



**Lake County
Flood Control and Water Conservation District**

Big Valley Ground Water Recharge Investigation Update



May 2003

Prepared By



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Flood Control and Water Conservation District
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1. Summary

This report prepared for Lake County Flood Control and Water Conservation District is an update of the Big Valley Ground Water Investigation carried out in 1967. Its purpose is to provide up-to-date information needed for planning and management of the Basin's ground water resources.

Big Valley Ground Water Basin

Big Valley is located in Lake County, California on the southwest side of Clear Lake. The valley is about 8 miles long by 6 miles wide and covers an area of 24,277 acres (about 38 square miles). It is bordered by Clear Lake to the North, Mount Konocti to the East and the Mayacamas mountains on the south and west sides.

Big Valley Ground Water Basin (Basin) underlies the valley bottom. The surface of the Basin is, for the most part, a broad plain that gently slopes toward Clear Lake and is bordered by terrace-like uplands on the west side of the valley and steeper slopes on the east side where it abuts Mount Konocti. A central upland in the south divides the upper part of the overall valley into two smaller valleys occupied by Kelsey and Adobe Creeks. The elevation of the floor of the Basin ranges from about El 1600 ft. in the central uplands to about El 1330 ft. near the shoreline of Clear Lake.

Agriculture is the main economic activity with over 10,400 acres in irrigated and dry farming. The topography, climate and soil are ideal for growing several varieties of fruit, including pears, walnuts, and premium wine grapes.

The Basin's aquifers are the primary water supply source for agriculture in Big Valley and municipal water supply for the communities of Kelseyville and Finley on the valley floor.

Agricultural water use is not metered, so it has to be estimated from land use data and information regarding typical irrigation practices.

Land use data from 2001 indicate that about 51% of the Basin is undeveloped land that is mainly covered with native vegetation. Agriculture accounts for about 43% of land use and 6% are urban.

Land Use (2001 data)	Area (acres)	Percent
Agricultural	10,403	43%
Urban	1,554	6%
Undeveloped (Native)	10,352	43%
Unclassified	1,919	8%
Total	24,227	100%

Based on DWR Provisional Land Use Data (2001)

Recently the total area of irrigated lands in Big Valley has declined about 13% from 9603 acres in 1995 to 8317 acres in 2001 due to a downturn in the economics of the local fruit growing industry. Some pear and walnut orchards have either been converted to vineyards or have become idle.

The estimated average annual ground water extractions for water supply based on land use data and estimated rates of water use for agricultural areas and metered water use for urban areas are as follows:

Land Use	Estimated Ground Water Consumption (ac-ft/year)	Percent
Agricultural		
Irrigation	12957	74%
Frost Control	4056	23%
Subtotal	17013	97%
Urban	600	3%
Total	17613	100%

Agricultural irrigation and frost control accounts for about 97% of estimated consumptive use of ground water in the Basin.

Ground Water Management Plan

Periodic overdraft of the Basin's aquifers during droughts has long been recognized as a growing water supply problem. Impacts include:

- Water shortages during droughts that impact agricultural production and local domestic water supplies.
- Deterioration of groundwater quality due to intrusion of geothermal water containing iron and boron.



- Drying up of shallower wells during droughts requiring deepening of wells or new sources of water supply.
- Increases in energy needed for pumping water from deeper levels.
- Ground subsidence which potentially reduces available groundwater storage and changes surface drainage patterns.
- Impacts on fish, wildlife and riparian vegetation due to reduced streamflow and earlier drying up of creeks due to lowered water table.

On May 18, 1999, the Lake County Flood Control and Water Conservation District (District) adopted the "Big Valley Ground Water Management Plan" pursuant to the State of California's Ground Water Management Act (AB 3030 - 1992). The purpose of the plan is to monitor, conserve and manage the Basin's groundwater resources.

Updated information about the Basin is needed to support the planning and management process. The last major study of the Basin was carried out 35 years ago. Since then much has changed including land use, water use, the 1976/77 and 87/92 droughts occurred, more is known about water quality, new analytical tools have been developed, and very little water resource development envisaged by earlier studies has been implemented.

Hence the District commissioned an update of previous studies to achieve the following goals:

- Evaluate patterns and changes in ground water quality.
- Determine aquifer conditions and evaluate changes over time.
- Develop a volumetric model of the Basin to facilitate management of groundwater and groundwater recharge and extractions.
- Identify threshold levels in specified wells within the Basin where groundwater problems occur.
- Present the update findings to the Zone Commission and the public.

Basin Geology

The Big Valley groundwater regime exists within the sequence of the late Pleistocene to recent age alluvial and lacustrine basin fill deposits that occupy the Big Valley subunit of the Clear Lake

Basin.

The Big Valley Basin fill sequence comprises two major units, the Kelseyville Formation, and the younger floodplain, channel, terrace, and lacustrine deposits.

The Kelseyville Formation was deposited by ancestral Kelsey, Adobe, Highland and other creeks flowing across floodplains or into the Big Valley arm of the Pleistocene Clear Lake, depending on the fluctuations in lake level. The fine-grained floodplain and lake deposits include many horizons of fine volcanic ash, and at least one 2 to 5 foot thick layer of lapilli tuff, referred to in geologic literature as the Kelsey Tuff and by well drillers as the "volcanic ash aquifer".

The Kelseyville Formation is present throughout the Big Valley area but is exposed only in the Central and Western upland areas where it has been uplifted over the Big Valley fault.

The younger floodplain, channel, terrace, and lacustrine deposits are mainly present beneath the northern floodplain margin of the valley between Highway 29 and Clear Lake, and beneath the Adobe Creek floodplain as far south as a confluence of Adobe and Highland Creeks. This sequence contains two sections of predominantly alluvial deposits that are partly overlain, and probably separated at depth, by sections of predominantly lacustrine deposits.

The channel of Kelsey Creek south of Kelseyville is eroded into and directly floored by strata of the Kelseyville Formation, which provides little opportunity for recharge. From the vicinity of Kelseyville north towards Clear Lake, Kelsey Creek flows within a relatively wide channel underlain by highly permeable coarse sand and small gravel alluvium. This channel reach of Kelsey Creek provides the principal recharge to the aquifers of the northern Big Valley area. The recharge occurs via direct percolation of surface flow and from underflow within the channel alluvial section.

Aquifers

The Basin has four main aquifers which define ground water conditions.

The most widespread alluvial aquifer, the A1 aquifer, is present beneath the floodplain in the area between Highway 29 and Clear Lake and also



it extends southward beneath the Adobe Creek sub basin south of Highway 29. Its main water source is infiltration of direct precipitation and recharge from Adobe and lower Kelsey Creeks. Near the lake this aquifer has a confined zone which is capped with a layer of clay and silt. This zone reduces aquifer recharge and creates seasonal artesian conditions in some wells when the water table is high.

A second, lower alluvial aquifer, the A2 aquifer, lies below the A1 aquifer in the northern Big Valley floodplain area, but is not present beneath the Adobe Creek floodplain. Recharge of the A2 aquifer is mainly by downward percolation from the A-1 aquifer and underflow from the Kelseyville Formation.

Ground water serving the Central and Western Upland areas is extracted from the A3 and volcanic ash aquifers in the Kelseyville Formation. The A3 aquifer is recharged by direct percolation from the upland surface and by some underflow from Kelsey Creek and from the A1 aquifer under the Adobe Creek floodplain. The path of recharge to the volcanic ash aquifer is not well understood.

Aquifer Conditions

Maps of groundwater surface contours show that the general groundwater flow direction is from the surrounding mountains towards Clear Lake. The general flow pattern is interrupted by pumping depressions that become more pronounced during the irrigation season. Data from the extreme droughts of 1975-77 and 1987-92 show a large cone of depression near Finley in the confined aquifer zone and a smaller steeper cone near the base of the Central Uplands. Extreme drawdowns in 1987-92 were deeper than the drought of 1975-77.

In average water years, drawdowns are typically in the range of 10 to 20 feet; however drawdown of the water table can reach up to 50 to 60 feet during drought periods. The Basin returns to a relatively full condition during average years, however, the Basin's capacity is not replenished during dry years which causes a progressive depression of ground water levels and deterioration in ground water quality.

Economic downturn in the Lake County pear and walnut growing industries coupled with conversion of orchards to more water-efficient vineyards has caused changes in land use and a

corresponding decrease in estimated agricultural water consumption in the Basin. This trend should be monitored. However, despite this recent decrease, existing levels of water demand in the Basin are still sufficient to cause overdraft during droughts.

Potential future growth of water demand in the Basin and the risk that the severity of future droughts will surpass the two most severe events of record, indicate that drought related ground water problems are likely to become more severe. In addition, localized problems may occur in parts of the Basin where the water balance is under greater stress due to change in land use or addition of new wells.

Ground Water Quality

Discrete areas of the Basin are experiencing progressive degradation of groundwater quality due to inflow and mixing of geothermal waters. This degradation is ongoing and suggests that locally, wells are not receiving sufficient freshwater recharge from rainfall or percolation to meet water demands. This results in greater extraction of deeper geothermal ground water which can elevate concentrations of dissolved minerals such as iron and boron.

Large portions of the Basin are experiencing a rise in nitrates and nitrate levels are approaching regulatory limits in parts of the Basin.

Some residents have complained that groundwater quality worsens during droughts. Unfortunately, insufficient data are available to definitively correlate water quality changes with groundwater elevations. More quantitative time series water quality data is needed to assess the magnitude of these changes.

Recommended Options for Addressing Overdraft

The following portfolio of potential options for addressing periodic overdraft during droughts focuses on improving the water balance in the Basin by reducing water demand and increasing water supply.

In developing an overall plan for managing the Basin's ground water resources the District could incorporate those measures which would best serve the District's needs. Further detailed investigations would be required to rank potential measures in terms of their effectiveness and



environmental acceptance and to quantify their potential costs and benefits.

Implement an Agricultural Water Management Plan

The State of California facilitates programs to improve water use efficiency. The Agricultural Water Management Planning Program provides technical, financial and administrative assistance to water districts throughout the State to develop Water Management Plans and to help implement cost-effective efficient water management practices.

Examples of these practices are as follows:

- Designate a Water Conservation Coordinator.
- Support the availability of water management services to water users.
- Improve communication and cooperation among water suppliers, water users and other agencies.
- Facilitate alternative land use
- Facilitate use of available recycled water
- Facilitate the financing of capital improvements for on-farm irrigation systems.
- Optimize conjunctive use of surface and groundwater.
- Water measurement and water use reporting.
- Conservation pricing or other economic incentives to increase demand flexibility.

As part of this plan, the District could also explore joining the CIMIS program and implementing an automatic climate monitoring station. The program provides accurate climate information and water management data so that growers can more efficiently manage their water use.

Implement Urban Water Efficiency Measures

Although urban water use currently represents a small percentage of water use in the Basin, this use is likely to grow with future increase in population. Early implementation of urban best management practices so that they are built in to new infrastructure can cost-effectively reduce the rate of growth of urban water use.

The following best management practices could be considered for implementation in urban areas in Big Valley. These measures would need to be facilitated by the Kelseyville and Finley municipal water supply agencies.

- Designate a Water Conservation Coordinator.
- Large landscape conservation programs & Incentives
- Drought-tolerant urban garden and landscaping programs
- System water audits, leak detection & repair
- Metering with commodity rates for all new connections and retrofit of existing connections
- Water survey programs for single-family residential & multi-family residential customers
- Conservation programs for commercial, industrial & institutional Accounts.
- Residential plumbing retrofit
- High-efficiency washing machine rebate programs.
- Residential ultra low flow toilet replacement programs.
- Public information and school education programs.
- Conservation- based water pricing.
- Water waste prohibition – especially during droughts

Increase Surface Water Supply

The most promising options appear to be:

- Adobe Creek conjunctive use project,
- In-lieu use of surface water for frost control,
- Off-stream storage.

The proposed Adobe Creek conjunctive use project is currently undergoing environmental and water rights permitting reviews.

Further investigation of frost control practices and conjunctive use of surface water for frost control could lead to reduced ground water demand and



improved ground water levels. The first step would be to inventory water use for frost control and investigate the feasibility of in-lieu use of surface water by riparian property owners.

There are many small private impoundments scattered across the Basin and there appear to be many more sites with suitable topography for small off-stream reservoirs. If the District wishes to further explore the feasibility of off-stream storage, the first step would be to carry out an inventory of available sites and rank them according to technical, environmental and cost factors.

Increase Ground Water Recharge

The most promising measures appear to be:

- Enhancing natural ground water recharge from streams.
- Spreading basins

Upstream storage on Kelsey Creek could improve recharge in lower Kelsey Creek however environmental constraints may preclude construction of on-stream surface water storage. Off-stream storage may be feasible and could be explored further. The proposed Adobe Creek Conjunctive Use Project would enhance recharge on Adobe Creek.

Detention structures regulate streamflow and increase the hydraulic gradient between the stream and the aquifer. The effectiveness of the Kelsey Creek Detention Structure is severely limited by environmental constraints designed to maintain fish passage. If the fish passage problem could be solved through installation of a fish ladder or elevator then the recharge process would probably be enhanced.

A detention structure at the downstream end of the Adobe Creek unconfined zone in the vicinity of the Merritt Road crossing would also help the recharge process. The structure could be a low profile rubber dam, or flap gate structure that would retard flow to aid the recharge process. It is understood that the county has already proposed a detention structure for Adobe Creek which was not pursued due to potential problems with fish passage. Some of the suggestions made in the previous discussion relative to the Kelsey Creek structure may apply.

Artificial recharge by the spreading method

consists of increasing the surface area of infiltration by releasing water from the source to a basin, pond, pit or channel. In Big Valley, spreading basins may be feasible at old gravel pits or on idle bottomland in the unconfined aquifer zones. Potential issues include feasibility of surface water diversions, impacts of higher water table on agriculture, and other land use/environmental issues. Nevertheless spreading basins may be useful in improving the water balance in localized areas in the Basin.

Recommended Ground Water Monitoring and Studies

The following ground water studies are recommended to support the ground water management:

Improve the current water level monitoring program

The District currently measures water levels from wells throughout Big Valley on a monthly schedule. This program is effective, but could be improved somewhat.

The District should first define clear goals for the water level monitoring program. Goals may include objectives such as collecting data for the groundwater storage model, estimating the stream – groundwater interactions, or estimating well interference effects.

Based on the stated goals, the County should reassess the current set of wells used in the monitoring program, and modify the set of wells in order to better focus on the stated goals.

Expand the current water quality monitoring program

The water quality monitoring program should be carried out in coordination with the water level monitoring program. As with the water level monitoring program, the District should first define clear goals for the water quality monitoring program. This water quality monitoring program may be used to further define the areal extent of various parameters, track the migration of parameters over time, or develop a relationship between water level and concentrations.

A set group of wells should be identified for the water quality monitoring system, and a sampling schedule should be implemented for each well. The sampling schedule should be adequate to define background water quality, as well as



changes over time and changes with water levels.

Investigate the aquifer properties including confinement of the A1-A2 aquifer system in the confined zone of the northern part of the Basin

Install a staged piezometer array in the vicinity of a suitable test pumping well with a good log and suitable screened intervals. Determine effect of long-term pumping on piezometric head in both aquifer and aquitard layers.

Investigate Enhanced Recharge of "Volcanic Ash" Aquifer

Investigate aquifer properties of "Volcanic Ash" Kelsey Tuff bed, in order to evaluate whether it is feasible, beneficial, and economic to recharge this aquifer and whether there is some threshold level of extraction from this aquifer beyond which either or both yield is permanently diminished, or water quality degrades.

The investigation could at simplest involve a long-term pumping test preferably from a well with a good log and if possible another none pumping well in the vicinity that is also screened in the volcanic ash. Water samples would be collected at set intervals and analyzed to detect any change in mineral quality with continued extraction.

A more elaborate test could involve installation of a staged piezometer system with the piezometers below, within, and above the ash layer in the vicinity of the pumped well.

Develop estimates of hydrogeologic parameters

The volumetric model relied on a number of uncertain hydrogeologic parameters, including hydraulic conductivity and specific yield. A series of aquifer tests throughout Big Valley would help define these parameters. Aquifer tests could be performed on existing production wells; however it will likely be necessary to install monitoring wells or piezometers to adequately define the hydrologic parameters. This data could further shed light on the interactions between the ash aquifer and the overlying sediments.

Monitor Land and Water Use Practices in the Basin

The District should maintain an updated water balance for the Basin. Periodic updating of land use data and water use information, including monitoring of water use practices, should be carried out to help keep the water balance current and to identify any significant trends.



2. Introduction

2.1 PURPOSE

The purpose of this study is to provide updated information needed for planning and management of the ground water resources of Big Valley pursuant to Lake County's groundwater management plan adopted on May 18, 1999.

Previous studies of the Basin¹ were carried out in 1967 and are to be updated to take account of changes that have occurred since the previous study.

2.2 AUTHORIZATION

The investigations were carried out pursuant to an agreement for engineering services for preparation of the Big Valley Ground Water Recharge Investigation Update dated April 2, 2002 between Lake County Flood Control and Water Conservation District (District) and Christensen Associates Inc. (CAI).

2.3 SCOPE

The study area is the Big Valley Ground Water Basin in Lake County, California. This is the largest ground water Basin in Lake County and carries the California Department of Water Resources designation of Basin No. 5-015.00 - Kelseyville Valley.

The scope of work defines the tasks required to achieve each of the five goals as follows:

Task 1 - Evaluate Patterns and Changes in Ground Water Quality

Evaluate patterns and changes in groundwater quality in Big Valley. Using existing groundwater quality data from DWR, USGS, etc.:

Current groundwater quality parameters will be determined spatially in the Basin.

Temporal groundwater quality changes and/or trends will be determined. These trends may be time dependent and/or dependent of groundwater levels.

If additional groundwater quality data is necessary, the Update should identify the needs for additional sampling.

¹ Big Valley Ground-Water Recharge Investigation, March 1967, Prepared by Soil Mechanics and Foundation Engineers for Lake County Flood Control and Water Conservation District.



Task 2 - Determine Aquifer Conditions and Evaluate Changes over Time.

Using available topographic, well construction and groundwater level data, determine the current hydrogeologic parameters of the Basin,

Evaluate how the hydrogeologic parameters have changed since the Investigation was completed and discuss the reason for these changes.

Task 3 - Develop a volumetric model of the Basin to facilitate management of groundwater and groundwater recharge and extractions.

Utilizing well construction logs, the Investigation, and other available data, determine a storage/groundwater level relationship that estimates the total volume of groundwater stored in the Basin.

Utilizing the District's water level database, changes in groundwater storage over time can be determined. Annual recharge and net groundwater use should also be quantified.

If additional groundwater data is necessary, the Update should identify the needs for additional data.

The County currently utilizes ArcView 3.2 for much of its information management tasks. Integration of the model into ArcView, or provisions for importing/exporting model information from/to ArcView are highly desirable,

Task 4 - Identify threshold levels in specified wells and the Basin where groundwater problems occur

Based on input from local groundwater users, determine threshold levels where groundwater problems begin. This input should be evaluated to ensure that the threshold levels are reasonable and hydrogeologically sound.

Identify specific wells to be monitored for threshold levels and the appropriate thresholds.

Task 5 - Present the Update findings to the Zone Commission and the Public

Progress updates will be provided to the Zone Commission throughout the development of the Update. Input from the Zone Commission will be provided to the consultant for incorporation in the Update.

A public meeting will be held at the beginning of the Update preparation to obtain public input

A second public meeting will be held to obtain information necessary for Goal 4.

A third public meeting will be held after the Draft Update is completed to present the findings to the public.



2.4 ACKNOWLEDGEMENTS

This study was carried out by CAI by a team comprised of John P. Christensen P. E. Project Manager, Douglas H. Hamilton PhD, C.E.G. Geologist, Mr. Derrick Williams R.G. C.H. Hydrogeologist, and Mr. Richard C. Harlan, C.E.G. R.G. Geologist.

CAI wishes to acknowledge the assistance of Mr. Thomas Smythe, Water Resources Engineer for Lake County Flood Control and Water Conservation District in planning and executing the work. Mr. Alex's Straessle of the District assembled and provided geospatial data and water level measurements used in the study.

During the course of the study, meetings were held with the Big Valley Ground Water Management Zone Commission to review the progress of work and discuss issues related to groundwater in Big Valley. These meetings were important in gathering background information and identifying issues to be addressed.

Two public meetings were also held during the course of the study to solicit input from local communities.

2.5 FORMAT OF REPORT

The report comprises nine sections and three appendices.

Following this introduction, *Section 3* covers the background to the present study and summarizes previous investigations of the Basin.

Section 4 provides an overview of the Big Valley area including its location, physiography, topography, climate, vegetation, history, land use and local economy.

Most of the information relevant to the 5 tasks specified in the scope of work is found in *Section 5 through Section 9* and in appendices as follows:

Patterns and Changes in Ground Water Quality are discussed in *Section 7* and supporting *Appendix C* contains copies of water quality data.

Aquifer Conditions are discussed in *Section 5 - Geology* and *Section 6 - Hydrology*. Data that show changes of water levels in the aquifers over time are shown in *Appendixes A and B*.

The volumetric model is discussed in *Section 8*. Much of the supporting information is found in *Section 5 - Geology* and *Section 6 - Hydrology*.

Water quality issues and thresholds related to irrigation and public health are discussed in *Section 7*.



Section 9 presents the findings and recommendations of the study. Relevant ground water hydrology and water quality data is attached in three appendixes.



3. Background

3.1 INTRODUCTION

The purpose of this section is to summarize background information to the present ground water recharge update. It briefly describes Lake County's ground water management plan, ground water issues and previous studies of the Basin.

3.2 GROUND WATER MANAGEMENT PLAN

On May 18, 1999, Lake County Flood Control and Water Conservation District (District) adopted the "Big Valley Ground Water Management Plan" pursuant to the State of California's Ground Water Management Act (AB 3030 - 1992).

A Ground Water Management Plan is defined by the State of California Department of Water Resources Bulletin 118-80 as "*Planned use of the groundwater basin yield, storage space, transmission capability, and water in storage.*"

Ground water management includes:

1. Protection of natural recharge and use of intentional recharge;
2. Planned variation in amount and location of pumping over time;
3. Use of groundwater storage conjunctively with surface water from local and imported sources; and
4. Protection and planned maintenance of groundwater quality.

The Plan is being implemented with the input of the Big Valley Ground Water Management Zone Commission. The Commission consists of seven citizens appointed by the District Board of Directors and comprises four representatives of agricultural water users, two representatives of public water supply users, and one at large representative.

Existing information limits management of the groundwater basin due to the following factors:

- ▶ Ground water quality data have not been evaluated in a quantitative manner.
- ▶ Current groundwater conditions are unknown.
- ▶ Ground water level thresholds below which problems occur have not been established.
- ▶ It is difficult to evaluate quantitatively how changes in groundwater recharge and groundwater use will affect groundwater supplies.
- ▶ It is difficult to estimate fall groundwater levels from the spring groundwater levels. Because there is essentially no natural groundwater



recharge during the summer, this is critical for evaluation of potential problems before they occur.

3.3 GROUND WATER ISSUES

Big Valley is primarily an agricultural area that is important to the economy of Lake County. Ground water is the primary water source for agriculture and public water supply in Big Valley.

Overdraft of groundwater has long been recognized as a problem especially during drought periods when there is insufficient natural recharge during winter to replenish aquifers in the ground water basin.

Potential impacts of overdraft include:

- ▶ Water shortages during droughts that impact agricultural production and local domestic water supplies.
- ▶ Deterioration of groundwater quality due to intrusion of geothermal water containing iron and boron.
- ▶ Drying up of wells during droughts requiring deepening of wells or new sources of water supply.
- ▶ Increases in energy needed for pumping water from deeper levels.
- ▶ Ground subsidence which potentially reduces available groundwater storage and changes surface drainage patterns.
- ▶ Impacts on fish, wildlife and riparian vegetation due to reduced streamflow and earlier drying up of creeks due to lowered water table.

3.4 PREVIOUS STUDIES

Efforts to study and improve groundwater supplies and groundwater reliability in Lake County began in the late 1940's. The two main previous studies are as follows:

- Bulletin 14 - Lake County Investigation – California Department of Water Resources 1957.
- Big Valley Ground-Water Recharge Investigation Lake County Flood Control and Water Management District May 1967.

Summaries of these reports follow:

3.4.1 DWR Bulletin 14 - Lake County Investigation – 1957

In 1948, members of the Lake County Board of Supervisors presented to the State Water Resources Board a resolution dated August 30, 1948 which proposed a State/County cooperative survey of water conservation problems in Lake



County.

At that time Lake County had experienced an increasing population concurrently with an expansion of irrigated agriculture. These two factors resulted in increased draft on groundwater resources creating an apparent shortage of irrigation and domestic groundwater in the latter part of irrigation season when shallow pumping installations failed to produce water sufficient to meet demands.

The scope of the investigation included assessment of existing surface and groundwater supplies, estimation of water supply needs, and development of plans for securing supplemental water supplies. The area investigated comprised three valley portions of Lake County lying adjacent to Clear Lake, namely Big Valley, Scotts Valley and Upper Lake.

In order to estimate future water use all valley floor lands were classified with regard to their suitability for irrigated agriculture. Irrigation practices were surveyed to determine consumptive use of water for irrigation of crops. Studies were made of the quality of surface and groundwater in order to evaluate their suitability for irrigation use.

Reconnaissance surveys were made to locate and evaluate possible dam and reservoir sites. At that time major features of the California Water Plan anticipated diversion of surface water from the Eel River through Clear Lake to the Sacramento Valley. It was anticipated that surplus water from the Eel River could more than meet the probable supplemental water requirements of the Clear Lake area.

The main findings of the study were that:

1. There was a need for supplemental water to meet requirements of irrigable lands presently not supplied with water.
2. Flood control was needed on major creeks tributary to these valley areas.
3. At that time there was no requirement for supplemental water since mean seasonal extraction of free groundwater had not yet exceeded average recharge.
4. Under the forecast ultimate conditions of development, seasonal requirements for supplemental water in Big Valley were estimated to be about 32,500 acre-feet/year.
5. Studies indicated that water supply and flood control needs could both be met by regulating the flow of tributary streams to Clear Lake.
6. The surface water supplies of the Clear Lake area were found to be generally of excellent mineral quality and well-suited for irrigation and



other beneficial uses

7. Ground water of good mineral quality occurs generally in the area except in certain locations in which the groundwater contains excessive concentrations of boron.
8. Plans for development of three flood control and water supply projects were proposed. Plans for the Big Valley project included construction of Kelseyville Dam and reservoir on Kelsey Creek about four miles upstream from Kelseyville, construction of a bypass channel which would convey the combined outflows of Kelsey Adobe and Highland creeks along the western edge of Big Valley to discharge into Clear Lake.

The main recommendations were:

1. A public district be created to pursue further study and implementation of potential water projects.
2. That development be accomplished by an orderly progression of phases in accordance with the California water plan.
3. Additional engineering investigations be made of potential water resource projects.
4. Stream gaging stations be installed to permit a more reliable determination of streamflow and water supply yield.
5. Work commence on acquisition of land necessary for construction of the proposed projects.
6. Further support be given to the study of major multipurpose water resource development under the California Water Plan.

3.4.2 Big Valley Ground Water Recharge Investigation – 1967

This investigation was undertaken by Lake County Flood Control and Water Conservation District and the West Lake Soil Conservation District to achieve three basic goals:

1. Determine the technical feasibility of carrying out supplemental recharge of the groundwater in Big Valley
2. Define the groundwater geology and hydrology of Big Valley,
3. Develop a preliminary plan for groundwater replenishment in the Valley.

The scope of the investigation included assessment of the geology, hydrogeology, hydrology, and water management in the Big Valley together with the assessment of the feasibility of ground water recharge and development



of preliminary plans for conjunctive use of surface and groundwater resources.

As a result of an extensive field reconnaissance, review of literature, and evaluation of logs of 77 existing water wells drilled in Big Valley, a comprehensive conceptual model of the ground water basin was developed.

Twelve principal geologic units grouped into four main categories were recognized and mapped during this investigation. The valley was divided up into nine distinct geologic regions according to the topography and underlying geology. The study also included assessment of groundwater quality and the effect of potential recharge operations on the quality of groundwater.

The primary recommendation was to construct a multipurpose reservoir on Kelsey Creek for flood control, groundwater recharge and recreation together with a diversion from Kelsey Creek to Adobe Creek. It was also recommended that water from Kelsey Creek be diverted to the central upland for use in recharging the volcanic ash aquifer in the central upland area.

3.4.3 Subsequent Events

Some significant events that have happened since these investigations were completed are as follows:

- ▶ Further growth in population and land development.
- ▶ Severe droughts occurred in 1976-77 and 1987-92 which have identified limitations in the ground water supply.
- ▶ Downtcutting of the streambed of Kelsey Creek due to gravel mining and channelization of its delta by California State Parks.
- ▶ Downtcutting of Adobe Creek due to gravel extraction and reduced replenishment of gravel downstream of Highland and Adobe Reservoirs.
- ▶ Changes in land use. Change of crops from pears and walnuts to grapes. Increased farming of uplands. Growth of ranchettes.
- ▶ Drilling of more wells and deeper wells in Big Valley.
- ▶ Reported ground subsidence.
- ▶ Addition of the Kelsey Creek Detention Structure in 1987.
- ▶ Advances in irrigation technology including drip irrigation, climate monitoring and automatic soil moisture control.
- ▶ Advances in state-of -the-art in mathematical modeling of groundwater basins.
- ▶ Advances in computers as tools for simulating surface and groundwater flow.
- ▶ More is known about adverse effects of poor water quality on humans and plant species.



- ▶ State of California has implemented groundwater management goals and procedures (AB 3030)
- ▶ Funding to support improvement of water supplies and water resources was approved by California voters.

The District has been monitoring groundwater levels biannually in cooperation with DWR since 1961. Starting in 1982, monthly groundwater monitoring was started in select wells to evaluate the impacts of the proposed Kelsey Creek Detention Structure.

In 1991, additional monitoring wells were added to evaluate the impact of a similar structure on Adobe Creek. Data from these wells have been entered into a Microsoft Access database to assist in evaluating the data (over 13,600 measurements). This has greatly improved the ability to evaluate changes from year to year and evaluate operations of existing and potential projects, however, these activities are limited to qualitative, not quantitative, analyses.



4. Big Valley Ground Water Basin

4.1 LOCATION

Big Valley Ground Water Basin (Basin) is located within Big Valley in Lake County, California about 90 miles north of San Francisco. The Valley lies on the southwest side of Clear Lake which is the largest natural lake within California.

The Valley lies to the south of the City of Lakeport (the County seat) Kelseyville (population 2861) is the main community within the valley. The smaller community of Finley also lies in the valley bottom.

Primary road access is via State Highway 29/175 which is one of the major road access routes to Clear Lake. Highway 29 and Highway 175 converge south of Mount Konocti and skirt the southern slopes of the mountain before entering Big Valley about 2 miles south of Kelseyville. The highway then traverses about 5 miles of the valley floor in a north-westerly direction toward Lakeport.

Lampson field, the main airport serving the Lakeport area is also located on the floor of Big Valley.

A location map (Figure 4-1), an area map (Figure 4-2), landforms map (Figure 4-3) and a series of photographs of Big Valley are found at the end of this chapter).

4.2 LANDFORMS

Big Valley lies in the interior of California's northern Coast Ranges about midway between the Pacific Ocean and the Sacramento Valley.

The Basin covers a total area of 24,227 acres (i.e. about 38 square miles). Its shape is roughly triangular with a base width of 6 miles in the east-west direction and a length of about 8 miles in the North-South direction. The southwest and southeast sides are bounded by the Mayacmas Mountains and by Mt. Konocti, respectively. The open north side is part of the shoreline of Clear Lake.

The surface of the groundwater basin area in the bottom of the valley is, for the most part, a broad plain that gently slopes toward the Lake, bordered by terrace-like uplands on the west side of the valley and steeper slopes on the east side that abuts Mount Konocti. A central upland in the southern part of the valley divides into two smaller valleys which have been incised by Kelsey and Adobe Creeks. Both of these creeks originate in the Mayacamas mountains south of Big Valley and flow northward through the uplands and across the broad bottomlands into Clear Lake.

Surface elevations on the bottomlands range from about El. 1400 ft. at the head of the valley to about El. 1325 ft. at the shoreline of Clear Lake. Upland areas on the



east side rise to about El. 1500 ft. before becoming steep. The central upland rises to about El. 1600 ft. The surrounding mountains to the south and east rise to elevations of about 3000 feet whereas Mount Konocti to the west reaches 4300 feet.

4.3 CLIMATE

The climate in the Big Valley area is the typical Mediterranean climate found in inland valleys of Northern California. Summers are hot and dry and winters are mild and wet.

Average daily maximum temperatures reach the low 90's in summer and are in the 50's during winter. During winter minimum temperatures dip below freezing, bringing some snowfall to the surrounding mountains and frost to the valley floor.

Most annual precipitation occurs as rainfall during the five month period from November through March. Mean annual precipitation at Kelseyville on the valley floor is about 23 inches/year.

4.4 VEGETATION

Vegetation in Big Valley is predominately agricultural crops in the bottomlands, mixed agricultural crops, dry farming and native vegetation in upland areas and mainly native vegetation on the steeper valley slopes.

Pear orchards predominate in the northern bottomlands where ground water for irrigation is readily obtainable, however in recent times economics have favored conversion of walnut and pear orchards to grapes. Some land is cultivated for feed crops, and some tracts are idle or undeveloped. Urban landscapes surround Kelseyville, and residential subdivisions. There are also a growing number of ranchettes in the valley.

Most of the upland areas are dry grasslands interspersed with oaks. A few of the upland tracts are in walnut orchards or are being developed into irrigated vineyards.

As the terrain steepens the vegetation changes to brush, chemise and scrub pine in the foothills becoming more dense in the southern slopes of the valley that is bordered by the Mayacmas Mountains.

4.5 HISTORY

Clear Lake and its surrounding watershed have a long historical record. It has one of the oldest documented "early man" sites near Borax Lake indicating human occupation about 10,000 years ago.

Native American population of the Clear Lake Area is estimated at about 3000 at



the time of European contact in the early 1800's. At that time there were 30 or so villages within the Clear Lake Basin. The inhabitants were supported by the abundant fish and waterfowl of the lake area. The Pomo tribe has historically inhabited the Big Valley area. The Big Valley Rancheria of the Big Valley Band of Pomo Indians is located in the northwest corner of the valley near the Shore of Clear Lake.

Hunters and trappers of the Russo-American Fur Company were the first Europeans to visit the area as early as 1811. About 1849, Salvador Vallejio took over much of the Big Valley area and started agriculture. By 1854 settlers began arriving and it was not long before the valley lands were in private ownership – mainly large holdings. Lake County was created by the legislature on May 20, 1861 from the northern portion of Napa County and Lakeport was made the county seat.

Early agriculture in the valley included dairy farms and production of feed including barley and corn. Several flour mills were built in Lake County and wheat was milled for both local consumption and outside sale. In early times, the streams of Lake County provided power to operate both mills for grinding grain as well as saw mills for processing local lumber. The Brown Mill (formerly called the Allsion Mill) was located on Kelsey Creek.

Mining was also an early activity in Lake County with small operations that extracted Borax commencing in 1864 and sulphur in 1865. Mercury mining also became a significant activity during the gold rush period.

Starting in the mid 1870's, the mineral springs associated with the areas geothermal activity began to attract thousands of visitors seeking rejuvenation in the warm mineral waters. Highland Springs in Big Valley later became one such popular destination.

The fruit industry began to assume some importance as early as 1868. Bartlett Pears, for which the region is now best-known, were first grown about 1885. Prunes planted extensively early in the 1920s were not profitable and were ultimately replaced with pears and other tree crops.

The first vineyards were also planted in the 1800's and by the 1900's the region was known for producing high quality wines. In the 1920's, prohibition brought an end to wine production causing vineyards to be replaced with orchards. However, a re-emergence of the wine industry in Lake County began in the 1960s when growers rediscovered the area's potential for growing varietal grapes and began planting new vineyards. Vineyards in the County have expanded from several hundred acres in the 1960's to over 7000 acres today.

Growth of recreational development around the shoreline of the lake followed construction of the state highway in the 1920s. Growth in demand for aggregate to build roads lead to expansion of gravel mining along Kelsey and Adobe Creeks. However, downcutting of the creek-beds resulted in later restrictions to



gravel mining.

Over the years, flooding has been a problem in Big Valley. In the 1960's, the Adobe Creek Flood Control Project was implemented to reduce flooding of the bottomlands. Adobe Reservoir and Highland Springs Reservoir were constructed in 1962 to attenuate peak flood flows in Adobe Creek. In 1987, the Kelsey Creek Detention Structure was constructed on Lower Kelsey Creek to enhance groundwater recharge in lower Kelsey Creek.

4.6 ECONOMY

Economic activities in Big Valley include agriculture, fruit processing and packing, commercial/residential development, and tourism/recreation.

Agriculture is the main activity with over 11,000 acres in irrigated and dry farming. The topography, climate and soil make it the ideal place for growing a variety of crops, including pears, walnuts, and premium wine grapes. There is also dry grazing and production of feed including hay and alfalfa.

No separate economic activity data is available for Big Valley, however Table 4-1 provides some recent data for Lake County which shows the dominance of the wine and pear industries in the County.

Table 4-1
Lake County Agricultural Production -2001

Winegrapes	\$28.8 million
Pears	\$17.5 million
Cattle & Calves	\$ 2.7 million
Walnuts	\$ 1.7 million
Livestock	\$737,000
Hay, other	\$557,000
Nursery Products	\$408,000
Other Fruit & nut crops	\$359,000
Hay, grain	\$264,000

Most residential development is located in the communities of Kelseyville, Finley and in several small lakefront communities. There are also many small farmsteads that provide for mixed residential/agricultural use.



Tourism facilities includes a new casino located in the Big Valley Rancheria, recreation home development near the Lake, and several campgrounds. Clear Lake State Park is visited by thousands of fishing and water sports enthusiasts every year. The park is on the Shore of Clear Lake near the mouth of Kelsey Creek. There is also a county park on the shore of Highland Springs Reservoir.



**Figure 4-1
Location Map**

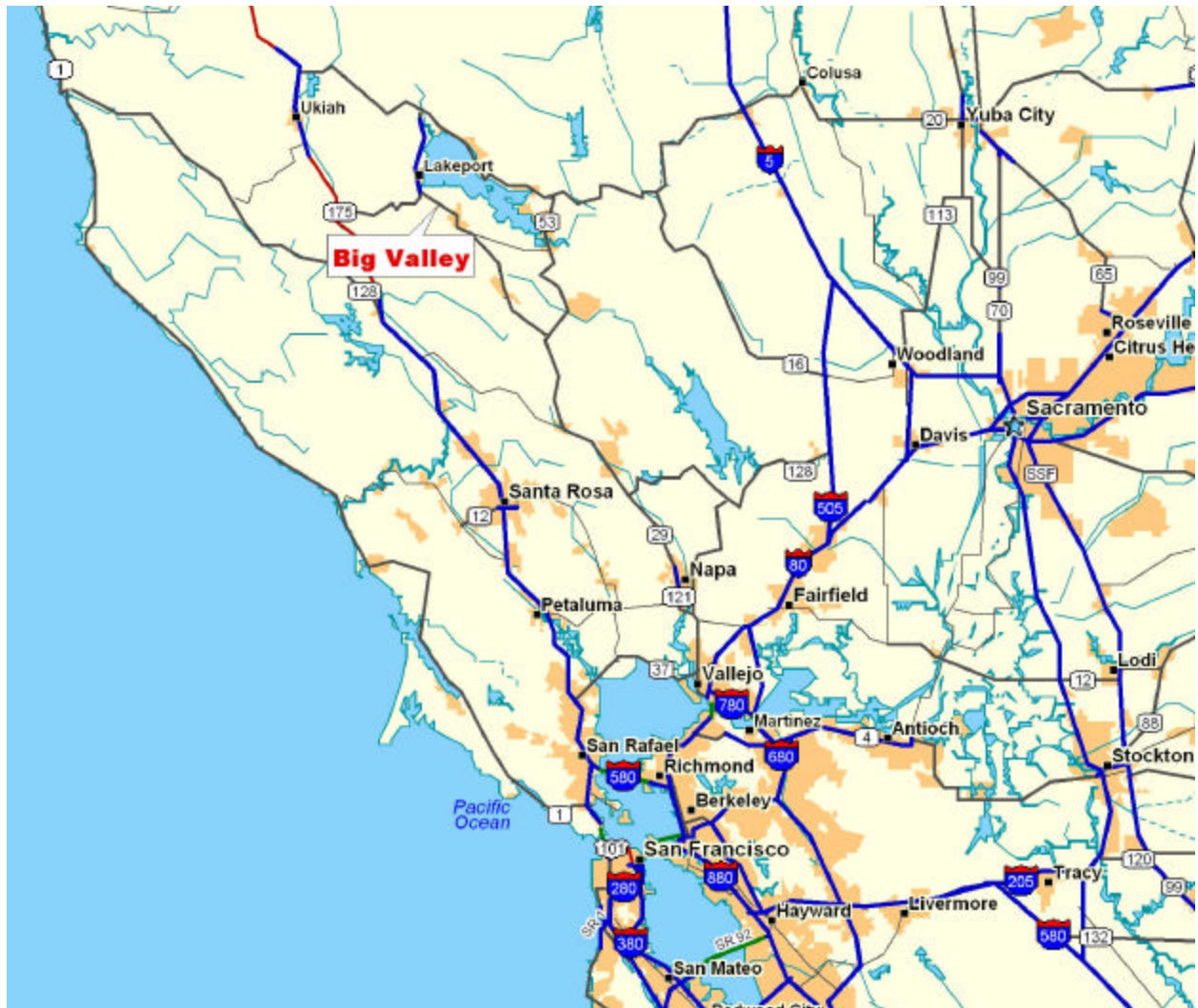


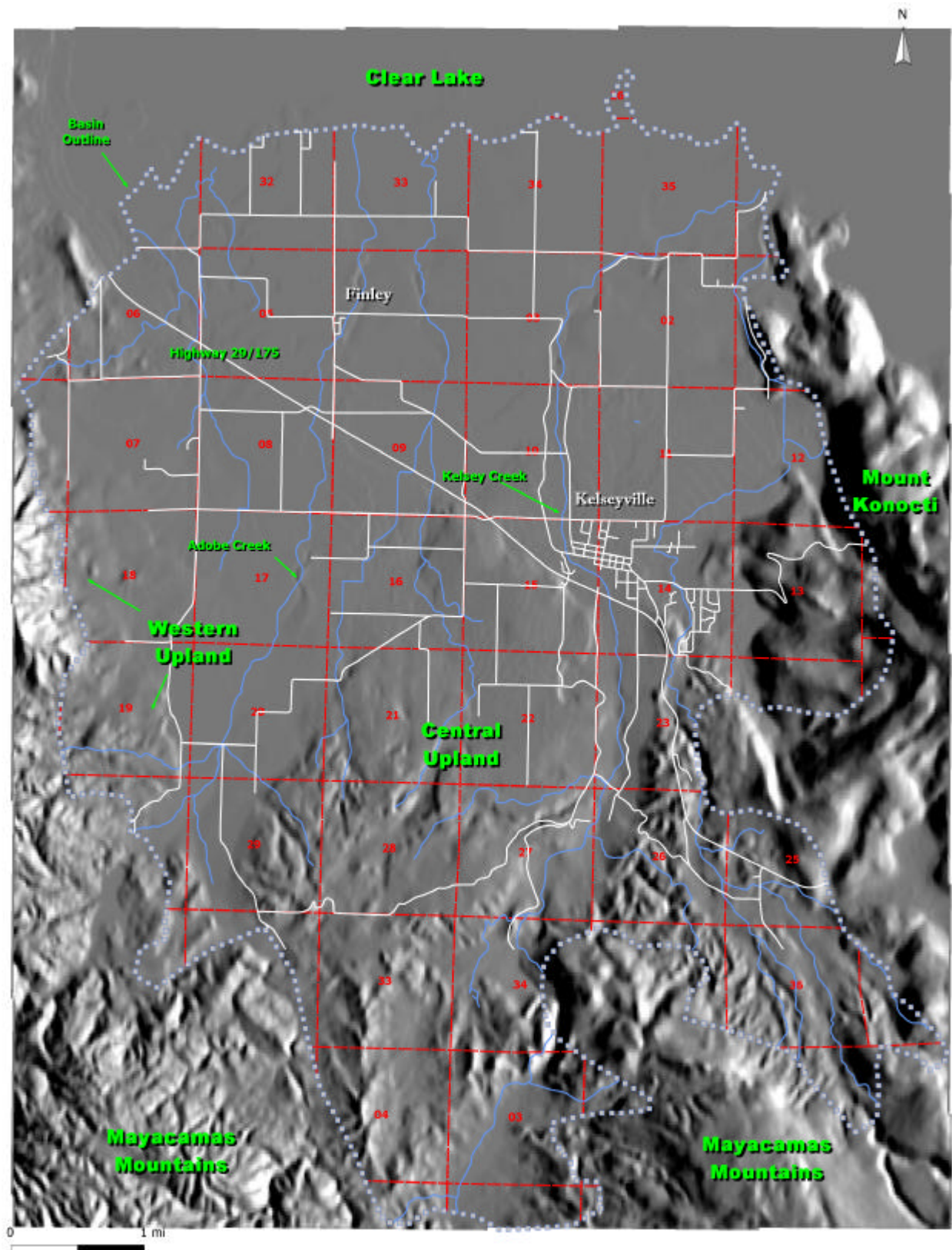


**Figure 4-2
Area Map**





Figure 4-3
Big Valley - Landforms





Photograph 4-1
Big Valley looking southeast toward Mount Konocti.



Photograph 4-2
Big Valley looking northwest from Mount Konocti towards Clear Lake
Kelseyville is on the left of the frame.



