAND USE

The principal use of land in the Joy Road Study Area is residential. Agricultural uses, primarily vineyards, also occur. Historically the area was used for timber harvest and then for apple orchards. Some timber harvest still occurs in the area but all but a few of the apple orchards have been removed or abandoned.

2.9 RESIDENTIAL LAND USE

As of 2000 there were 323 property owners with permanent addresses at lots in the Joy Road Study Area according to Metroscan. Residential development occurs almost exclusively on the broad ridge tops of the Study Area. A map of structures visible in 2000 aerial photography illustrates this (Plate 4). Despite minimum lot size requirements, steep slopes limit the availability of suitable building sites and force the concentration of homes on the ridges. The resulting concentration of housing can be seen in the density distribution map shown on Plate 5.

2.10 HISTORIC RESIDENTIAL USE

As a basis of comparison, Kleinfelder compared the number of structures visible in aerial photographs from 2000 to the earliest complete coverage available. The dates and areas covered by historic aerial photographs of the Study Area are shown on Plate 6. The earliest photos for which complete coverage is available were taken in 1980. However, photos from 1953 picture most of the southern portion of the Study Area. 47 percent of the structures visible in 2000 are located within the footprint of the 1953 photos. There are 43 structures visible in these early photos. In 2000 there were 172 structures visible in the same area. In the 47 years separating the two photos, 129 structures were constructed. This represents an annual rate of 2.7 new structures per year.

The Joy Road Plan (Sonoma County Planning Department, 1974) notes the presence of 256 households within an area of 6,984 acres that includes the Joy Road Study Area. Assuming that the distribution of households is proportional, there were about 210 households in the Study Area in 1974. According to Metroscan data, there were about 323 households in the Joy Road Study Area in 2000, an increase of 113 households or, about 4.3 households per year.

The plan also notes that there were 434 parcels of land in 1974, roughly 359 in the Study Area. Assessor's records from 2000 indicate that there were 466 parcels in the Study Area. Since 1974 the number of parcels within the Study Area has increased by 107 parcels or about 4 parcels per year.

2.11 CURRENT RESIDENTIAL WATER DEMAND

On average, Northern California households use from ½ to 1 acre-feet of water per year. An acre-foot is slightly less than 325,829 gallons. Using this assumption, the 323 permanent households of the Joy Road Study Area can be expected to use from 162 to 323 acre-feet (52 to 156 million gallons) of water per year.

2.12 HISTORICAL RESIDENTIAL WATER DEMAND

Increase in water demand should be proportional to residential growth. If water consumption has grown at a rate comparable to the increase in structures (6.3 percent per year) and the consumption rate per household has not changed, the total consumption has grown from between 22 to 43 acre-feet (7 and 14 million gallons) per year in 1953 to the current rates noted above.

The Joy Road Plan (Sonoma County Planning Department, 1974) indicates that in 1974 there were about 210 households in the Joy Road Study Area. At ½ to 1 acre-foot per household per year, the residential water demand in 1974 was between 105 and 210 acre-feet (34 and 68 million gallons) per year.

2.13 FUTURE RESIDENTIAL USE TRENDS

The Sonoma County Permit and Resource Management (PRMD) Department estimates that the Joy Road Study Area is developed to about 70% of the maximum build-out allowable by zoning. The department estimates that 159 units can still be built, 131 of which will be single units on existing vacant lots and the remainder will be on lot splits. These numbers do not take into account the possibility of second units constructed on developed lots. Mr. Carr cautions that the estimates are based on assessor files, which might undercount existing units and therefore undercount potential units.

If the remaining 159 potential units are developed and water use rate per household remains constant, the total water demand will increase by as much as 159 acre-feet (51 million gallons) per year.

2.14 AGRICULTURAL USE

Active commercial agriculture in the Joy Road Study Area is limited in size and is composed almost entirely of recently planted vineyards. Analysis of aerial photographs indicates that, in addition to vineyards, there are a few relatively small plots that appear to be used for production of truck crops. Many former apple orchards are still apparent in aerial photos, but most do not appear to be actively farmed. The distribution of cultivated land is shown by crop type on Plate 7.

Vineyards of the Joy Road Study Area occur primarily on former grasslands on Fitzpatrick and Taylor lanes. The total area devoted to vineyards in 2000 was about 80 acres.

2.15 HISTORIC AGRICULTURAL USE

Land use in the Joy Road Study Area was almost entirely agricultural until the mid 1960s. Apples were the primary crop grown. Other agricultural activities included livestock grazing and timber harvesting.

Vineyards are a fairly new activity in the Joy Road Study Area. Of the 80 acres planted in 2000, just 30-acres were present in 1990. Only 21-acres of vines were apparent in aerial photos from 1980, all of them along Taylor Lane.

2.16 CURRENT AGRICULTURAL WATER DEMAND

According to Sonoma County Farm Adviser, Rhonda Smith, the amount of irrigation water applied to vineyards in Sonoma County ranges from none to nearly 8 acre-inches per acre per year. The amount varies with the proximity of the vineyard to riparian zones, the depth, permeability and holding capacity of the soil, and the degree of slope on which the vineyard is planted. In Smith's experience 90 percent of Sonoma County vineyards apply 4-acre-inches per year or less. Irrigation requirements in the Joy Road area are likely much less due to marine influences, primarily summer fog. However, to be conservative Kleinfelder used this figure to estimate total vineyard demand. At this rate the Joy Road vineyards apply 27 acre-feet (8.7 million gallons) of water per year. The actual source of this water is not presently known but is assumed to be from wells near the vineyards.

There does not appear to be any active farming of the Joy Road apple orchards. Even if some orchards are still active, irrigation water was not typically applied to apples in the west county area.

The irrigation demands of truck crops vary greatly by crop growing season and site conditions. As a conservative estimate, Kleinfelder assumed that the small truck crop plot within the Joy Road Study Area apply 6 acre-inches per year. At this rate, the truck crops consume about 1.5 acre-feet (501 thousand gallons) per year.

In total, the agricultural water demand in the Study Area is estimated to be about 28 acre-feet (9.2 million gallons) per year.