Photograph 4-3
Pear Orchard



Photograph 4-4
Walnut Orchard



Photograph 4-5
Irrigated Pasture



Photograph 4-6
New Vineyard showing High Spring Water Table



Photograph 4-7
Kelsey Creek at the USGS Streamgage



Photograph 4-8
Adobe Creek at Bell Hill Road Crossing



Photograph 4-9
Ground Water Well



Photograph 4-10
Irrigation and Frost Control Reservoir and Pump System



Photograph 4-11
Highland Springs Reservoir



Photograph 4-12
Kelsey Creek Detention Structure



5. Geology

5.1 INTRODUCTION

This section of the report update presents the results of our investigation of geologic conditions as they relate to the occurrence of ground water in the Big Valley area. This part of our investigation has encompassed three principal activities:

1. Review of relevant literature and research concerning the Clear Lake Basin and Big Valley area.
2. Characterization of the Big Valley area as to present geologic condition and Quaternary geologic evolution and
3. Detailed study and characterizations of the Quaternary stratigraphy that forms the aquifer system in Big Valley, based on plotting and analysis of the logs of some 280 wells in the area.

Activities (1) and (2) were undertaken in order to provide a conceptual and physical framework for the definition of the stratigraphic aquifer system of activity (3).

Knowledge of the geology of the Clear Lake region has been vastly expanded during the 35 years since the original Big Valley Ground Water Recharge Investigation was completed, in 1967. The various studies that resulted in this improved understanding were mainly carried out by geoscientists of the U.S. Geological Survey. These researchers were pursuing two different programs that had very different objectives.

The first program was mainly concerned with characterization of the Quaternary geology of Clear Lake, with one objective being the testing of a theory that originated with the observation that the fine-grained sediment on the bottom of Van Norman Reservoir in the San Fernando Valley in Southern California, was notably disturbed by the violent shaking of the 1971 San Fernando earthquake. Following this recognition, it was reasoned that the sediment accumulated in Clear Lake might contain evidence of similar past earthquakes and therefore merited study based on collection and analysis of undisturbed core samples. Studies of the lake sediments were subsequently extended to include the paleo lake sediments that form the stratigraphy of Big Valley.

The second program was related to a much larger scale research effort directed toward characterizing and understanding the geology of the Geysers geothermal field, which is the largest and most valuable such resource known in the world. This included study of the origins and geology of the Clear Lake Volcanics and related hot springs, in the immediate vicinity of Clear Lake and Big Valley.



The principal results of these two investigation programs were published as series of articles in U.S. Geological Survey Professional Paper 1141, "The Clear Lake Volcanics; Tectonic setting and magma sources" by Hearn and others (1981) and in Geological Society of America Special Paper 214, "Late Quaternary Climate, Tectonism and Sedimentation in Clear Lake" edited by John D. Sims (1988).

Many other more narrowly focused articles have been published subsequently but the two cited above provide the most comprehensive background geologic information. Despite this, however, the source describing the geology of Big Valley that is commonly cited and that is used for map compilations showing the geology of Big Valley has remained the 1967 "Big Valley Ground Water Recharge Investigation" report. The following section is intended to bring together all relevant data and studies from the intervening 35 years to update knowledge of the geology and geohydrology of the Big Valley area.

5.2 REGIONAL GEOLOGIC AND TECTONIC SETTING OF THE BIG VALLEY AREA

The Big Valley area is part of the large intra montane structural depression referred to as the Clear Lake Basin, located in the south central part of the northern Coast Ranges of California. The tectonics of this region are broadly dominated by the regional right shear of the San Andreas Fault system part of the Pacific-North American plate boundary. This tectonic system is manifested by long relatively continuous right lateral strike slip faults oriented parallel to the NNW-SSE trend of the San Andreas fault along the coastline to the west. The strike slip faults form a pronounced regional grain, that is seen both in the geologic structure (Figure 5-1) and in the terrain (Figure 5-2).

As shown on Figure 5-1, the Clear Lake basin occupies the central part of a large structural block defined by the Mayacama fault zone on the west and the Bartlett Springs fault zone on the east. This block is internally deformed by a complex pattern of faulting which, however is also dominated by strike slip faults oriented parallel to the block boundary faults. Interactions among these faults during late Cenozoic including late Quaternary time, have resulted in formation of the greater Clear Lake structural depression that includes both Big Valley and the constructional landforms of the Clear Lake volcanics.

Figure 5-2 shows the principal faults that appear to form the Quaternary structural framework of the greater Clear Lake basin. Some of these faults have established names (e.g. Collayomi, Big Valley faults) while others are assigned names herein for convenience of reference (e.g. "Clear Lake", "Scotts Valley", "Kelsey Creek" faults).

The gross structural pattern shown on Figure 5-2 is one of several linear NNW-SSE oriented faults, the general trends of which are interrupted by more westerly oriented cross faults in the Big Valley area. Overall, however, the principal fault reaching this area from the southeast is the Collayomi fault which dies out northward between Big Valley and Mount Konocti in the southwest part of the



basin, and the principal faults extending to the north are the Clover Valley and Clear Lake faults, on the northeast side of the basin. This pattern describes a "right stepover" of lateral movement which in a right lateral fault system, results in a local region of extension that tends to be expressed by a structural depression and, at the surface, a topographic basin such as, in this case, the Clear Lake basin. This mechanism is illustrated on Figure 5-3 diagrams A and B, and its application to the Clear Lake structural depression is noted in McLaughlin, 1981, among others. Figure 5-3 diagrams C and D illustrate the compressional effects that result from a left step of faults in a right slip system. As is discussed in Section 5.4 we consider this mechanism to be a likely explanation of the uplift of the Kelseyville Formation in the southern part of Big Valley.

5.3 GEOTECTONIC EVOLUTION OF THE CLEAR LAKE BASIN AND VOLCANICS

Various aspects of the geotectonic evolution of the Clear Lake basin and the Clear Lake Volcanics are discussed in the series of articles that are presented in U.S. Geological Survey Professional Paper 1141. The two aspects that have special relevance for this ground water investigation update are

1. The structural evolution of the Clear Lake intra montane basin, and
2. Some of the eruptive history of the Clear Lake volcanics field

These provide the basis for defining the conditions of the present ground water regime in the Big Valley.

McLaughlin (1981) Hearn and others (1981) and Sims (1988) all cite evidence that the eruption of the Clear Lake volcanics began around 0.6 ma or possibly as early as 1.1 ma. This eruptive activity formed the earliest positive evidence for the existence of a structural depression in the area of the present Clear Lake basin. However, this followed development of the structurally similar Cache basin to the southeast, starting around 2.9 ma, with sedimentation there continuing to <1.66 ma. The initiation of deposition of the mainly lacustrine Kelseyville Formation is thought to have been roughly contemporaneous with eruption of the rhyolite of Thurston Creek, age dated as about 0.6 ma. Sedimentation continued in a basin corresponding in location to present day Big Valley and the main body of Clear Lake until around 0.3 ma, and included the air fall deposition of the Kelsey lapilli tuff that now forms an important aquifer in the central and upper Big Valley area. The Kelsey Tuff is thought by Hearn and others (1988) to have been erupted from a vent on or south of Mt. Konocti and to be around 0.35 to 0.4 ma. Construction of the Clear Lake volcanic field including its principal edifice Mt. Konocti, occurred during and following deposition of the Kelseyville Formation in the contiguous shallow lake. Despite the proximity of this eruptive activity, the Kelsey Tuff is the only known deposit of fragmental volcanic debris in the mostly fine-grained Kelseyville strata. Detailed analysis of cores of the basin sediments of Clear Lake has shown, however, that numerous layers of silt and clay-like volcanic ash are present throughout both the younger basin deposits and the older but otherwise similar Kelseyville strata.



The eruptive activity of the Clear Lake volcanic field continued long past the termination, owing to uplift, of deposition of the Kelseyville Formation. The youngest known eruptive activity produced an obsidian flow about 10,000 years ago, and geothermal activity continues at present.

5.4 QUATERNARY STRUCTURE, STRATIGRAPHY AND LANDFORMS OF THE BIG VALLEY AREA

From mid to late middle Pleistocene time (c. 0.6-0.3 ma) the Pleistocene Big Valley – Clear Lake basin was the site of essentially continuous deposition as it gradually subsided. The subsidence was partly an on-going tectonic structural process but may also have resulted in some degree from transfer of magma from the underlying chamber to the surface as the Clear Lake volcanics eruptions continued. Studies of the paleontology and palynology (fossil pollen) content of the Kelseyville strata show that they mostly accumulated within a shallow freshwater lake although the lake receded enough for a forest to grow during at least one interval. At around 0.3 ma, however, the Big Valley area was uplifted above lake level, and the streams that had supplied the Kelseyville Formation sediment now began to flow across and erode the uplifted area.

It appears that the uplift of the southerly half of the Big Valley area resulted from an episode of tectonism involving the interaction between the two major strike slip faults consisting of the Collayomi fault on the east and the Scotts Valley fault on the west, that formed the structural boundaries of the Big Valley basin as shown on Figure 5-4. This interaction appears to have been related to the compressional left stepover between the north end of the Collayomi fault and the south end of the Scotts Valley fault, across the Big Valley basin, and probably was triggered by an episode of right slip on one or both of these faults. The resulting compression was accommodated by thrust and left lateral movement, on NE-SW oriented cross faults, and by south side up thrust uplift along the WNW-ESE oriented Big Valley fault. Based on an approximate correlation between the exposed uplifted upper surface of the Kelseyville Formation at 1640 feet elevation and the base of the basin deposits present along the southern part of Big Valley at about 1215 feet elevation, the vertical displacement across the Big Valley fault may be roughly 400-425 feet.

The landform that existed in the Big Valley part of the Big Valley-Clear Lake basin as the post c.0.3 ma fault uplift progressed, was of a valley floor terrace that terminated on the north at a degrading fault scarp lake shoreline. The geomorphic form of the lower canyons of Kelsey, Sweetwater and possibly even Cole Creeks south and southeast of Big Valley suggest that the drainage from the watersheds of these canyons may have continued northwest to join the flows of Adobe and Highland Creeks at this time. The combined flow of the four or five drainages then continued across the newly exposed Big Valley former lake floor and entered the now reduced Clear Lake basin. This eventually resulted in the erosional excavation of the Adobe Creek valley and the deposition of a delta in the new south margin of the Clear Lake basin. Ultimately the bottom of the new



valley reached an elevation of about 1280 feet, which is the approximate elevation of the present bottom of Clear Lake. The valley was then backfilled to its present surface elevation of about 1380 feet, possibly as a result of reduced flow when Kelsey Creek was diverted back to its present course along the east margin of Big Valley.

The history of the drainage of Kelsey Creek between its source in the mountains southeast of Big Valley and the Clear Lake basin, is of considerable significance for the understanding of the present geohydrologic regime of Big Valley.

The patterns of both elevations and thickness distribution of the A3 and "Ash" aquifers in the Kelseyville Formation suggests that the deposition of both units reflects the existence of channels entering the Pleistocene Big Valley basin from its southwest and southeast corners. This was similar to the present drainage pattern with Adobe and Highland Creeks entering and flowing down the west side of the valley and Kelsey and Cole Creeks entering on the southeast. During accumulation of the Kelseyville Formation, however, the Kelsey/Cole Creek drainage appears to have followed northwest-aligned channels that extended diagonally across the center of the basin, as shown on Figure 5-9.

This pattern changed with the partial disruption of the basin that resulted from uplift of the ground south of the Big Valley fault. At that time the tectonism that gave rise to the uplift and local tilting of the Kelseyville Formation apparently also shifted the course of Kelsey and probably also Cole Creeks, where these creeks flowed across the Collayomi fault southeast of Big Valley. Following this derangement, the outlet of Kelsey Creek into the Big Valley basin was shifted to the southwest corner of the valley, resulting in a single principal discharge of Kelsey, Adobe and Highland Creeks into the valley that underlies the present Adobe Creek floodplain along the west side of the basin. The coarser alluvium carried by the combined drainage through this valley was then deposited as the delta in the new lake margin to form the A2 aquifer, as shown on Figure 5-7.

This pattern of deposition was modified by a subsequent diversion of the course of Kelsey Creek upstream from Big Valley, back to a point of entry in the south center of the valley basin margin.

Following this diversion, which probably occurred in response to deformation along the Kelsey Creek fault as shown on Figure 5-4. Kelsey creek eroded a new channel floored by Kelseyville Formation and graded to the delta that had been deposited along the south margin of the smaller Clear Lake basin at the base of the Big Valley fault scarp. The revised drainage pattern then resulted in the development of a pair of younger outwash deltas that coalesced and continued the encroachment of Big Valley into the remaining Clear Lake basin forming the A1 aquifer system.



5.5 HYDROGEOLOGY OF THE BIG VALLEY AREA

5.5.1 General features

The hydrogeologic regime of the Big Valley area comprises two systems; 1.) the younger alluvial and basin deposits system, and 2.) the Kelseyville Formation. The younger alluvial and basin deposits underlie the floor of lower Big Valley and extend northward beneath the margin of Clear Lake. These deposits also extend southward within the buried valley beneath the floor of the Adobe Creek flood plain approximately as far upstream as the surface confluence of Adobe and Highland Creeks. The Kelseyville Formation that is exposed in the uplands of the southern part of Big Valley consists of older lake basin and alluvial strata that are similar in origin and composition to the younger alluvial and basin deposits present beneath the valley margin and flood plain, but that have been uplifted and locally deformed by tilting and faulting.

The younger floodplain and basin deposits system contains two principal aquifers, each of which consists of relatively more permeable floodplain and channel alluvium carried into the basin mainly by the flow of Adobe, Highland and Kelsey Creeks. The aquifers form a vertical sequence with an intervening clay-rich lake deposits layer, and another partly overlapping wedge of lake deposits along the northern margin of the present valley flood plain. The lower of the two aquifers is mostly confined or semi confined and the upper (A1) is confined where it is overlapped by the upper wedge of lake deposits.

The Kelseyville Formation also includes two aquifers. The upper (A3) aquifer of this system is similar in character to the A2 aquifer of the younger system, except that it is not subject to recharge by the present streams crossing the valley flood plains and is locally tilted and faulted. The lower aquifer in the Kelseyville Formation is a thin (2-5 feet) but widespread "volcanic ash" layer of permeable lapilli tuff.

The southern part of the Kelseyville Formation is uplifted approximately 400 feet across a structure that we interpret to be a south dipping reverse or thrust fault. North of this fault the formation is overlain by the younger alluvial and basin deposits. Strata corresponding to the A3 and Kelsey Tuff "ash" aquifers probably exist in the Kelseyville Formation north of the Big Valley fault but at greater depth that is reached by most wells.

The general geology of the Big Valley area is shown on Figure 5-4. Diagrams showing the stratigraphy of the area based on interpretation of well logs, are shown on Figure 5-11 through Figure 5-17. The areal distribution and well log-interpreted thickness of the A1, A2, A3 and "volcanic ash" (Kelsey Tuff) aquifers are shown on Figure 5-7, Figure 5-8 and Figure 5-9.

Observed increases or drops in the stabilized levels of groundwater in wells relative to the level at which the ground water was found as the wells were being drilled, indicating respectively either artesian or perched ground water



conditions.

5.5.2 Ground Water in the younger alluvial and basin deposits

Usable ground water occurs in the younger alluvial and basin deposits hydrogeologic unit chiefly within aquifers A1 and A2 which are present in the area indicated on Figure 5-6 and Figure 5-7. Much of the ground water present in the northern approximately two miles margin of the flood plain area and in the lower reach of the Adobe Creek flood plain area, was artesian when first encountered as wells were drilled. This condition results from the hydrostatic head of unconfined ground water in the upper margin and reach of the flood plain acting within the more or less confined downstream continuation of the A1 and A2 aquifers. (Note that the term "artesian" as used herein refers to ground water under some amount of confining pressure, rather than only to ground water under enough pressure to cause surface outflow from wells or springs). The artesian condition still exists throughout most of this area during spring high ground water/high piezometric head levels.

During late season conditions when the ground water levels are lowered by pumping drawdown and some amount of natural outflow to Clear Lake, the artesian head in the aquifers is mostly eliminated even though the aquifers are still geologically confined.

The upstream margin of the younger alluvial and basin deposit hydrogeologic regime is mostly unconfined except in the downstream reach of Adobe Creek Valley where fine-grained lake deposits extend into the lower part of the valley. The areas of unconfined ground water are the only part of the younger alluvial and basin deposits system where changes in water level in wells provides a direct specific yield measure of changes in ground water in storage.

Recharge of ground water into the A1 and A2 aquifers is primarily by direct infiltration of surface flow and underflow from Kelsey and upper Adobe Creeks into the aquifer system. Additional recharge occurs from some amounts of direct downward percolation of rainfall and applied early season frost control spraying and mid-late season irrigation. Some underflow from the higher level parts of the A3 aquifer in the central and eastern upland into the A1 and A2 aquifers probably also occurs during early season high ground water conditions, but this may reverse during the late season when heavy pumping of wells in the Kelseyville Formation creates local deep drawdown cones as shown on Figure 6-19 and Figure 6-20. Although the A1 aquifer always provided underflow to Clear Lake under natural conditions, the underflow must reverse during present conditions of late season drawdown when the piezometric head in the northern margin of the A1-A2 aquifer system is as much as about 20 feet below the lake elevation.

5.5.3 Ground Water in the Kelseyville Formation

Ground water occurs in two distinct and separate aquifers within the Kelseyville



Formation. The upper aquifer, identified herein as the A3 aquifer, is similar in origin, character, and thickness to the A2 aquifer in the younger basin and flood plain deposits. The lower aquifer is the "volcanic ash" Kelsey Tuff bed in the lower part of the Kelseyville Formation. The base of the A3 aquifer typically lies 80 to 200 feet above the top of the Kelsey Tuff bed in the Kelseyville Formation. Profiles constructed using interpreted stratigraphy from well logs together with outcrop data suggest that the Kelsey Tuff horizon is affected by some folding and probably also by deposition on a channeled surface. The higher A3 aquifer is of variable thickness which probably results from a flood plain and meandering channel environment of deposition. Because of their considerable vertical separation and differing character, the A3 and "volcanic ash" aquifers are discussed separately.

5.5.3.1 A3 Aquifer

The A3 aquifer has been identified in the logs of wells located throughout the central and west margin upland areas of Big Valley, where the Kelseyville Formation has been uplifted along the Big Valley fault. The thickness and elevation of the base of this aquifer section as interpreted from the well logs is shown on Figure 5-8. The aquifer horizon of the formation is missing only where it has been removed by erosion of the valley that underlies the flood plain of Adobe Creek south of the Big Valley fault.

The pattern of base elevations and maximum aquifer thickness suggests that a northwest draining channel beneath the central part of the present central upland contributed to deposition of the coarser grained sediment that forms the A3 aquifer. Lower aquifer base elevations in two wells located in Section 10, on the hanging wall side of the Big Valley fault, may indicate either a second channel or, possibly, down warping along the fault.

Initial versus stabilized water level data from logs of wells in the A3 aquifer indicate that the aquifer is generally unconfined. Its distribution and elevation are such that it probably is recharged by direct downward percolation of rainfall, and by the surface flow of Kelsey Creek south Kelseyville. Ground water elevation contours (e.g. Figure 6-16, Figure 6-17, Figure 6-18, Figure 6-19, Figure 6-20) suggest that except in areas of summer and fall pumping-induced cones of depression, the A3 aquifer generally contributes underflow to the A1 and A2 aquifers beneath the Adobe Creek and Kelsey Creek flood plains.

It appears that ground water in the A3 aquifer is mostly unconfined, so changes in water level in this aquifer probably provide a fairly direct measure of changes in storage.

5.5.3.2 "Volcanic ash" (Kelsey tuff) aquifer

The Kelsey lapilli tuff which forms the "volcanic ash" aquifer is an interbed in the lower Kelseyville Formation that underlies the upland and Adobe Creek flood plain area of central Big Valley. The area of this aquifer defines a band



approximately 3 miles wide that extends diagonally across the valley from the Cole Creek upland on the southeast to the northwest sector of the valley north of Lampson Field airport, as shown on Figure 5-9. The northeast boundary of this area is defined by the concealed Big Valley fault. The southwest boundary appears to correspond to onlap and/or upwarp or fault-controlled termination of the layer. Overall, the uplifted area of Kelseyville Formation that includes the Kelsey tuff-volcanic ash aquifer amounts to about 15 square miles.

The volcanic ash aquifer probably also exists in the Kelseyville Formation on the footwall north side of the Big Valley fault but there lies at depths below the reach of wells in the northern flood plain margin of Big Valley. The plot of the elevations of well intercepts of the base of the Kelsey Tuff suggest that the lapilli tuff air fall that created the "ash" layer may have been spread over a terrain of relatively low relief which, however was featured by several north to northwest-draining channels.

The thickness of the tuff layer as described in well logs is mostly between two and five feet. Two wells report intervals more than fifty feet thick, which if accurately observed, probably represent local channel fills.

Except in its few areas of outcrop, ground water in the Kelsey tuff "ash" is always confined. Initial versus stabilized water level data from logs of wells penetrating the "ash" aquifer show artesian head ranging from a few feet around the margins of the basin, to between 100 and 175 feet in much of the central and lower upland areas. Many wells drawing from the "ash" aquifer report capacities of 1000 gpm, although it is not known (to us) how long pumping at this rate can be sustained, given the minimal thickness of the aquifer layer.

Neither the recharge nor the movement of water within the "ash" aquifer are well understood. Laboratory tests of the permeability of outcrop samples of the lapilli tuff performed in connection with the 1967 recharge investigation indicated a permeability of around 3.5×10^{-3} cm/sec. or approximately 4000 feet/year. This is a relatively high permeability value but it cannot account for flow only within the 2-5 feet thick confined layer to support the area-wide pumping from this aquifer. Instead, we suggest that the "ash" aquifer functions somewhat like a drain blanket in an earth dam, with water moving into the thin permeable aquifer layer from the saturated but less permeable enclosing strata in response to gradients created by well pumping-induced local drawdown of the piezometric head. This phenomenon was suggested in the 1967 recharge investigation report.

Natural recharge to the Kelsey tuff layer is probably mainly by underflow from adjacent uplands across fault and onlap contacts into the layer. Some recharge also occurs by direct infiltration of ephemeral stream flow into the outcrops present in the canyon floor exposures of the tuff in Section 27 of the central upland area. It seems doubtful, however, that significant amounts of downward percolation from the surface or even from the overlying A3 aquifer pass through the C3 and C4 aquitards to reach the ash layer.



Figure 5-1
Geologic Structure and Faults in the Clear Lake Area

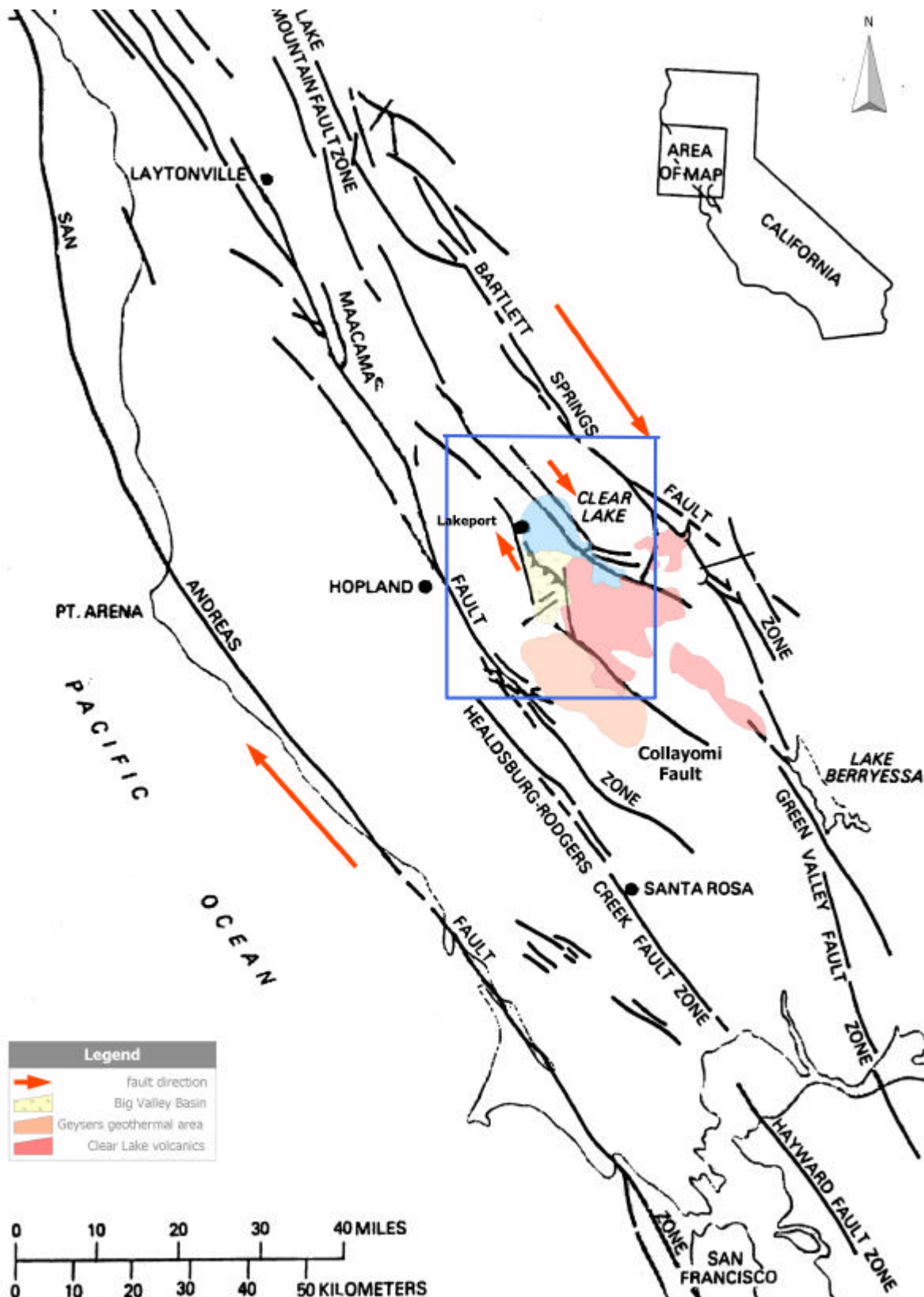




Figure 5-2
Terrain and Quaternary Faults
Big Valley - Clear Lake Area

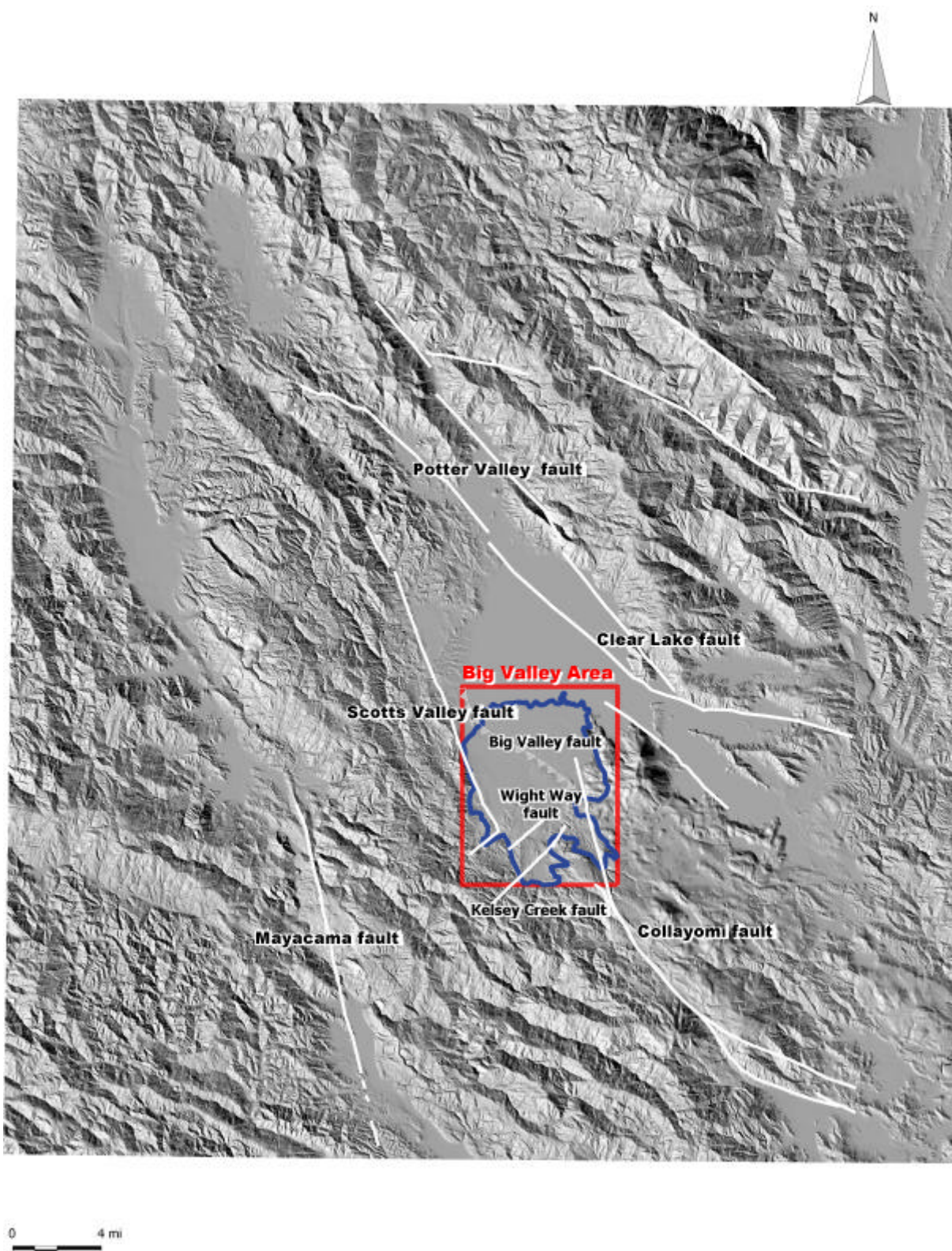




Figure 5-3
Major Modes of Deformation along a Right Lateral Strike Slip Fault

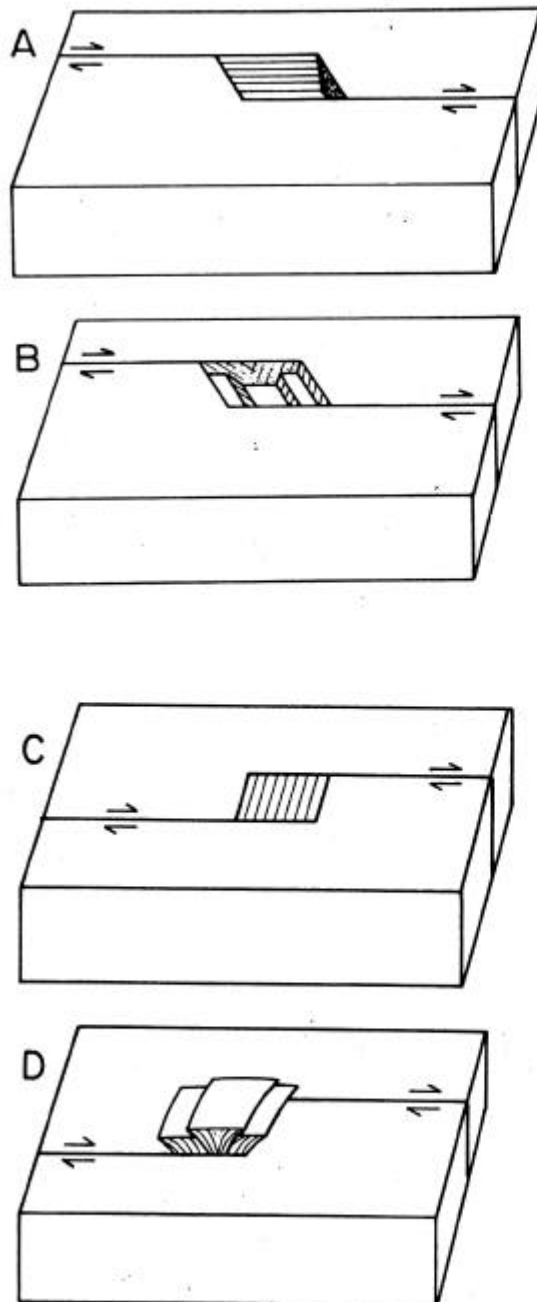


Illustration of major modes of deformation at along-strike stepovers in a right lateral fault.

A and B show extensional down-chop in a right stepover representative of the formation of the Clear Lake basin.

C and D show compressional uplift in a left stepover representative of the uplift of the southern Big Valley area.



**Figure 5-4
Geologic Map**

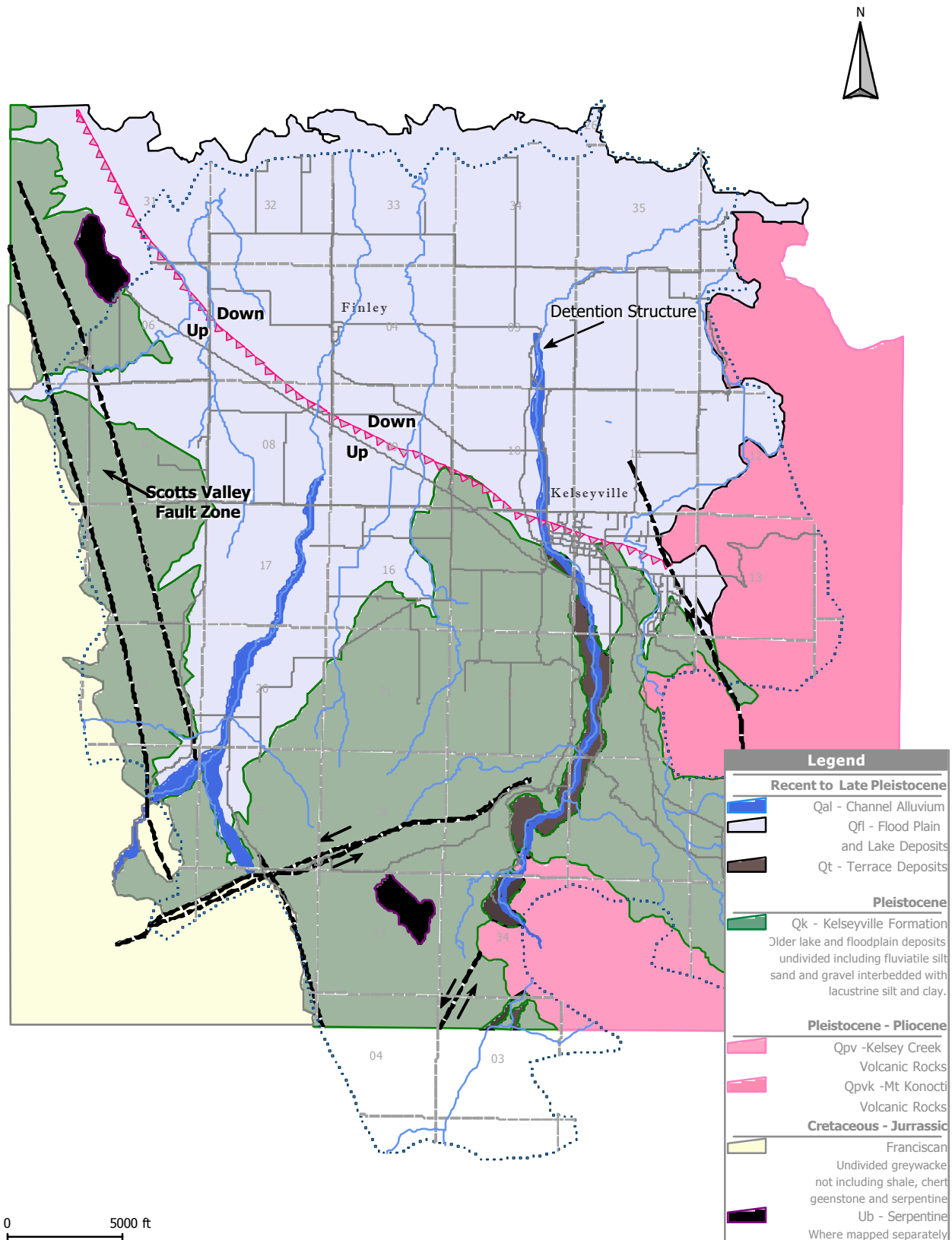
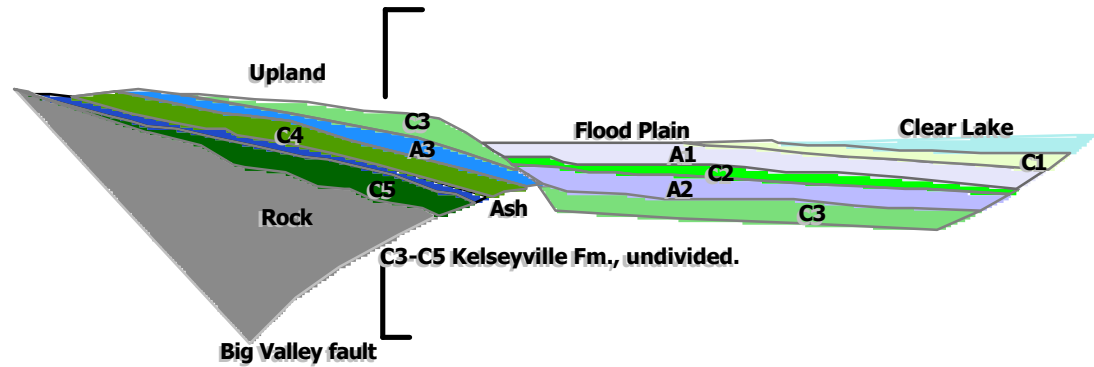
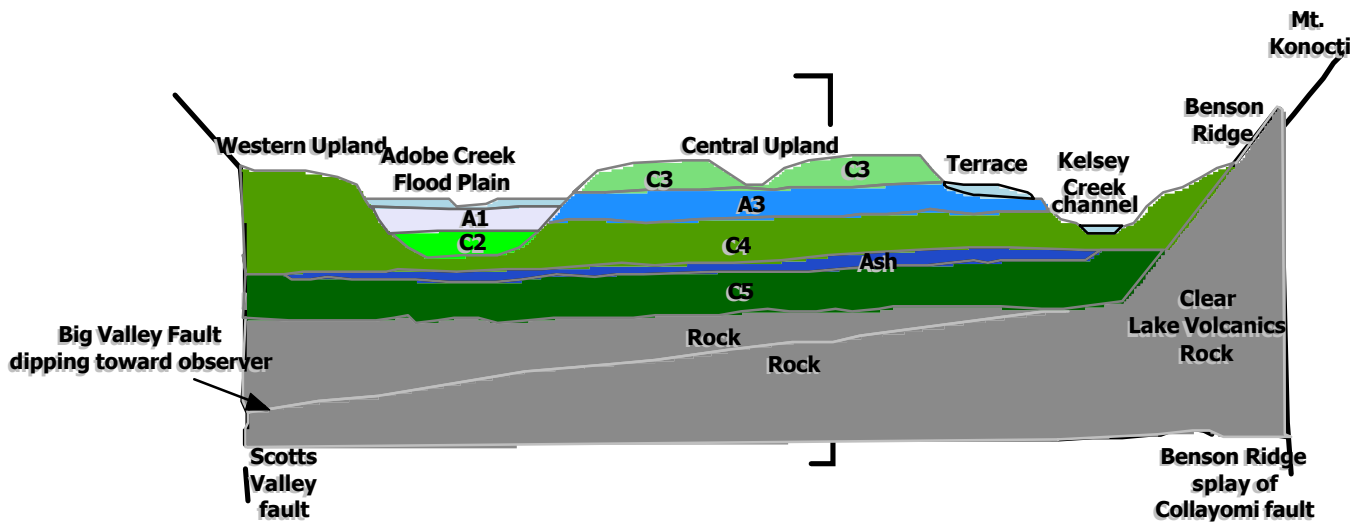




Figure 5-5
Diagrammatic Cross Sections



Diagrammatic North-South Section
Looking West



Diagrammatic East-West Section
Looking North



**Figure 5-6
A1 Aquifer**

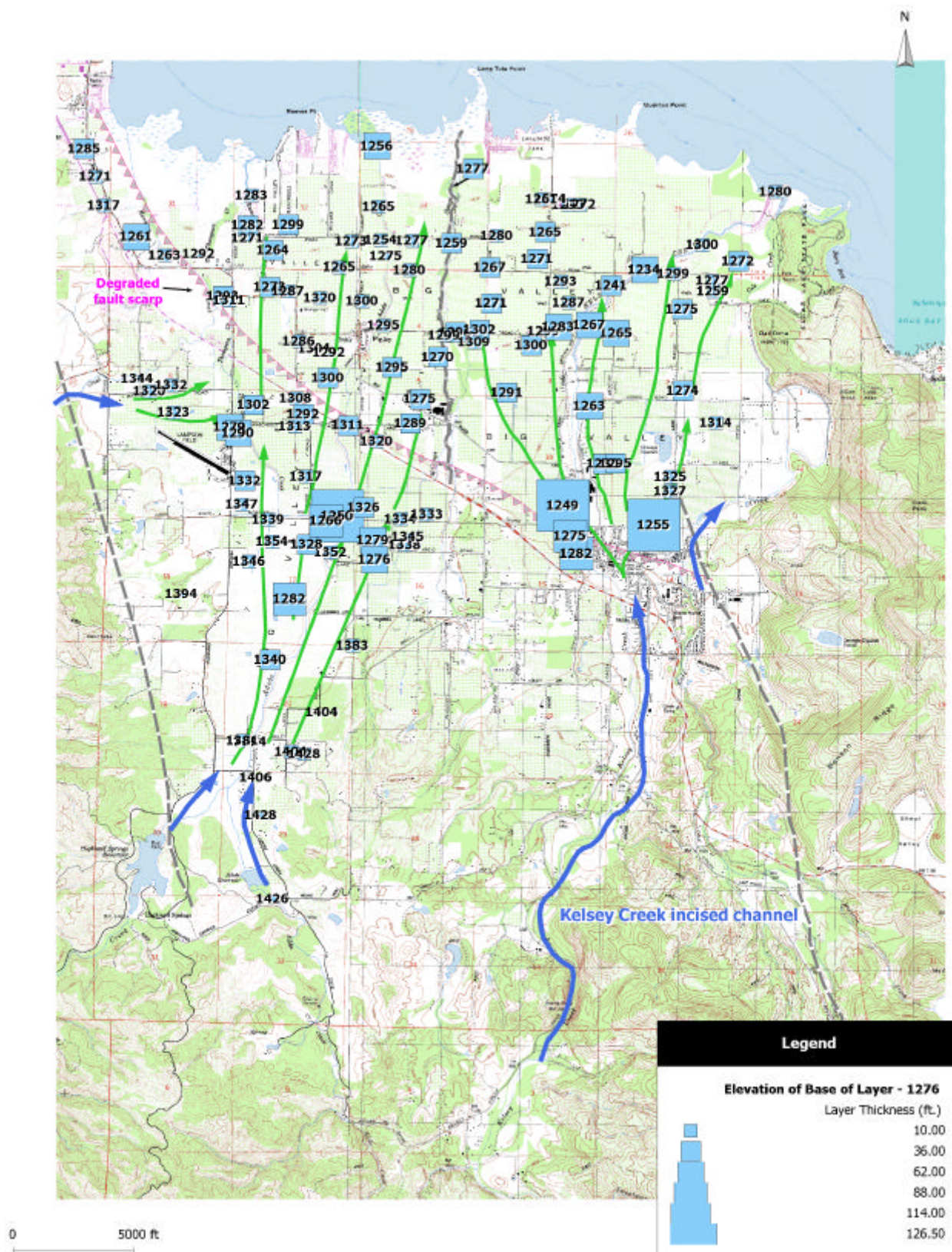


**Figure 5-7
A2 Aquifer**

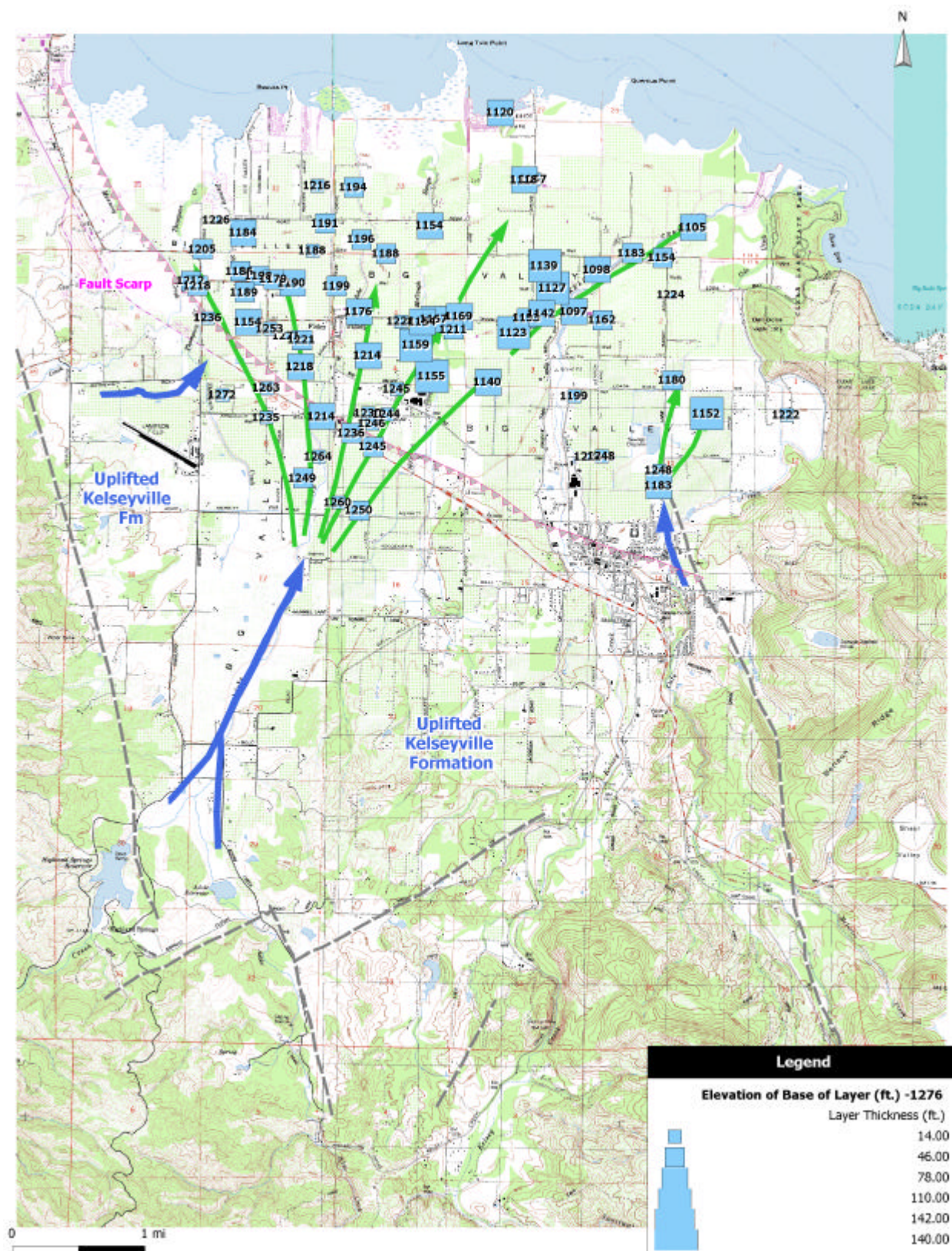




Figure 5-8
A3 Aquifer (In Kelseyville Formation)