2.17 HISTORICAL AGRICULTURAL WATER DEMAND

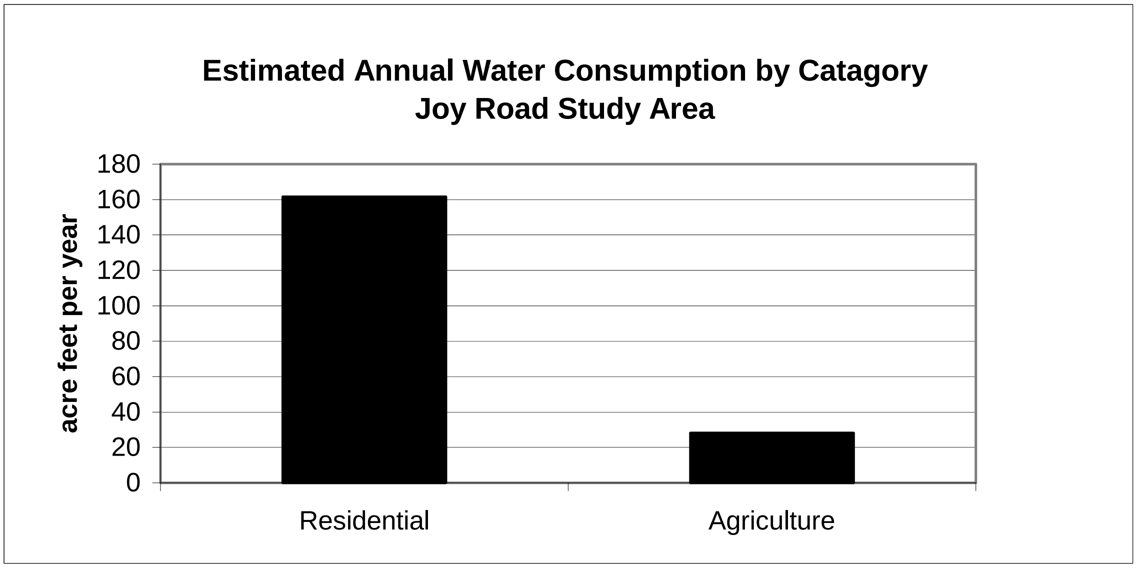
Past agricultural use of the Joy Road Study Area was more intensive than it is today. In the 1940s and 1950s, about 143 acres were cultivated, 44 percent more than 2000.

2.18 FUTURE AGRICULTURAL TRENDS

According to the Sonoma County Farm Advisors office, vineyard development in the west county can be expected to grow. Ultimately, the area used for vineyard will be controlled by topography, geology, the availability of water, and competition with residential and other uses.

2.19 COMPARATIVE WATER USE

A comparison of water use within the Study Area is shown by category on the chart below:



2.20 CONSTRAINTS ON GROUNDWATER AVAILABILITY

The principal constraint on the availability of groundwater in the Joy Road Study Area is the underlying geologic framework of the area. About 56 percent of the Study Area rests on the Franciscan Formation, which typically has yields of less than 3 gpm. A list of lots with water availability problems was compiled by a citizens group of Joy Road residents. The group identified lots with no water and lots that seasonally run dry. A comparison of the location of these properties relative to the bedrock geology shows a strong correlation between water availability and geology. Of the 11 lots with no water, 5 appear to be on Franciscan bedrock and the other 3 are on the Merced Formation in areas where it appears to be less than 100 feet thick (Plate 8). Maps with greater detail are needed to evaluate this relationship.

The topography of the Joy Road Study Area constrains the availability of groundwater in a number of ways. Steep slopes and canyons encourage run-off and limit the area suitable for building. This has forced most construction onto the rounded ridge tops resulting in the concentration of homes and wells in narrow bands that parallel the ridges (See Plates 4 and 5). The groundwater recharge potential on ridge-top lots is limited by this topography. Recharge to any one lot is derived from infiltration of precipitation that falls directly on it and from surface and groundwater flow from up gradient lots. Because lots on hilltops and ridges receive little or no input from up-gradient sources, the recharge potential is mostly limited to the surface area of the lot itself.

The existing aquifer from which many of the homes obtain their well water leaks. Numerous springs exist between the contact of the overlying Merced Formation and the underlying Franciscan Formation. These springs are fed by groundwater accumulated in the Merced Formation that cannot penetrate downward into the Franciscan, and as such, moves laterally to lower hydraulic head. Flow from the springs limits the amount of water that can be held in storage. However, spring flow is important to wetland and riparian habitats as well as downstream fisheries.

3. MARK WEST STUDY AREA

The Mark West Study Area is an intermountain valley just north of the city of Santa Rosa. It is about 4 miles long and 3-miles wide encompassing an area of about 7.5 square miles. The west boundary crosses Mark West Springs Road about 1¼ -miles east of Highway 101. From there it follows the drainage divide north until it drops and crosses Mark West Springs Road near the beginning of Leslie Road. The boundary then rises along a ridge on the opposite side and follows the divide until it descends to Foothill Ranch Road near its intersection with Wallace Road. Continuing south, the boundary climbs the ridge behind Fountain Grove and then turns west. On the opposite side of the Fountain Grove golf course, the boundary turns northwest down the ridge top to Mark West Springs Road. A portion of the Study Area near the Fountain grove golf course lies within the City of Santa Rosa. The Study Area is outlined on Plate 9.

3.1 TOPOGRAPHY

The Mark West Study Area is a bowl shaped valley bound by parallel ridges of the Mayacama Mountains. It is separated from Rincon Valley by a saddle of low hills that stretch between the more prominent ridges and from the Santa Rosa Plain by a narrow canyon along Mark West Creek. The topographic features of the Study Area are illustrated on Plates 9 and 10.

3.2 DRAINAGE

The drainage of the Mark West Study Area is a fan-shaped network of seasonal tributaries that drain to the northwest toward Mark West Springs Creek. The Creek enters the Study Area at the extreme north edge and flows southward just inside the western boundary through most of the Study Area. It then turns sharply to the west and exits the Study Area through a narrow canyon. Mark West Springs Creek drains an area of about 30 square miles before entering the Study Area.

3.3 GEOLOGY

The rocks of the Mark West Study Area are comprised of the Sonoma Volcanics and the Glen Ellen Formation (Plate 11). The rocks of the Sonoma Volcanics are older and lie stratigraphically beneath the Glen Ellen Formation.

3.3.1 Sonoma Volcanics

The Sonoma Volcanics are composed of thick layers of volcanic ejecta and sediments eroded from them. Resistant dikes and plugs locally pierce inter-fingering lenses and wedges of flows, tuff, and obsidian. The Study Area is sandwiched between Healdsburg Fault to the west and the Mayacama Fault to the east.

The yield of wells drilled into the Sonoma Volcanics is highly variable and unpredictable according to Ford (1975). Wells tapping volcanic sediments and tuffs with high porosity or highly fractured rock can be highly productive with little draw-down. But, massive rock with little primary porosity and no secondary fractures may not yield water at all. A short distance can separate successful wells and dry holes. Productivity ranges from less than ten to several hundred gallons per minute. The depth of wells is also highly variable, 500–feet deep wells are common.

3.3.2 Glen Ellen

The Glen Ellen formation consists of poorly sorted alluvial materials ranging from clay to cobble-sized particles. In the Study Area, the Glen Ellen rests on top of the older Sonoma Volcanics in relatively thin deposits that are only a few hundred feet thick.