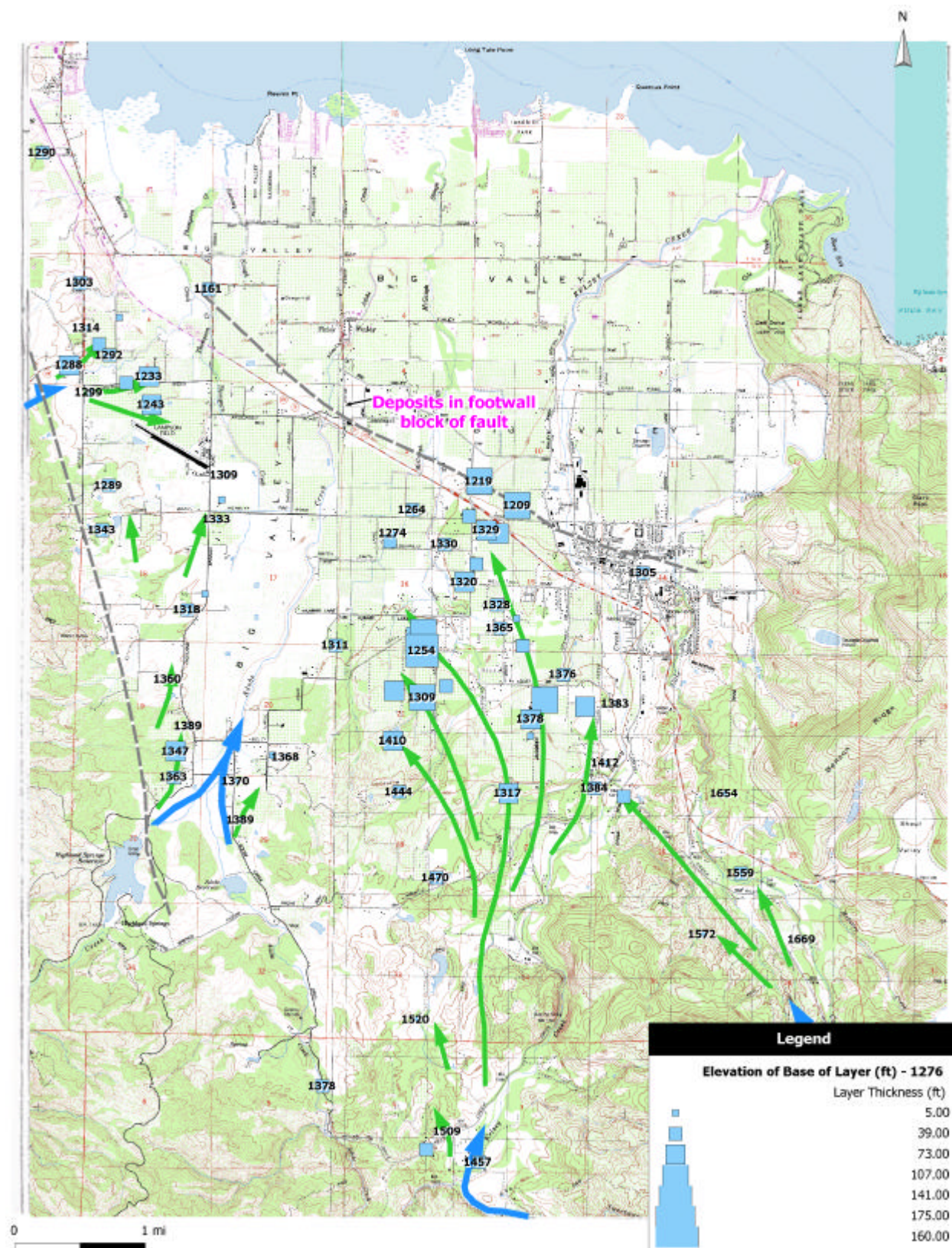




Figure 5-9
Ash Aquifer (Kelseyville Tuff in Kelseyville Formation)





Figure 5-10
Locations of Selected Well Logs

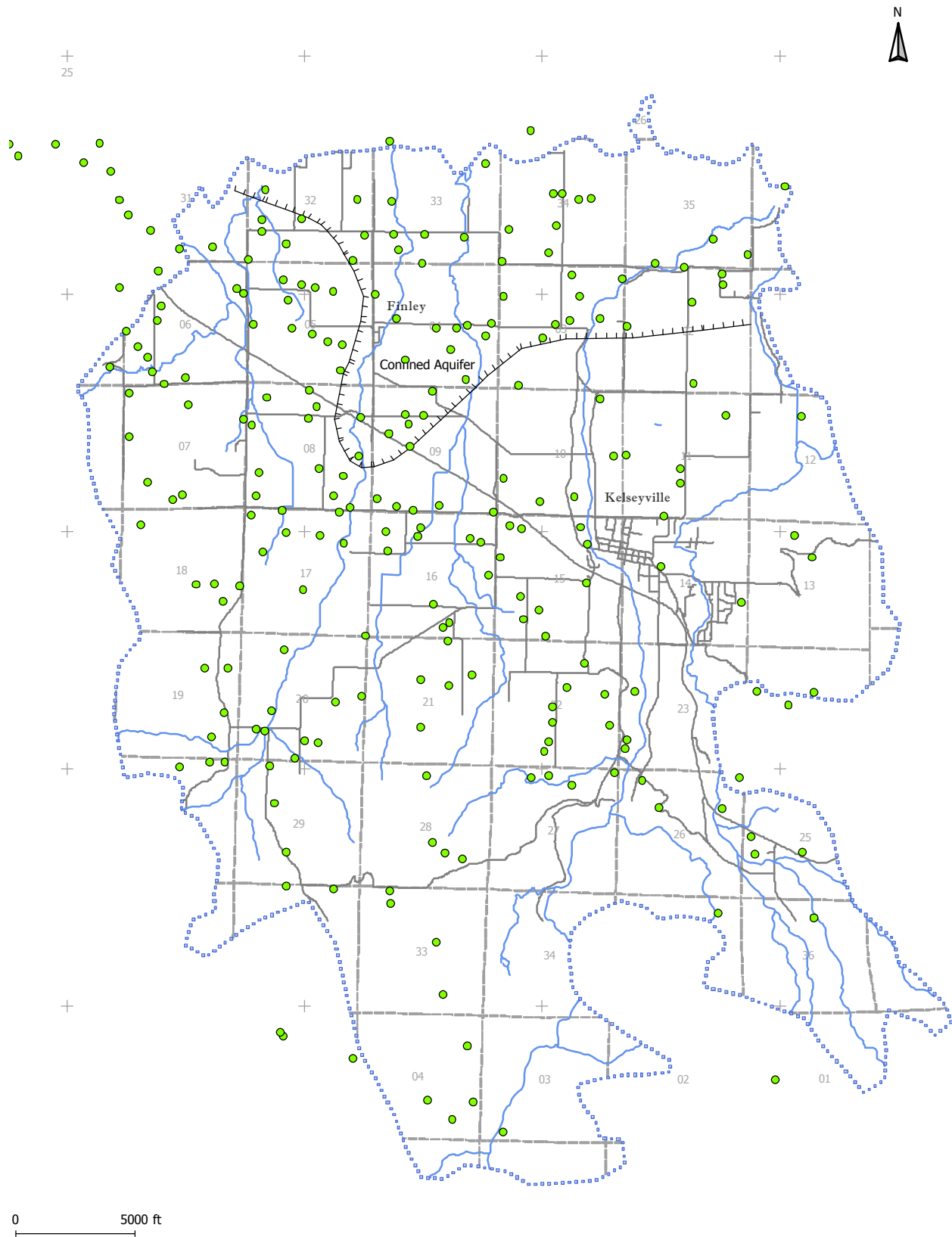




Figure 5-11
North South Stratigraphic Section at Kelsey Creek

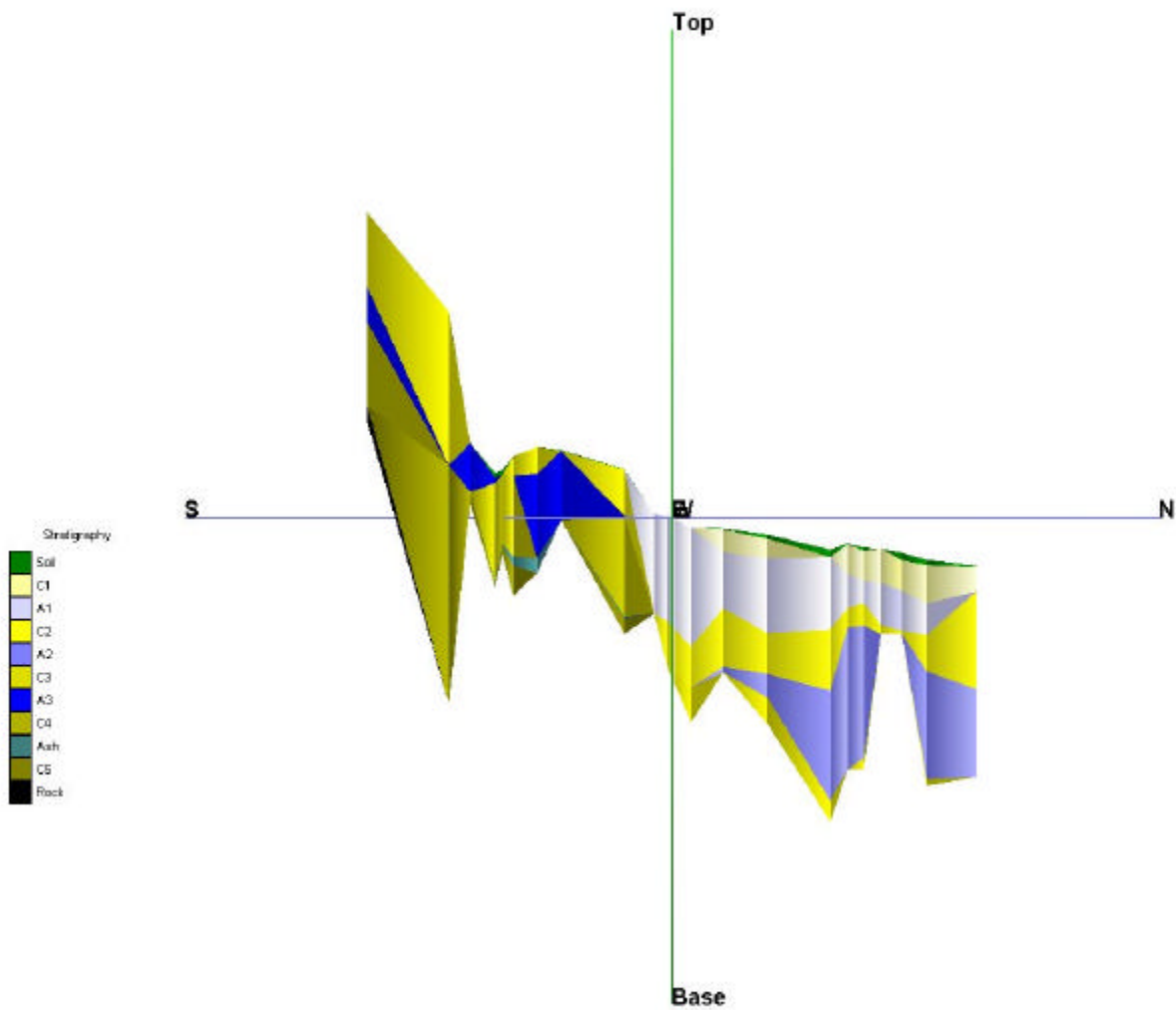




Figure 5-12
North-South Section at Hill Creek

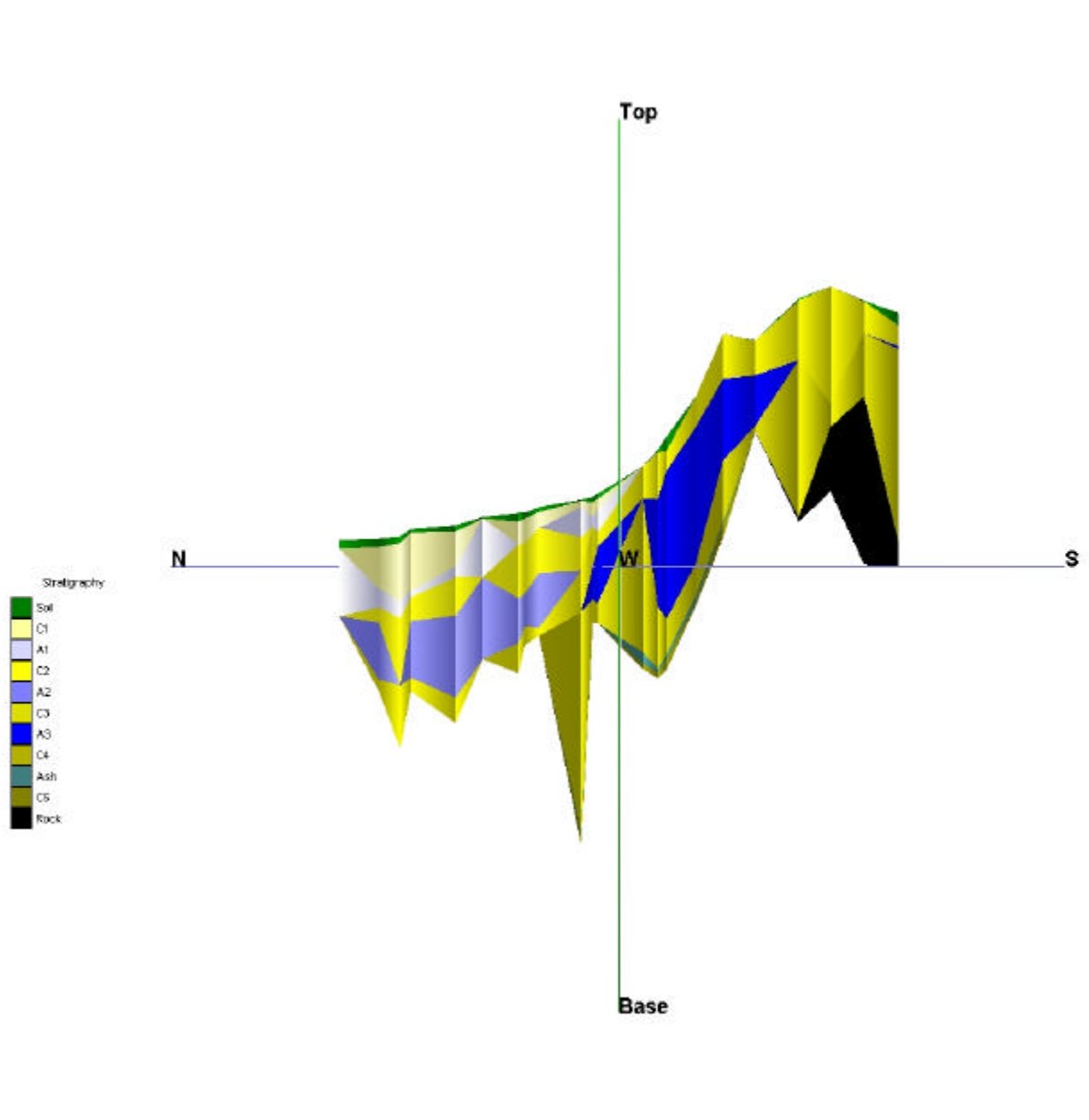




Figure 5-13
North South Section at Adobe Creek

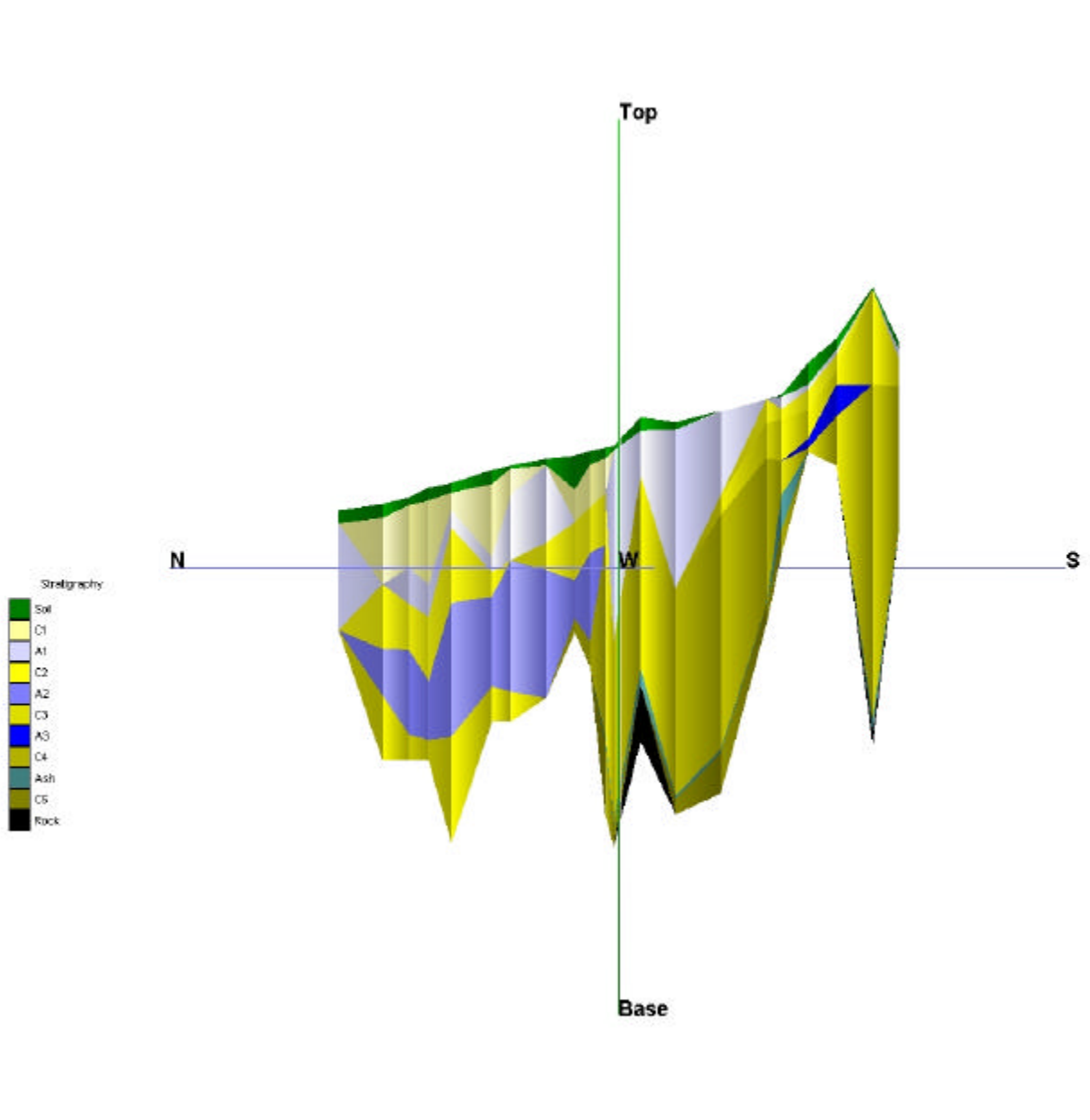




Figure 5-14
East -West Section at Soda Bay Road

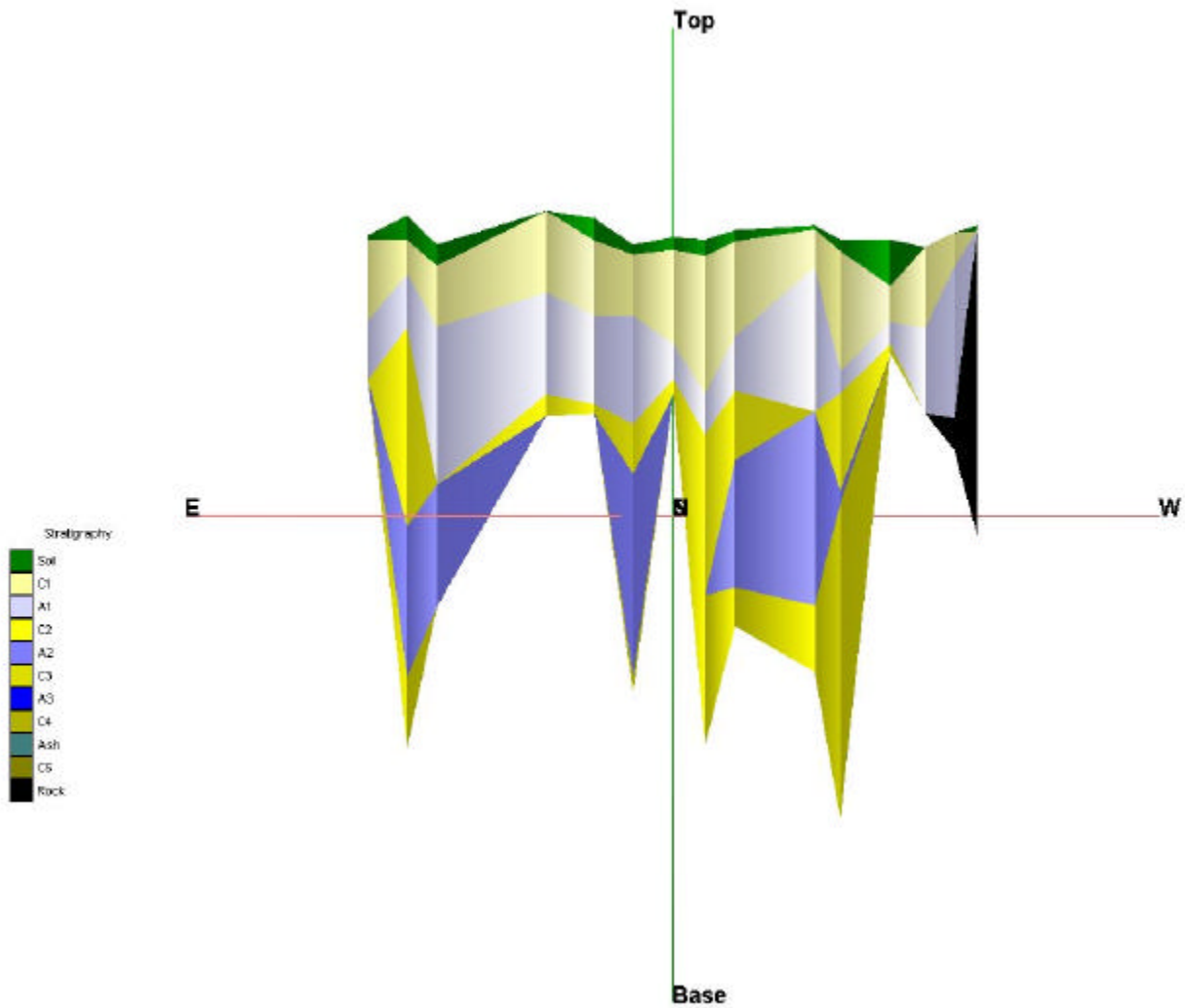




Figure 5-15
East West Section at Argonaut Road

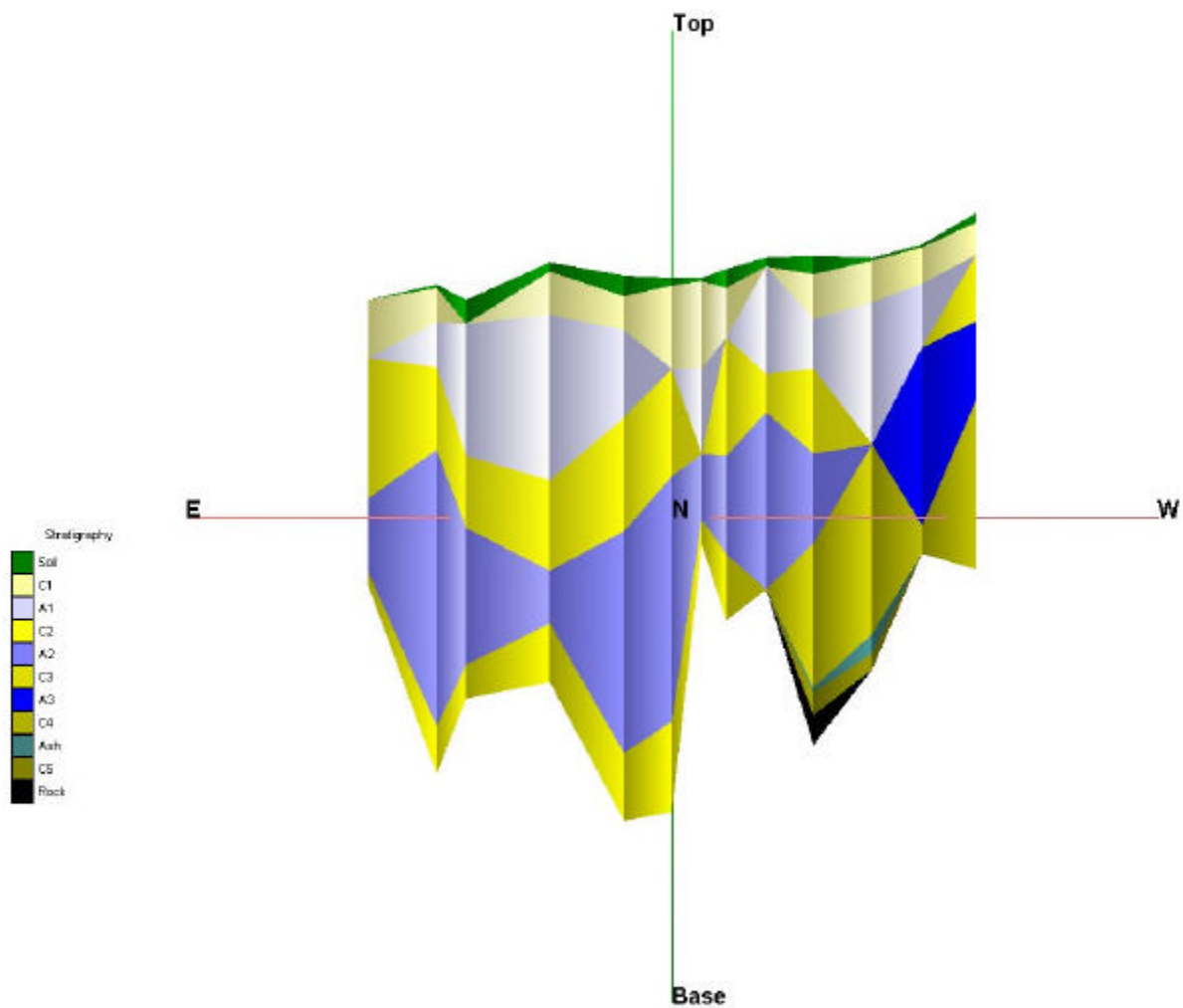




Figure 5-16
East-West Cross Section at Hummel Lane

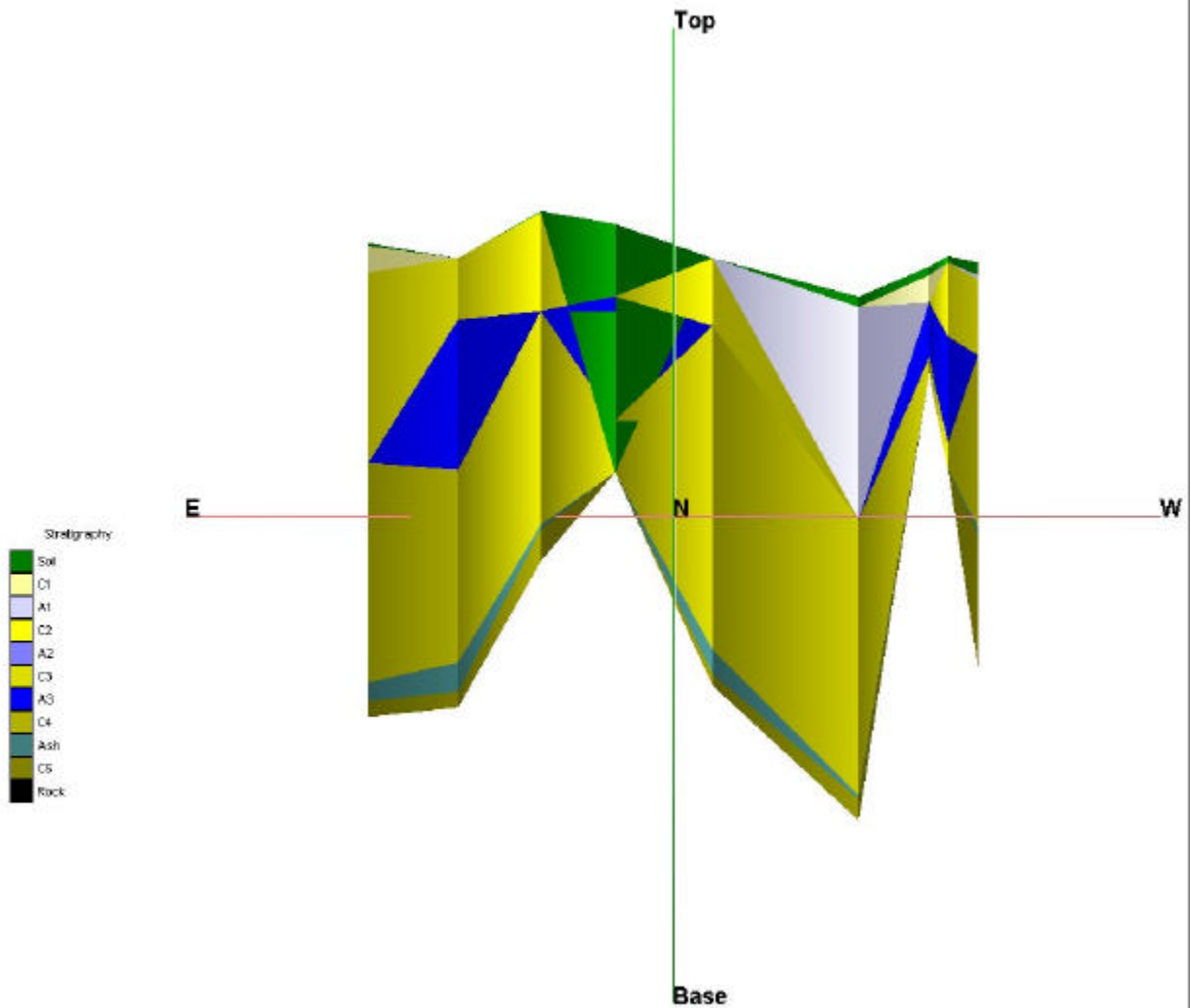
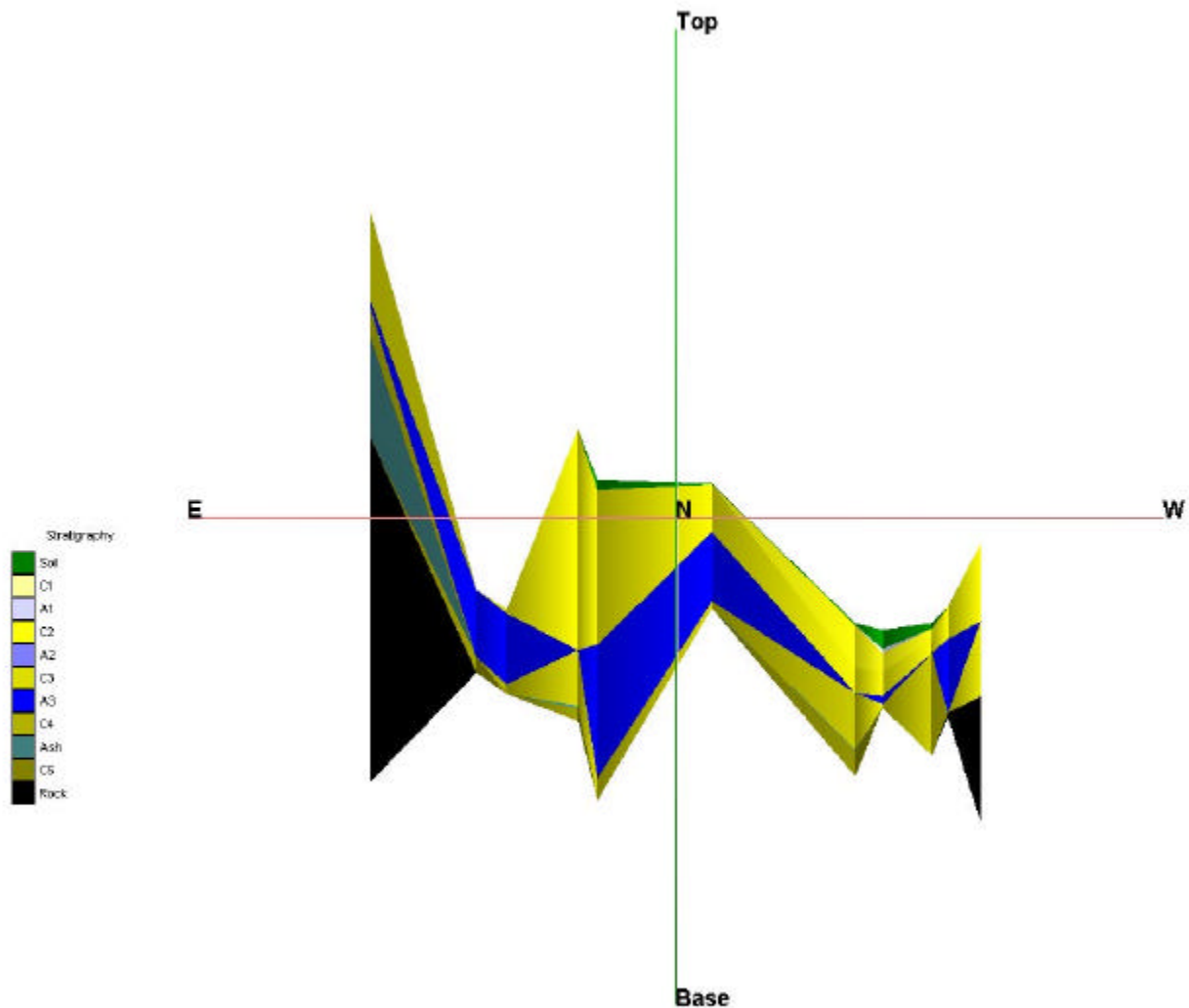




Figure 5-17
East-West Section at Highland Springs





6. Hydrology

6.1 GENERAL

The purpose of this hydrology section is to provide information needed to develop an overall water balance model of Big Valley in order to assist in management of ground water resources and water supply.

Specific information presented includes:

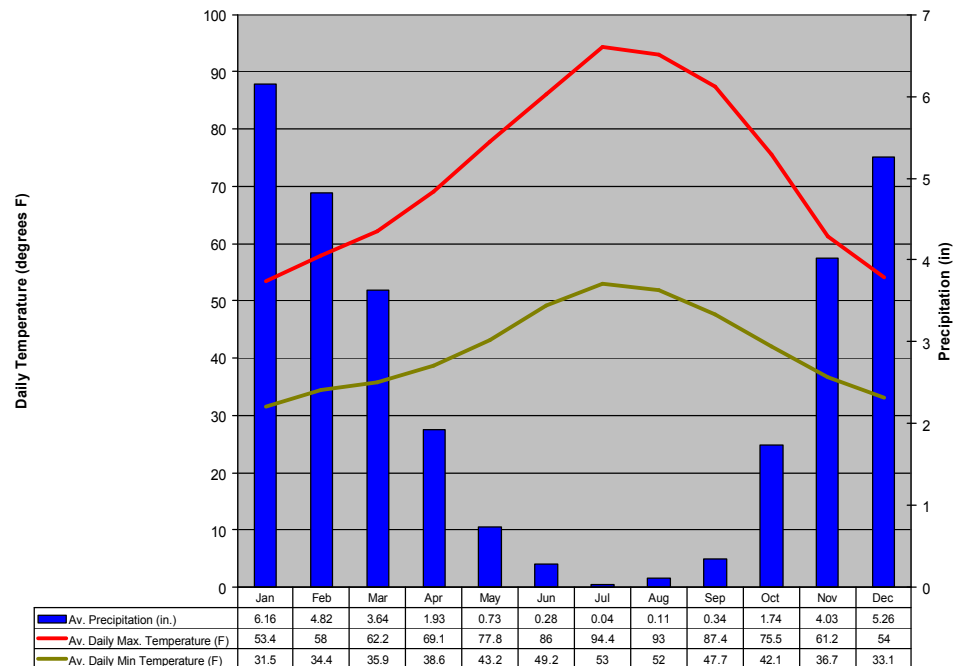
1. Precipitation
2. Surface Runoff
3. Recharge
4. Consumptive water use
5. Ground water

6.2 PRECIPITATION

6.2.1 Climate data

The longest record of climate data in the general area is from Lakeport. A summary of annual temperature and precipitation data is shown on Figure 6-1.

Figure 6-1
Monthly Summary of Precipitation and Temperature Data for Lakeport



Most annual precipitation occurs during the five month period from November

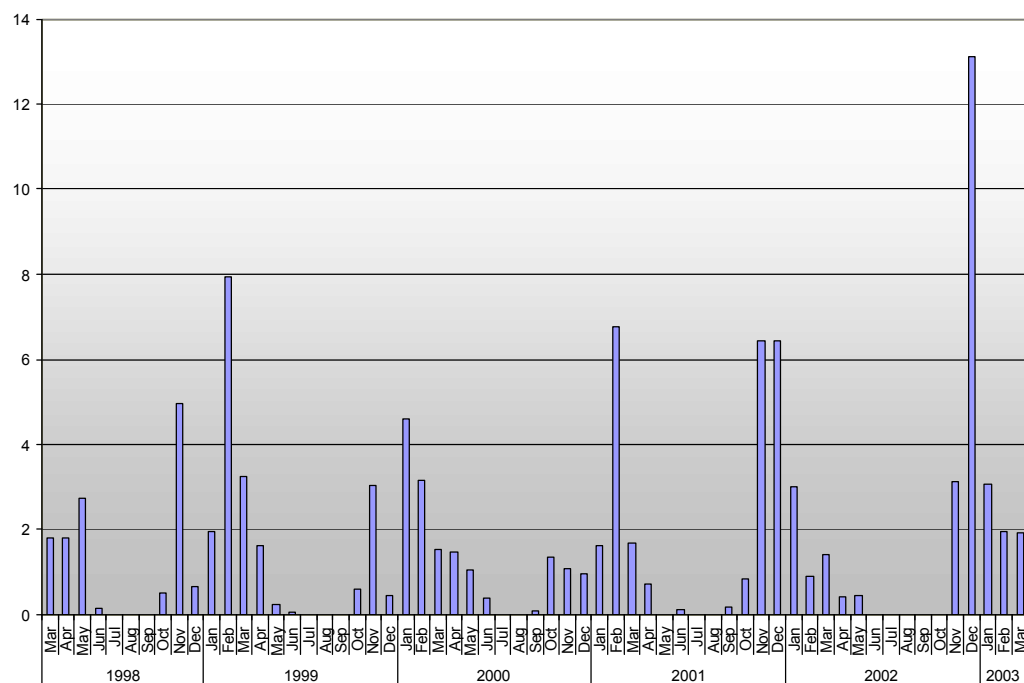


through March with a dry summer period from June through September.

Average daily maximum temperatures reach the low 90's in summer and are in the 50's during winter. Average daily minimum temperatures drop to the low 30's in midwinter. During winter daily minimum temperatures dip below freezing, and are sometimes accompanied by snowfall on the surrounding mountains and frost on the valley floor.

At present the only operational rain gauge in Big Valley is at Kelseyville. This gauge is operated as part of the University of California Statewide Integrated Pest Management Program and commenced operations in 1998. Precipitation data are shown on Figure 6-2.

Figure 6-2
Published Monthly Precipitation Records for Kelseyville in Big Valley



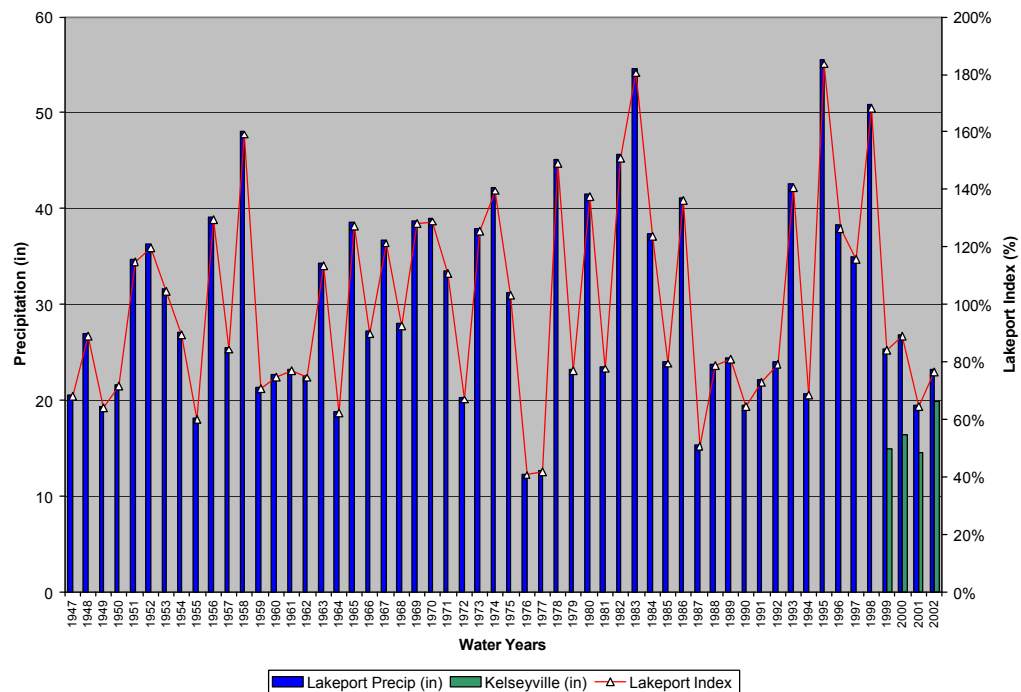
The nearest long-term gage is at Lakeport. Records of annual average precipitation for Lakeport during the period 1947 through 2002 and the Kelseyville gage from water year 1999 through 2002 are shown on Figure 6-3. The mean annual precipitation at Lakeport for water years 1947 through 92 is 30.2 inches.

The shorter-term Kelseyville record indicates that precipitation at Kelseyville is approximately 70% of that at Lakeport – probably due to a rain-shadow effect due to Mount Konocti. Previous water resources investigations conducted in 1957 by the Department of Water Resources indicated that mean annual precipitation in Big Valley varies from about 23 inches a year at Kelseyville to



about 33 inches a year near the base of the surrounding mountains.

Figure 6-3
Annual Precipitation Data
Water Years 1947 - 2002



The data also demonstrate fluctuations in annual precipitation. Lower than average precipitation occurred during the following five periods: 1947 through 1950, 1959 through 1962, 1976 through 1977, 1987 through 1992 and 1999 through 2002. Higher than average precipitation occurred during the periods 1982 through 1984 and 1995 through 1998.

Data from the Lakeport gage has been analyzed to develop an annual precipitation index which represents the ratio of current year precipitation to the longer term average. This index is shown on Table 6-1.



Table 6-1
Water Years sorted by Lakeport Precipitation Index

Water Year	Lakeport Precip (in)	Lakeport Index
1995	55.5	184%
1983	54.6	180%
1998	50.9	168%
1958	48.1	159%
1982	45.6	151%
1978	45.1	149%
1993	42.5	141%
1974	42.2	139%
1980	41.6	137%
1986	41.1	136%
1956	39.1	129%
1970	38.9	129%
1969	38.7	128%
1965	38.5	127%
1996	38.2	126%
1973	37.9	125%
1984	37.4	124%
1967	36.7	121%
1952	36.2	120%
1997	35.0	116%
1951	34.7	115%
1963	34.3	113%
1971	33.5	111%
1953	31.6	105%
1975	31.2	103%
1968	28.0	93%
1966	27.2	90%
1954	27.0	89%
1948	26.9	89%
2000	26.9	89%
1957	25.5	84%
1999	25.4	84%
1989	24.4	81%
1985	24.0	79%
1992	24.0	79%
1988	23.8	79%
1981	23.5	78%
1961	23.3	77%
1979	23.3	77%
2002	23.2	77%
1960	22.6	75%
1962	22.6	75%
1991	22.1	73%
1950	21.7	72%
1959	21.4	71%
1994	20.8	69%
1947	20.6	68%
1972	20.2	67%
1990	19.5	65%
2001	19.5	64%
1949	19.4	64%
1964	18.8	62%
1955	18.1	60%
1987	15.4	51%
1977	12.7	42%
1976	12.3	41%



6.3 SURFACE RUNOFF

6.3.1 Big Valley Watershed

The watershed that drains to Big Valley covers an area of 80648 acres or about 126 square miles. Main tributaries are Kelsey Creek, Adobe Creek, Highland Creeks, Manning Creek, and Cole Creek. Hill Creek, McGough Slough, and Rumsey Slough are smaller watercourses that originate in the bottom of the valley.