Like in the Sonoma Volcanics, the yield of wells in the Glen Ellen is highly variable. Ford (1975) reports that well yields commonly range from 15 to 30 gpm, but deep wells in thick sections of Glen Ellen to north of the Study Area near the town of Windsor have recorded yields of up to 500 gpm.

Ford (1975) reports that the quality of water from the Glen Ellen Formation varies more than that from any other formation in the Sonoma County. The water can be excellent, but in some areas there is so much sodium and other minerals that it is not potable.

3.4 PRECIPITATION

NOAA has no monitoring stations in the Mark West Study Area. The closest station is the Santa Rosa station 3 miles south of the Study Area. Precipitation data from the station are summarized in Appendix A. Variation in annual rainfall from place to place within the Study Area is expected due to the presence of microclimates. The average of annual precipitation recorded at the Santa Rosa Station is about 30-inches and varies from 11-inches per year recorded in 1976 to 63 inches in 1983.

In an average year, precipitation adds about 11,988 acre-feet (3.9 billion gallons) of water to the Mark West Study Area. The input ranges from about 4529 acre-feet (1.4 billion gallons) in the driest year to 25.102 acre-feet (8.2 billion gallons) in the wettest.

3.5 RUN-OFF

Limited stream-flow data is available from a stream gauge on the north edge of the Study Area in Mark West Creek near the Intersection of Leslie Road and Mark West Springs Road. This location is about where Mark West Creek enters the Study Area. Annual peak stream-flow value in cubic-feet per-second were collected from 1958 to 1962. Because of its upstream location, the data provide some insight on stream-flow entering the Study Area but not on flow generated within the Study Area. The data are included in Appendix B.

3.6 EVAPOTRANSPORATION

Evapotransporation (Et) data are not available specifically for the Mark West Area. However, the California Irrigation Information System produces data representing conditions in the north coast valleys. The data is collected from stations in Healdsburg, Santa Rosa, Windsor, Petaluma, Bennett Valley, and Valley of the Moon as well as several stations in Mendocino Counties. The evapotransporation precipitation, and other relevant data from the Sonoma County stations are summarized in Appendix A.

3.7 RESIDENTIAL LAND USE

As of 2000 there were 537 property owners with permanent addresses in county portion of the Mark West Study Area. Residential development occurs mostly within the bowl-like center of the Study Area. A map of structures visible in aerial photography illustrates this (Plate 12). Most of the hillside development occurs on the north side of the Fountain Grove ridge. Of the 173 Fountain Grove homes, 157 are in the City of Santa Rosa (Water for these homes is supplied by the City of Santa Rosa). The density of homes in this part of the Study Area is significantly greater than found elsewhere. The concentration of housing can be seen in the density distribution map shown on Plate 13. Hillside homes are also present, but widely spaced, on the prominent ridge on the eastern boundary of the Study Area.

3.8 HISTORIC RESIDENTIAL USE

As a basis of illustrating residential growth, Kleinfelder compared the number of structures visible in aerial photographs from 2000 to the earliest complete coverage available. The dates and areas covered by historic aerial photographs of the Study Area are shown on Plate 14. The earliest photos for which complete coverage is available were taken in 1951. There are 41 structures visible in these early photos. In 2000 there were 911, of which, 157 were in the city. In the 47 years separating the two photos, 870 new structures were added, a rate of 18.5 structures per year.

3.9 CURRENT RESIDENTIAL WATER DEMAND

On average, Northern California households use from ½ to 1 acre-foot of water per year. An acre-foot is slightly less than 325,829 gallons. If consumption rates in the Mark West area are comparable, the 537 permanent households in the county portion of the Study Area can be expected to use from 269 to 537 acre-feet (87 to 175 million gallons) of water per year.

3.10 HISTORICAL RESIDENTIAL WATER DEMAND

Increases in residential use are directly related to an increase in water demand. If water consumption has grown at a rate comparable to the increase in structures (42 percent per year) the total consumption has grown from between 20 and 41 acre-feet (6.7 and 13.3 million gallons) per year in 1953 to the current rates noted above.

3.11 FUTURE RESIDENTIAL USE TRENDS

PRMD estimates that the Mark West Study Area is developed to about 75% of the maximum build-out allowable by zoning. The department estimates that 206 units can still be built, 144 of which will be single units on existing vacant lots and the remainder will be on lot splits. These numbers do not take into account the possibility of second units constructed on developed lots. PRMD cautions that the estimates are based on assessor files, which might undercount existing units and therefore undercount potential units.

If the remaining 206 potential units are developed, the total water demand will increase by as much as 206 acre-feet (67 million gallons) per year.

3.12 AGRICULTURAL USE

Active commercial agriculture in the Mark West Study Area is limited relative to residential use and is composed mostly of recently planted vineyards. In 2000, vineyards in the Mark West Study Area occupied about 55.2 acres. Analysis of aerial photographs indicates that, in addition to vineyards, there are about 19 acres planted with orchards. Several former walnut orchards are apparent in aerial photos, but most do not appear to be actively farmed. The distribution of cultivated land is shown by crop type on Plate 15.

3.13 HISTORIC AGRICULTURAL USE

Until quite recently agricultural land use in the Mark West Study Area was primarily limited to cattle ranching, dairy farming, and some walnut production. Aerial photography shows that in 1950 the dominant crop was walnut and there were no vineyards apparent in the Study Area.

3.14 CURRENT AGRICULTURAL WATER DEMAND

Sonoma County vineyards typically apply 4-acre-inches of water per year or less. At this rate the Mark West vineyards apply 18.4 acre-feet (5.9 million gallons) of water per year. The actual source of this water is not presently known but is assumed to be from wells near the vineyards.

There does not appear to be any active farming of the Mark West walnut orchards but other orchards appear to be active. Assuming that all of the orchards are still active and irrigated at rates similar to vineyards, the irrigation demand would be about 6.2 acre-feet (2 million gallons) per year.

In total, the agricultural water demand in the Mark West Study Area is estimated to be about 24.6 acre-feet (8 million gallons) per year.

3.15 HISTORICAL AGRICULTURAL WATER DEMAND

Past crop production in the Mark West Study Area used about the same acreage as it does today. In the 1950s, the crops were different but the water demand is thought to be roughly the same. The irrigation methods employed at that time required more water to meet plant demands than methods like drip irrigation that are used today. Therefore, it is likely that more water was required in the past to meet the irrigation requirements of crops occupying the same acreage. A reliable estimate of the amount of water used would require a more detailed understanding of the irrigation practices that were actually used.

3.16 FUTURE AGRICULTURAL TRENDS

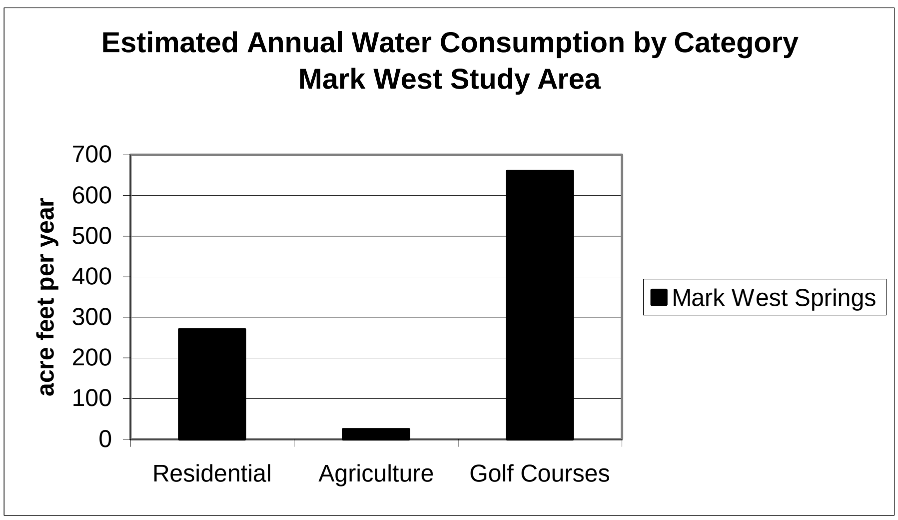
There has been some recent vineyard development in the Mark West Springs area. New vineyards have been established near the intersection of Reibli Road and Hidden Hills Road and at higher elevations on the ridge that forms the northeastern boundary of the Study Area. However, the future of agricultural development appears to be limited because much of the land has been converted to residential use.

3.17 GOLF COURSES

There are two golf courses in the Mark West Study Area, the Fountain Grove course and the newly developed Mayacama course. The courses are shown on Plate 16. Both courses are irrigated with well water; although, development plans call for use of reclaimed wastewater from future homes to water the Mayacama course. According to estimates in the Shiloh Meadows EIR and subsequent responses to comments, irrigation of the Mayacama course is expected to require about 330 acre feet per year. Irrigation of the Fountain Grove Course is expected to require a similar amount.

3.18 COMPARATIVE WATER USE

A comparison of water use within the Study Area is shown by category on the chart below:



3.19 CONSTRAINTS ON GROUNDWATER AVAILABILITY

Kleinfelder's pilot study of the Mark West area did not reveal specific and significant constraints on the availability of groundwater. The aquifer underlying the Study Area is primarily fractured bedrock of the Sonoma Volcanics; though thick deposits of the Glen Ellen formation occur in the northwest portion of the area were there is relatively little development. The availably of groundwater in these formations is not predictable but, where groundwater is found, it is generally sufficient to supply current demand.

Despite the dramatic increase in residential use of the land over the last 50 years, there are no recognized areas experiencing water availability problems. Such problems may exist, but unlike the Joy Road and Bennett Valley Study Areas, the existence and general location of such problems in the Mark West Study Area is not common knowledge.

Further research is needed to identify the constraints on groundwater availability in the Mark West Study Area. These constraints may also be revealed as the number of groundwater users increase, the distribution of wells becomes denser and the overall rate of groundwater consumption rises.

4. BENNETT VALLEY STUDY AREA

The north end of the Bennett Valley Study Area crosses Matanzas Creek in a cluster of low hills that lie between the summits of Bennett Peak and Taylor Mountain. The boundary rises from these hills, to the summits of both mountains and then follows the ridgelines, which define the upper watershed of Matanzas Creek. The east and west boundaries meet in the south at the summit of Sonoma Mountain. The boundaries of the Study Area are shown on Plate 17.

4.1 TOPOGRAPHY

The ridges surrounding Bennett Valley form an elongated trough with sides that drop steeply to the valley floor. Relative to the surrounding peaks the valley appears somewhat level; but the uneven valley floor encompasses a number of low hills and rises gradually to the peak of Sonoma Mountain. These features are shown with the color relief map on Plate 17 and the oblique hillside shade map on Plate 18.

4.2 DRAINAGE

Matanzas Creek and its minor tributaries drain the Bennett Valley Study Area. The creek divides near the center of the Study Area into two streams of nearly equal size. The only point of outflow is where Matanzas Creek flows north across the northern boundary of the Study Area.

4.3 GEOLOGY

The rocks of the Bennett Valley Study Area are comprised of the Sonoma Volcanics and the Petaluma Formation (Plate 19). The rocks of the Sonoma Volcanics are older and lie stratigraphically beneath the Petaluma Formation. The Study Area is divided into uneven thirds by the Bennett Valley Fault, which runs along the base of Bennett Peak and the Rogers Creek Fault that cuts along the western edge.

4.3.1 Sonoma Volcanics

The Sonoma Volcanics are composed of thick layers of volcanic ejecta and sediments eroded from them. Structurally, the Sonoma Volcanics consist of inter-fingering lenses and wedges of flows, tuff, and obsidian pierced locally by more resistant dikes, plugs. Tectonic forces have deformed and fractured much of the Sonoma Volcanics.

The yield of wells drilled into the Sonoma Volcanics is highly variable and unpredictable according to Ford (1975). Wells tapping volcanic sediments and tuffs with high porosity or highly fractured rock can be highly productive with little draw-down. But, consolidated rock with little primary porosity and no secondary fractures may not yield water at all. Very short distances often separate successful wells and dry holes. Productivity ranges from less than ten to several hundred gallons per minute. The depth of wells is also highly variable, 500–feet wells are common.

4.3.2 Petaluma Formation

The Petaluma Formation consists of clay, shale, and sandstone with minor amounts of conglomerate. Some limestone and dolomite are present in lesser amounts. In most areas, the formation is composed predominantly of clay and other fine-grained materials. The Petaluma deposits are folded and, in the Bennett Valley area, they are in fault contact with the older Sonoma Volcanics, which they overlie in some places.

According to Ford (1975) the Petaluma formation is noted for its low yield to wells. Yields of less than 5 gpm are common. The quality of water is fair, but in places, the mineral content and electrical conductivity can be high.

4.4 PRECIPITATION

The Californian Irrigation Information System recorded weather information at a station in Bennett Valley in 2000. NOAA has no active monitoring stations in the Bennett Valley Study Area. The closest station is the Santa Rosa station 4-miles northeast of the Study Area. The data are summarized in Appendix A. Variation in annual rainfall from place to place within the Study

Area is expected due to the presence of microclimates. The average of annual precipitation recorded at the Santa Rosa Station is about 30-inches per year and varies from 11-inches per year recorded in 1976 to 63 in 1983. In 2000, the only year for which data from the valley is available, 26.92-inches were recorded at the Santa Rosa station and 11.11-inches were recorded in Bennett Valley. However, the Bennett Valley data are flagged with notes stating, "One or more daily values are missing or flagged."