A map of the Big Valley Watershed is shown on Figure 6-21 and watershed areas are shown on Table 6-2.

Table 6-2
Watershed Areas

Watershed	Area	
	Acres	Sq. Miles
Kelsey Creek		
Upper Kelsey Creek	8772	13.7
Mid Kelsey Creek	10215	16.0
Lower Kelsey Creek	10321	16.1
Kelsey Creek.	29307	45.8
Adobe Creek		
Upper Adobe Creek	5313	8.3
Highland Creek	9384	14.7
Lower Adobe Creek	5996	9.4
Adobe Creek.	20693	32.3
Manning Ck./Rumsey Slough	7574	11.8
Hill Creek/McGough Slough	4810	7.5
Cole Creek	18264	28.5
Totals	80648	126.0

6.3.2 Streamflow Records

Available streamflow records for tributary streams are shown on Table 6-3.



Table 6-3
USGS Streamflow Records

Gage No.	Name	Elevation (ft)	Area (sq. Miles)	From	To	Average Flow (cfs)
11449500	Kelsey Creek Near Kelseyville	1475.44	36.6	10/1/1946	9/30/2000	73.8
11449000	Highland Creek Near Kelseyville	1444.46	12.6	10/1/1954	9/30/1962	20.1
11448500	Adobe Creek Near Kelseyville	1476.06	6.36	10/1/1954	10/2/1978	12.0
11448900	Highland Creek Above Highland Creek Dam	1490.07	11.9	10/1/1962	9/30/1978	20.8
11449010	Highland Creek Below Highland Creek Dam	1416.2	14.2	12/1/1965	9/30/1977	22.0

In addition to these US Geological Survey records, streamflow measurements were taken by the California Department of Water Resources at several temporary stream gauging sites in the period 1948-1951.

6.3.3 Analysis of data

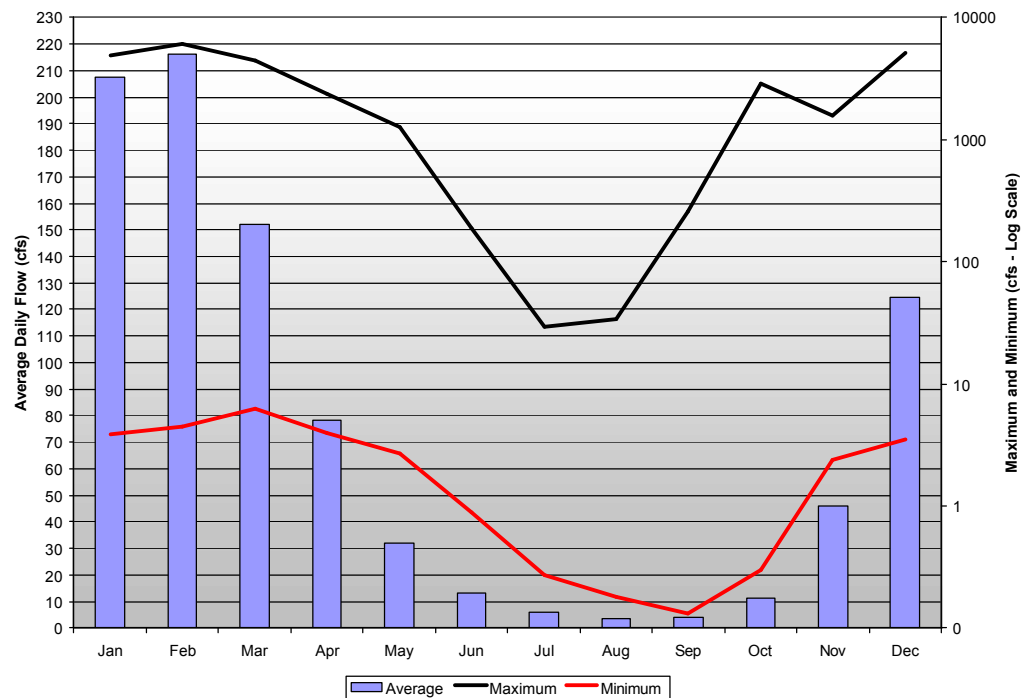
The only active streamflow gage in the Big Valley Basin is on Kelsey Creek about 4 miles upstream of Kelseyville, near the point where Kelsey Creek enters the ground water basin. The gage is at Elevation 1475 ft. and has a drainage basin area of 36.6 square miles.

The monthly distribution of streamflow at this streamgage is shown on Figure 6-4. The vertical bars on the Figure show the monthly average of daily average flows measured on the left hand scale. The two lines show the range of daily average flows which is read on the right hand logarithmic scale.

The monthly distribution reflects the distribution of precipitation except that the peak monthly average flow occurs in February whereas the peak precipitation occurs in January. This may be caused by some short term storage of precipitation as snow or as stream underflow in the ground water system. The Figure also shows the low flow period during summer when inflow to the basin drops to a trickle.



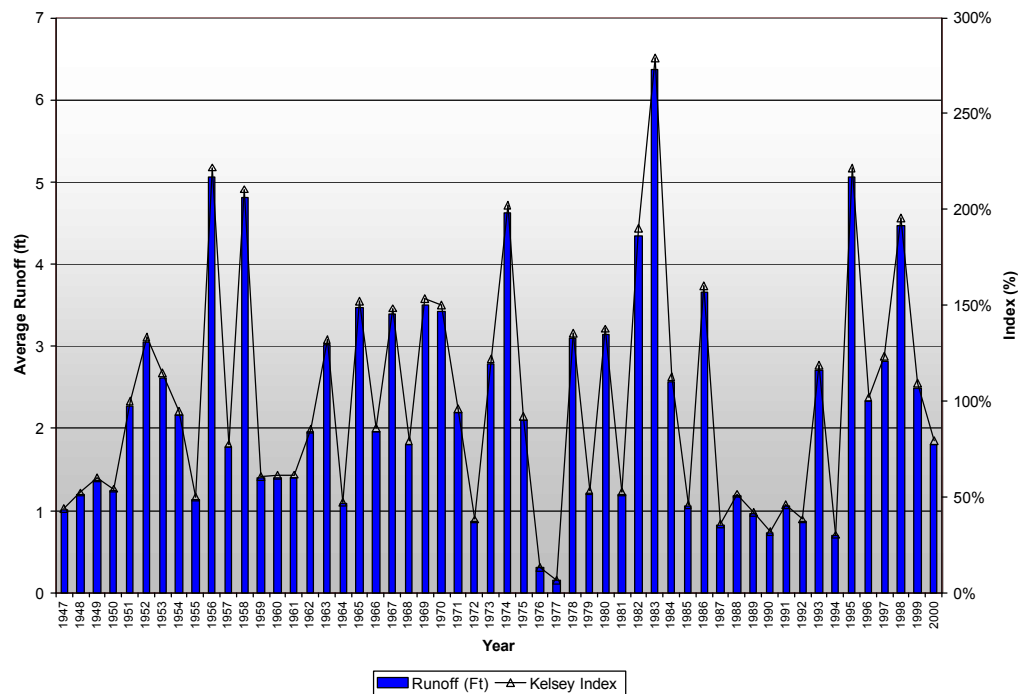
Figure 6-4
Kelsey Creek near Kelseyville USGS 11449500
Flow Range - Water years 1947-2000



The history of annual runoff at the Kelsey Creek gage and a computed runoff index are shown on Figure 6-5. The data show the fluctuations of annual streamflow in response to fluctuations in precipitation.



Figure 6-5
Kelsey Creek near Kelseyville - USGS 11449500
History of Annual Runoff



The history of runoff years and the Kelsey runoff index is shown on Table 6-4. The ranking of annual runoff years is slightly different from annual precipitation years due to other factors such as differences in evaporative losses, groundwater recharge and water stored in the basin.



Table 6-4
Kelsey Creek near Kelseyville USGS 11449500

Water Year	Streamflow (cfs)	Runoff (Ft)	Kelsey Index
1983	206.1	6.4	279%
1956	163.9	5.1	222%
1995	163.6	5.1	222%
1958	155.5	4.8	211%
1974	149.4	4.6	202%
1998	144.4	4.5	196%
1982	140.4	4.3	190%
1986	118.5	3.7	160%
1969	113.2	3.5	153%
1965	112.4	3.5	152%
1970	111.0	3.4	150%
1967	109.6	3.4	148%
1980	101.9	3.2	138%
1978	100.1	3.1	135%
1952	98.5	3.0	133%
1963	97.5	3.0	132%
1997	91.3	2.8	124%
1973	90.3	2.8	122%
1993	87.8	2.7	119%
1953	84.6	2.6	115%
1984	83.2	2.6	113%
1999	80.7	2.5	109%
1996	75.4	2.3	102%
1951	73.8	2.3	100%
1971	70.9	2.2	96%
1954	70.1	2.2	95%
1975	68.2	2.1	92%
1966	63.5	2.0	86%
1962	63.2	2.0	86%
1968	58.7	1.8	79%
2000	58.6	1.8	79%
1957	57.4	1.8	78%
1961	45.5	1.4	62%
1960	45.3	1.4	61%
1959	45.0	1.4	61%
1949	44.3	1.4	60%
1950	40.2	1.2	54%
1979	39.3	1.2	53%
1981	39.0	1.2	53%
1948	38.8	1.2	52%
1988	38.2	1.2	52%
1955	37.0	1.1	50%
1964	35.2	1.1	48%
1991	34.2	1.1	46%
1985	34.0	1.1	46%
1947	32.6	1.0	44%
1989	31.2	1.0	42%
1972	28.4	0.9	38%
1992	28.3	0.9	38%
1987	26.8	0.8	36%
1990	23.8	0.7	32%
1994	22.3	0.7	30%
1976	10.0	0.3	14%
1977	4.8	0.1	6%
Average	73.8	2.3	100%

6.4 RECHARGE

Ground water levels in Big Valley fluctuate with seasonal drawdown and recharge. Most drawdown occurs during the irrigation season from April



through September. The recharge period depends on water conditions. In average and above-average rainfall years recharge commences with the first winter storms (which usually start in October) and the basin becomes fully replenished by mid-winter (December-January). In drought years there is insufficient recharge to fully replenish the aquifers and recharge may continue throughout the winter because it is limited by water availability.

Recharge of the aquifers in the Basin stems from

1. Direct infiltration of precipitation,
2. Percolation of surface water from lakes or ponds or from streamflow flowing in creeks and streams,
3. Regional downslope migration of groundwater due to gravity,
4. Percolation from agricultural irrigation, urban landscape irrigation, and wastewater disposal operations.

From the perspective of the overall water balance of the groundwater basin, increasing recharge during drought years involves reducing water losses either as evaporation or evapotranspiration to the atmosphere or as runoff or underflow into Clear Lake.

Atmospheric losses of precipitation are primarily controlled by climate, vegetation and soils. Theoretically these losses can be modified by changes in land management practices but, from a practical standpoint, this may conflict with land uses on private and public lands and therefore be institutionally and economically infeasible.

Previous studies of the Basin have identified enhanced recharge from creeks and streams as being a promising source of additional recharge. Recharge from creeks and streams is affected by the availability of streamflow, permeability of the streambed and aquifer system, and the relationship between water level in the stream and water table elevations in the streams banks.

In Big Valley, the timing of surface water flows and changes in groundwater levels are important. During winter when the water table is normally high, recharge may be limited by hydraulic gradient. However in summer when the water table is drawn down, recharge may be limited by the lack of flow in the stream since many streams in Big Valley completely dry up during summer.

One way to quantify recharge from streams is to take a series of gage measurements at the upstream and downstream end of a reach and compute the accretions and losses from the differences in streamflow measured between the gages.



6.4.1 Analysis of Accretions to and Losses from Kelsey Creek

There are three sets of streamgage data that can be used to explore accretions in Lower Kelsey Creek.

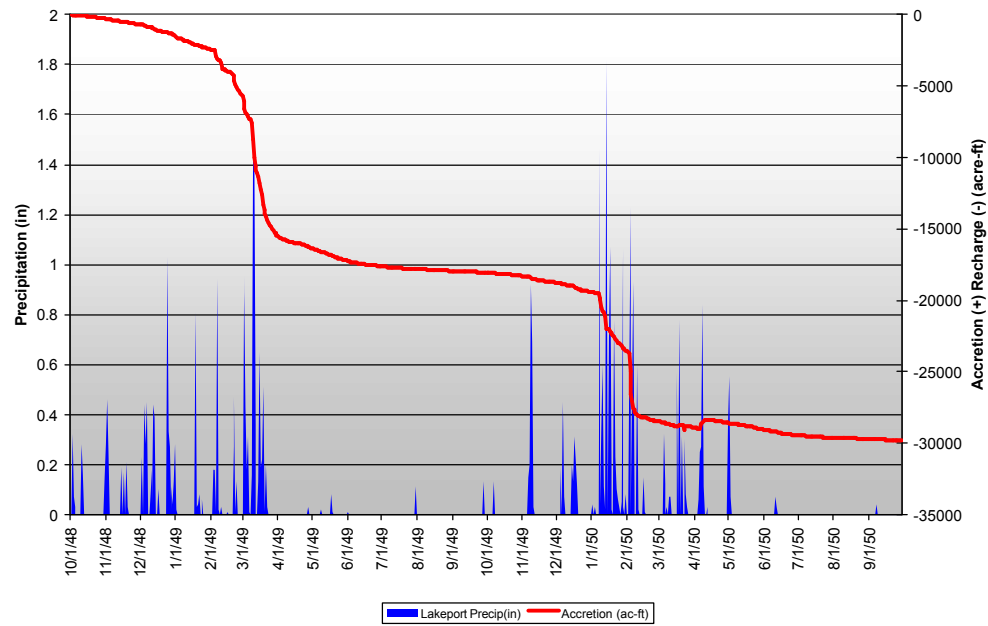
1. The long term record of streamflow at the USGS Gage (USGS 11449500) on Kelsey Creek upstream of Kelseyville.
2. A short record of data from upper and lower Kelsey Creek from the DWR water resources investigations in 1949-50
3. Data recorded in the period 1981 – 1997 by DWR near Soda Bay Road and the USGS Gage upstream on Kelsey Creek.

Both sets of data show that recharge (i.e. losses or negative accretions) is occurring but they differ considerably in the amount of recharge indicated. This may be due to limitations in the accuracy of the streamgages since the differences between flow measurements at the upstream and downstream gage are very sensitive to errors in the accuracy of either gage. The accuracy of gages on small streams depends on the stability of the control section used to correlate water surface elevations with streamflow.

The records from 1949 and 1950 were collected in years which were drier than average. Precipitation at the Lakeport gage and total runoff gaged at the upstream gage at the entry to the groundwater basin and Soda Bay Road (which is near the exit to Clear Lake) are compared on Figure 6-1.



Figure 6-6
Lower Kelsey Creek
Flows at USGS gage and Soda Bay Road
Water Years 1949 and 1950



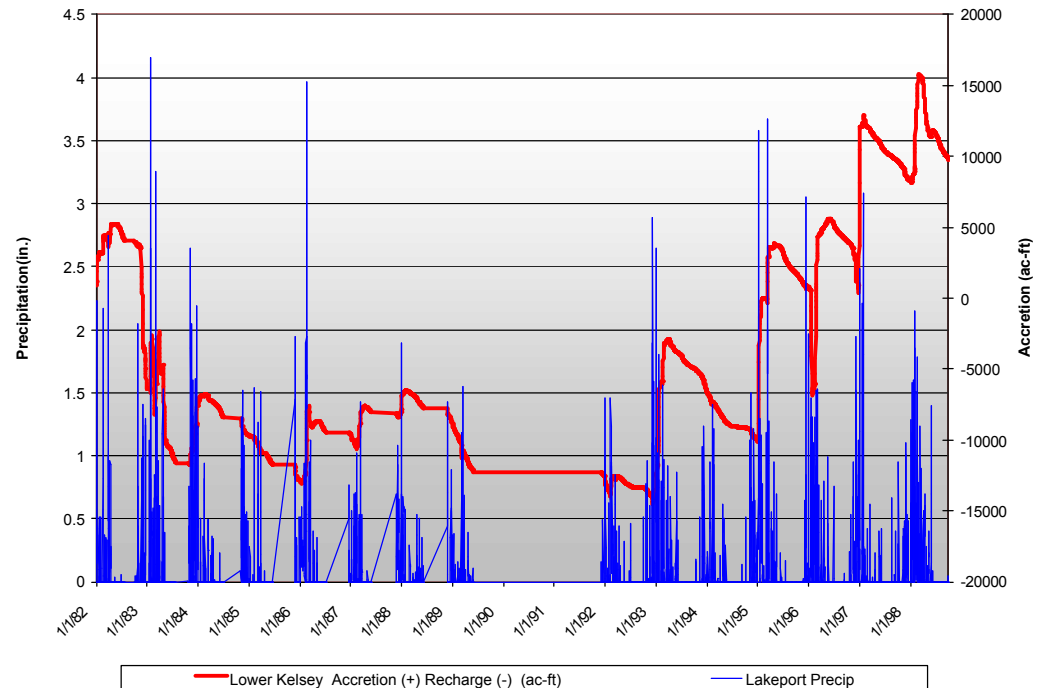
The data show the net recharge (i.e. negative accretion) between the gages amounted to an average of about 15,000 acre-feet a year. In addition there is a further 9 square miles of drainage basin between the upper and lower gages which probably also contributed some runoff that was also lost to ground water recharge.

Available records for the period 1981 through 1997 are shown on Figure 6-7. These data show recharge occurring during the first part of the 1987-92 drought before the record breaks in the period 1989 through 1992. During the wetter period in the late 1990's the data show accretions during winter storms and recharge both early and late in the season.

Overall these data show that recharge is occurring but the amount is uncertain due to possible inaccuracies in the data and difficulty in estimating other accretions from the watershed between the two gages.



Figure 6-7
Lower Kelsey Creek
Flows at USGS gage and Soda Bay Road
1982 -1989 and 1992 - 1997



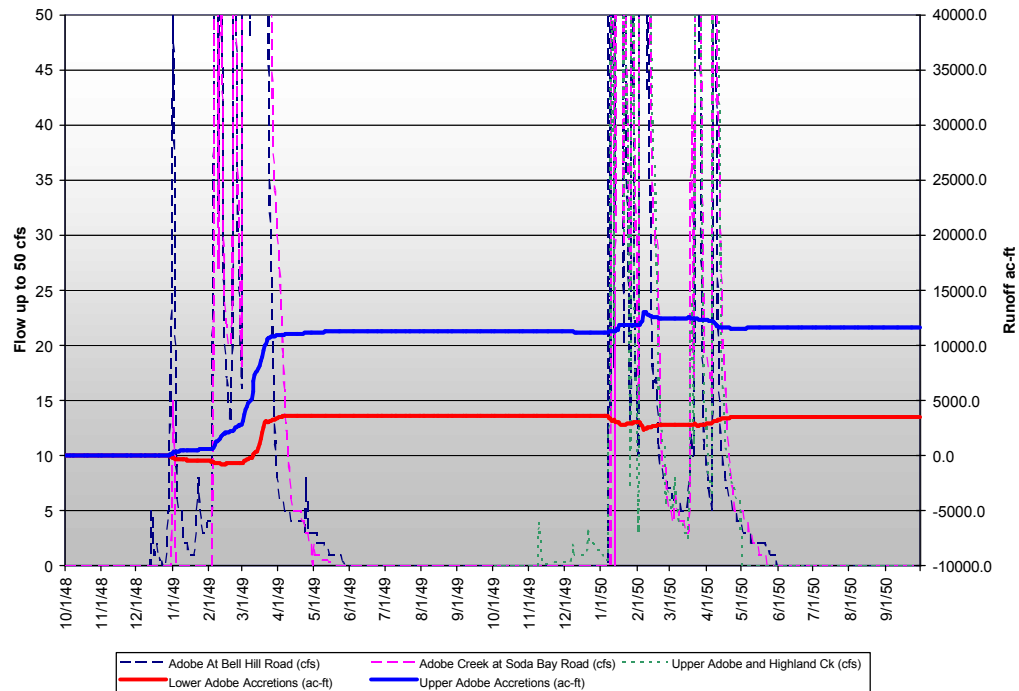
6.4.2 Analysis of Accretions to and Losses from Adobe Creek

Precipitation and accretion data for Adobe Creek are shown on Figure 6-8. In this case accretions at two points on the stream are explored: the upper reach between the confluence of Highland and Adobe Creeks and the Bell Hill Road crossing, and the lower reach between Bell Hill Road and Soda Bay Road.

In this case the data show positive accretions in both reaches which indicates a net gain to the stream from runoff and/or ground water. The hydrographs show that there is some recharge early in the winter when groundwater levels are low, but later in the spring there is positive accretion. The data also show a significant difference in accretions/recharge between water years 1949 and 1950. Both these years were quite dry so the greater recharge in the second year may be explained by lower ground water levels in the second year of a dry period.



Figure 6-8
Lower Adobe Creek
Recorded Flows at Highland Cutoff, Bell Hill Road and Soda Bay Road
Water Years 1949 and 1950



6.4.3 Analysis of runoff from Hill Creek

Analysis of records from Hill Creek/McGough Slough indicate a total gaged runoff of only 325 acre feet in two years from a watershed area of about 4800 acres. This corresponds to a total runoff of about 0.03 feet whereas the corresponding runoff from the basin in that period averaged about 1.3 feet per year – i.e. about 50 times greater. This indicates that in dry water years there is very little surface runoff, with most precipitation falling directly in the groundwater basin lost to evaporation, evapotranspiration or percolation into the groundwater system.

6.4.4 Conclusions regarding additional recharge from streams

The existing dataset shows that recharge from streams is occurring but limitations in the accuracy of the gage data limit the accuracy of estimates of recharge. Because accretions have been estimated by subtracting one gage record from the other, the calculation is quite sensitive to error at either gage.

Since Adobe Creek was dry for 6 months of the year the amount of recharge is probably limited more by the duration of flow in the creek than by the percolation characteristics of the stream channel.

Water level data from wells near Kelsey and Adobe Creek indicate that recharge



in late winter is limited by hydraulic gradients as ground water storage becomes near full. This occurs in average and above average water years. At that time recharge of the water table above stream levels is due to direct infiltration of precipitation and lateral flow.

Previous studies also have found that creeks can be effluent (i.e. losing water to recharge in an upper reach) and influent (gaining ground water) in a lower reach.

Additional recharge from streams can be induced by either:

1. **Conjunctive Use** of surface and ground water storage so as store surface water during winter when the ground water table is high for recharge during summer when the ground water table is lower.
2. **Changing the relationship between water levels in the stream and the groundwater table** by either raising water levels in the stream via an impoundment or reducing groundwater elevations by pumping.

6.5 WATER USE

6.5.1 General

The purpose of this section is to present information on water use in the Basin which can be used to estimate overall water needs and to help calibrate a water balance model that is based on estimated inflows, outflows and changes in storage.

Water use in Big Valley is not measured and therefore can only be estimated. Agriculture is the primary water user. Most applied irrigation water comes from groundwater wells which are not metered so the most practical way to estimate water use is from land use data and information on crop water use and irrigation efficiency. The following sections present land use and crop water use information.

6.5.2 Land Use

Approximately 50% of the Basin is developed and the remainder is undeveloped land.

Agriculture is the main use of developed lands (43% of the basin) and urban uses accounts for the other 7%. Most of the farmland is in the rich bottomlands of the valley and is concentrated in the northern part of the basin. Most of the urban land is in the Kelseyville area with other pockets in Finley and near the Shore of Clear Lake.

Most of the undeveloped land is in the southern part of the floor of the basin and around its steeper fringes. These lands include grasslands, riparian vegetation,



open water, mixed grass/woodlands, brush and tree covered slopes.

A more detailed breakdown of land use is shown on Table 6-5.

Table 6-5
Big Valley Ground Water Basin
Land Use based on Provisional 2001 DWR Land Use Data

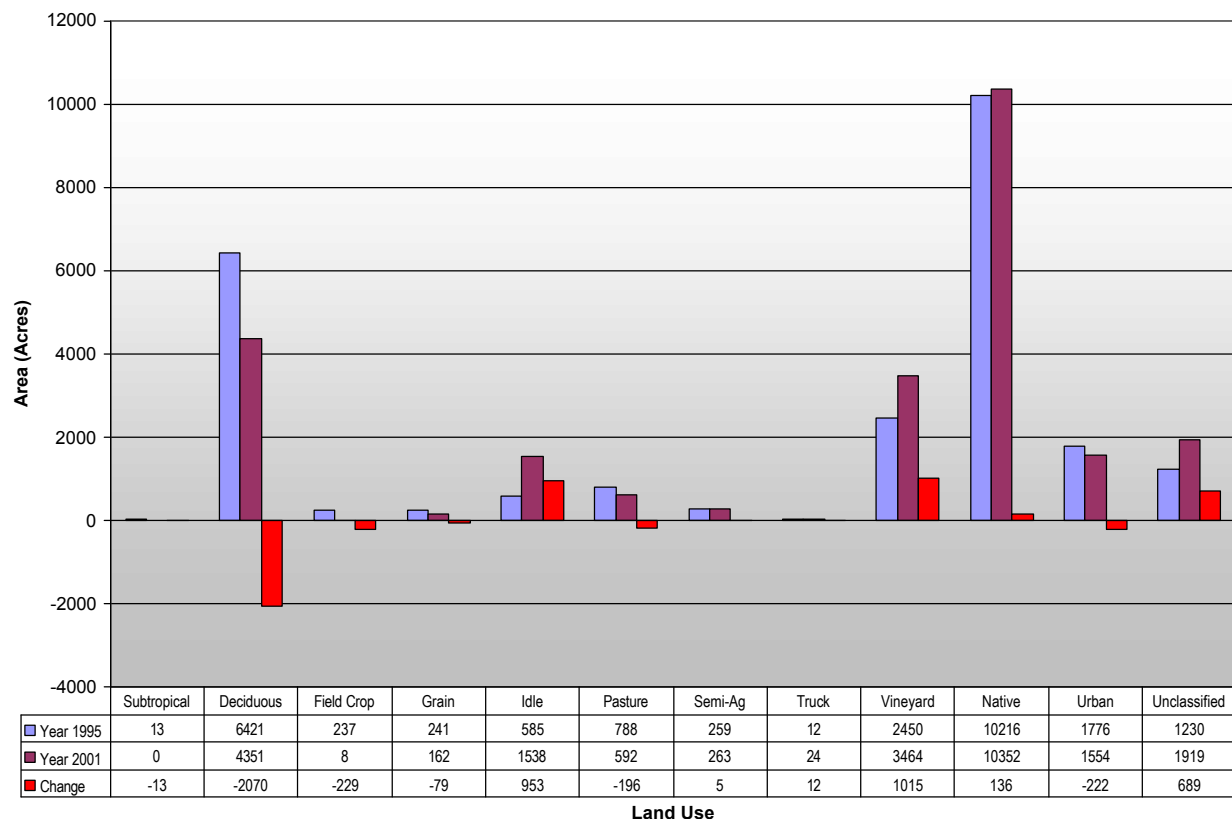
Land Use	Area (Acres)			Percent
	Irrigated	Non-irrigated	Total	
Agricultural				
Deciduous	2,983	1,368	4,351	18.0%
Field Crop	8	0	8	0.0%
Grain	39	123	162	0.7%
Idle	1,515	23	1,538	6.3%
Pasture	290	302	592	2.4%
Semi-Agricultural	0	263	263	1.1%
Truck crops	24	0	24	0.1%
Vineyard	3,458	6	3,464	14.3%
	8,317	2,086	10,403	42.9%
Native				
Riparian	0	23	23	0.1%
Vegetation	0	10,264	10,264	42.4%
Water Surface	0	65	65	0.3%
	0	10,352	10,352	42.7%
Urban				
Commercial	0	184	184	0.8%
Industrial	0	130	130	0.5%
Landscape	15	8	23	0.1%
Residential	0	1,133	1,133	4.7%
Vacant	0	84	84	0.3%
	15	1,539	1,554	6.4%
Subtotal	8,332	13,977	22,309	92.1%
Other				
Unclassified			1,919	7.9%
TOTAL			24,227	100.0%

These data show that vineyards are the largest irrigated crop in Big Valley terms of land use followed by deciduous orchards (mainly pears and walnuts). Although the total area of orchards is greater than that of vineyards, some orchards are not irrigated. There is a substantial amount of idle irrigated land which reflects weakness in the farm economy and transition from orchards to vineyards.



Figure 6-9 shows changes in land use in the period 1995 through 2001. The data show a trend of conversion from deciduous orchards to vineyards or idle lands. In this 6 year period there was a loss of 2070 acres of deciduous orchards, and about 500 acres of pasture, field crops and grain. Major increases were vineyards (+1015 acres) and idle lands (+ 953 acres).

Figure 6-9
Comparison of DWR Land Use Data from 1995 and 2001



Further comparison of historic data indicates that the total irrigated acreage is 8317 acres which compares to 9603 acres in irrigation in 1995 and 6850 acres in irrigation at the time of the previous DWR study of 1957. Overall, irrigated agriculture has grown since the previous studies but has recently contracted primarily due to adverse economic conditions in the pear and walnut growing industries.

The spatial distribution of land use in Big Valley is shown on Figure 6-22. These data are also derived from provisional 2001 land use data published by the California Department of Water Resources. .



6.5.3 Estimated Water Use

This section provides estimates of average annual water use in Big Valley based on 2001 land use data. The data summarized on Table 6-6 show that the estimated net use of groundwater 17,340 feet/year.

Agriculture is the primary user accounting for 98% of the total (comprised of 79% of the total for irrigation and 19% for frost control). The remaining 2% is estimated urban use.

Table 6-6
Estimated Average Year Water Use

Use	Amount (Ac-ft)	Percent
Irrigation	12957	75%
Frost Control	3783	22%
Urban	600	3%
Total	17340	100%

The following sections provide the basis for these estimates.

6.5.3.1 Agriculture

The agricultural sector primarily uses water for irrigation during the growing season and for frost control in spring.

Irrigation

Estimated water use for irrigation of crops is shown on Table 6-7. The estimates are based on California Department of Water Resources Provisional 2001 Land Use data and crop water use data for Lake County used in the 1998 California Water Plan with some adjustments.



Table 6-7
Estimated Agricultural Water Use for Irrigation

Land Use	Gross Area (acres)	Irrigated (%)	Net Irrigated Area (acres)	Unit ET of Applied Water (ft)	Growing Season Precipitation (ft)	Net ET (ft)	Irrigation Efficiency (%)	Unit Applied Water (ft)	Applied Water (ac-ft)	Recoverable Return Flow (% ETAW)	Recover able Return Flow (ac-ft)	Net Ground Water Use (ac-ft)
Irrigated												
Deciduous	2982.5	95%	2833.4	2.6	0.27	2.3	75%	3.1	8,787	15%	1,105	7,682
Field Crops	7.7	95%	7.3	1.8	0.27	1.5	70%	2.2	16	15%	2	14
Grain/Hay	38.8	95%	36.8	0.5	0.27	0.2	85%	0.3	10	15%	3	7
Idle land	1515.1	95%	1439.4	0.0	0.27	0.0	0%	0.0	0	15%	0	0
Nursery	24.3	95%	23.1	2.0	0.27	1.7	80%	2.2	50	15%	7	43
Pasture	290.2	95%	275.7	3.2	0.27	2.9	75%	3.9	1,075	15%	132	943
Vineyards	3458.2	95%	3285.3	1.5	0.27	1.2	85%	1.4	4,738	15%	739	3,999
Subtotal	8316.8		7901.0						14,676			12,687
Non Irrigated												
Deciduous	1,368											
Farmsteads	263.3	50%	105.3	2.0	0.27		70%	2.9	301	15%	32	269
Grain/Hay	123.3											
Idle land	22.9											
Pasture	302.2											
Vineyards	6.1											
Subtotal	2086.2		105.3						301			269
TOTAL	10403.1		8,006						14,977		2,020	12,957

The estimated total applied water is about 15,000 acre-ft per year (i.e. 14,977 ac-ft rounded). Assuming an average recoverable return flow to the groundwater system of 15%, the net average consumption of groundwater is estimated to be about 13,000 acre-ft /year (i.e. 12,957 rounded).

The data also show that deciduous fruit orchards (Pears & Walnuts) consume the most water followed by vineyards and then irrigated pasture.

Frost Protection

Frost protection is an important element of the commercial orchard and wine industries. Cold injury results from frost which damages new buds. The critical time for frost protection is during spring when the new buds have formed.

The following excerpt illustrates the economic impacts of frost damage to Lake County farmers.

“Growers in the Lake County region suffered an incredible hit in early April when they experienced two days of frost damage when temperatures dropped to the low 20s. A good portion of fruit went to concentrate markets due to the frost damage. Charles March, Lake County Farm Bureau executive director, said the county filed for disaster status after the Lake County agricultural commissioner reported an estimated \$12 million worth of frost damage to pears. Of that amount, \$11.3 million in damage was to Bartlett pears. March expects assistance will be given to growers in the form of low-interest, 3-percent loans.”



Source California Farm Bureau Federation September 2001

Water sprinklers have become the primary method of frost control on pears and grapes replacing smudge pots and elevated air circulation fans. This has substantially improved air quality in Big Valley on chilly spring nights but has also increased the demand on the basin's ground water resources.

Water applied by overhead sprinklers supplies heat to the vine-water-atmosphere system. Heat is released as water cools and then freezes to ice. Some water evaporates which actually absorbs heat but this is accounted for in the amount of water applied. The water that freezes on the vines and trees also helps to protect the plant from sub-zero temperatures.

On a cold night when temperatures dip below freezing, sprinklers are turned on in the early hours of the morning and run for several hours. Typical water use is in the order of one half inch/night for grapes and one inch/night for pears, depending on temperature conditions.

Most growers build small ponds which are used to store pumped groundwater water for frost control. A typical water storage pond will hold about 5 to 10 acre feet of water.

The timing and amounts of water used in any year depend on climate and specifically on minimum temperatures. Use can occur sporadically or be concentrated into an extended cold snap. Some of the water applied for frost control is lost to evaporation and surface runoff, some will be used by the crop and some may percolate back into the groundwater basin.

A preliminary water balance calculation shown on Table 6-8 indicates that, on average, an estimated 1.5 feet of water would be applied to pears and 0.5 feet to grapes. Including adjustments for precipitation and crop water use, the estimated net impact on ground water levels is 0.85 feet for Pears and 0.5 feet for grapes.



Table 6-8
Estimated Water Balance for Frost Protection
Average Year

	Pears	Grapes
Inflows		
Precipitation - April & May (ft)	0.20	0.20
Frost Application (in)	1.00	0.50
Number of Applications	18.00	12.00
Applied Water (ft)	1.50	0.50
Total Inflow (ft)	1.70	0.70
Outflows		
Losses to direct runoff/evaporation (25%) (ft)	0.43	0.18
Consumptive Use Factor - April & May	10.80	10.80
Crop Consumptive Use coeff - K	0.70	0.60
Crop Consumptive Use - April & May (ft)	0.63	0.54
Total Outflow (ft)	1.06	0.72
Residual (Inflow - outflow) (ft.)	0.65	0.00
Net Impact on ground water (Applied water-residual) (ft.)	0.85	0.50

As shown in Table 6-8, use of water for frost control could offset some early season irrigation of crops. This offset would depend on the soil-moisture balance at the time the frost control operations occur. If the soil is already saturated, much of the water applied for frost control could run off as surface drainage. If the soil is dry then much of the water applied for frost control would contribute to soil moisture.

Preliminary planning level estimates of average water use based on the data in Table 6-8 is shown on Table 6-9.

Table 6-9
Estimated Net Ground Water Consumption for Frost Control

	Pears	Grapes	Totals
Applications/year	18	12	
Application rate (in)	1	0.5	
Gross Application (ft)	1.5	0.5	
Gross Area (acres)	2983	3458	6441
Net Area (95% gross) (acres)	2833	3285	6119
Applied Water (ac-ft)	4250	1643	5893
Net Groundwater Consumption (ft)	0.85	0.50	
Net Annual Ground Water Use (ac-ft)	2414	1643	4056



So for planning purposes, we estimate that under normal conditions frost control operations in the Basin would require a total application of about 5900 ac-ft/yr (i.e. 5,893 rounded) of water and have an estimated net impact on ground water storage of about 4000 ac-ft/yr (i.e. 4,056 rounded).

During wet and normal water years when the ground water basin fully recharges, the effect of water extraction for frost control on the ground water balance is probably less significant since this extraction may offset natural drainage of groundwater to creeks and streams which would also be lost from the Basin. However during drought years when the ground water table is in deficit, use of water for frost control would have a more significant impact on ground water storage available for water supply. During droughts any such activity which helps to conserve the reduced surface water flows within the Basin would benefit the overall water balance and ground water levels.

Use of surface water for frost control in lieu of groundwater could be achieved by riparian owners either taking surface water directly from creeks or existing impoundments (with appropriate water rights) or by extracting water from shallow aquifers that are hydraulically connected to flow in streams or creeks. Furthermore, this process would enhance recharge by distributing water to recharge zones that are not hydraulically connected to existing watercourses.

Further investigation of frost control practices and conjunctive use of surface water for frost control could lead to reduced ground water demand and improved ground water levels. The first step would be to inventory water use for frost control and investigate the feasibility of in-lieu use of surface water by riparian property owners.

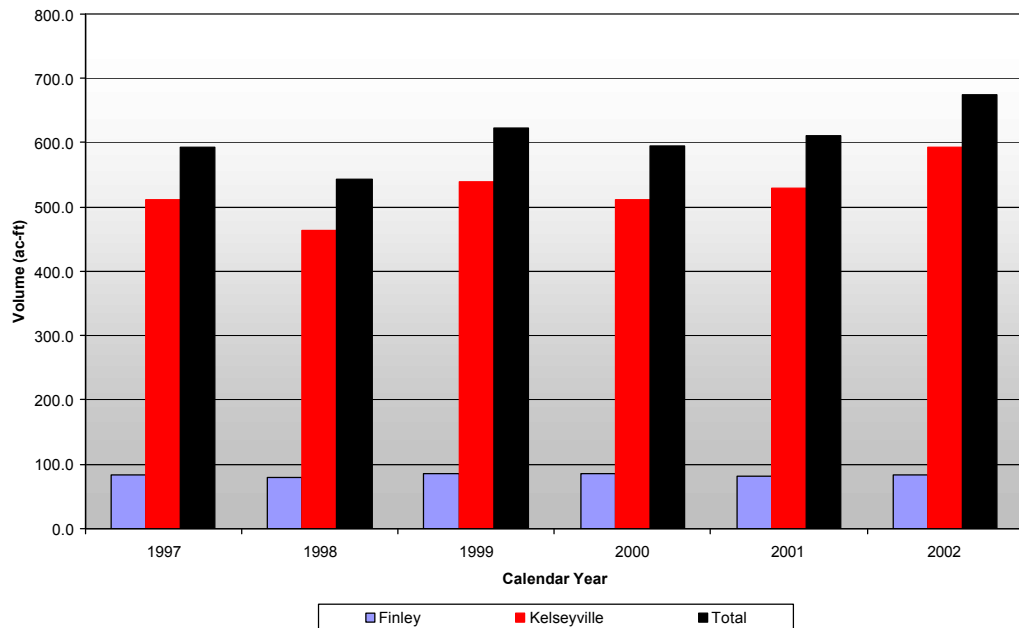
Urban

Information on urban water use was provided by the local water utilities at Kelseyville and Finley. Kelseyville Water District serves Kelseyville. Finley Water serves Finley, Reeves Point and portions of Big Valley Rancheria.

Average urban water use is about 600 acre-ft /year as shown on Figure 6-10.



Figure 6-10
Urban Water Use in Big Valley



6.6 GROUND WATER

6.6.1 Monitoring well records

The Lake County water level database contains water level data for 88 wells in Big Valley. The water level data were collected between June 1948 and April 2002. Prior to 1992, water level data were collected semi-annually or quarterly. Beginning in approximately 1992, some water level data were collected monthly. At present, monthly water level data are collected from approximately 16 wells in Big Valley.

The location of measured wells is shown on Figure 6-23 which is found at the back of this section of the report.

6.6.2 Analysis of data

Figure 6-11 through Figure 6-15 show example hydrographs from Big Valley wells. These example hydrographs display features common to many of the hydrographs from Big Valley. In particular, the hydrographs show a regular seasonal fluctuation, corresponding to agricultural pumping during the growing season.

Additionally, the hydrographs show the impact of droughts on groundwater levels in Big Valley. The spring water levels decline between spring 1975 and



spring 1977. A similar decline can be seen between 1986 and 1992. These declines correspond to the two most recent severe droughts in Northern California. No clear long-term trend of change in groundwater levels is evident over the last 30 years.

The relative lack of long-term trends, even with the groundwater elevation declines that occur during droughts, suggest that the groundwater basin returns to a relatively full condition during average and above average water years. The basin's capacity, however, not fully recharged during dry years, suggesting that without expanded recharge capabilities or other management extended droughts may have serious consequences on water supplies.

Time series of average annual and minimum annual water levels measured in the wells are shown on Figure 6-24 through Figure 6-35 (also found at the back of this section.) Each graph shows data from a five mile long transect of Big Valley starting at the shoreline of Clear Lake and proceeding south at intervals of about 1 mile. Detailed hydrographs of these well records are found in the appendices.

Overall, average annual flow measurements show that water levels fluctuate and trend downwards for several years during drought periods, but there is sufficient recharge in average and above-average water years to fully recharge the basin. The effects of the droughts of 1976-77 and 1987-92 can also be clearly seen. Some of the data from the central uplands at the south end of Big Valley show large fluctuations.

The annual minimum level data show more variability that appears to be increasing with time indicating that water levels are being drawn down deeper and are fluctuating over a wider range as more pumping occurs. Also as time goes on, even more extreme climatic events are possible, in which case minimum water levels during droughts may further decrease.

Figure 6-16 through Figure 6-20 show contour maps of ground water surface elevations and seasonal drawdown. The first three figures show data for 1994 which was a drier than normal year but not a drought year. This map shows that the general groundwater flow direction is from the surrounding mountains towards Clear Lake. The general flow pattern is interrupted by pumping depressions that become more pronounced during the irrigation season.

Figure 6-19 and Figure 6-20 show multiyear drawdown during the extreme droughts of 1975-77 and 1987-92. The data show a large cone of depression near Finley in the confined aquifer zone and a smaller steeper cone near the base of the central uplands. Extreme drawdowns in 1987-92 were deeper than during the drought of 1975-77.

Additional maps of water level fluctuations are presented in the appendices to this report.