Precipitation adds about 21,657 acre-feet (7 billion gallons) of water to the Bennett Valley Study Area in an average year. The input ranges from about 8,182 acre-feet (2.6 billion gallons) in the driest year to 45,349 acre-feet (14.7 billion gallons) in the wettest.

4.5 RUN-OFF

Limited streamflow data are available from a stream gauge on Matanzas Creek about 4 miles north of the Study Area. This station only records gauge height in real-time and data are not kept more than 31 days. The data can be viewed at:
http://waterdata.usgs.gov/ca/nwis/uv?site_no=11466170.

4.6 EVAPOTRANSPORATION

Evapotransporation (Et) data from Bennett Valley are available for one year (2000). However, the California Irrigation Information System produces data representing conditions in the north coast valleys. The data is collected from stations in Healdsburg, Santa Rosa, Windsor, Petaluma, and Valley of the Moon as well as several stations in Mendocino Counties. The evapotransporation precipitation and other relevant data from the Sonoma County stations are summarized in Appendix A.

4.7 RESIDENTIAL LAND USE

As of 2000 there were 576 property owners with permanent addresses in the Bennett Valley Study Area according to Metroscan's report of assessor's data. Residential development occurs mostly near the center of the Study Area along Sonoma Mountain Road. Two notable exceptions are the Bennett Ridge and Ponderosa subdivisions. Ponderosa has the highest housing densities in the Study Area. A map of structures visible in aerial photography illustrates this (Plate 20) Most of the hillsides are too steep for development but ridge top homes do occur on the southern ridge of Bennett Peak (Bennett Ridge) and the northwest ridge of Sonoma Mountain. Housing density varies greatly within the Study Area as can be seen in the density distribution map shown on Plate 21.

4.8 HISTORIC RESIDENTIAL USE

As a basis of illustrating residential growth, Kleinfelder compared the number of structures visible in aerial photographs from 2000 to the earliest complete coverage available. The dates and areas covered by historic aerial photographs of the Study Area are shown on Plate 22. The earliest photos for which nearly complete coverage is available were taken in 1971. There are 268 structures visible in these early photos. In 2000 there were 940. In the 29 years separating the two photos, 672 structures were constructed, a rate of 23 structures per year.

4.9 CURRENT RESIDENTIAL WATER DEMAND

On average, Northern California households use from ½ to 1 acre-foot of water per year. An acre-foot is slightly less than 325,829 gallons. If consumption rates in the Bennett Valley area are comparable, the 576 permanent households in the Study Area can be expected to use from 288 to 576 acre-feet (94 to 188 million gallons) of water per year.

4.10 HISTORICAL RESIDENTIAL WATER DEMAND

Increases in residential use are directly related to an increase in water demand. If water consumption has grown at a rate comparable to the increase in structures (8.65 percent per year) the total consumption has grown from between 75 and 150 acre-feet (24.4 and 48.8 million gallons per year in 1971 to the current rates noted above.

4.11 FUTURE RESIDENTIAL USE TRENDS

PRMD estimates that the Bennett Valley Study Area is developed to about 69% of the maximum build-out allowable by zoning. The department estimates that 274 units can still be built, 135 of which will be single units on existing vacant lots and the remainder will be on lot splits. These numbers do not take into account the possibility of second units constructed on developed lots. PRMD cautions that the estimates are based on assessor files, which might undercount existing units and therefore undercount potential units.

If the remaining 274 potential units are developed, the total water demand will increase by as much as 274 acre-feet (89 million gallons) per year.

4.12 AGRICULTURAL USE

Active commercial agriculture is a significant activity in the Bennett Valley Study Area. Irrigated crops in the Study Area are almost exclusively recently planted vineyards. Analysis of aerial photographs indicates that, in addition to vineyards, there are a few acres planted with walnut orchards but these do not appear to be actively farmed. There are also many acres of non-irrigated pasture. The distribution of cultivated land is shown by crop type on Plate 23. In 2000, vineyards in the Bennett Valley Study Area occupied about 644 acres.

4.13 HISTORIC AGRICULTURAL USE

Until quite recently, agricultural land use in the Bennett Valley Study Area was primarily limited to cattle ranching, dairy farming, and walnut production. Aerial photography shows that in 1971 most of the land used today for vineyards was pasture or range and the dominant crop on cultivated land was walnut. At that time there were no vineyards in the Study Area apparent in aerial photographs.

4.14 CURRENT AGRICULTURAL WATER DEMAND

Sonoma County vineyards typically apply 4-acre-inches of water per year or less. At this rate the Bennett Valley vineyards apply 215 acre-feet (69.9 million gallons) of water per year. The actual source of this water is not presently known but is assumed to be from wells near the vineyards.

Water is also needed to supply the needs of Matanzas Creek Winery. The winery was established in 1977 and produces 35,000 cases of wine annually. About one third of the grapes used are grown in the Study Area. Water is required in the wine making process for washing grapes and cleaning equipment. According to PRMD, Matanzas Creek Winery uses about 1.54 acre-feet of water per year. PRMD's estimate is derived from calculations he made of evaluation of the winery's use permit.

4.15 HISTORIC AGRICULTURAL WATER DEMAND

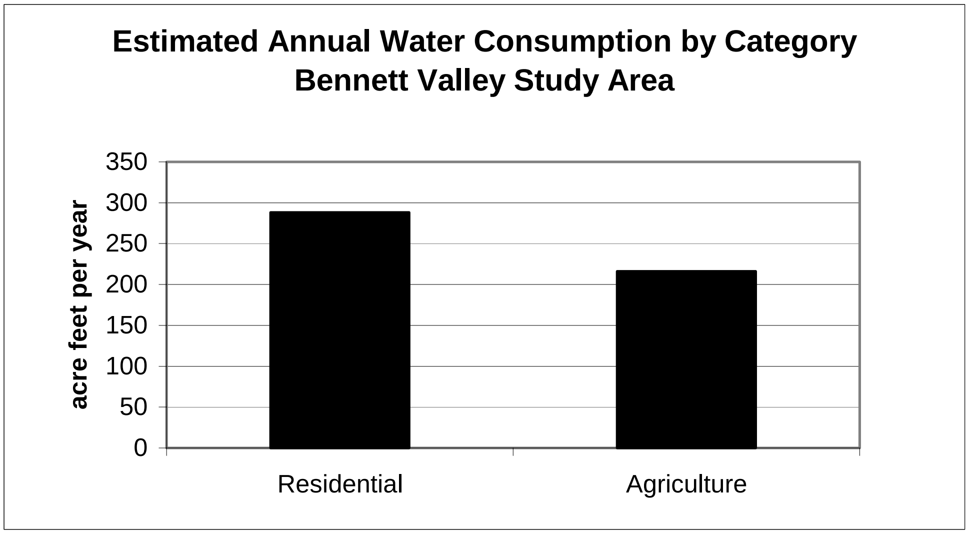
Past crop production in the Bennett Valley Study Area used considerably less acreage than it does today. In the 1970s, the irrigated crops occupied far less acreage and, therefore, the water demand is thought to have been much less. However, The irrigation methods employed then required more water to meet plant demands than methods like drip irrigation that are used today. A reliable estimate of the amount of water used would require a more detailed understanding of the irrigation practices that were actually used.

4.16 FUTURE AGRICULTURAL TRENDS

There continues to be vineyard development in the Bennett Valley area and acreage of suitable size and character is still available in the Study Area. If market trends continue to favor high-end varietal wines from Sonoma County, future development of vineyards in the Bennett Valley Study Area can be expected.

4.17 COMPARATIVE WATER USE

A comparison of water use within the Study Area is shown by category on the chart below:



4.18 GEOLOGIC CONSTRAINTS

The most significant constraint on the availability of groundwater in the Bennett Valley Study Area is the concentration of groundwater users on the poor aquifer materials of the Petaluma Formation. The formation consists mostly of fine-grained materials that offer very poor yield to wells. The successful wells in the Petaluma Formation are those that intersect the few beds of sand gravel or cobble.

The limited water-bearing capacity of the Petaluma Formation is significant because a considerable percentage of the residential and agricultural land use in the Study Area occurs on the Petaluma Formation as shown on Plate 24. The Petaluma Formation occupies 32 percent of the Study Area; yet, it contains 41 percent of the structures and 50 percent of the vineyard acreage. This unbalanced distribution is probably because slopes within the Petaluma are generally less steep than in the Sonoma Volcanics and are therefore more accessible.

Water availability is problematic in the Petaluma Formation. Kleinfelder questioned a number of Bennett Valley residents and community leaders about water availability problems within the Study Area. They reported a number of well failures, wells that go dry seasonally, and properties where sufficient water supplies could not be developed (The interviewees asked that Kleinfelder keep the location of affected properties confidential). A number of residents reportedly supplement their well water supplies with truck deliveries or store water for use during dry months. Without exception, all the properties mentioned are located on the Petaluma Formation.

5. STATISTICAL EVALUATION OF WELL LOG DATA

5.1 OBJECTIVE

The overall objective of Kleinfelder's qualitative statistical analysis of well log data was to analyze and evaluate existing data to reveal any general trends in water supply from the aquifers.

5.2 DATA SOURCE

Kleinfelder used data from driller's well logs obtained from the California Department of Water Resources. The data set is derived from the Department's collection of digitized logs for wells drilled in California. With the assistance of PRMD, Kleinfelder made a formal request to the Department for digital copies of the logs representing wells in Sonoma County. The department supplied the requested information on three CDs. The logs are stored as images in TIFF format indexed by image number. The Department also supplied a Microsoft Excel spreadsheet and Access database that catalogs the images according to image ID, file location, log number, and the well's location relative to township, range and section. The collection includes logs from the middle 1940s to 1990 and a few logs from the late 1990s. Data obtained for each Study Area cover the following time periods:

- Bennett Valley (1941 to 1997).
- Mark West (1942 to 1997).
- Joy Road (1953 to 1997).

The data sets do not include many logs from 1990 to the present because the Department of Water Resources has not cataloged them. It is important to note that the collection does not include logs for wells with undetermined locations or wells for which no log was submitted.

5.3 APPROACH

A combination of graphical and quantitative statistical techniques was employed to characterize and compare reported depth-to-water (DTW) and total well depth data for individual wells installed within a given Study Area. The statistical methodology employed includes four main elements:

- Data Set Preparation
- Initial (*a priori*) Data Screening
- Outlier Testing
- Graphical Trend analysis

5.4 DATA SET PREPARATION

Depth-to-water and total well depth data were obtained directly from well drillers logs, entered into a Microsoft Access database and downloaded into Microsoft Excel to form data sets suitable for statistical analysis. The data sets are included in Appendix C. After the database was completed, a manual check of 10 percent of the data records in each data set was performed. The data sets include 599 logs of wells in the Joy Road Study Area, 246 logs of wells in the Mark West Study Area, and 530 logs of wells in the Bennett Valley Study Area.

5.5 INITIAL (*A PRIORI*) DATA SCREENING

The goal of the initial (*a priori*) data screening process was to identify, isolate and remove unwanted, irrelevant, and unusable data from each data set. For example, 13 records (1 Joy Road and 12 Bennett Valley records) with depths to water values of “0” were removed. Zeros were used for wells where water flowed freely from the casing. Allowing the water to flow out of the casing relieved the pressure head. If there had been a casing above ground surface, the water level would have risen and actual values could have been determined. Because it was not, these values serve no useful purpose in the statistical analysis. No other data values were removed from the data sets during this phase of analysis.

5.6 OUTLIER TESTING

Statistical outlier tests give the analyst probabilistic evidence that an extreme value (potential outlier) does not "fit" with the distribution of the remainder of the data. These tests are used to identify data points that require further investigation to determine if they should be discarded or corrected.

Outliers in well data sets may result from various sources including, but not limited to:

- Legitimate, but unusually high natural values.
- Physical obstruction in the well during measurement.
- Error associated with the measurement of depths.
- Data transcription or coding errors involving decimal places or units of measurement.

In this study, if a data point was found to be an outlier, it was automatically discarded from the data set. Depth-to-water and total well depth data were screened by visually examining a spreadsheet column of sorted concentration values and/or by visual examination of the temporal plots. Excessively high values (values that are a factor of five times higher than their nearest neighbor value) were evaluated using the robust Grubbs (Tn) Outlier Test. This test is appropriate for both parametric and nonparametric data sets (Grubbs and Beck 1972, ASTM 1994).

Grubb's test assumes that the parent population follows a normal distribution. In the Grubb's test, the data is sorted by rank order and the mean and standard deviation is calculated. The test statistic is calculated as:

$$T_n = \frac{X_n - \overline{X}}{s}$$

Where:

Xn	=	Concentration of data point n
Tn	=	Test statistic
$\overline{X}$	=	Arithmetic average of the data
s	=	Standard deviation of the data set

The test statistic (Tn) is then compared to the appropriate tabled one-sided critical value (Tc), which depends on n and the chosen level of significance. If the Tn > Tc this is statistical evidence that the data point is an outlier. Alternatively, the equation is rearranged and Tc is used to calculate a critical concentration value (Xc) above which a data point may be an outlier:

$$X_c \quad T_c \times S_d \quad \overline{X}$$

If a data point was determined to be an outlier by this methodology, it was investigated for typographic, sampling or analysis errors.