Figure 6-11
Hydrograph - Well 13N-09W-02C2

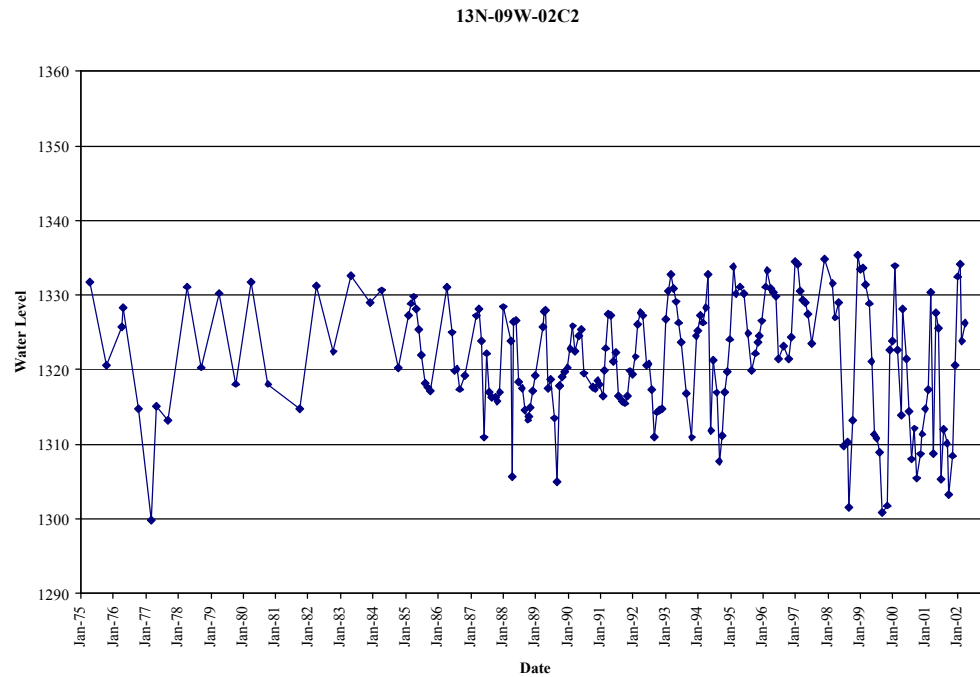


Figure 6-12
Hydrograph - Well 13N-09W-14P2

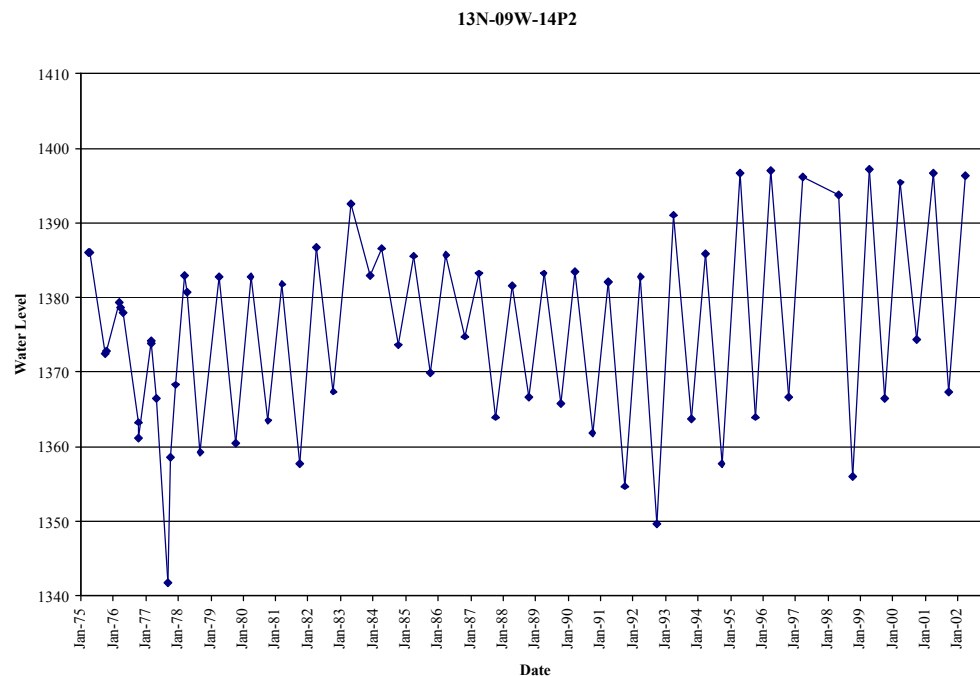




Figure 6-13
Hydrograph- Well 13N-09W-15B2

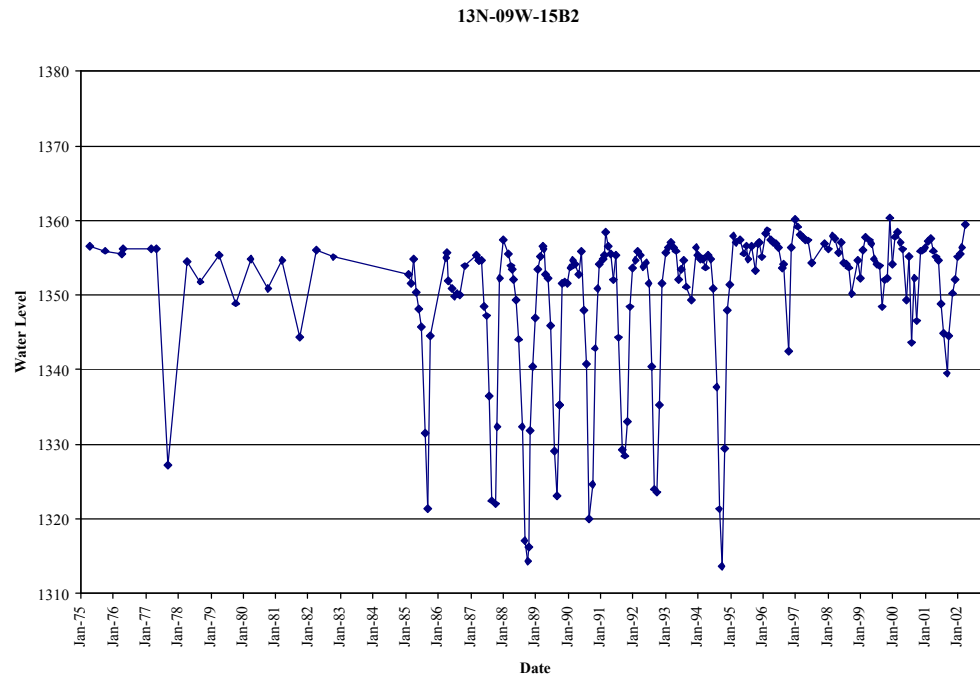


Figure 6-14
Hydrograph - Well 13N-09W-21J1

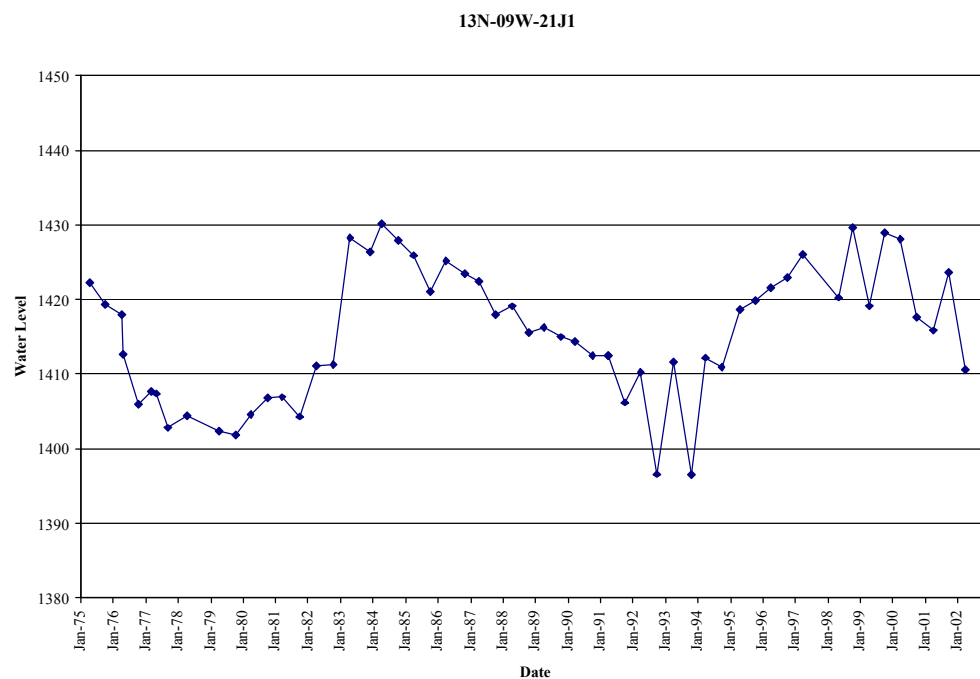




Figure 6-15
Hydrograph - Well 13N-09W-27Q1

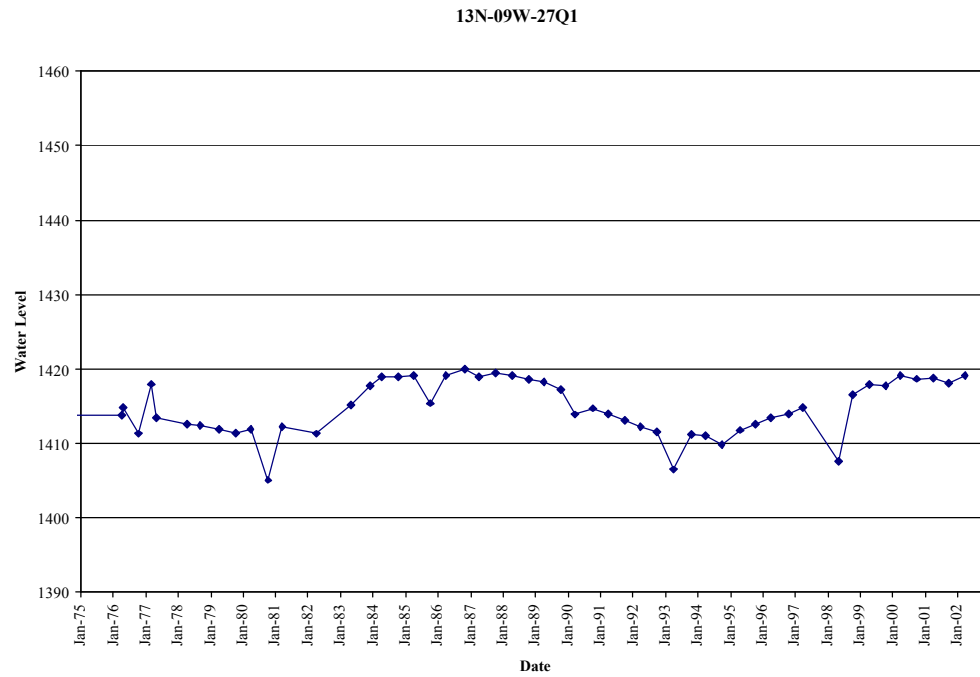




Figure 6-16
Ground Water Contours Spring 1994
Precipitation 69% of Long Term Average

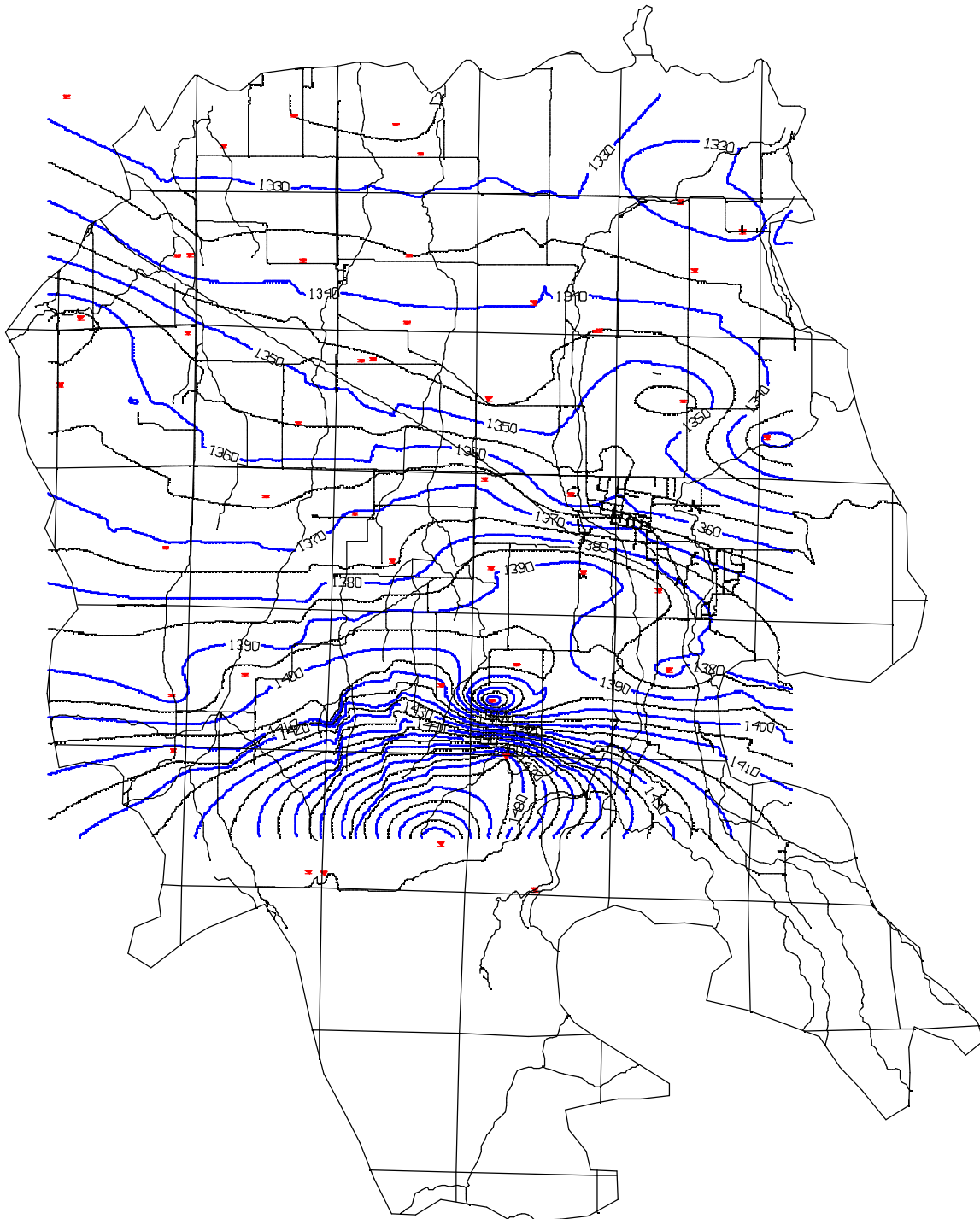




Figure 6-17
Ground Water Contours Fall 1994
Precipitation 69% of Long Term Average

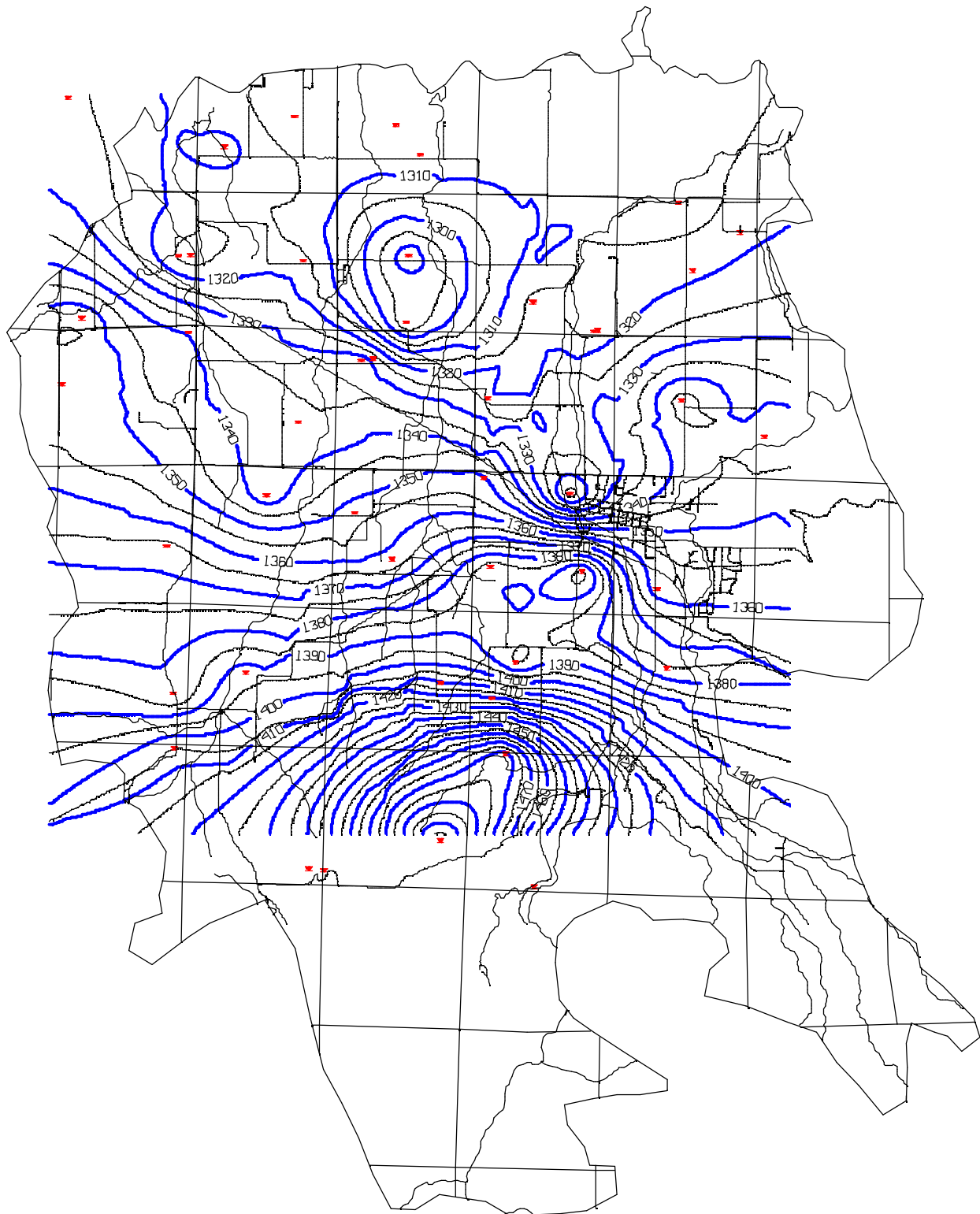




Figure 6-18
Contours of Ground Water Elevation Decline - 1994
Precipitation 69% of Long Term Average

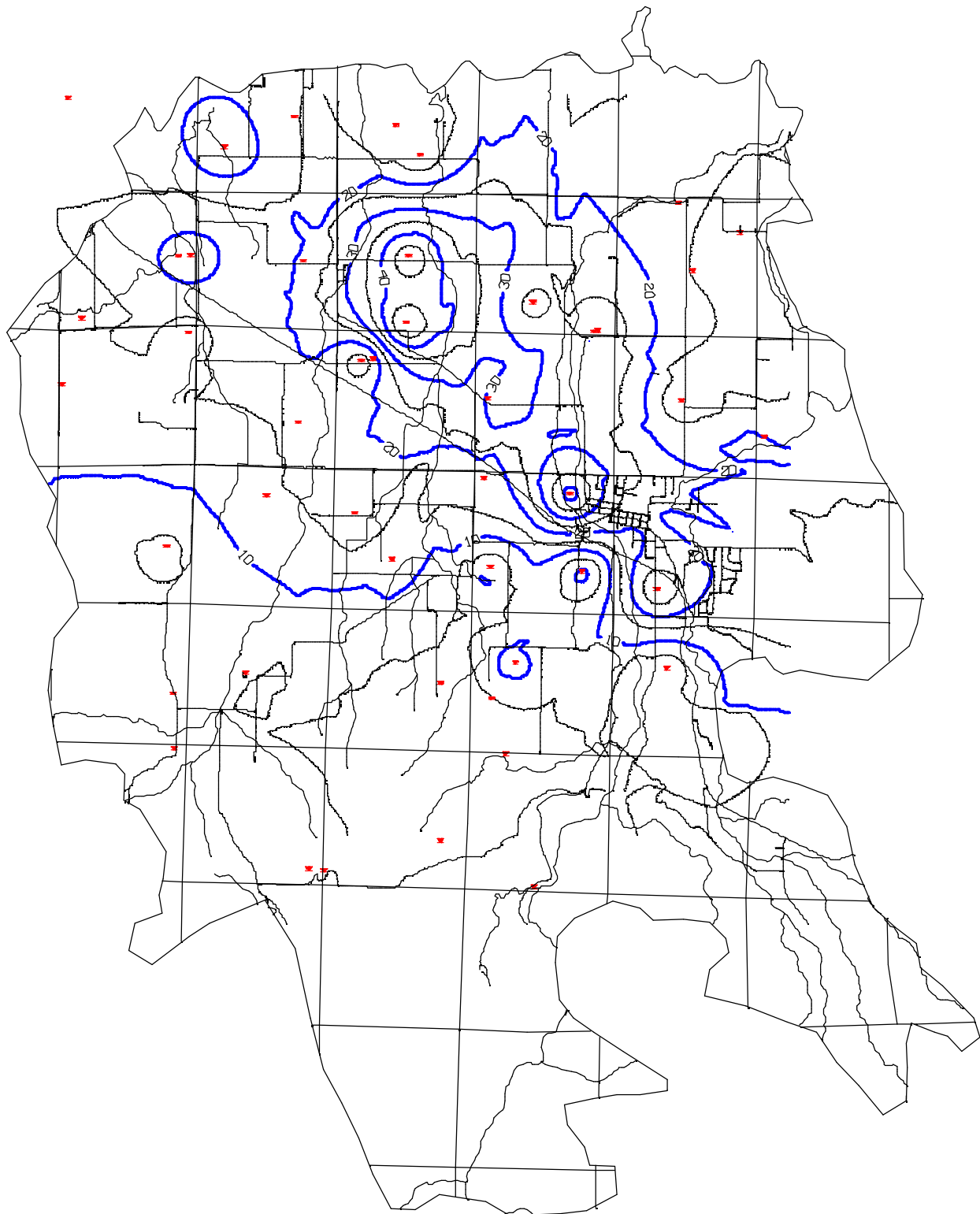




Figure 6-19
Contours of Ground Water Elevation Decline during 1975-77 Drought

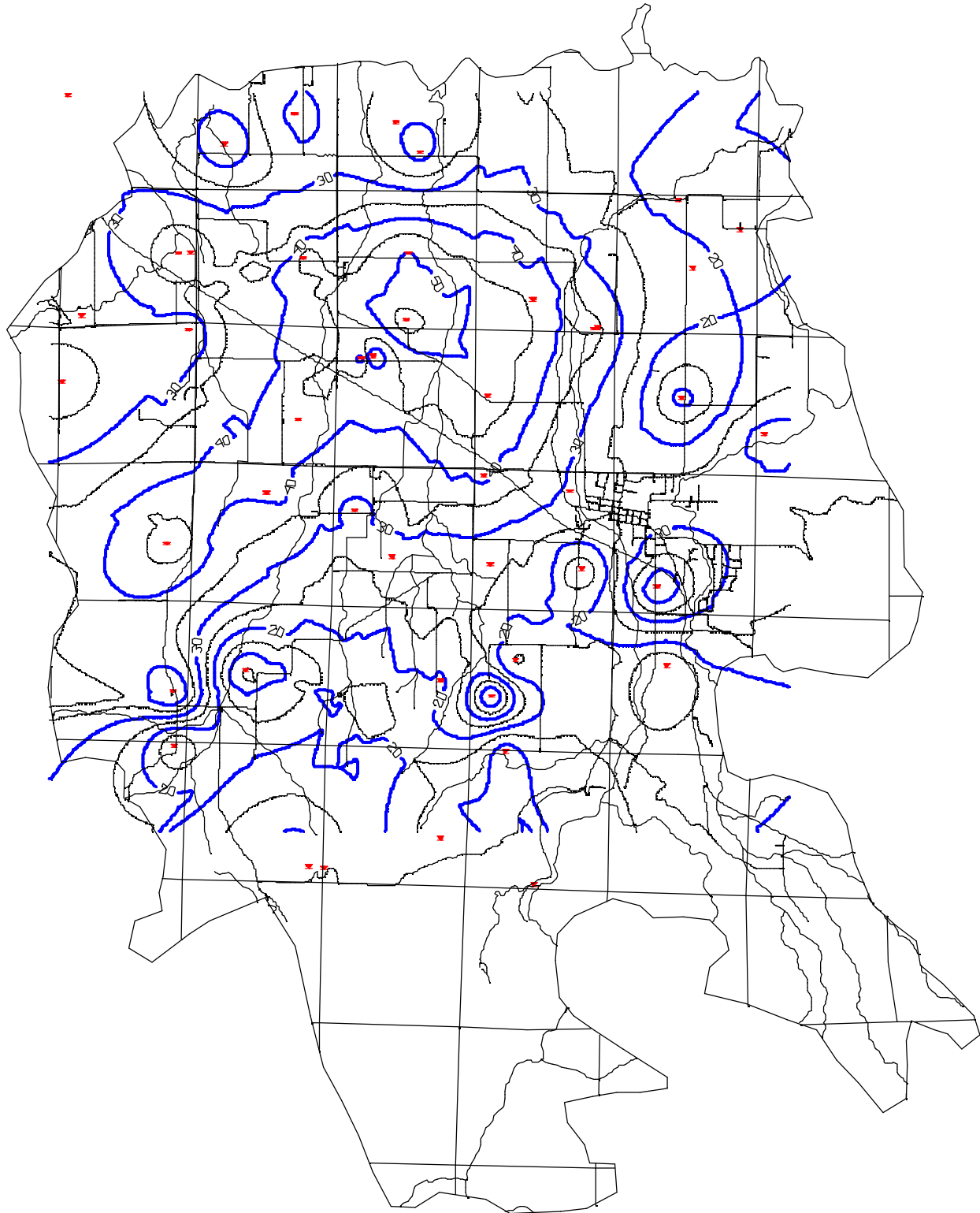
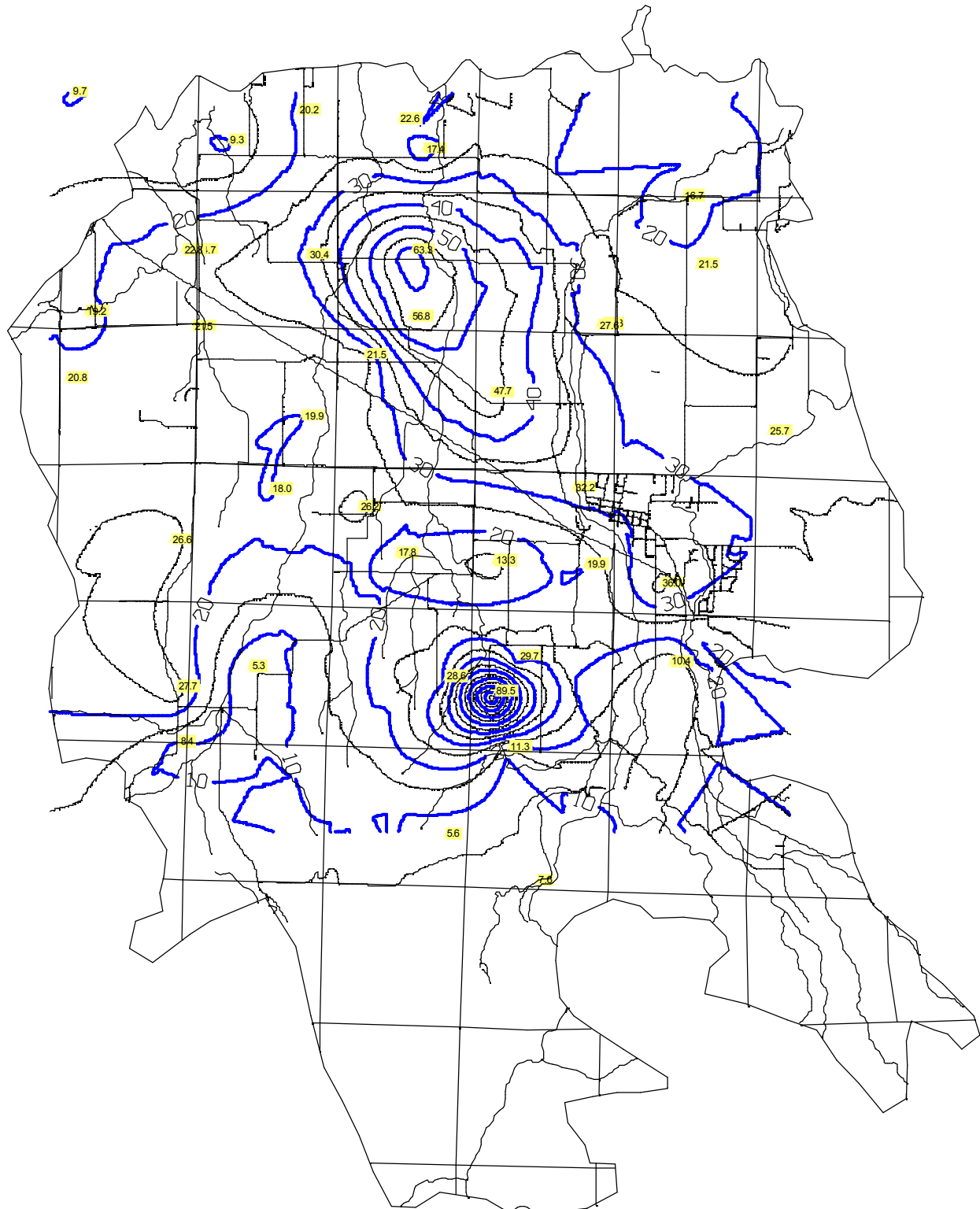




Figure 6-20
Contours of Ground Water Elevation Decline during 1987-92 Drought





6.7 WATER BALANCE

A water balance is developed based on quantitative estimates of all of the inflows, outflows, and change in storage for the Big Valley basin. If estimates of the individual water balance components are accurate, the sum of all recharge, discharge, and boundary flows over a period of time equals the change in groundwater storage during the same period. The standard water balance equation is written as:

$$\Sigma(\text{inflows}) - \Sigma(\text{outflows}) = \Delta(\text{storage})$$

A suitable time period for estimating the water balance is one during which accurate measurements of each of the water balance components were collected. These include measurements of all inflows, outflows, and groundwater levels. Because gains and losses from streams are an important component of the water balance, it was necessary to select a time period with streamflow measurements. Currently streamflow is only measured at one point in Big Valley in Kelsey Creek. By contrast, DWR Bulletin 14 contains streamflow measurements from 12 different stream gages in Big Valley, along with groundwater level data, crop use patterns, and rainfall data. After reviewing the data in Bulletin 14, the period between December 1 1949 and March 31 1950 was selected for estimating the water balance.

6.7.1 Inflow

Important components of inflow to the Big Valley basin include the following;

- Direct percolation of rainfall
- Streamflow into Big Valley
- Return flow from irrigation
- Subsurface inflow from surrounding mountains
- Possible late season subsurface inflow from Clear Lake

Table 4 in Bulletin 14 (DWR, 1957) estimates the total amount of rainfall reaching the Big Valley basin floor as 25,600 acre-feet. Appendix B of the same bulletin reports that 76% of the rainfall at the Kelseyville 2N rain gauge during the 1949-1950 water year fell between December 1 1949 and March 31 1950. Based on these two facts, the total amount of rainfall in Big Valley between December 1 1949 and March 31 1950 was approximately 16,960 acre-feet.

Appendix C in Bulletin 14 (DWR, 1957) lists the monthly stream flows entering Big Valley for Adobe Creek, Cold Creek, Hill Creek, and Manning Creek. Monthly data for Kelsey Creek streamflow entering Big Valley was obtained



from the USGS web site at

http://waterdata.usgs.gov/nwis/discharge/?site_no=11449500

The streamflows into Big Valley from each stream between December 1 1949 and March 31 1950 were as follows:

Adobe Creek 10858 acre-feet
Cold Creek 557 acre-feet
Hill Creek 162 acre-feet
Manning Creek 1135 acre-feet
Kelsey Creek 22772 acre-feet
Total 35484 acre-feet

As discussed previously, there is no estimated irrigation pumping between December 1 1949 and March 31 1950. Therefore, it was not necessary to independently estimate return flow from irrigation. Additionally, there is only outflow to Clear Lake during this period of time, and therefore inflow from Clear Lake is not estimated here.

Estimation of mountain front recharge involved estimating the average annual rainfall on each watershed above Big Valley, subtracting out the average annual runoff entering Big Valley, and subtracting out ET of the natural vegetation. The catchment basin size was taken from page 5 of DWR Bulletin 14. The average annual precipitation of 37 inches was derived from the map of S.E. Rantz (1969). Average annual runoff for each watershed was taken from Table 8 of DWR Bulletin 14. The average annual ET rate for native vegetation was taken from Table 12 in Appendix K of DWR Bulletin 14. The calculations on Table 6-10 show that the average annual ET demand exceeds the average annual percolation. Therefore the mountain front recharge is likely minimal, and has been set to zero in these calculations.

Table 6-10
Annual ET Demand

Creek	Catchment Area (acres)	Annual Precipitation (inches)	Annual Runoff	Annual Percolation	Et rate	Annual ET	Annual Recharge
Adobe Creek	15360	37	14100	33260	58.8	75264	0
Cold Creek	16640	37	1200	50107	58.8	81536	0
Kelsey Creek	24320	37	42000	32987	58.8	119168	0
Manning Creek	3200	37	1900	7967	58.8	15680	0



6.7.2 Outflow

Important components of outflow from the Big Valley basin include the following:

- Irrigation pumping
- Municipal pumping
- Streamflow out of Big Valley
- Evapotranspiration
- Subsurface flow into Clear Lake

As mentioned earlier, irrigation pumping between December 1 1949, and March 31 1950, was set to zero. This is based on Table 29 in DWR Bulletin 14. This is not unexpected, as the natural rainfall likely provides all the needed irrigation water during this period. Municipal pumping for the town of Kelseyville was estimated by DWR at 31 acre-feet per year (DWR, 1957, pg 26). We assumed the municipal use was constant throughout the year, and therefore the municipal water use for the four month period between December 1 1949 and March 31 1950 was approximately 10 acre-feet.

Appendix C in Bulletin 14 (DWR, 1957) lists the monthly streamflows leaving Big Valley for Adobe Creek, Cold Creek, Hill Creek, Kelsey Creek, and Manning Creek. The streamflows out of Big Valley for each stream between December 1 1949 and March 31 1950 were as follows:

Adobe Creek	10122 acre-feet
Cold Creek	391 acre-feet
Hill Creek	243 acre-feet
Manning Creek	2447 acre-feet
Kelsey Creek	12622 acre-feet
Total	25825 acre-feet

Table 6 of Appendix K in Bulletin 14 suggests that 22% of the total evapotranspiration in Big Valley occurs between December 1 and March 31. The total seasonal water requirement for Big Valley is estimated at 41,200 acre-feet, as reported on Table 26 of Bulletin 14. The evapotranspiration for the period between December 1 1949 and March 31 1950 was therefore estimated as 22% of 41,200, or 9060 acre-feet.

Subsurface flow into Clear Lake is difficult to estimate because of the limited understanding of the groundwater interaction with Clear Lake, and the need for



estimates of hydraulic conductivity. We attempted to estimate the flow rate towards Clear Lake by contouring water level data from both November 1949 and March 1950.

We first estimated a gradient between the contoured area and Clear Lake. The edge of the contoured area is approximately 2,600 feet from the edge of Clear Lake. The average water level at the north edge of the contoured data is approximately 1,328 feet msl during November 1949, and approximately 1,333 feet msl during March 1950. This yields an average water level of 1330.5 at the north edge of the contoured data. Bulletin 14 reports the average water level of Clear Lake is approximately 1,320 feet msl. The groundwater gradient between the contoured water levels and Clear Lake is therefore:

$$i = \frac{1330.5 - 1320}{2600}$$
$$i = 0.004$$

The length of the gridded data perpendicular to flow is 25,000 feet. Conversations with local farmers suggest that early wells in Big Valley were on the order of 70 feet deep near Clear Lake. Therefore, an effective depth of the aquifer of 100 feet was used in these calculations. The measured gradient of 0.004 is a horizontal gradient; therefore we estimated a representative horizontal conductivity for the flow calculations. A hydraulic conductivity of 20 feet/day was estimated as a conductivity of a silty sand. Using these values, the flow towards Clear Lake was estimated using Darcy's Law.

$$Q = K \times i \times A$$
$$Q = 20 \frac{ft}{day} \times 0.004 \times (25,000 ft \times 100 ft)$$
$$Q = 200,000 \frac{ft^3}{day}$$
$$Q = 4.6 \frac{acre - feet}{day}$$

For the 121 day period between December 1 and March 31, the flow towards Clear Lake is estimated at 557 acre-feet.

6.7.3 Storage

Change in groundwater storage is commonly calculated using measured water levels. Subtracting the contoured spring water surface from the contoured autumn water surface provides an estimate of the total volume of soil that has been dewatered or recharged. Multiplying this soil volume by an assumed specific yield results in an estimated change in groundwater storage.

The Rockworks program was used to contour water level data and estimate the



amount of soil between the two contoured surfaces. The program estimated that approximately 7,756,340,000 cubic feet of soil, or 178,060 acre-feet of soil was recharged between December 1 1949 and March 31 1950. The California Department of Water Resources estimated that the specific yield of the top 20 feet of Big Valley is approximately 7%, and the specific yield of the interval between 20 and 40 feet bgs is approximately 10%. Using the value of 7%, the amount of water stored between December 1, 1949 and March 31 1950 was 12,460 acre-feet.

6.7.4 Water Balance Calculations

The water balance can now be calculated using the previously mentioned water balance equation.

$$\begin{aligned}\sum \text{inflows} - \sum \text{outflows} &= \text{Change in Storage} \\ (19,690 + 35,480) - (10 + 25,820 + 9,060 + 557) &= 12,460 \\ 55,170 - 35,447 &= 12,460 \\ 19,723 &= 12,460\end{aligned}$$

This discrepancy in the water balance may indicate a number of things including:

- The effective specific yield may be closer to 11% than 7%.
- There is likely some error in the flow from Big Valley towards Clear Lake, however it likely does not account for the entire discrepancy.
- There may be some error in the some of the raw data in Bulletin 14. Of particular note is the stream gauging data. A 10% error on a Kelsey Creek stream gauge could account for roughly half of the observed error.