5.7 GRAPHICAL TREND ANALYSIS

There are no proven "automatic" techniques to identify trend components in the time series data; however, as long as the trend is monotonous (consistently increasing or decreasing) that part of data analysis is typically not very difficult in a qualitative sense. Many monotonous time series data can be adequately approximated by a linear function. However, seasonal dependency (seasonality) is a general component of the time series pattern for water level behavior. For example, the average rainfall has been consistent in the last half century but it varies from year to year.

Depth-to-water and total well depth data for each of the three study areas were plotted with respect to time. Many wells were constructed in most of the years. Information regarding the location of each well and intended use of that well were not consistently available but variation due to these factors is to be expected. Because the goal is to represent general groundwater conditions of the study area as a whole, the mean and 95% confidence limit of the mean of data from all wells drilled each year were plotted rather than individual data values. Plotting the mean is also useful for the ease of presentation. A linear regression line and associated regression bands representing 95% confidence intervals were fitted to each data set. The slope of this line and the variability of the data in a given year were analyzed graphically.

5.8 DEPTHS TO WATER TREND

Two trends are apparent in depths-to-water in new wells, a short-term response to precipitation and a long-term decline in depth to water. In each of the three study areas, the mean depth to water in new wells drilled each year varies from year to year. The variation appears to be correlated with variation in precipitation. This can be seen by plotting precipitation and the mean depth-to-water in new wells together on a single graph. See Figures 1 and 2. These plots show that the mean depth-to-water in new wells generally corresponds to the amount of precipitation from the preceding year. While this is generally true, there are data points from each data set that do not conform to this relationship and demonstrate that other variables are also at play.

The mean depth to water in new wells trends downward in each study area. In the Joy Road Study Area, the mean trend drops from about 20 feet below surface in 1955 to about 42 feet in 1990 (Figure 3). The trend in the Mark West Study Area drops from about 90 feet in 1950 to about 175 in 1997 (Figure 4). In Bennett Valley the trend drops from about 42 feet below surface in 1950 to over 100 feet below surface in 1997(Figure 5).

Over the period of matching data, the precipitation trend does not match the trend of mean depth-to-water in new wells. From the 1940s to the late 1990s, the trend in total annual precipitation measured in stations near the Study Areas has been nearly level with a slight increase. Over the same period, the mean depth to water in new wells has deepened over time in all three-Study Areas. On the basis of this relationship, it can be said that the downward trend in water levels is not due to changing weather conditions.

The downward trend in depth-to-water in new wells corresponds to the trend of overall development but not at the same rate. Depth to water in new wells has deepened in each of the three Study Areas since the 1940s. At the same time, the rate of growth, as represented by the number of structures and cultivated acreage, has greatly increased. The nature and rate of development has been different in each of the Study Areas; but, in every case it is far greater than the rate of declining depth to water in new wells. The most extreme example is residential growth in the Mark West Study Area. Since 1951 the number of residences in the Study Area has increased by at least 2000 percent. In the same period, the mean depth to water in new wells has deepened by a little less than 100 percent. Such a marked difference between the rate of increase in water consumption and the rate of lowering average water levels in new wells suggests that the effect of increased extraction on water levels is being buffered by annual recharge from precipitation.

5.9 DEPTH OF WELLS TREND

There is a clear trend of increasing average well depths over time. This is evident in each of the three Study Areas. The average depth of wells drilled in the Joy Road Study Area has increased from about 50 feet in 1955 to over 140 feet in 1990 (Figure 6). In the Mark West Study Area the average depth of new wells has increased from about 120 feet in 1950 to about 300 feet in 1997 (Figure 7). The average depth of Bennett Valley wells has increased from about 150 feet in 1940 to about 350 in 1990 (Figure 8).

The trend seems to reflect lower water levels not improvements in drilling technology. There has been some suggestion that the deepening trend in the depths of wells is more indicative of changing technology than it is of changing groundwater conditions. The data do not support this view. The mean depth of new wells parallels the mean depth to water (Figures 9 and 10). Wells are shallower in wet years, when water levels are high, and deeper in dry years. This suggests that drillers, acting rationally, drill only as far as necessary to meet the design objectives. The data indicate that drillers go only as deep as necessary regardless of the equipment used.

In the Mark West and Bennett Valley Study Areas, the trend may also reflect a migration of drilling sites from low-lying valley sites to higher elevations and ridge tops. If for example all early wells were in the valleys and over time the drilling sites were at progressively higher elevations, the increase in depth of wells would correlate more with elevation than with time. Because we do not know the exact location of each well, we do not know if there is a pattern of drilling at higher elevations or not. It seems improbable though that drilling has proceeded systematically from lower to higher elevations. Its is more likely, however, that drilling did first occur at lower elevations in association with early agricultural use, but that, as more wells were drilled, there has been a mix of both low lying and higher elevation sites. The location of each well in the data set and further analysis of the data would be needed to evaluate the potential correlation between well depth and elevation over time.

6. CONCLUSIONS

1. Geologic Conditions Are The Principal Constraint On The Availability Of Groundwater

Water availability is limited in all water scarce areas of the county but it is particularly scarce in geologic materials such as the Franciscan and Petaluma formations. The composition and hydrologic characteristics of these formations and the nature of the materials in them limit key aquifer characteristics such as recharge potential, water storage capacity, and the ability of the formation to yield water. Or, in other words, these factors determine how much water gets into the formation, how much water it can hold and how freely water flows from it.

These poor aquifers have insufficient storage to supply some residents through the dry months of the year. In some areas, residents must supplement their water supply by trucking water to their homes. This is evidenced by the frequent presence of water trucks on the roads of the Joy Road and Bennett Valley Study Areas in the late summer months.

2. Changes In The Depth To Water In New Wells Are Trending Downward

An analysis of the annual average depth to water in new wells shows a trend over time of decreasing water levels in the three Study Areas. From year to year, the average depth to water in new wells appears to reflect changes in precipitation. But, unlike the precipitation trend, which has been relatively flat over time, the depth to water is trending toward deeper water levels.

The data suggest, as a general trend, that static water levels in new wells occur at deeper levels over time. But, the data do not show whether water levels in existing wells are dropping nor do they account for the possibility that new development is occurring in areas with more marginal groundwater conditions. Further study would be needed to evaluate the conditions in individual wells for evidence of change over time and to evaluate the relationship between those conditions and the well's location relative to geology, topography and competing groundwater uses.

3. The Trend In Depth To Water In New Wells Shows Evidence Of An Overdraft Condition

Overdraft occurs when more water is taken from an aquifer than is replaced. The result of overdraft on an aquifer is the dropping water levels. Analysis of well logs shows that the average depth to water in new wells drilled each year is increasing indicating that water levels are dropping. Lowering water levels reflect either decreased input or increased outflow. Input to the Study Areas is almost exclusively from precipitation, which does not appear to have decreased. The trend line on a plot of annual rainfall since 1950 is nearly flat with a very slight increase. The change in water levels is, therefore, most likely due to a decrease in recharge rates, an increase of groundwater extraction, or a combination of both. The most likely explanation is that groundwater extraction has increased.

The trend analysis of depth to water in new wells together with reports of dropping water levels, seasonal well failures, and complete well failures all suggest overdraft conditions. However, comparison of the actual volume of groundwater extracted with reliable estimates of annual groundwater recharge would be needed to determine if overdraft conditions actually exist. Determination of the actual volume of water extracted would require monitoring of total volume of water produced by a representative number of wells in each Study Area.

4. Lower Depths To Water In New Wells Correlates With Development

The change in average depth to water in new wells appears to be correlated to development, primarily residential. There may be many reasons for increased outflow but the most significant change since 1950 is increased groundwater extraction from wells. In the Joy Road and Mark West Study Areas, this increase is mostly from residential development. In the Bennett Valley Study Area it is from both residential and agricultural development.

5. Additional Development Will Likely Increase Overdraft

There is a potential for further residential and agricultural development in the Study Areas because they have not been developed to the maximum density allowed by existing zoning ordinances. New homes and vineyards require water and more wells would be needed to meet demand. Additional groundwater extraction is likely to increase the rate of overdraft and result in further decline of groundwater levels. In fact, if an overdraft condition currently exists, groundwater levels may continue to decline even if no additional extraction occurs. Levels will continue to drop as long as extraction exceeds recharge.

7. QUESTIONS FOR FURTHER STUDY

Evaluation of development proposals or regulation of groundwater use requires a detailed understanding of groundwater conditions. However much of the needed information is not currently available. Existing regulations and ordinances provide groundwater information when a project is proposed but no ongoing monitoring of conditions is required. People building homes in water scarce areas of the county are required to establish a water supply of at least 1 gallon per minute and construct adequate storage. Industrial and commercial developers are required to conduct groundwater availability studies to demonstrate that enough groundwater is available to meet their proposed needs without adversely affecting supply to existing users. However, once a home or facility is built the long term cumulative affect on groundwater conditions is not monitored.

This study has shown that groundwater conditions are changing in the Study Areas and that there are geologic, physiographic, and competitive constraints on the availability of groundwater. In the Joy Road and Bennett Valley Study Areas, water supply problems are evident. The groundwater resources in these areas may not be sufficient to fully supply the existing users, yet further demand on these resources can be expected with new development. And, while some areas are experiencing declining water levels or suffering yearly shortfalls, other areas may have enough groundwater to supply more than current needs.

Development of regulations or control of groundwater use should be based on the answers to four basic questions:

- What are the groundwater conditions now?
- What are the capabilities of the aquifers?
- How are conditions changing over time and what is the significance of those changes?
- What is responsible for the change?

While this study provides some information on each of these questions, groundwater conditions are not fully understood at the present time. To fully answer these questions we need to know:

- What are the static and pumping water levels in existing wells?
- How much water is being used?
- Where is it being produced?
- Where is it being used?
- What is it being used for?
- How much water is available in storage?
- How much water can be produced without further decrease in water levels?
- How much water can be produced without threat to neighboring wells?
- How are conditions in individual wells changing with time?

With answers to these questions the County can:

- Establish actual groundwater conditions.
- Understand water consumption rates and patterns.
- Assess the effect of water conservation measures.
- Evaluate changes over time.
- Calculate sustainable extraction rates.
- Evaluate the impact of proposed extraction increases.
- Locate undeveloped or underutilized groundwater resources.

8. RECOMMENDATIONS FOR FURTHER STUDY

Providing answers to the questions discussed in Section 7 will require further study including additional research and fieldwork. Development of a scope of work should be a collaborative effort between the groundwater users in the study area, County planning, permitting and policy staff, and groundwater scientists. A separate scope should be tailored to reflect the unique physical conditions and address the perceived problems and future needs of each study area. In general, further study can be expected to consist of the following tasks:

Task 1: Establish Current Groundwater Conditions and Refine Conceptual Model of Aquifer:

- Prepare Work Plan and Task Schedule
- Survey Reported Groundwater Problems and Well Failures
- Identify Test Wells and Obtain Access Permission
- Measure Depth to Water in Wells
- Calculate or Estimate Run-off
- Test or Obtain Groundwater Chemistry
- Integrate Data with GIS based Data Management System.
- Refine GIS Maps of Land Use and Geology
- Prepare Technical Memorandum on Baseline Conditions

At the completions of Task 1, the scope of work can be further refined to meet the specific needs and conditions within each study area. Further assessment may include elements of the following tasks.

Task 2: Determine Aquifer Characteristics

- Prepare Work Plan and Task Schedule
- Conduct Aquifer Tests
- Prepare Technical Memorandum on Aquifer Characteristics

Task 3: Monitor Groundwater Conditions Over Time

- Prepare Work Plan and Task Schedule
- Identify Test Wells and Obtain Access Permission
- Install Monitoring Equipment
- Collect Well Data Quarterly
- Measure and Record Precipitation
- Measure or Calculate Run-off
- Integrate Data with GIS based Data Management System
- Prepare Quarterly Report of Groundwater Conditions

Task 4: Develop Groundwater Model

- Identify critically impacted areas
- Locate undeveloped groundwater resources
- Calculate Maximum Extraction Rates

9. LIMITATIONS

Kleinfelder prepared this report in accordance with generally accepted standards of care, which exist in Sonoma County, California at this time. It should be recognized that definition and evaluation of geologic and environmental conditions is a difficult and inexact art. Judgments leading to conclusions and recommendations are generally made with an incomplete knowledge of the subsurface conditions present. More extensive studies, including subsurface investigations, may be performed to reduce uncertainties. If the County of Sonoma wishes to reduce the uncertainties of this investigation, Kleinfelder should be notified for additional consultation. No warranty, expressed or implied, is made.

This report may be used only by the client and only for the purposes stated, within a reasonable time from its issuance. Land use, site conditions (both on- and off-site) or other factors may change over time, and additional work may be required. Any party other than the client who wishes to use this report shall notify Kleinfelder of such intended use by executing the "Application for Authorization to Use" which follows this document as an Appendix. Based on the intended use of the report, Kleinfelder may require that additional work be performed and that an updated report be issued. Non-compliance with any of these requirements by the client or anyone else will release Kleinfelder from any liability resulting from the use of this report by any authorized party.

10. REFERENCES

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