Figure 6-21
Big Valley Watershed Map



0 >1 mi



Figure 6-22
Big Valley Land Use -2001

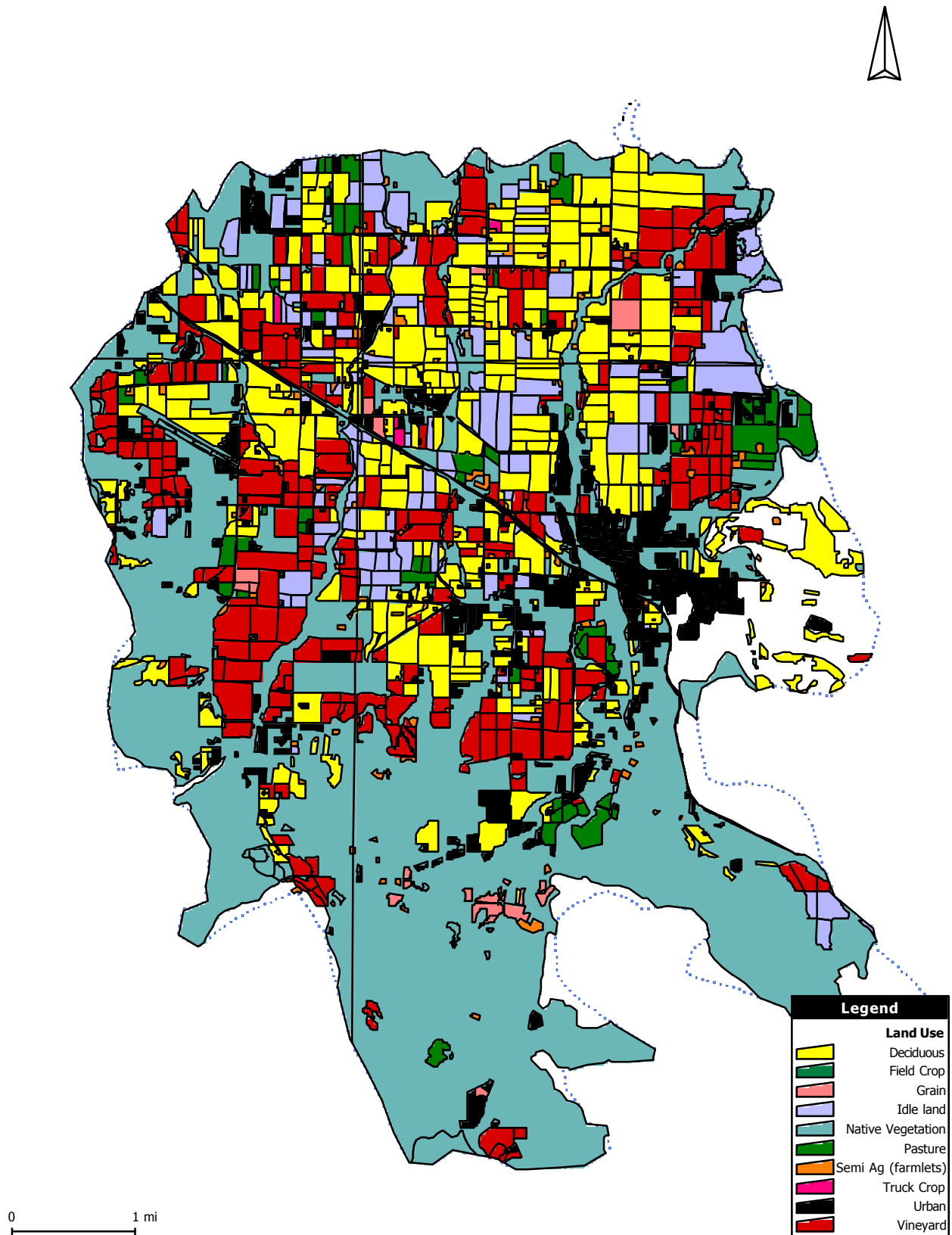




Figure 6-24
Average Annual Ground Water Levels - 14N-09W -Sections 30 through 36

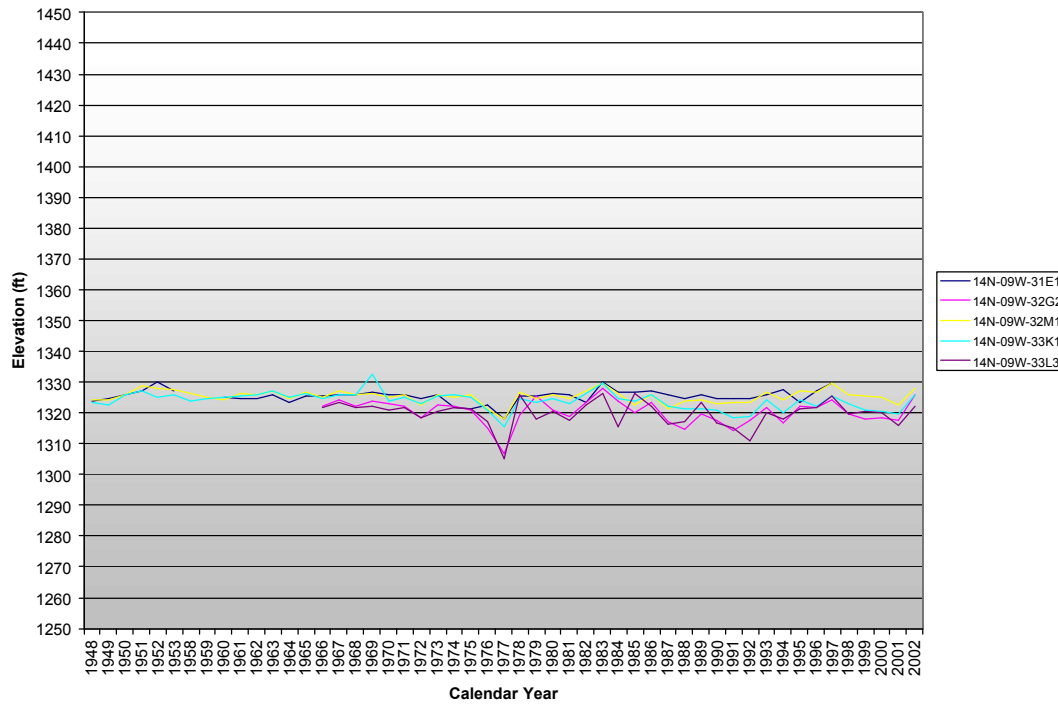


Figure 6-25
Minimum Annual Ground Water Levels - 14N-09W -Sections 30 through 36

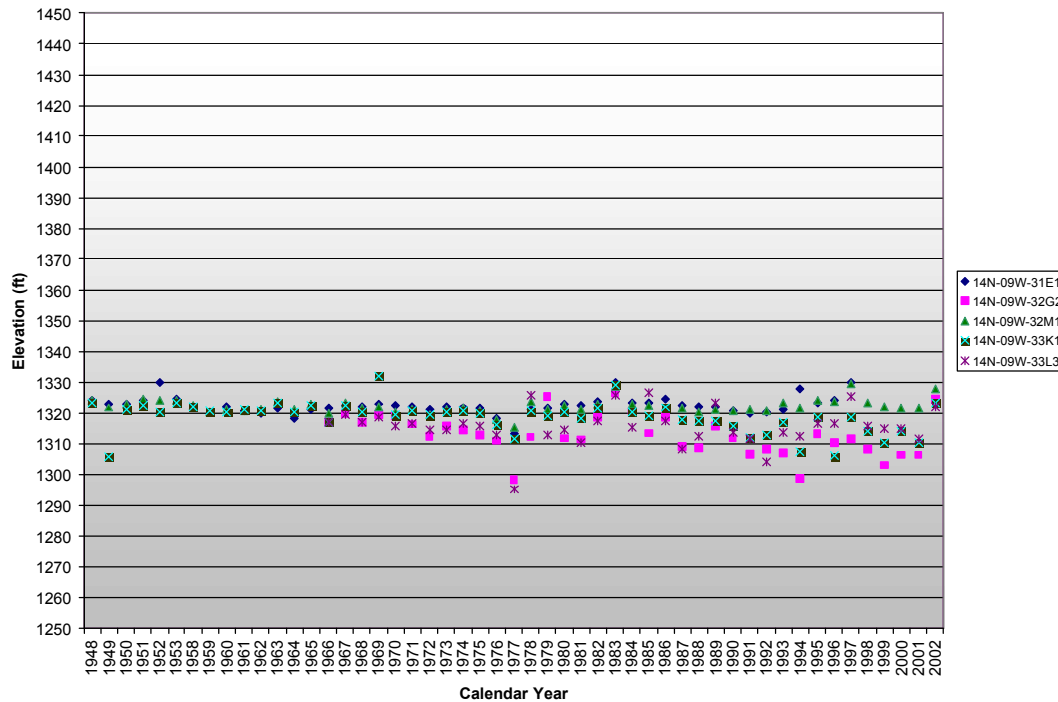




Figure 6-26
Average Annual Ground Water Levels - 13N-09W -Sections 1 through 6

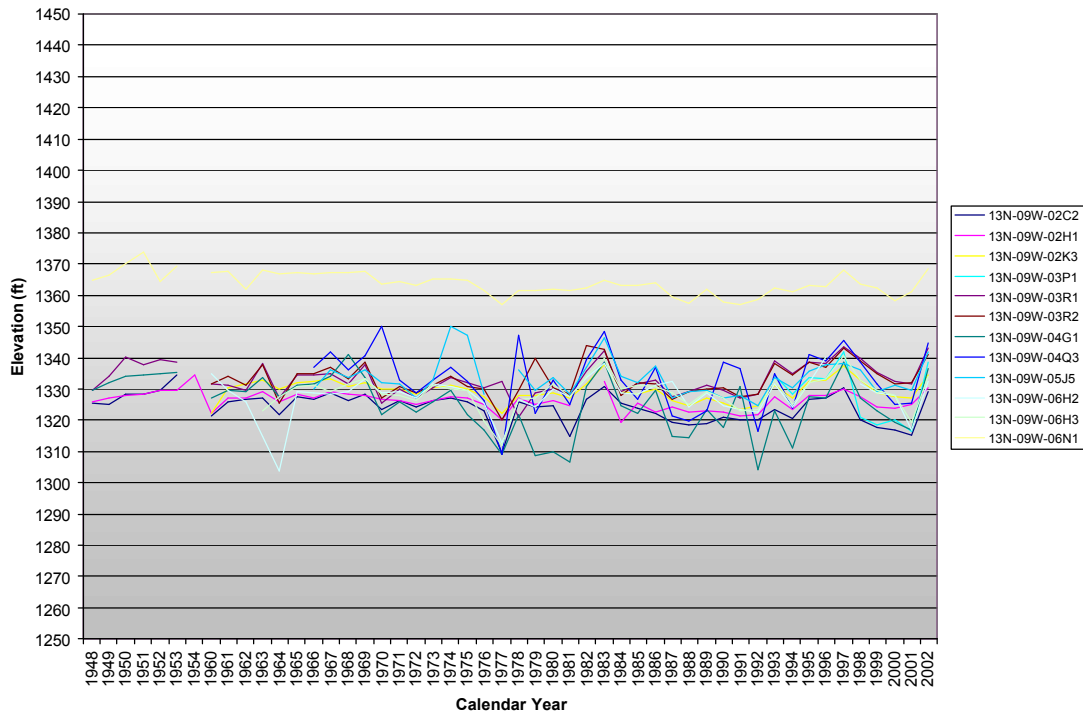


Figure 6-27
Minimum Annual Ground Water Levels - 13N-09W -Sections 1 through 6

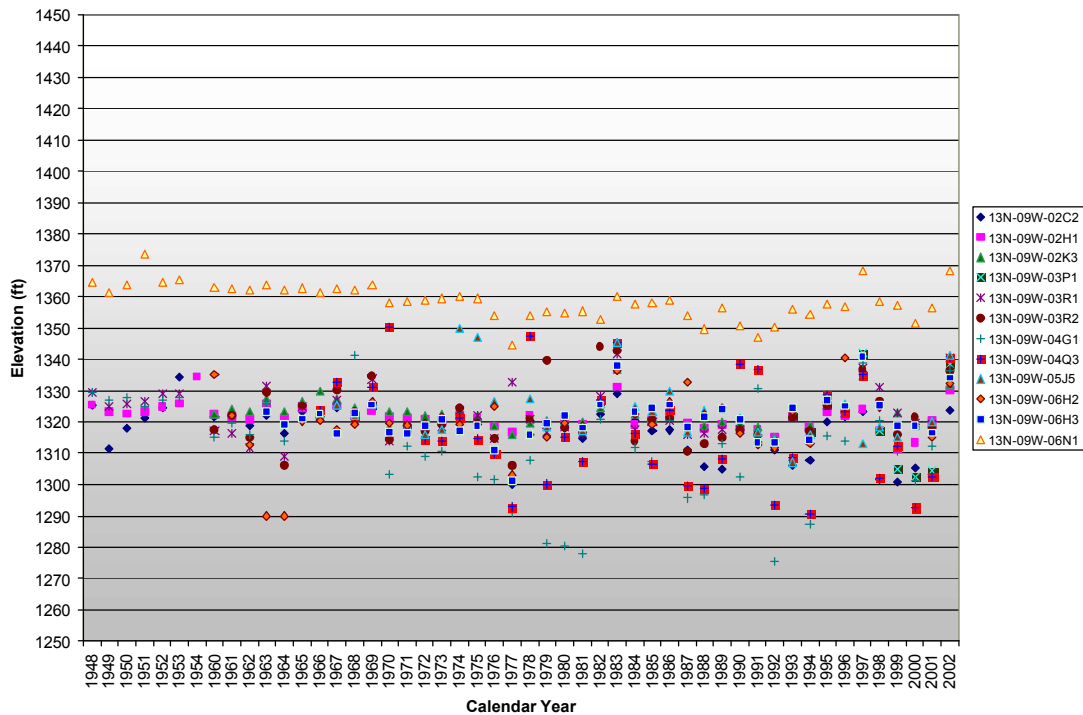




Figure 6-28
Average Annual Ground Water Levels - 13N-09W -Sections 7 through 12

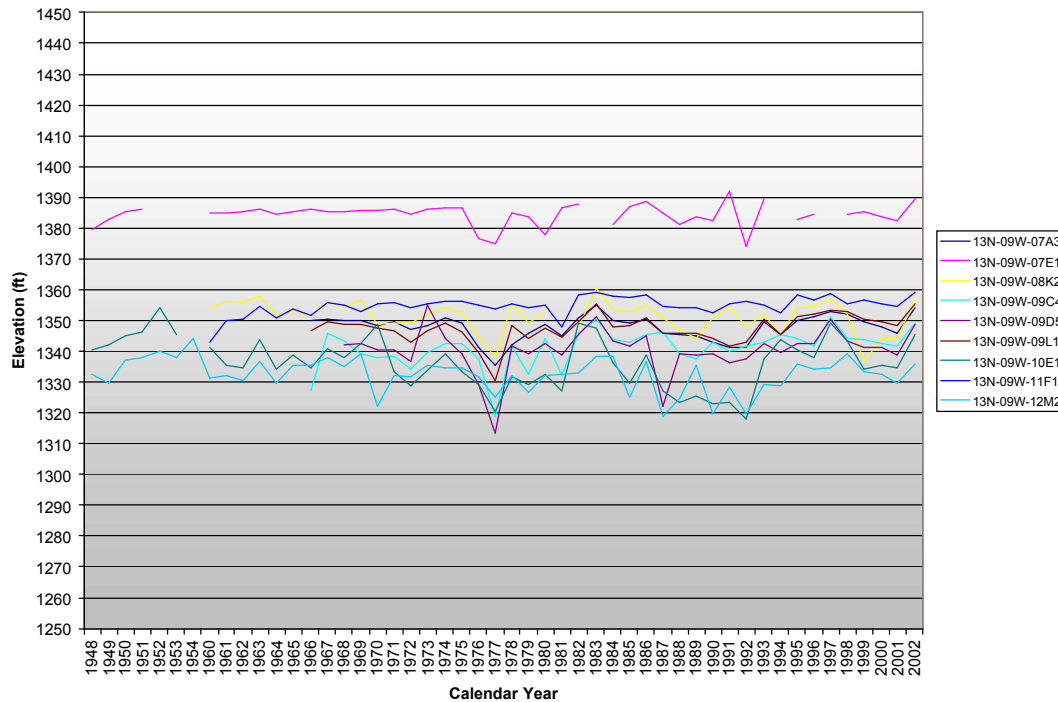


Figure 6-29
Minimum Annual Ground Water Levels - 13N-09W -Sections 7 through 12

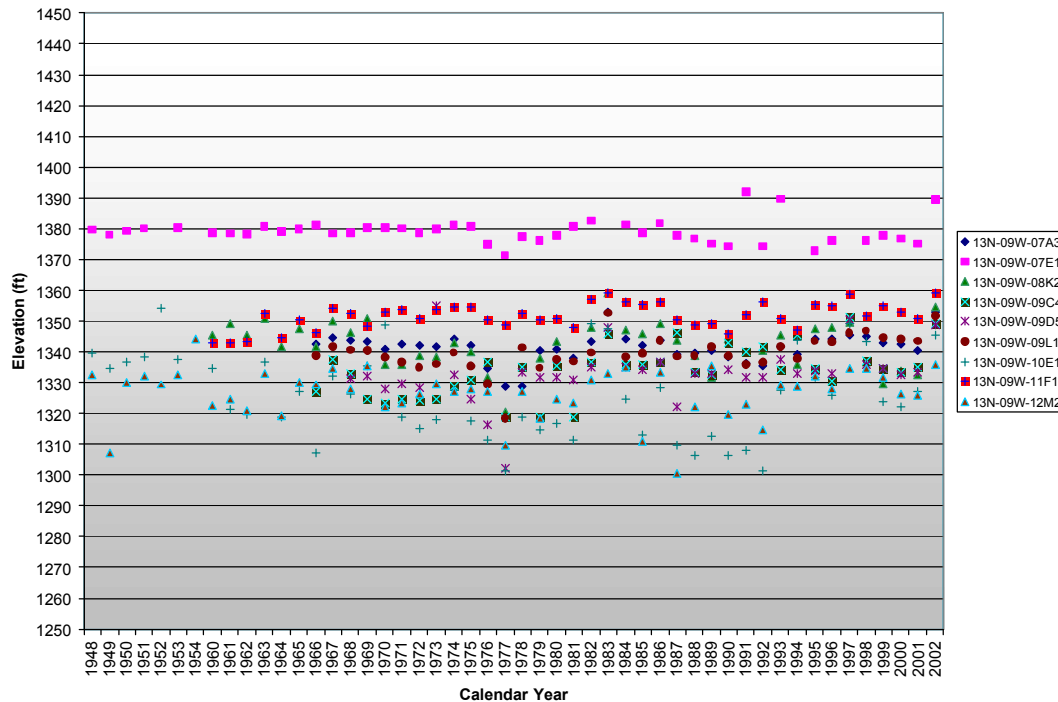




Figure 6-30
Average Annual Ground Water Levels - 13N-09W -Sections 13 through 18

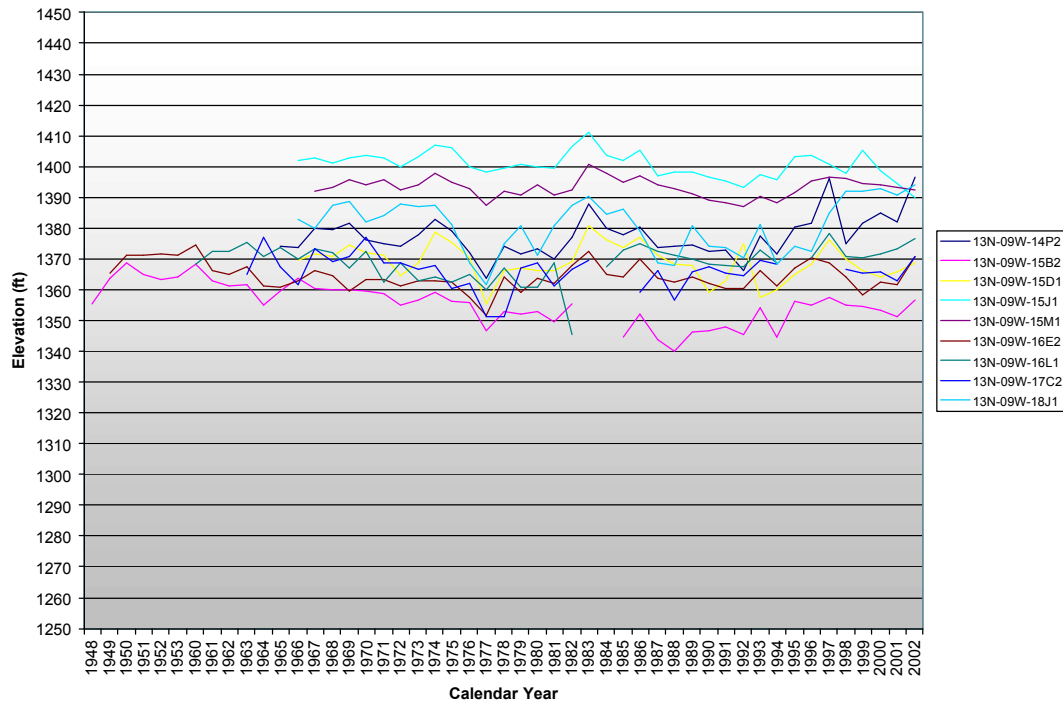


Figure 6-31
Minimum Annual Ground Water Levels - 13N-09W -Sections 13 through 18

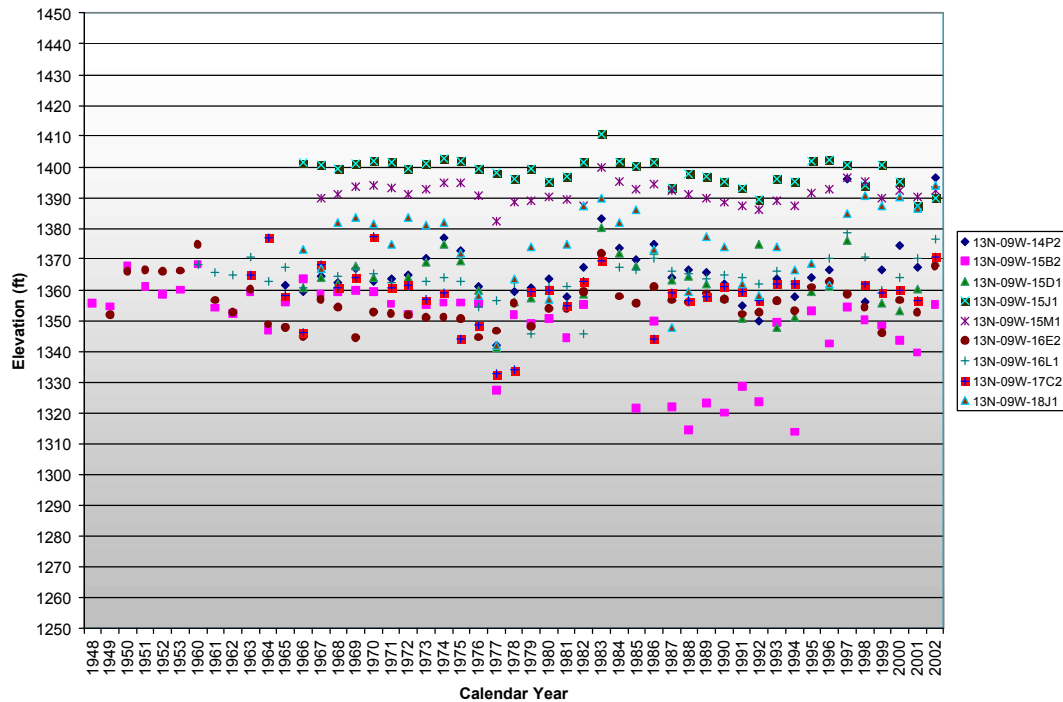




Figure 6-32
Average Annual Ground Water Levels - 13N-09W -Sections 19 through 24

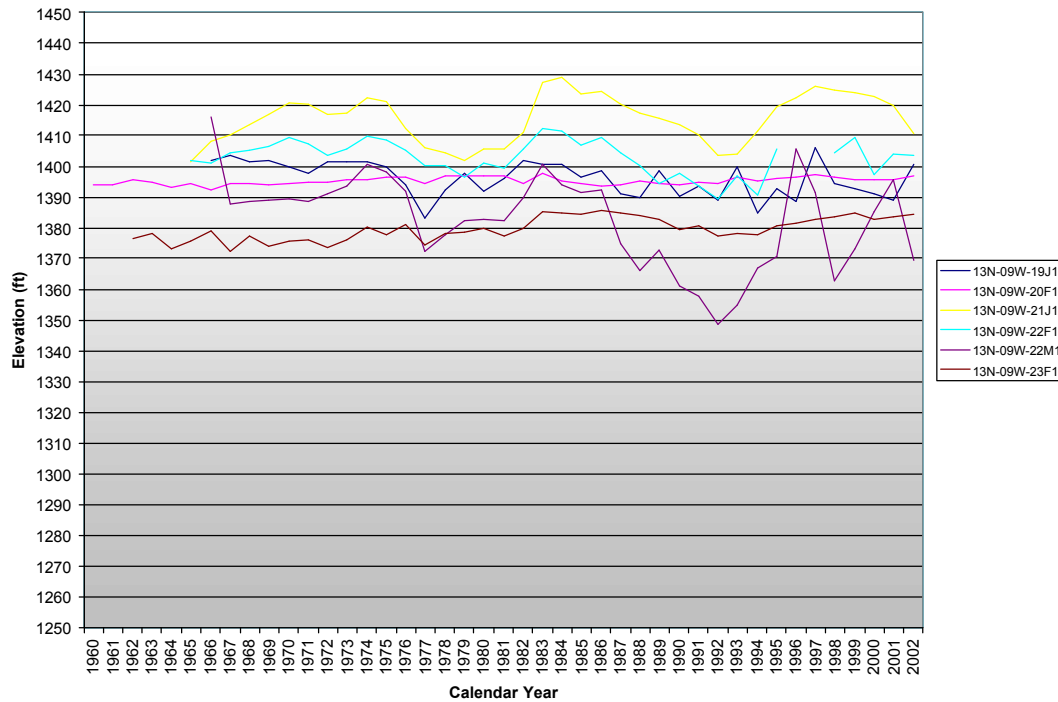


Figure 6-33
Minimum Annual Ground Water Levels - 13N-09W -Sections 19 through 24

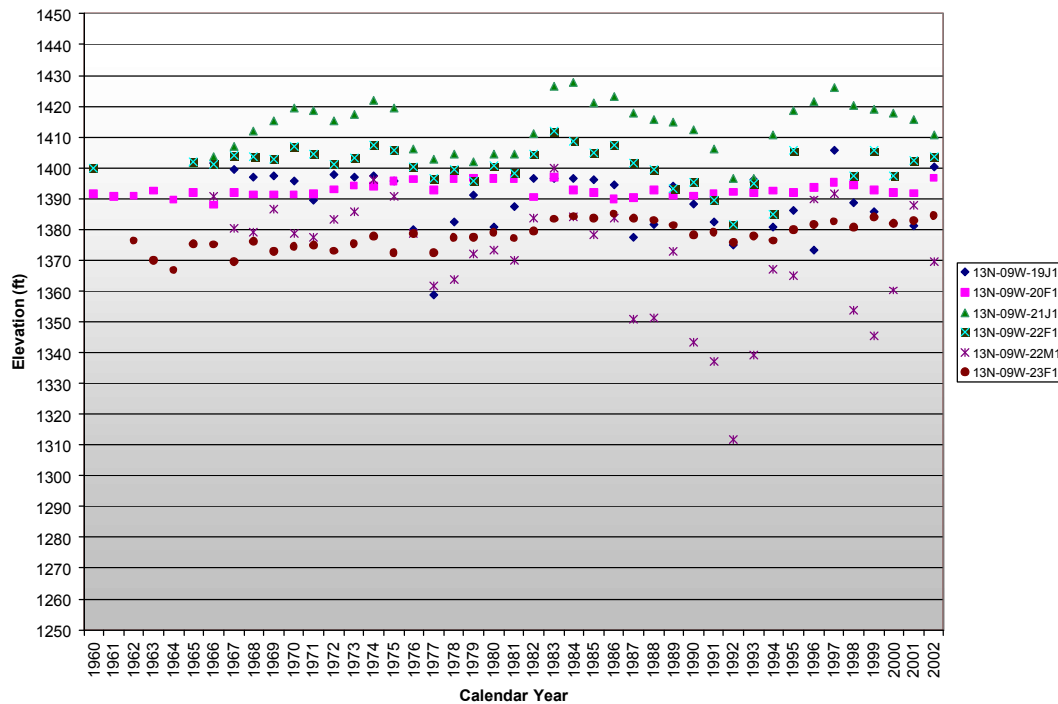




Figure 6-34
Average Annual Ground Water Levels - 13N-09W -Sections 25 through 30

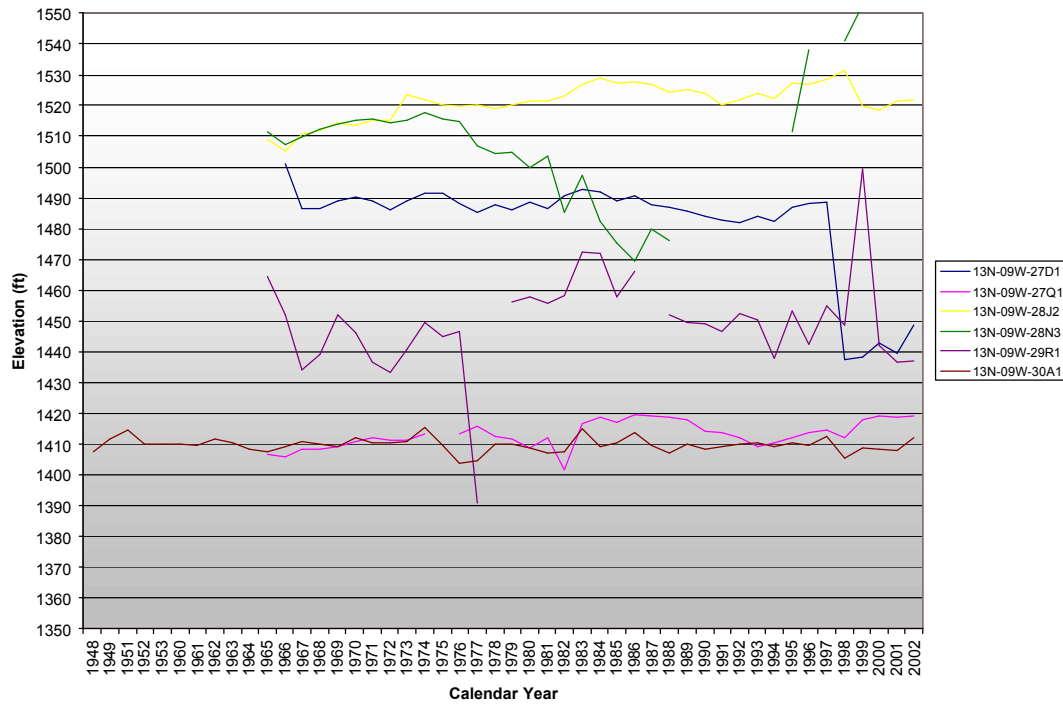
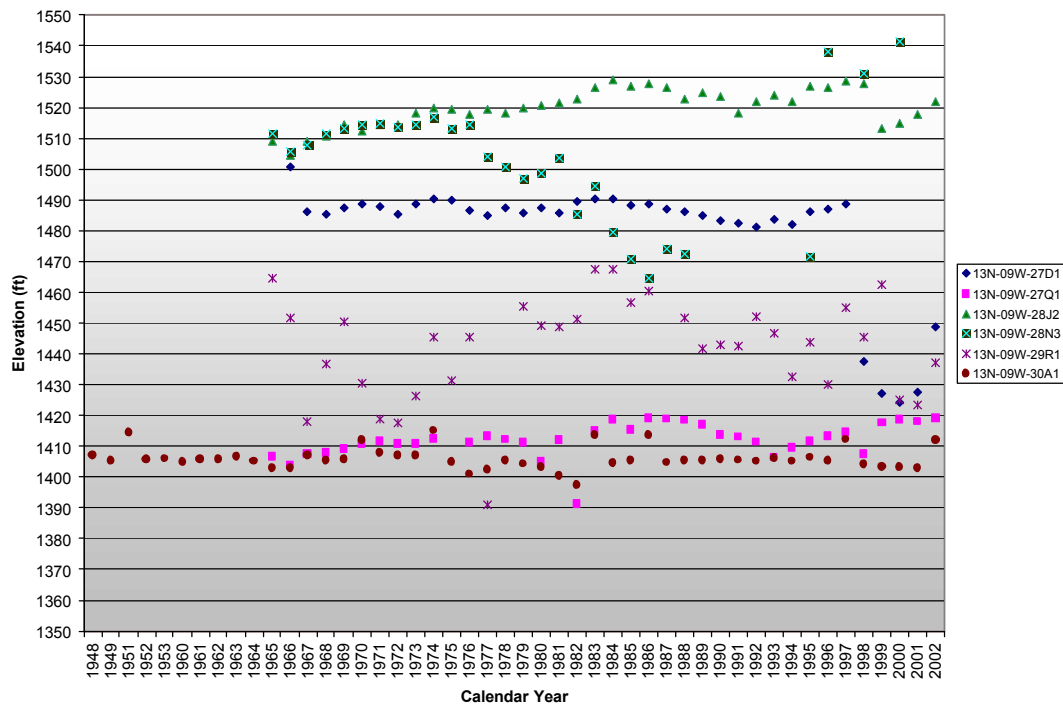


Figure 6-35
Minimum Annual Ground Water Levels - 13N-09W -Sections 25 through 30





7. Water Quality

7.1 INTRODUCTION

The purpose of this section of the report is to describe the analyses of water quality data from wells in the Big Valley Basin and the implications for management of the groundwater resources.

7.2 MONITORING PROGRAM

Ground water and surface water quality data were provided by Mr. Thomas Smythe of the Lake County Water Resources Division. Water quality data were derived from two monitoring programs: one program managed by Lake County and one program managed by the California Department of Water Resources (DWR).

The two programs collect groundwater samples from wells throughout Big Valley. With minor exceptions, both programs analyze water samples for the same set of constituents. The analyzed constituents include general minerals, boron, silica, nutrients, and metals. Table 1 shows the list of analyzed compounds, and equates the names from the County analyses with the names from the DWR analyses.

Lake County's water quality collection program began in 1985. The most recent data provided from the program is from the year 2000. The earliest data provided from DWR's water quality collection program was from 1944. The most recent data provided from DWR's program is from 1991. Data from both programs were combined into a single database for analysis. A map showing locations of wells from which water quality data is available is shown on Figure 7-1 (found at the back of this chapter).



**Table 7-1
Water Quality Analyses**

County Analysis	State Analysis
Temp_C	Temp_C
Temp_F	Temp_F
pH_field	pH_field
EC_field	EC_field
Total_Coliform	Total_Coliform
Coliform_flag	Coliform_flag
Ca_flag	Ca_flag
Mg_flag	Mg_flag
Na_flag	Na_flag
K_flag	K_flag
SO4_flag	SO4_flag
Cl_flag	Cl_flag
NO3_flag	NO3_flag
B_flag	B_flag
Al_flag	Al_flag
Arsenic_flag	Arsenic_flag
Barium_flag	Barium_flag
Cadmium_flag	Cadmium_flag
Chromium_flag	Chromium_flag
Copper_flag	Copper_flag
Iron_flag	Iron_flag
Lead_flag	Lead_flag
Manganese_flag	Manganese_flag
Mercury_flag	Mercury_flag
Ni_flag	Ni_flag
Selenium_flag	Selenium_flag
Zinc_flag	Zinc_flag
Total_NH3_flag	Total_NH3_flag
NO2+NO3_flag	NO2+NO3_flag
NO2_flag	NO2_flag
Diss_NH3_flag	Diss_NH3_flag
NO3_flag	NO3_flag
NH4_flag	NH4_flag
PO4_flag	PO4_flag
P_flag	P_flag

County Analysis	State Analysis
Diss_NO2_as N	Dissolved Nitrite as N
Total_NH4_as N	Total Ammonium as N
Al	Al mg/L T
Arsenic	As mg/L D
Barium	Ba mg/L D
Cadmium	Cd mg/L D
Chromium	Cr mg/L D
Copper	Cu mg/L D
Diss_NH3	DISSOLVED AMMONIA as N
Dissolved B	DISSOLVED BORON
Dissolved Ca	DISSOLVED CALCIUM
Dissolved Cl	DISSOLVED CHLORIDE
Diss_Hardness	DISSOLVED HARDNESS CaCO3 mg/L
Dissolved Mg	DISSOLVED MAGNESIUM
Diss_NO2+NO3	DISSOLVED NITRATE AND NITRITE
Diss_NO3_as N	DISSOLVED NITRATE as N
Dissolved NO3	DISSOLVED NITRATE NO3 mg/L
Diss_Ortho-P04	DISSOLVED ORTHOPHOSPHATE as P
Dissolved K	DISSOLVED POTASSIUM
Dissolved Na	DISSOLVED SODIUM
TDS	DISSOLVED SOLIDS mg/L at 180C
Dissolved SO4	DISSOLVED SULFATE SO4 mg/L
Alkalinity (Lab)	DISSOLVED TOTAL ALKALINITY
Iron	Fe mg/L D
Mercury	Hg mg/L T
pH_lab	LAB pH
Turbidity	MINERAL TURBIDITY HACH
Manganese	Mn mg/L D
Ni	Ni mg/L T
Lead	Pb mg/L D
Selenium	Se mg/L D
EC_lab	SPECIFIC CONDUCTANCE 25C
Total_NH3+	TOTAL AMMONIA & ORGANIC NITROGEN
Total P	TOTAL PHOSPHORUS as P
Zinc	Zn mg/L D

7.3 ANALYSIS OF DATA

The water quality data were analyzed by a number of methods, including piper diagrams, time series plots, and maps. Each analysis method provides different information about the groundwater quality in Big Valley. Combining results from all three analyses allows development of an overall picture of groundwater quality in the basin.



7.3.1 Piper Diagrams

Piper diagrams provide a method to visually classify water quality based on the relative concentrations of cations and anions. The cations plotted on the piper diagram are calcium, magnesium, sodium, and potassium. The plotted anions are chloride, sulfate, carbonate, and bicarbonate.

Water analysis data plotted on the piper diagram are measured in milliequivalents per liter; the measured concentration in milligrams per liter divided by the molecular weight of the cation or anion. The relative concentrations of cations are plotted on the lower left triangle, and the relative concentrations of anions are plotted on the lower right triangle. The complete suite of cations and anions are plotted on the central diamond.

Water samples with similar cation and anion compositions will plot in a cluster on piper diagrams. A mixture of two waters will plot along a straight line connecting the two end member waters on a piper diagram. Furthermore, if the major cation/anion ratios evolve over time, this can be observed on a piper diagram by plotting historical records from a single water source.

A typical Piper diagram is shown on Figure 7-2 and Piper diagrams for several other wells with adequate data are included in Appendix C. Piper diagrams were produced for all wells with a minimum of four historical data points.

Additionally, a Piper diagram was developed for surface water samples, and is presented on Figure 7-3. This Figure shows that both the streams and Clear Lake have generally similar water type. If the local surface water is the sole source of the groundwater, the groundwater analyses will likely not show any differentiation between two water types.

The piper diagrams generally show that the groundwater is of the same type as the surface water, and has not varied historically. Piper diagrams for certain wells show some variation. These include:

- Wells 13N-09W-02K02, 13N-09W-03C01, 13N-09W-08B01, 13N-09W-08C01, 13N-09W-09F02, and 13N-09W-16D02 all appear to show an evolution of increasing sulfate. This is shown on the piper diagrams with red arrows. The source of the sulfate is unknown.
- Well 13N-09W-12M01 is anomalously high in magnesium and bicarbonate.
- Wells 13N-09W-02K02, 13N-09W-06B01, 13N-09W-09F02, 13N-09W-16D01, 13N-09W-16D03, 13N-09W-17A01, 13N-09W-21F02, and 13N-09W-22J01 show at least one sample with anomalously high magnesium concentrations, compared to surface water samples.



7.3.2 Time Series Plots

Time series plots allow visual interpretation of chemical trends for one or two constituents. Time series plots were produced for contaminant parameters of concern, including boron, nitrate, total dissolved solids (TDS), and magnesium to calcium ratios. Boron was graphed because it can affect crops, and may indicate the presence of geothermal waters. Similarly, extreme magnesium to calcium ratios may indicate the presence of geothermal waters, while moderately elevated magnesium to calcium ratios likely result from groundwater passing through serpentinized rocks. Nitrate is usually derived from fertilizer or animal waste. Nitrate is harmful to infants, causing methemoglobinemia ("blue baby" syndrome.) TDS is a broad indicator of potential changes in water quality. As with the piper diagrams, wells were graphed that included at least four analyses.

Time series plots were developed for four different areas in Big Valley: the western upland, the Kelseyville sub-basin, the Adobe Creek sub-basin, and the central upland and Upper Big Valley. The four areas were based on analyses included in the Big Valley Ground Water Management Plan (Lake County, 1999).

7.3.2.1 Kelseyville Sub-basin

Time series plots of water quality data for the Kelseyville Sub-basin are presented in Figure 7-4 through Figure 7-8. Several water quality trends are apparent in these Figures.

Boron concentrations appear to be slowly rising in the western portion of the Kelseyville Sub-basin, with a significant rise observed along the most western margin at well 13N-09W-12M01. Both wells 13N-09W-02K02 and 13N-09W-09F02 display apparent increases in boron concentrations over time, although the concentrations do not yet approach levels that may be harmful to crops.

Magnesium to Calcium ratios do not show a trend, however one particularly anomalous spike was recorded in 1987 along the western most margin of the basin at well 13N-09W-12M01. Less dramatic spikes in magnesium to calcium ratios were recorded in 1990 in well 13N-09W-09F02, and in 1973 in well 13N-09W-02K02.

Graphs of both nitrate and TDS in the Kelseyville Sub-basin show a consistent rise beginning in the late 1950's and early 1960's. The rise in TDS likely reflects the rise in nitrate. These graphs suggest a consistent pattern of nitrate loading from either fertilizer or animal/human waste.

7.3.2.2 Adobe Creek Sub-basin

Time series plots of water quality data for the Adobe Creek Sub-basin are presented in Figure 7-9 through Figure 7-12.

Although trends in boron concentrations are not apparent in most of the wells in the Adobe Creek Sub-basin, boron concentrations have risen steadily in well



13N-09W-17A01 since the early 1950's. Well 13N-09W-08B01 appears to show a minor increase in boron concentration since the late 1970's, however the rise is not yet of significant magnitude.

Magnesium to calcium ratio data in the Adobe Creek Sub-basin do not show any discernable trends. This is particularly significant for well 13N-09W-17A01, which displayed a notable rise in boron concentrations.

Trends are not apparent in the nitrate and TDS data from the Adobe Creek Sub-basin; however the nitrate data displays significant fluctuations. Wells 13N-09W-08N01, 13N-09W-08B01, and 13N-09W-09F02 all show fluctuations of nitrate from less than 5 mg/l to greater than 30 mg/l. This may indicate either seasonal fertilization, or fluctuations in the amount of rainfall recharge carrying nitrate from the soil into the groundwater.

7.3.2.3 Central Upland – Upper Big Valley

Time series plots of water quality data for the Central Upland – Upper Big Valley sub-basin are presented in Figure 7-13 through Figure 7-16.

Boron concentrations in the Central Upland – Upper Big Valley area are relatively low, and show no clear temporal trends. If any trend is apparent, the concentrations have declined slightly since the early 1950's. The same is true for nitrate and TDS data.

Two wells display a slight increase in the magnesium to calcium ratios measured in the central upland – Upper Big Valley sub-basin: well 13N-09W-22C03 and 13N-09W-32J01. The rise in magnesium to calcium ratios in both of these wells is minor, and does not particularly suggest an influx of geothermal waters.

7.3.2.4 Western Upland

Time series plots of water quality data for the Western Upland Sub-basin are presented in Figure 7-17 through Figure 7-20. Only limited data are available for this sub-basin. No definitive trends are apparent for any of the graphed constituents in the Western Uplands Sub-basin. Additionally, no constituents show anomalously high concentrations of any graphed constituents.

7.3.3 Spatial analysis

Maps are used to show the distribution of chemical constituents or chemical ratios throughout Big Valley. Maps were produced for Boron, Nitrate, and Magnesium:Calcium ratios. As discussed earlier, boron was graphed because it can affect crops, and may indicate the presence of geothermal waters. Similarly, extreme magnesium to calcium ratios may indicate the presence of geothermal waters, while moderately elevated magnesium to calcium ratios likely result from groundwater passing through serpentinized rocks. Nitrate is usually derived from fertilizer or animal waste. Nitrate is harmful to infants, causing methemoglobinemia.



Maximum recorded Boron concentrations are shown on Figure 7-21 . The highest boron concentrations are found near the town of Kelseyville. Additional anomalously high boron concentrations are found in wells near Highland Springs Road and near Bell Hill Road. The boron data do not exhibit any spatial trend that may suggest migration of Boron from one area to another.

Maximum recorded Magnesium:Calcium ratios are shown on Figure 7-22. The highest ratios are found generally south of the Big Valley fault. No spatial trend is readily apparent in the map of Magnesium:Calcium ratios

Maximum recorded Nitrate levels are shown on Figure 7-23. Relatively high nitrate values have been recorded throughout much of the cropped portion of the basin. This suggests that high nitrate levels are a result of common agricultural practices, and are not tied to any one area of the basin.

7.4 WATER QUALITY ANALYSIS RESULTS

No single analysis suggests widespread water quality degradation in Big Valley. All of the analyses in aggregate, however, suggest certain trends in water quality. Conclusions that can be drawn from these trends include:

- Water quality in a few wells is being degraded possibly from some admixture of geothermal waters. While no single analysis points to this conclusion, the combination of increasing boron, changes in general mineral composition, and spikes in magnesium:calcium ratios suggest this.
- Trends suggesting water quality degradation from geothermal waters is evident in only a limited number of wells, representing small distinct areas of the Big Valley Basin. Wells 13N-09W-12M01 and 13N-09W-02K02 both lie near the western margin of the basin. Well 13N-09W-09F02 lies near the Big Valley Fault. In all, it appears as though localized water quality degradation from geothermal waters may be structurally controlled. The faults along the basin margins and the faults that bisect the basin appear to be sources of geothermal water. Geothermal waters have not affected wells away from faults to date.
- The water quality degradation from geothermal waters is ongoing. This suggests that locally, wells are not receiving adequate freshwater recharge from rainfall or percolation. As this freshwater deficit increases every year, geothermal waters are drawn into the basin, resulting in increasing water quality degradation. Continued overpumping of areas near faults may exacerbate this problem
- Nitrate levels are approaching regulatory limits in parts of the Big Valley basin. In agricultural areas, elevated nitrate levels in ground water are often due to leaching of nitrogen fertilizer or animal waste into the ground water system. Eventually, this may present a health risk to babies



and small children and therefore it should be carefully monitored.

The limited amount of water quality data constrains the level of analysis. In particular, it is impossible to attempt to correlate low water levels with impaired water quality.

Additional data may show more definitive trends, allow further delineation areas of impaired water quality, or allow correlation of diminished water quality with water levels.



Figure 7-1
Map showing Locations of Water Quality Wells

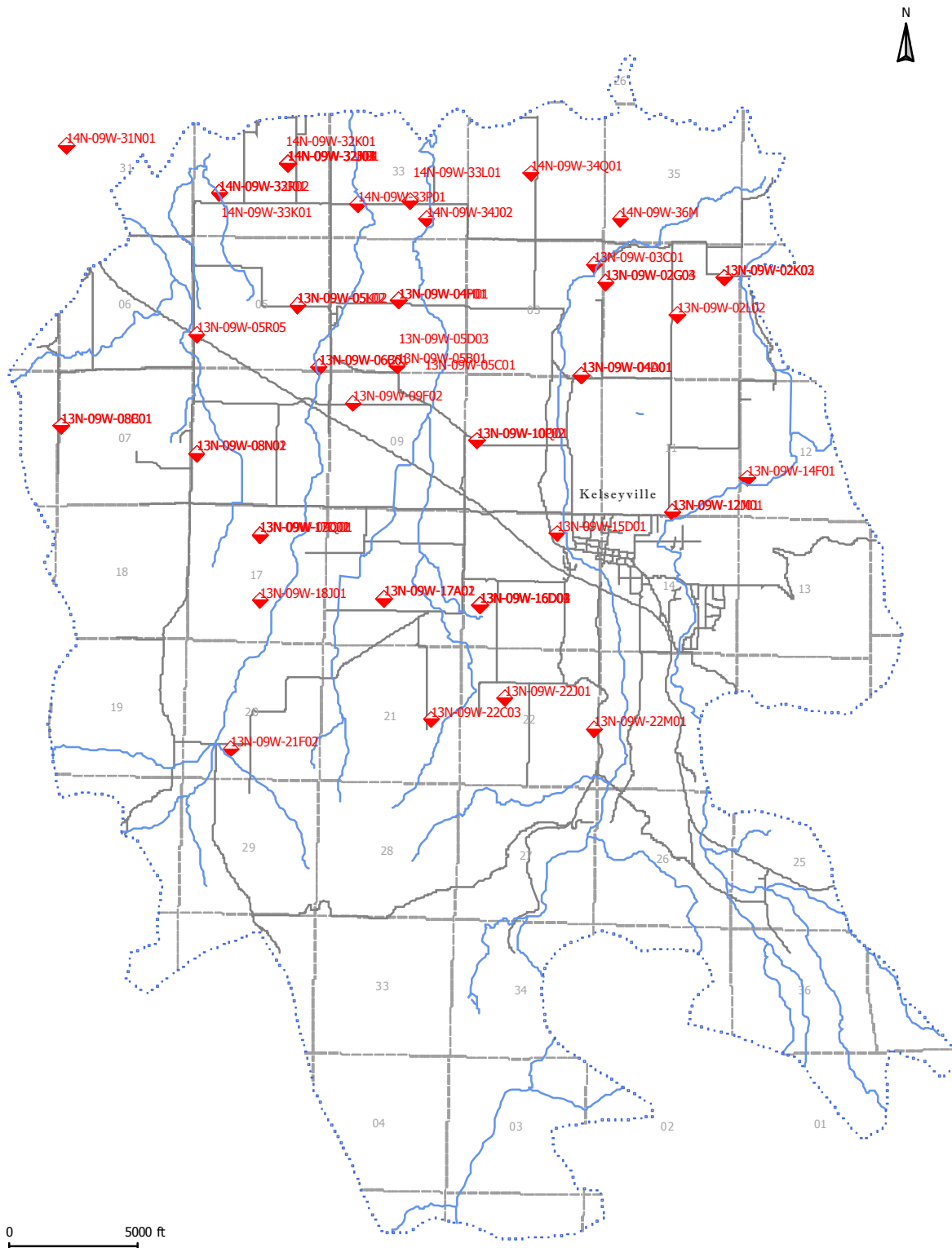


Figure 7-2
Piper Diagram - Well 13N-09W-02K02

Well 13N-09W-02K02

EXPLANATION

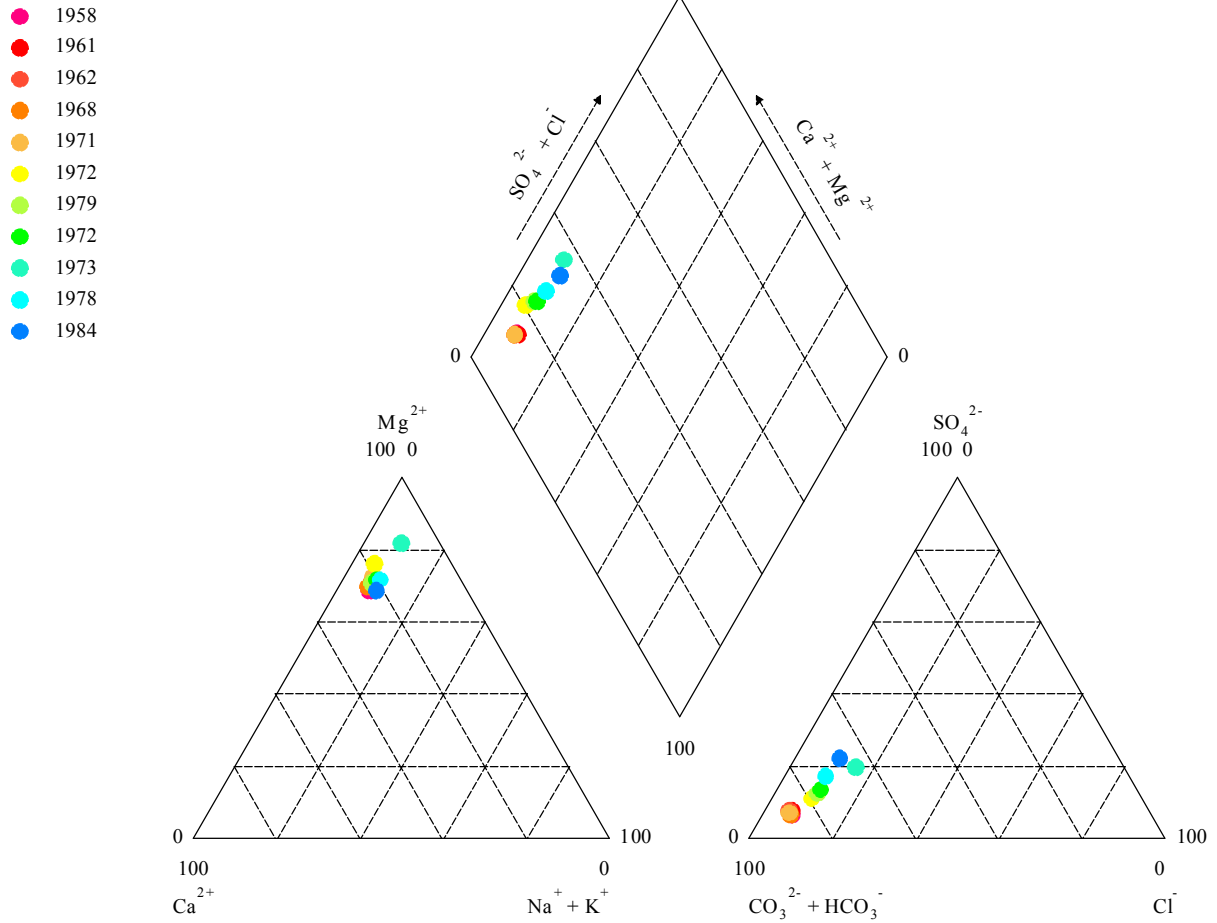




Figure 7-3
Piper Diagram for Surface Water Samples

Surface Water Samples (From DWR)

EXPLANATION

- Clear Lake
- Kelsey Creek
- Adobe Creek

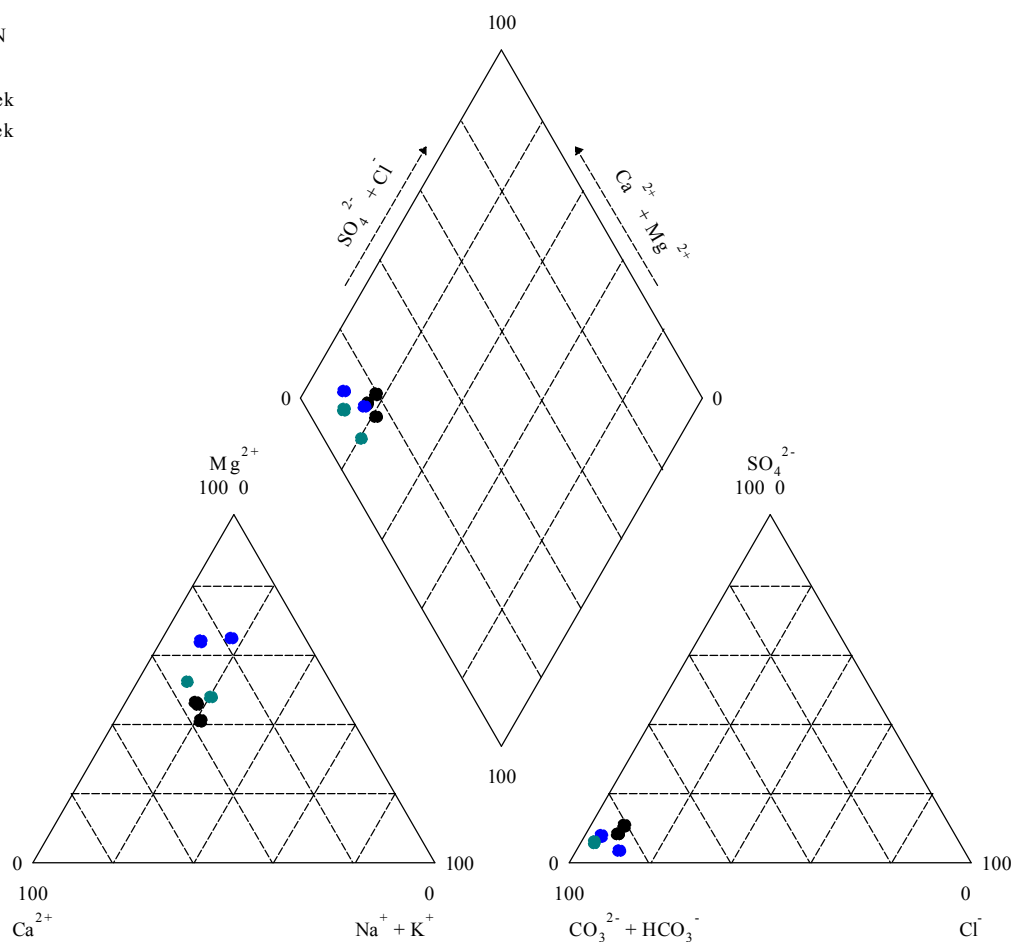




Figure 7-4
Magnesium Calcium Ratios – Kelseyville Sub-Basin

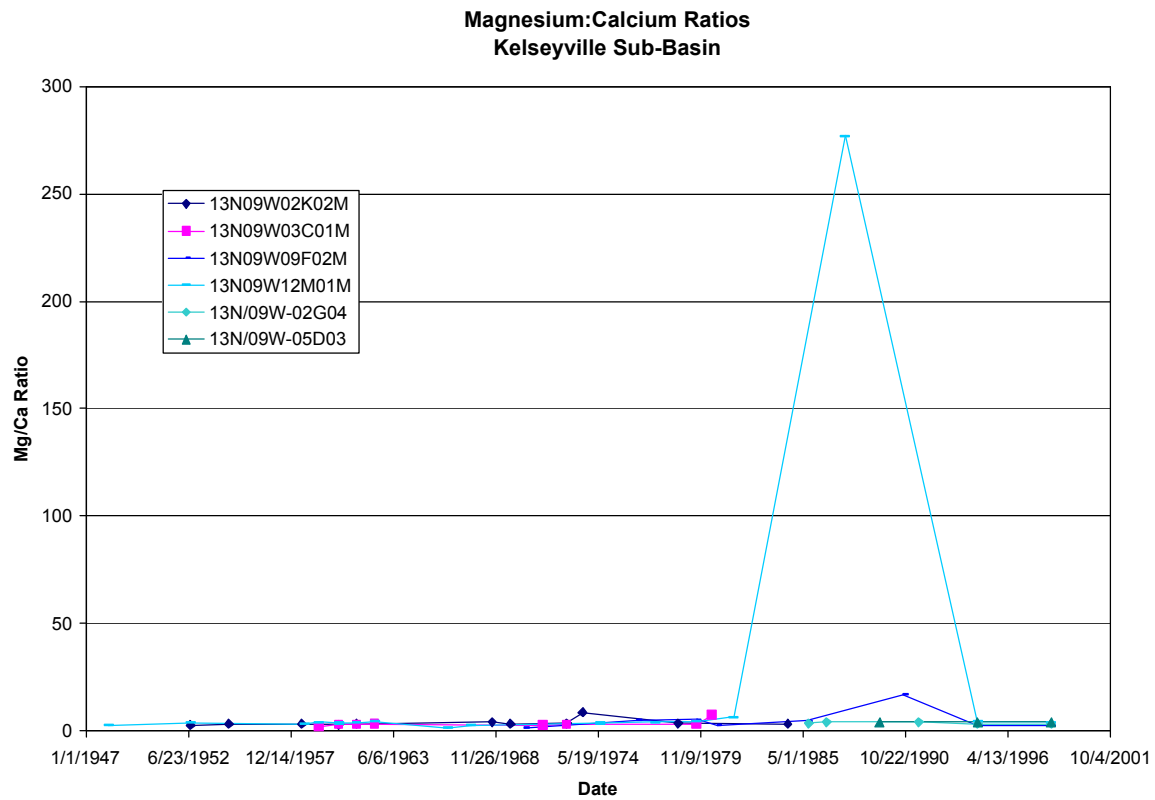




Figure 7-5
Total Nitrate (as NO₃) - Kelseyville Sub-Basin

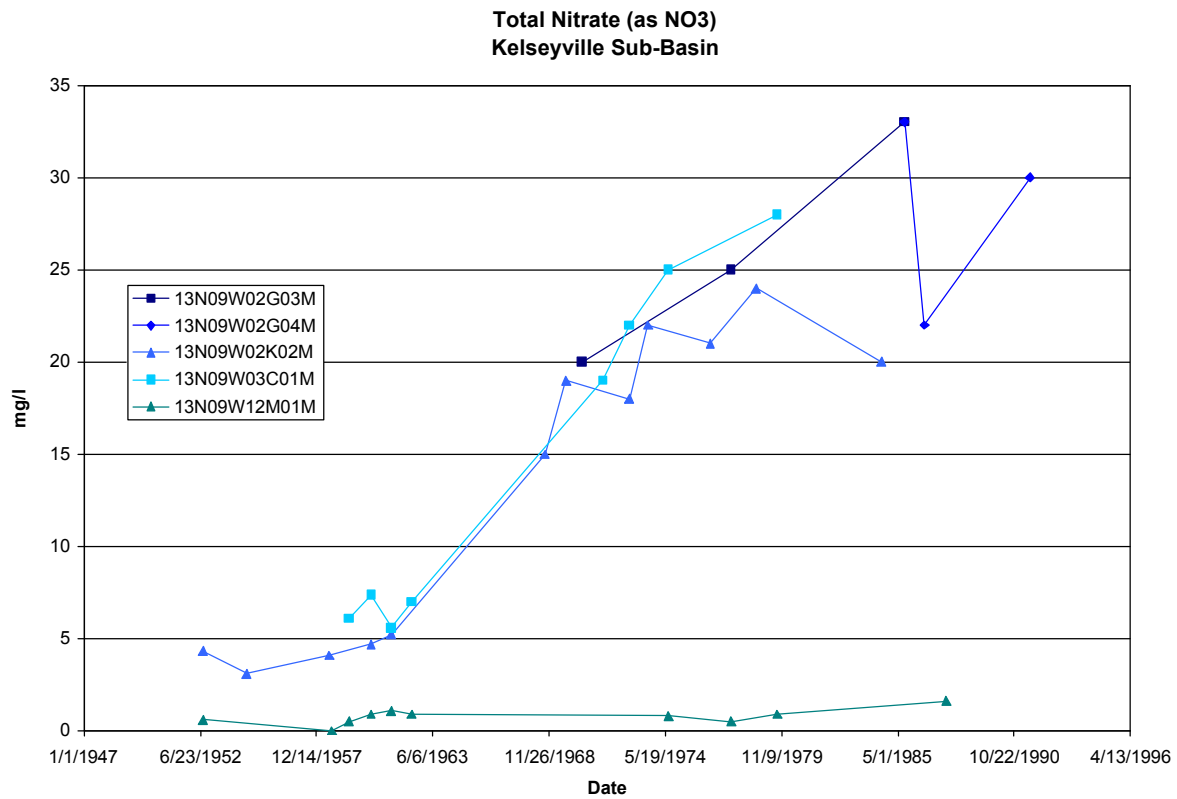




Figure 7-6
Boron Concentrations – Kelseyville Sub-Basin

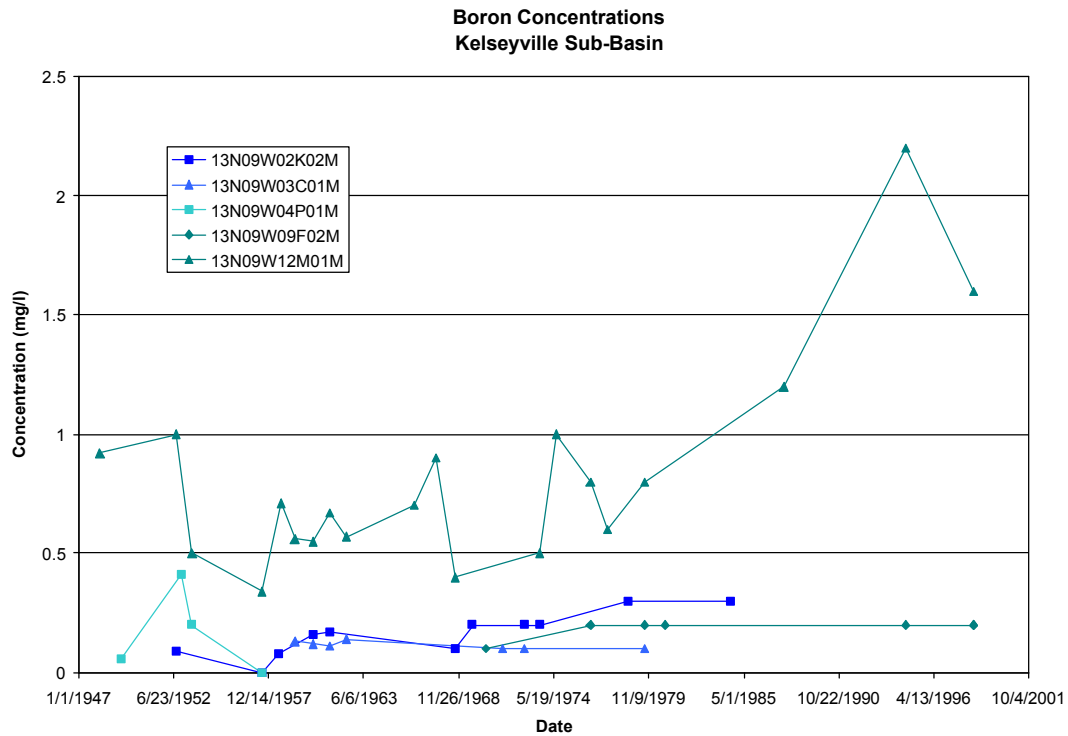




Figure 7-7
Total Dissolved Solids - Kelseyville Sub-Basin

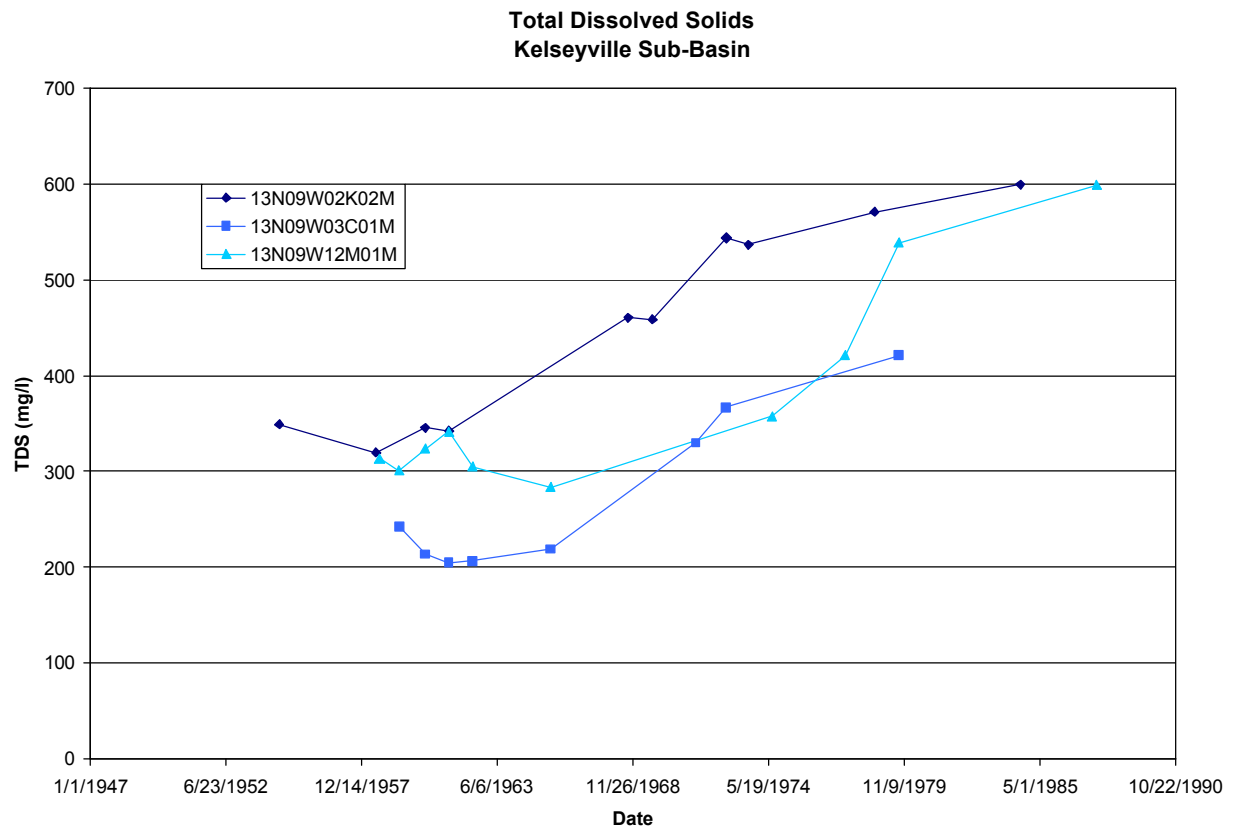




Figure 7-8
Total Nitrate - Kelseyville Sub-Basin

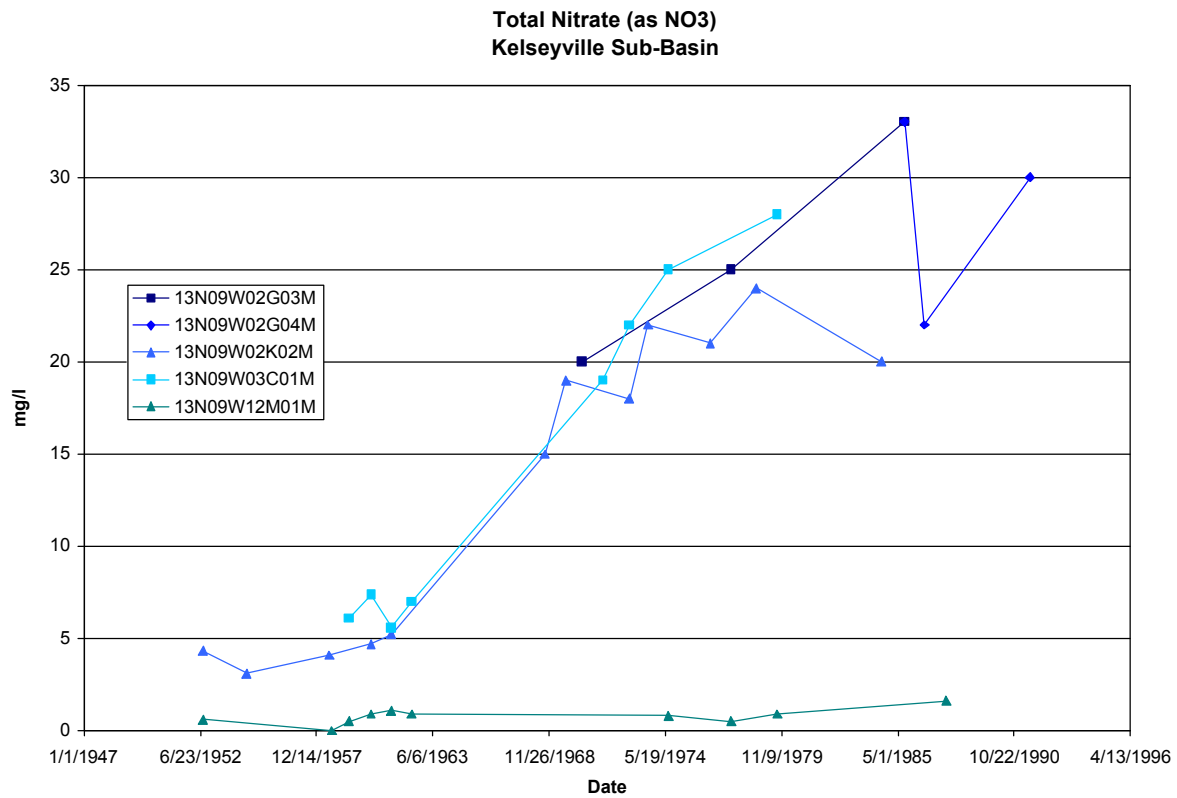




Figure 7-9
Magnesium Calcium Ratio- Adobe Creek Sub-basin

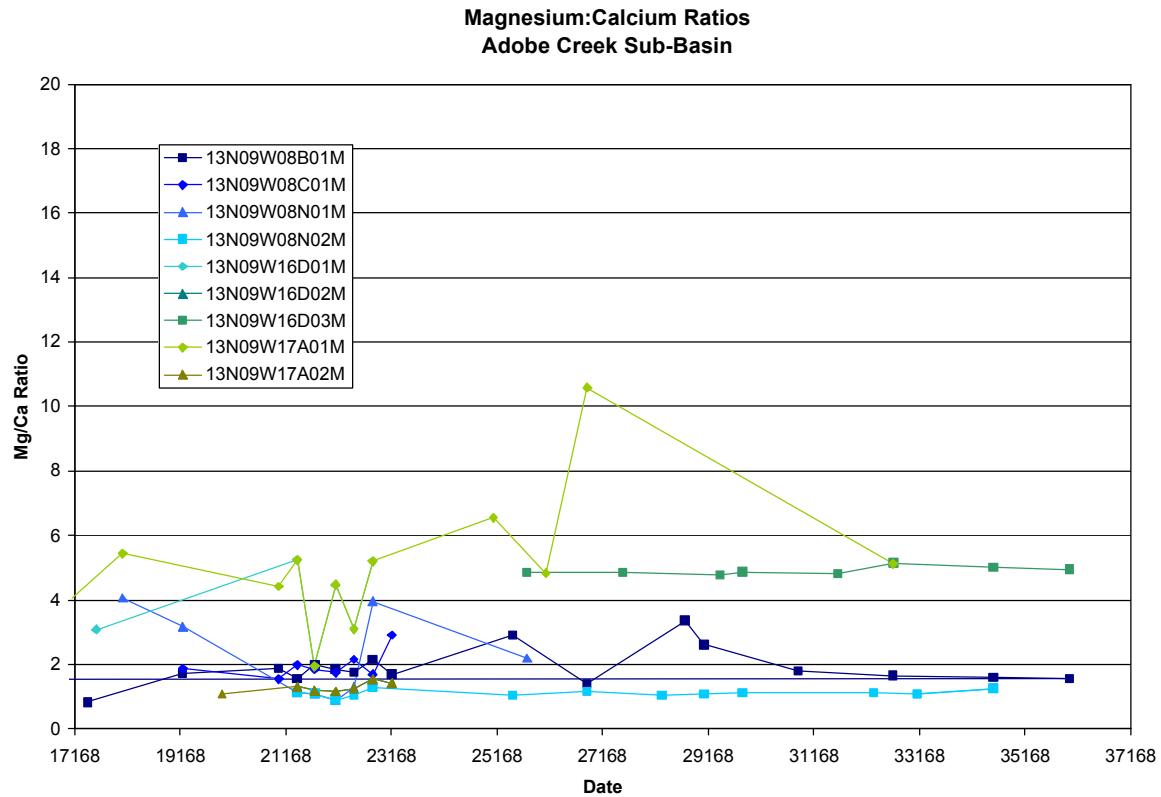




Figure 7-10
Boron Concentrations - Adobe Creek SubBasin

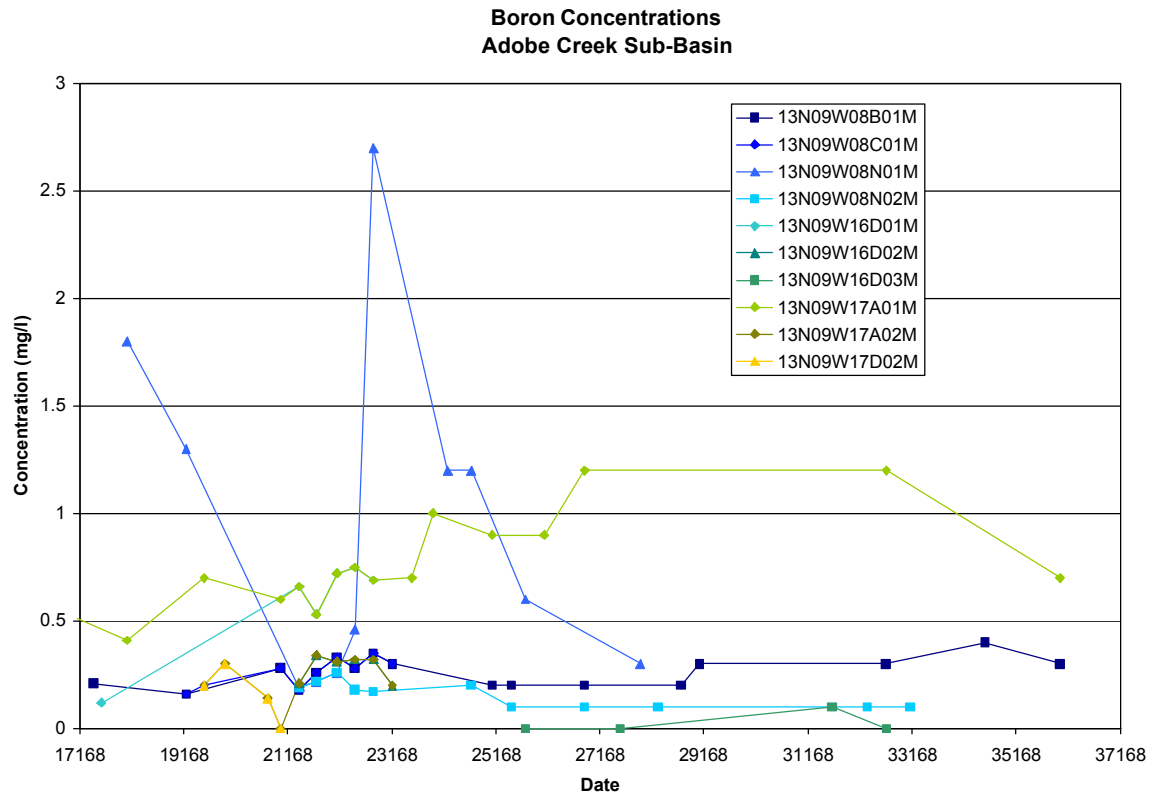




Figure 7-11
Total Dissolved Solids - Adobe Creek SubBasin

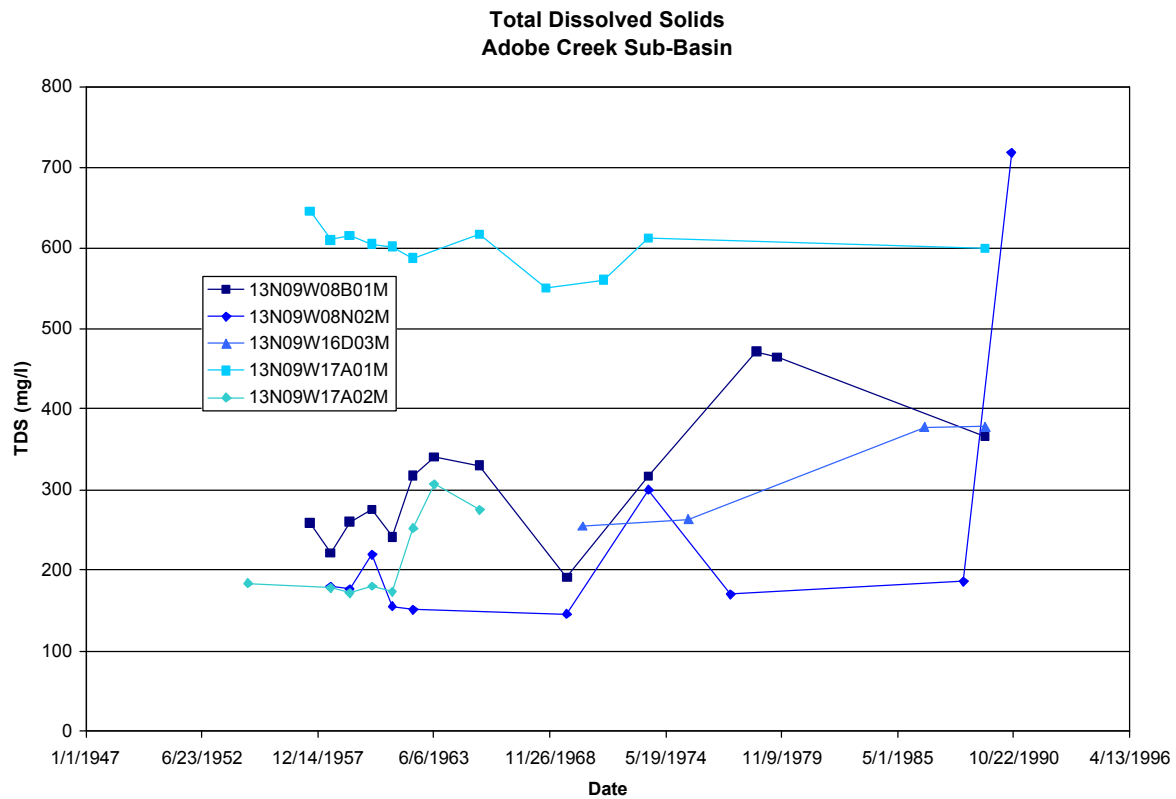




Figure 7-12
Total Nitrate (as NO₃) - Adobe Creek Sub-Basin

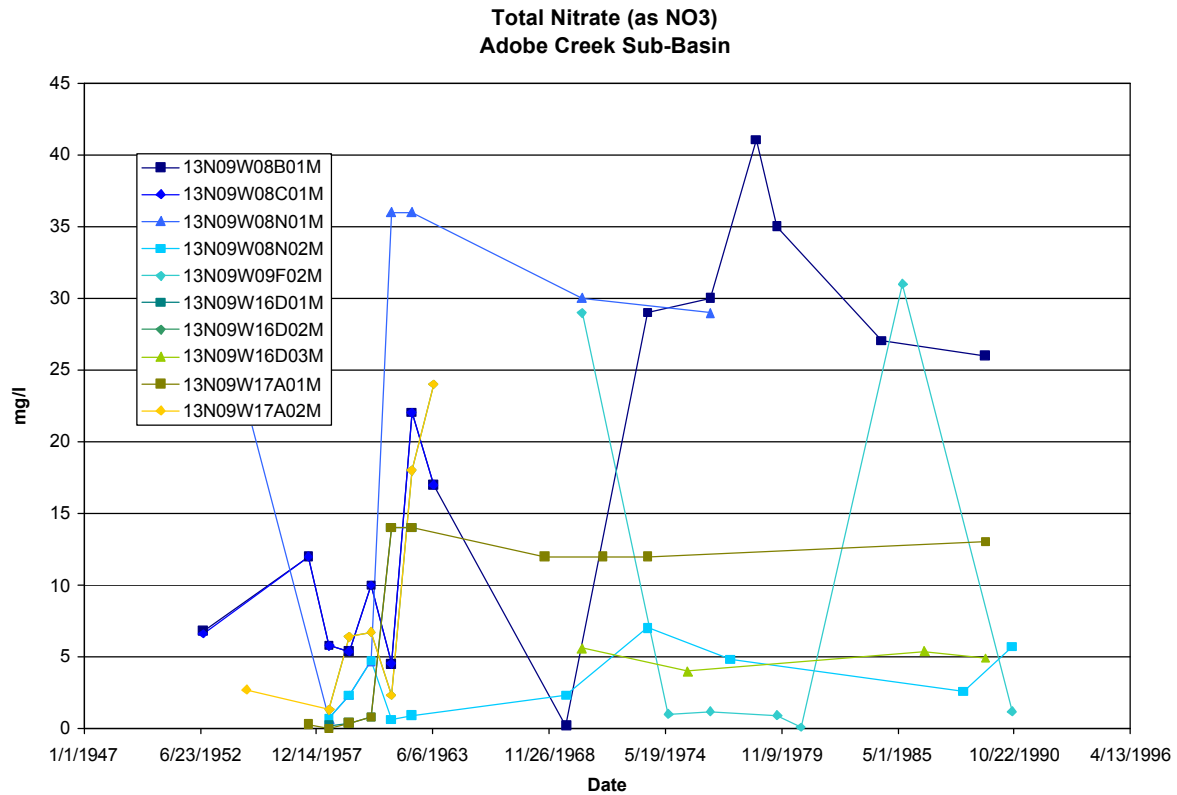




Figure 7-13
Magnesium Calcium Ratio - Central Uplands

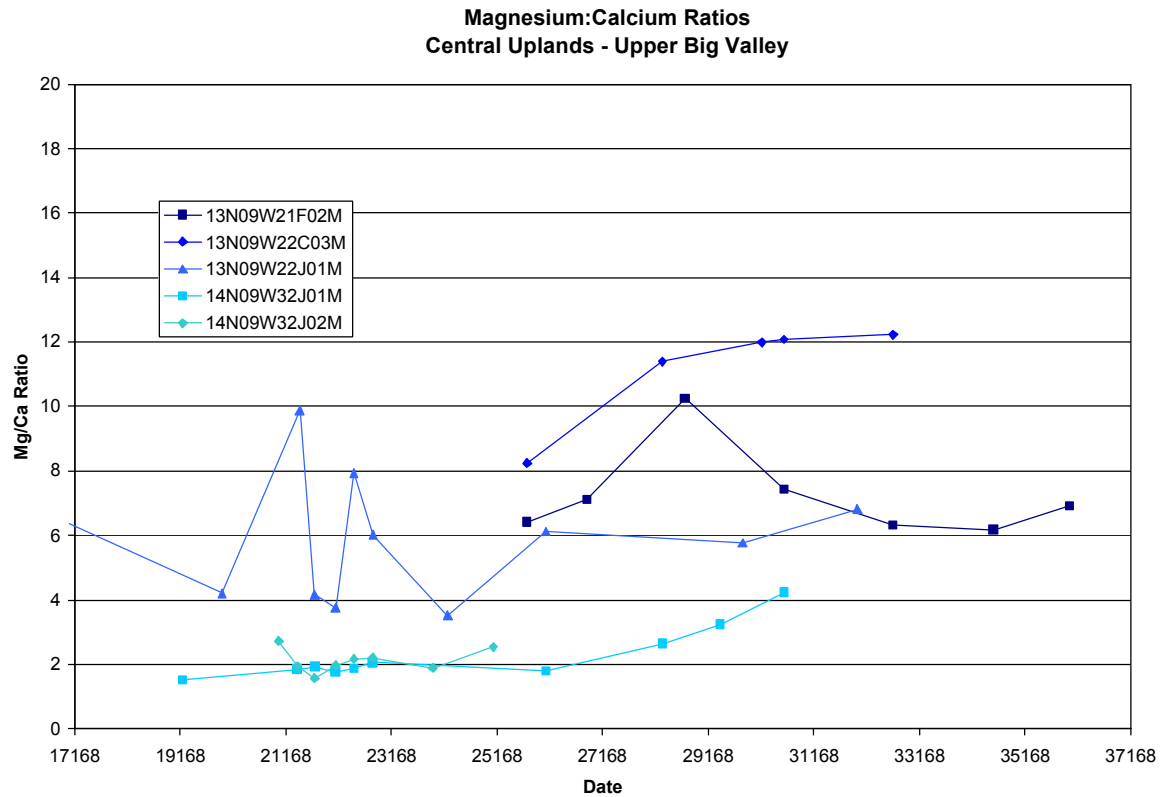




Figure 7-14
Boron Concentrations - Central Uplands

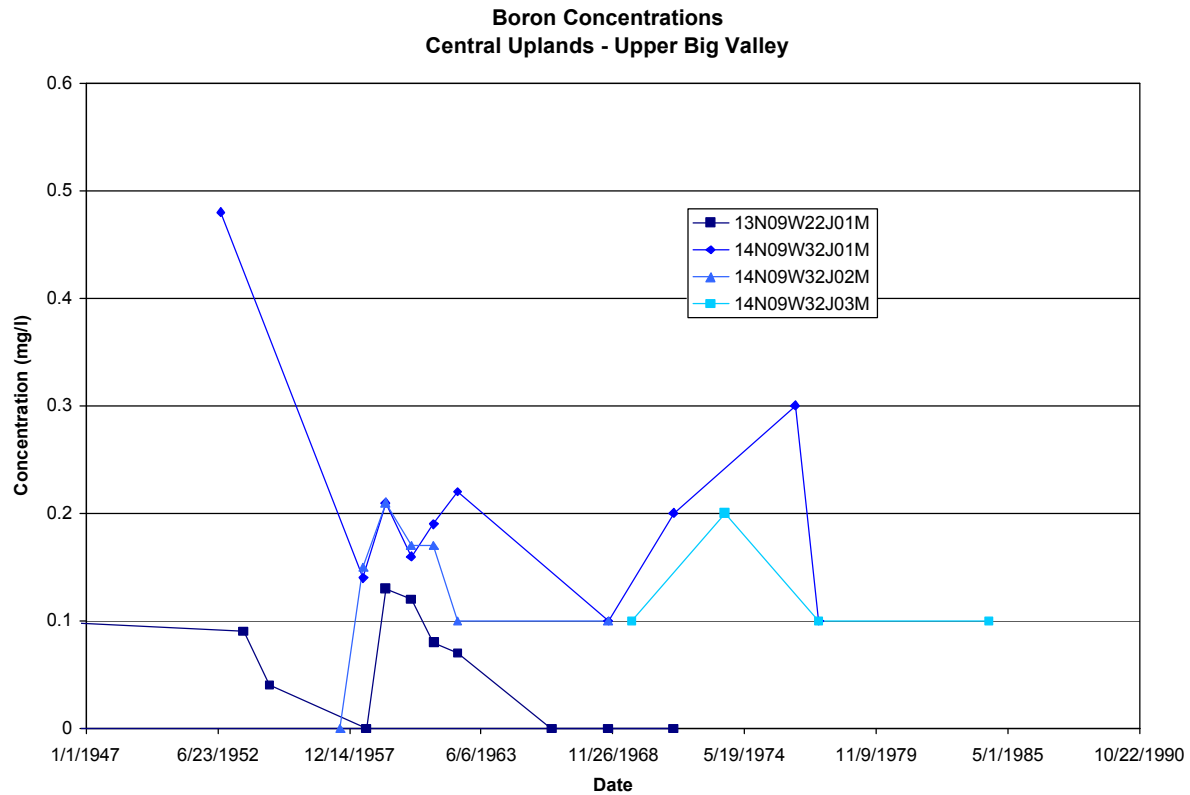




Figure 7-15
Total Dissolved Solids - Central Uplands

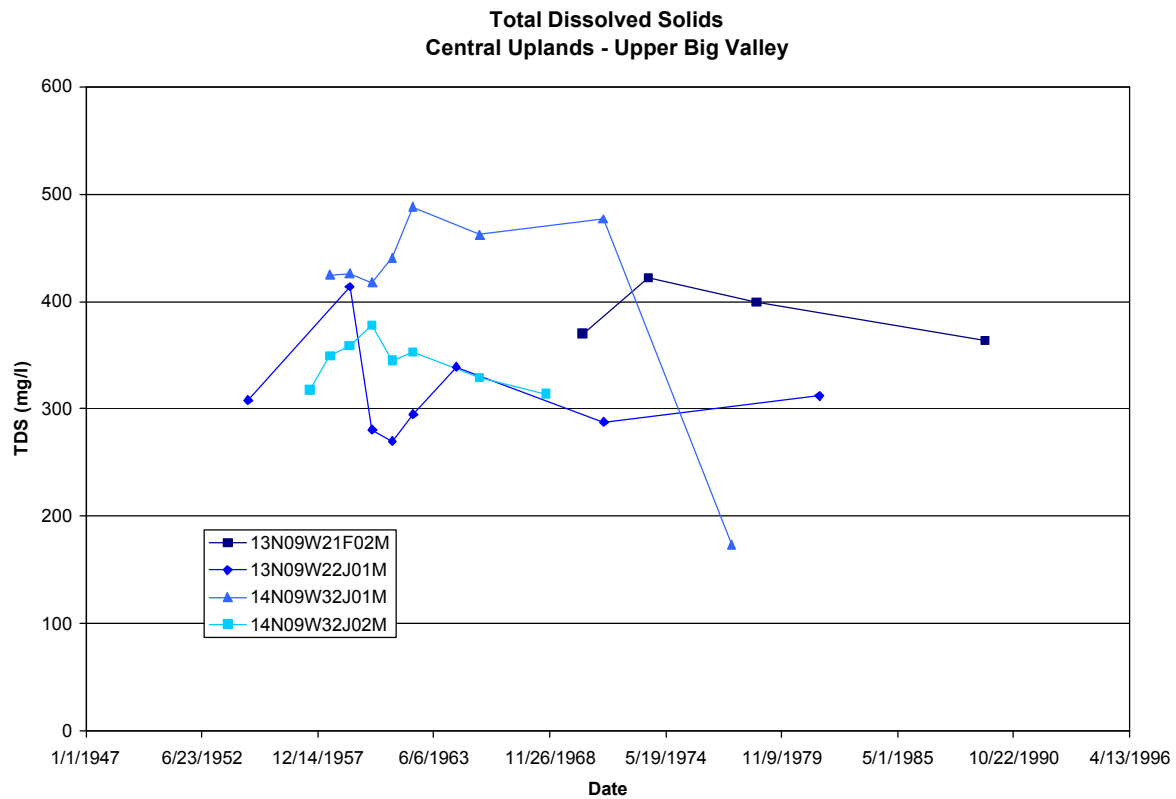




Figure 7-16
Total Nitrate (as NO₃) - Central Uplands

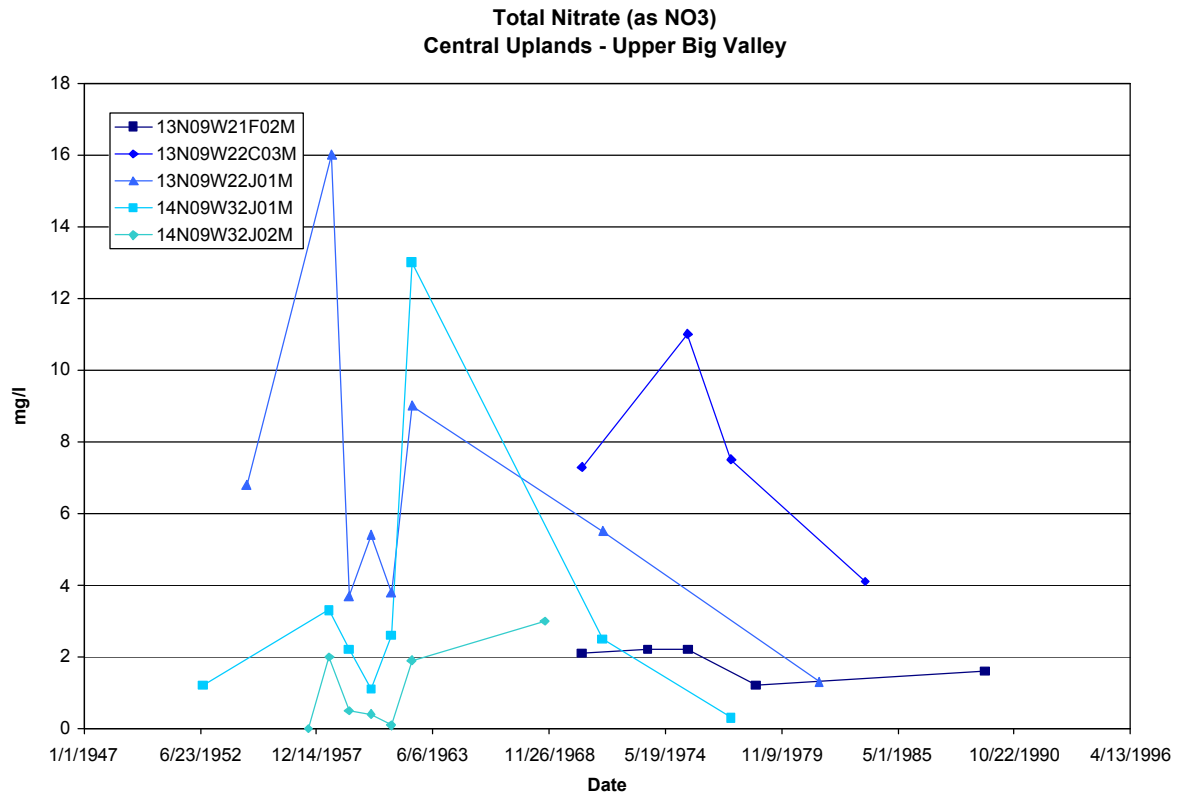




Figure 7-17
Magnesium Calcium Ratio - Western Uplands

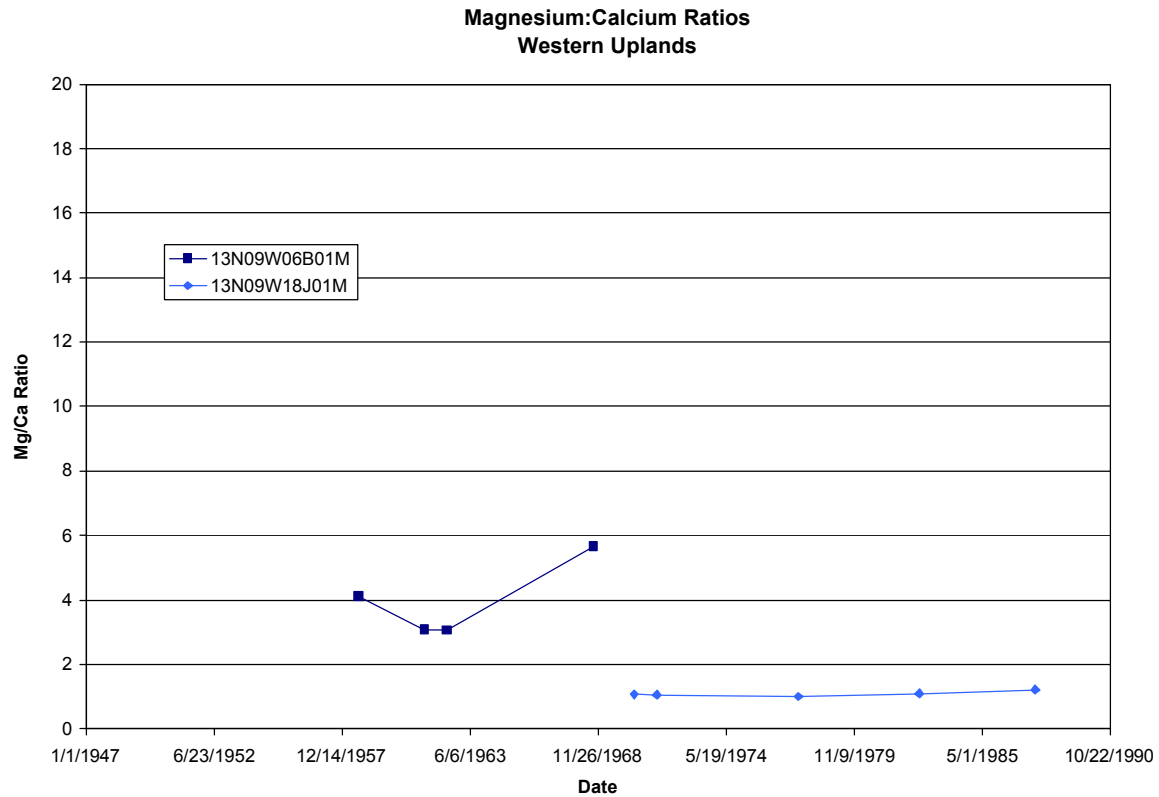




Figure 7-18
Boron Concentrations - Western Uplands

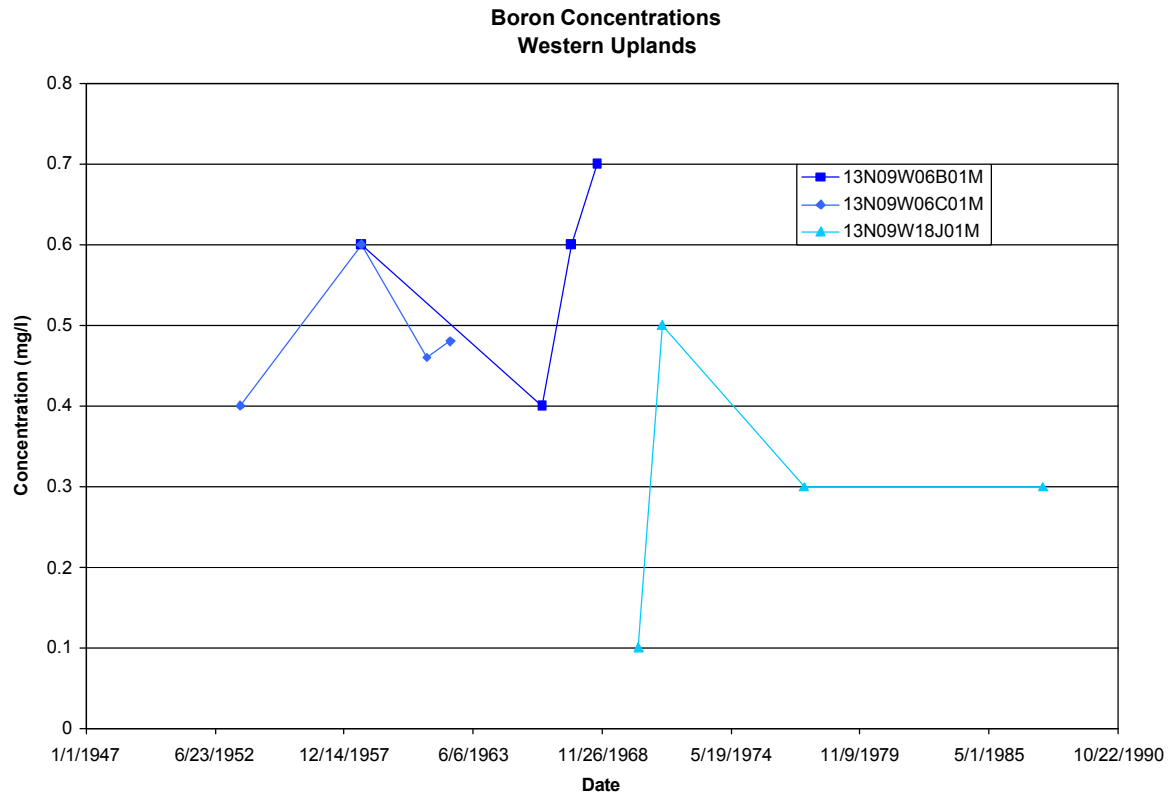




Figure 7-19
Total Dissolved Solids - Western Uplands

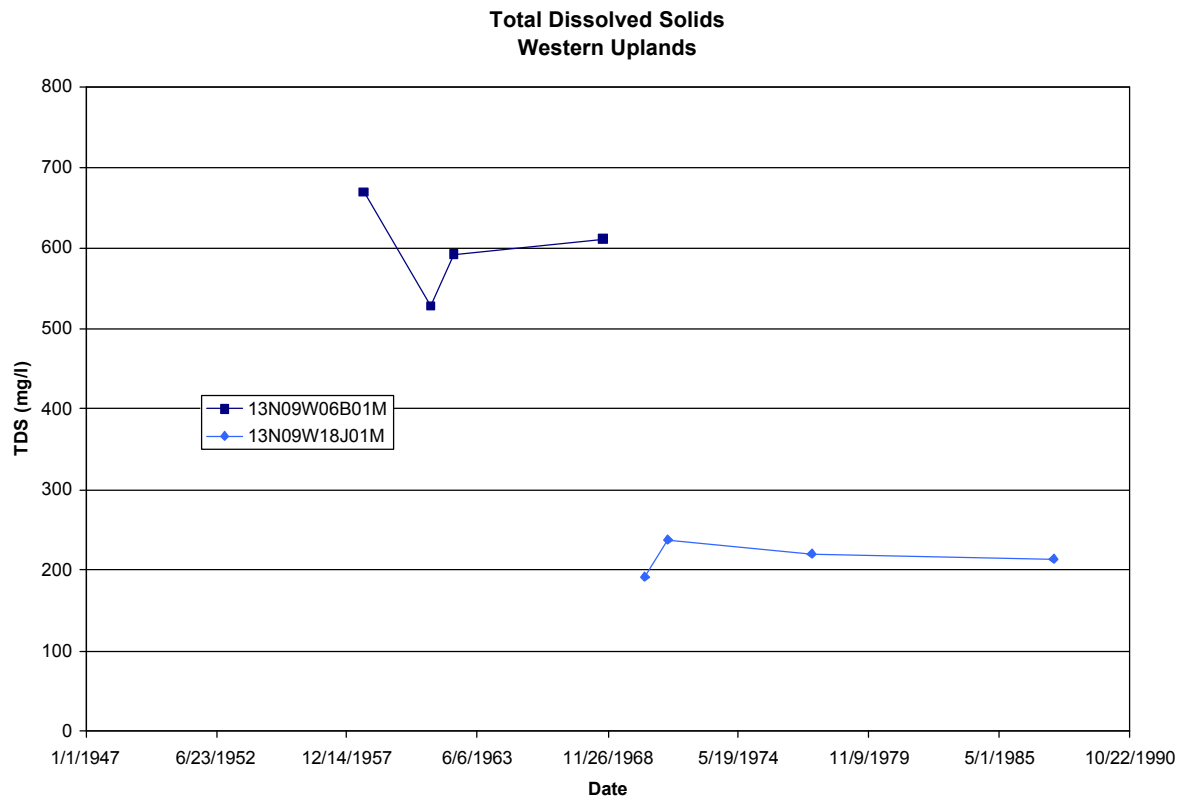




Figure 7-20
Total Nitrate (as NO₃) - Western Uplands

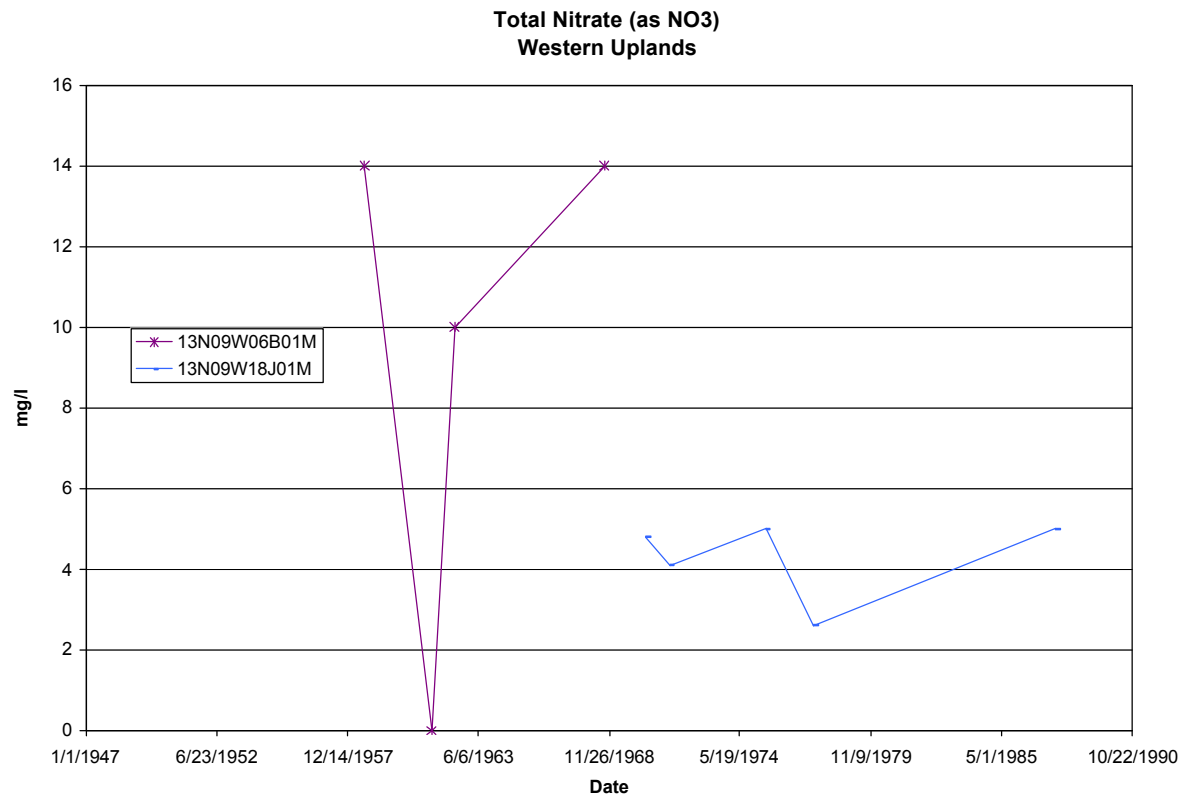




Figure 7-21
Map Showing Maximum Boron Concentrations

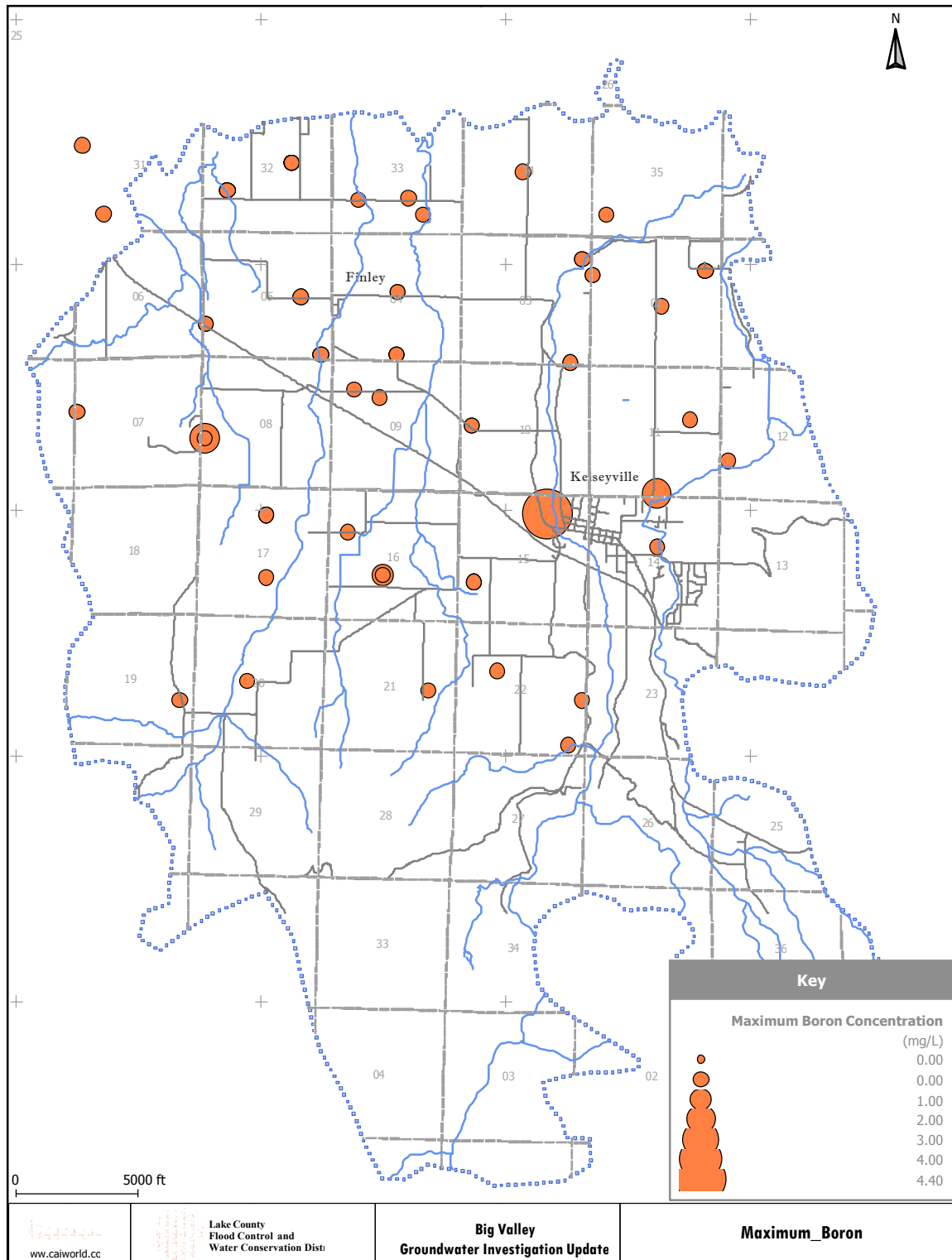




Figure 7-22
Map Showing Maximum Magnesium/Calcium Ratios

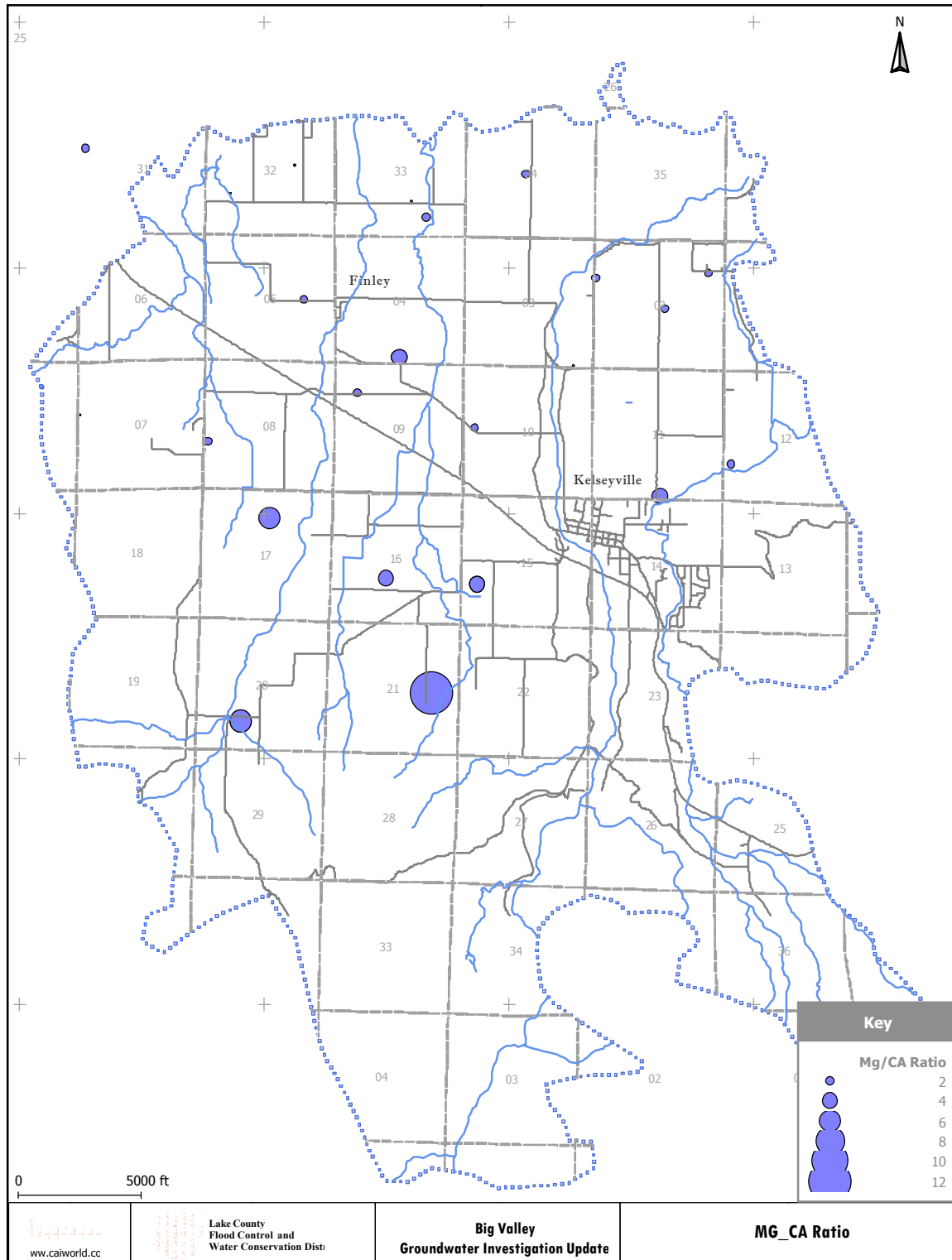
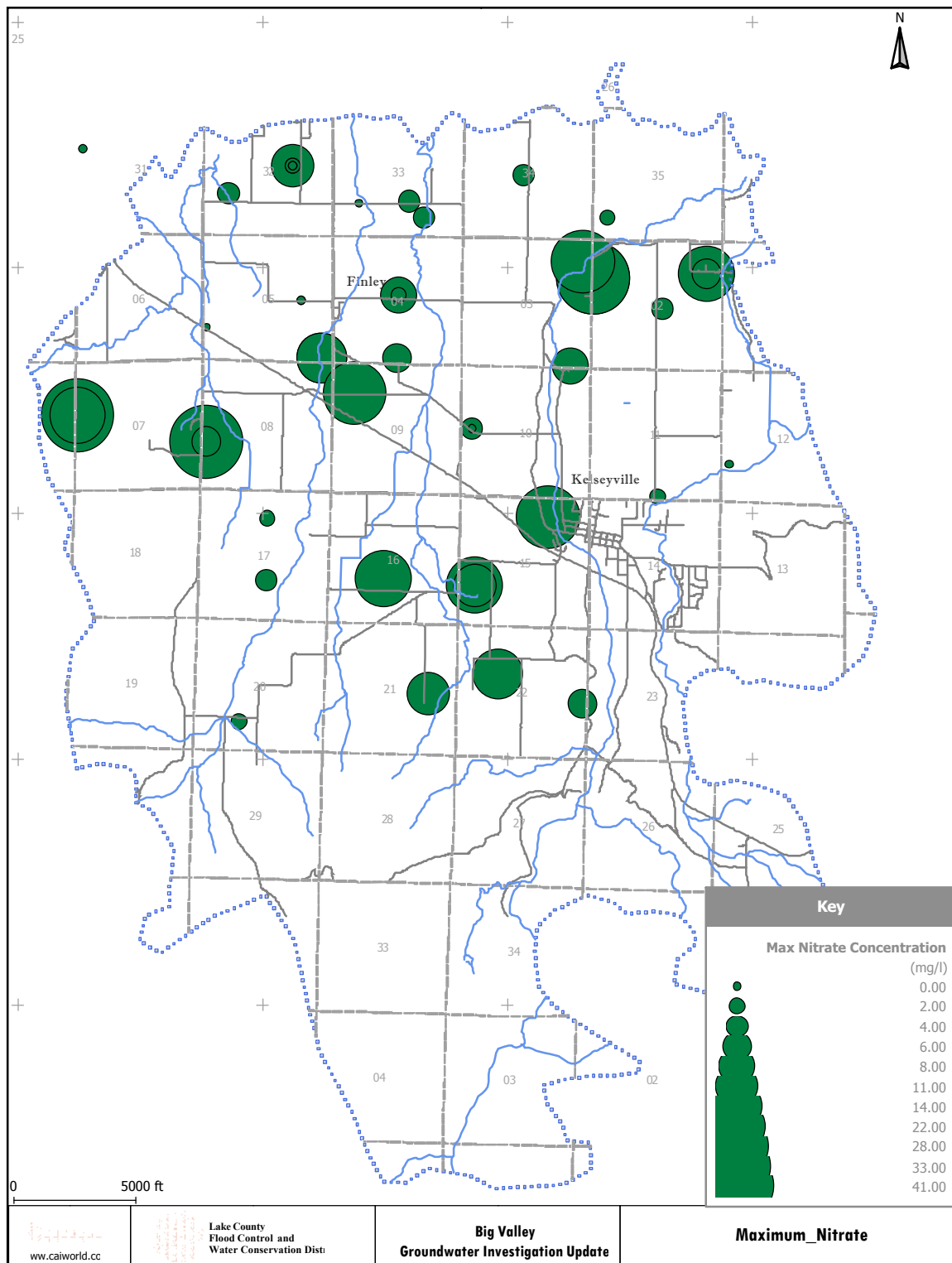




Figure 7-23
Map Showing Maximum Nitrate Concentrations





8. Volumetric Model

8.1 INTRODUCTION

The volumetric model is a quantitative mathematical model used to correlate measured groundwater levels with amounts of ground water in storage.

Because the functional bottom of the Basin is difficult to define, estimating a definitive maximum ground water storage capacity for the entire basin is not possible. The practical use of the groundwater storage model is for comparing the difference in stored groundwater between two time periods for example the spring and fall of a water year, or the beginning and end of a drought period.

8.2 AVAILABLE DATA

Two data sets were used to build the model:

1. Copies of well logs from wells drilled in Big Valley that are archived by the Department of Water Resources. These were provided by Lake County. Well logs are treated as confidential information.
2. Ground Water measurement data provided by Lake County.

8.3 METHODOLOGY

The groundwater storage model is a three dimensional mathematical model that simulates the relationship between water levels and the amount of water stored in the basin. The specific software used to build the model is Rockworks 2002 which is a system for creating cross sections, fence diagrams, solid models, stratigraphic layer models and surfaces, contour maps and terrain models.

The model computes volumes of complex solids which can be used to determine the amounts of stored water. To do this, the model relies on a reasonably accurate estimate of specific yield for the subsurface materials in the Big Valley basin. Specific yield is the amount of water that can be released from an unconfined aquifer under the force of gravity (i.e. by free drainage). Because different materials have different specific yields, it was first necessary to develop an accurate representation of the types of subsurface materials in the basin.

Two classification methods were used:

1. **Lithology** This classification separates materials into groups based on the driller's expression of material types encountered during the drilling of the well. Material types include soil, clay, sand, gravel, rock and mixtures of each of these components. A total of 20 classification types were developed.
2. **Stratigraphy** This classification involves the interpretation of different



horizons or layers within the overburden based on both the lithology observed in the well logs and interpretation of the structure of the basin. Typical classifications include soil, aquifers, aquitards, rock etc.

The main difference between the two is that Stratigraphy implies a uniform structure whereas lithology is solely based on material types. Whereas lithology can repeat itself in a borehole, the stratigraphic interpretation implies a series of layers one above the other.

The Big Valley overburden consists of lake bottom and floodplain sediments that originated as fallout from volcanic eruptions and fluvially distributed by creeks. As a result many layers are discontinuous. This creates a problem for stratigraphic models that rely on mathematical representations of continuous surfaces to model the upper and lower faces of stratigraphic layers. The result is that for a borehole where layers are missing they are expressed as zero thickness layers which maintains the continuity of the upper and lower surfaces but implies no volume of material present. On the other hand the lithologic solid model is not constrained by structure so it can better deal with discontinuous stratigraphy. Rather than select one approach over the other - both approaches were used.

The general steps involved in constructing the groundwater storage volumetric model were as follows:

1. All available boring logs in Big Valley were compiled and reviewed. Boring logs were then selected that contained complete lithologic descriptions, could be accurately located in Big Valley, and provided geographic coverage of the basin.

Out of the original 4816 boring logs provided by Lake County, a total of 1008 were determined to be in Big Valley and of those 242 logs were chosen for the geologic interpretation of the basin.

One of the main criteria for a log to be included in the study was that its location could be determined from the information provided on the well log. Many of the logs were excluded because it was impossible to determine the exact location of the boring. Many other logs were excluded because the information was difficult to interpret, incomplete or did not add any new information relative to other adjacent logs.

2. All drillers' expressions on the chosen logs were assigned to one of the Unified Soil Classification System (USCS) designations.
3. Data from the boring logs were entered into the Rockworks database which has a series of data forms for storing information regarding well log location, lithology, stratigraphy, geophysics, water levels etc.
4. A series of north-south and east-west sections of the valley was created



from the borehole data and used to interpret the stratigraphy of the basin.

5. The stratigraphy data were then added back into the database.
6. The lithology between boring logs was interpolated by the mathematical model by a process called horizontal lithoblanding. In this process the program creates a three-dimensional mathematical representation of the basin lithology by interpolating material types between boreholes. A series of voxels are created (a voxel is the three-dimensional equivalent of a 2-D pixel). The voxel size used in the Big Valley model was 100 feet north-south by 100 feet east-west by 1 foot deep.
7. The stratigraphy between boring logs is also interpolated by the model using a mathematical representation of the upper and lower surfaces of each horizon in the form of two dimensional grid. The composite stratigraphic model was then converted into a solid model with voxels similar to the lithologic model. In this case the material property of each voxel is the type of stratigraphic horizon instead of the material classification used in the lithologic model.
8. Water level data collected during spring of a year were entered into model, and the spring data were interpolated into a grid file of water surface elevations within the model. The elevations were contoured to provide a visual interpretation of the data.
9. Similarly, water level data collected during autumn of the same year were entered into the model and the fall data were gridded and contoured.
10. The solid volume between the two contoured surfaces is calculated by model and the volume is reported according to of each of the lithologic and stratigraphic classifications.
11. A specific yield is assigned to each lithologic type. Multiplying the volume of each lithologic type by the corresponding specific yield results in the difference in volume of the total amount of water in storage between the spring and fall.
12. The same process can be accomplished using the stratigraphy classifications.

This approach can be used for any two time periods. Comparing spring water levels with fall water levels provides an approximate measure of how much groundwater was lost from storage during the growing season (neglecting effects of subsurface inflow and outflow etc.) Comparing current spring water levels with a previous year's spring water levels gives an estimate of how much more or less water is available for the current growing season. Visual renderings of Lithology and Stratigraphy are shown on Figure 8-1 through Figure 8-3.



Figure 8-1
View of Volumetric Model Showing Lithology

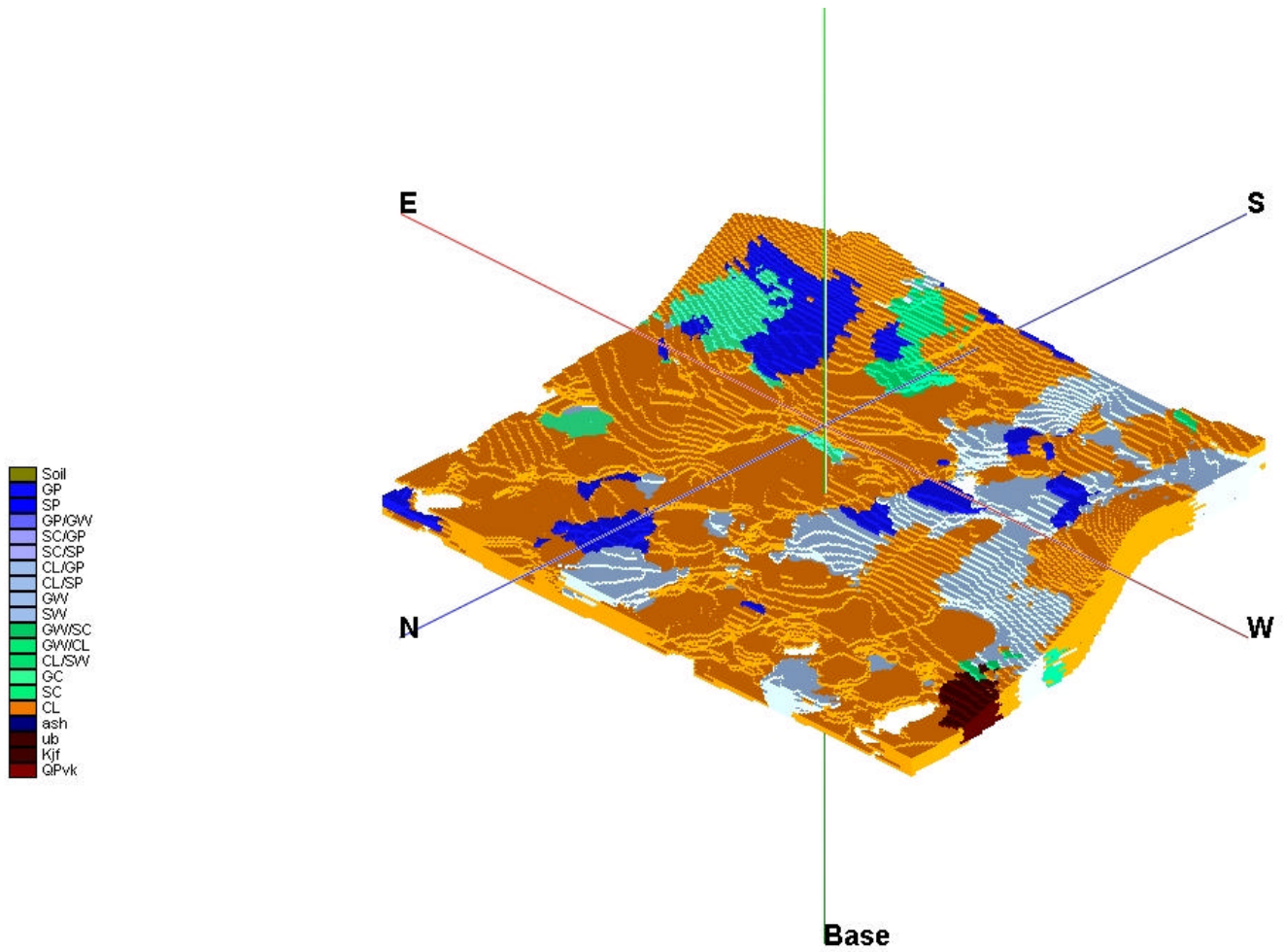




Figure 8-2
View looking Southeast Showing Stratigraphy

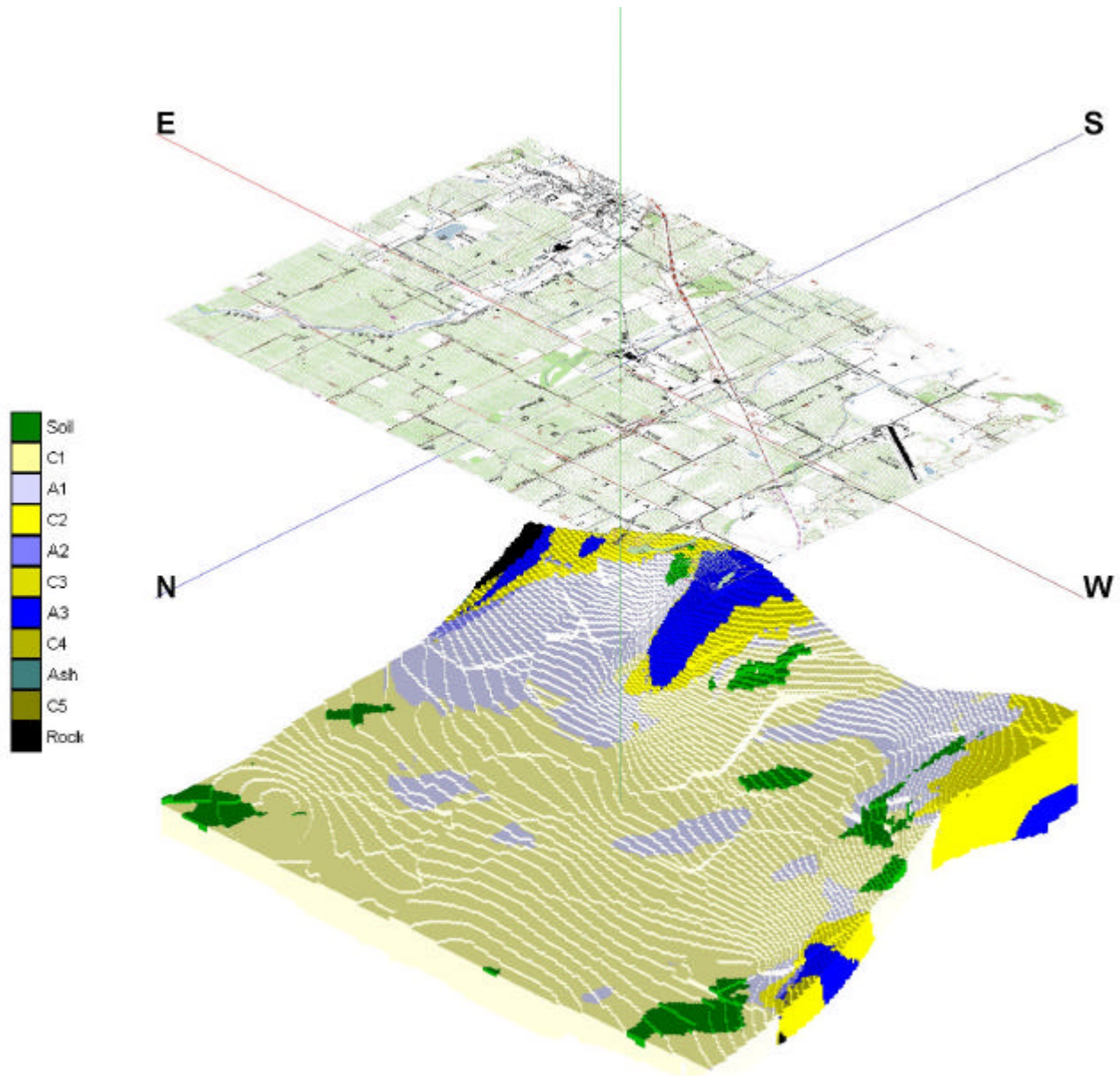
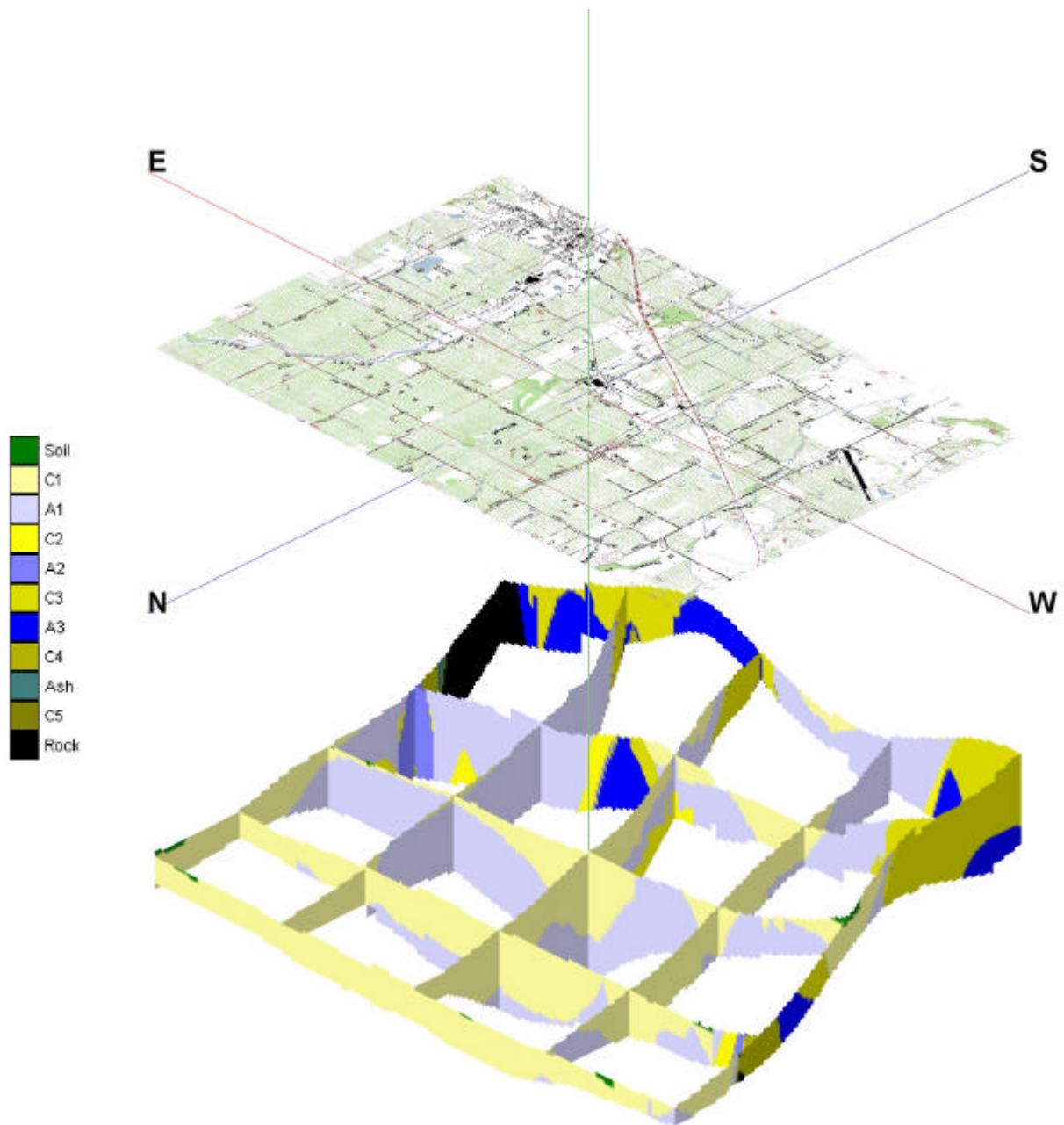




Figure 8-3
View looking South East Showing Stratigraphy Fence Diagram



8.4 INTERPRETATION OF WELL LOGS

Several assumptions were made during the review of information presented on the well drillers' reports. These assumptions include the following:

1. The indicated well location information on the well driller's report is correct. For instance, it was assumed that documented distances from the



well to nearby roads or other landmarks are correct. These distances were then used to locate the wells on the topographic base maps. If the indicated distances are incorrect or off by some amount, then the location of the well as plotted on the well location plan is likewise off or incorrect.

2. If the location information indicated distances to only a non-specific landmark (e.g., "2 miles south of Kelseyville on Big Valley Road"), the location information was judged inadequate and the well log was not used.
3. The plotting of well locations was greatly assisted by comparison of county assessor parcel numbers (shown for numerous wells on the driller's reports) with the parcel addresses plotted on the well location base map. A number of the wells plotted via this method are only located to a degree of accuracy that is defined by the limits of the parcel, i.e., the precise location of the well within the limits of the parcel is not known.
4. The material descriptions presented on the logs are accurate representations of the actual material. For example, it was assumed that, in the absence of any other descriptive information, a description stating "sand and gravel" referred to sand and gravel only, without other material such as clay. If, for instance, the driller misidentified sand as clay, then incorrect information would have been entered into the lithologic data base.

8.4.1 Lithology

In developing the lithology of the basin considerable interpretation of drillers' well logs was necessary. The wells had been drilled by several different drillers over the past 60 or so years. There is no uniform system used for classifying the material types encountered in the well and in many instances the driller is interpreting this information from a highly disturbed mixture of drill cuttings, and water or drilling mud.

Interpretations of drillers' expressions commonly used to classify materials shown on well reports are shown on Table 8-1.

Typical Classification of Material Types Based on Driller's Expressions



Table 8-1
Typical Classification of Material Types Based on Driller's Expressions

Drillers' Expression	Assumed Material Type	Selected Lithology Unit	Tentative Specific Yield (%)
Clay and imbedded gravel	Clay with intermixed gravels (encased in clay)	CL	1
Hardpan	Clay	CL	1
Clayey sand or gravel	Clayey Sand or Gravel	SC or GC	5
Soil	Unspecified near surface material	Soil	5
Muddy sand or gravel	Sand or gravel with some fines	SW or GW	10
Cemented sand or gravel	Sand or gravel with permeability decreased by some cementation or grading with finer materials	SW or GW	10
Clay and gravel or sand; alternating layers of clay and cemented gravel, etc	Sequence of interbedded layers	CL/SW, GW/SC, etc	Average of discrete units (5 - 15)
Gravel or sand (or both), with no other modifier	Clean Gravel or Sand	GP or SP	20
Volcanic sand or gravel	Ash	Ash	25

Figure 8-4 shows the lithology table used in the mathematical model including the visual legend used to display the materials.



Figure 8-4
Lithology Table Used in Model

Row#	Name	Pattern	Percent	Density	G-Value
1	Soil		100	5.000000	1.000000
2	GP		100	20.000000	2.000000
3	SP		100	20.000000	3.000000
4	GP/GW		100	15.000000	4.000000
5	SC/GP		100	12.000000	5.000000
6	SC/SP		100	12.000000	6.000000
7	CL/GP		100	10.000000	7.000000
8	CL/SP		100	10.000000	8.000000
9	GW		100	10.000000	9.000000
10	SW		100	10.000000	10.000000
11	GW/SC		100	7.000000	11.000000
12	GW/CL		100	5.000000	12.000000
13	CL/SW		100	5.000000	13.000000
14	GC		100	5.000000	14.000000
15	SC		100	5.000000	15.000000
16	CL		100	1.000000	16.000000
17	ash		100	25.000000	17.000000
18	ub		100	1.000000	18.000000
19	Kjf		100	1.000000	19.000000
20	QPvk			1.000000	20.000000
21					

8.4.2 Stratigraphy

The stratigraphic interpretation system used includes a surface soil layer, three alluvial aquifers (A-1 through A-3) and the ash aquifer. Each is separated by a clay layer (C-1 through C-5). The lowest clay layer, (C5) is defined where clay separates the ash layer from bedrock.

The upper two aquifers are mostly concentrated within the younger alluvial deposits in the Kelseyville Basin north of the Big Valley fault. The third alluvial aquifer only occurs within the Kelseyville Formation along the margins of Big Valley and south of the Big Valley fault.

The interpretation of two alluvial aquifers in the younger alluvium and one within the older alluvium seems to fit the data reasonably well; the screened intervals for the deeper wells north of the Big Valley fault help to highlight the distribution of the two aquifers in the younger alluvium.

A case for a fourth alluvial aquifer, in the Kelseyville Formation could probably be made only very locally, so the decision was made that this was not feasible given the difficulty of modeling this site.

The stratigraphy classification system used in the model is shown on Figure 8-5.



**Figure 8-5
Stratigraphy Table**

Row#	Name	Pattern	Percent	Density	G-Value
1	Soil		100	0.050000	1.000000
2	C1		100	0.010000	2.000000
3	A1		100	0.200000	3.000000
4	C2		100	0.010000	4.000000
5	A2		100	0.200000	5.000000
6	C3		100	0.010000	6.000000
7	A3		100	0.200000	7.000000
8	C4		100	0.010000	8.000000
9	Ash		100	0.250000	9.000000
10	C5		100	0.010000	10.000000
11	Rock		100	0.010000	11.000000
12					

8.5 CALIBRATION

8.5.1 Basin using DWR 1949 -1950 Water Balance

The groundwater storage model was calibrated by adjusting the specific yield of various lithologies. The model was tested for the period between December 1 1949 and March 31 1950. This period was chosen because water balance data was already available for this period.

As mentioned in Section 5, approximately 7,756,340,000 cubic feet of soil (178,060 acre-feet) of soil was recharged between December 1 1949 and March 31 1950. The Rockworks program partitioned this soil into component lithologies. The component lithologies and their respective volumes are listed in Table 8-2.



Table 8-2
Lithologies and Volumes 1949/50 Recharge Layer

USCS Code	Volume (ft ³)
Soil	856,900,000.00
GP	427,610,000.00
SP	22,240,000.00
GP/GW	0.00
SC/GP	0.00
SC/SP	0.00
CL/GP	523,020,000.00
CL/SP	810,000.00
GW	203,980,000.00
SW	160,030,000.00
GW/SC	0.00
GW/CL	3,710,000.00
CL/SW	48,130,000.00
GC	521,320,000.00
SC	106,450,000.00
CL	4,560,680,000.00
ash	1,080,000.00
ub	61,340,000.00
Kjf	2,630,000.00
QPvk	256,410,000.00
Total Soil	7,756,340,000.00

Initial estimates of specific yield were derived from the California Department of Water Resources classification system. Table 8-3 lists the initial specific yield values, along with the calculated volumes of water for each lithology.



Table 8-3
Volume and Specific Yield (1949/50 Recharge)

USCS Code	Volume (ft ³)	Specific Yield	Water (ft ³)
Soil	856,900,000.00	5.00%	42,845,000.00
GP	427,610,000.00	20.00%	85,522,000.00
SP	22,240,000.00	20.00%	4,448,000.00
GP/GW	0.00	15.00%	0.00
SC/GP	0.00	12.00%	0.00
SC/SP	0.00	12.00%	0.00
CL/GP	523,020,000.00	10.00%	52,302,000.00
CL/SP	810,000.00	10.00%	81,000.00
GW	203,980,000.00	10.00%	20,398,000.00
SW	160,030,000.00	10.00%	16,003,000.00
GW/SC	0.00	7.00%	0.00
GW/CL	3,710,000.00	5.00%	185,500.00
CL/SW	48,130,000.00	5.00%	2,406,500.00
GC	521,320,000.00	5.00%	26,066,000.00
SC	106,450,000.00	5.00%	5,322,500.00
CL	4,560,680,000.00	1.00%	45,606,800.00
ash	1,080,000.00	25.00%	270,000.00
ub	61,340,000.00	1.00%	613,400.00
Kjf	2,630,000.00	1.00%	26,300.00
QPvk	256,410,000.00	1.00%	2,564,100.00
Total Soil	7,756,340,000.00	Total Water	304,660,100.00

Dividing the total amount of stored water by the total amount of soil yields an effective specific yield of 3.9%. This is a very low specific yield. It is roughly half the specific yield originally estimated by the California DWR.

The total amount of water shown on Table 8-3 is equivalent to approximately 7,000 acre-feet of water. Using the California DWR estimate of 7% specific yield, we would expect a change in storage of approximately 12,460 acre-feet. Furthermore, as discussed in Section 5, our water balance suggests a change in storage of approximately 17,500 acre-feet, or a 10% specific yield.

Example specific yields were gathered from other sources to establish a possible range of values that may help calibrate the groundwater storage model. Two Water Supply Papers from the USGS (Johnston, 1967; Morris and Johnson, 1967) were used to develop a possible range of specific yield values. Results from these two publications are summarized in Table 8-4. The minimum measured specific yield, maximum measured specific yield, and average specific yield are reported for each publication. Average specific yields were rounded to the nearest whole number.



Table 8-4
Typical Specific Yield Values

	Johnson, 1967			Morris and Johnson, 1967		
	Min. SY	Max. SY	Avg. SY	Min. SY	Max. SY	Avg. SY
Clay	1	5	2	1.1	17.6	6
Silt	3	19	8	1.1	38.6	20
Sandy Clay	3	12	7	---	---	---
Fine Sand	10	32	21	1.0	45.9	33
Medium Sand	15	32	26	16.2	46.2	32
Coarse Sand	20	35	27	18.4	42.9	30
Gravelly Sand	20	35	25	---	---	---
Fine Gravel	17	35	25	12.6	39.9	28
Medium Gravel	13	26	23	16.9	43.5	24
Coarse Gravel	12	26	22	13.2	25.2	21
Siltstone	---	---	---	0.9	32.7	12
Fine Sandstone	---	---	---	2.1	39.6	21
Medium Sandstone	---	---	---	11.9	41.1	27
Loess	---	---	---	14.1	22.0	18
Eolian Sand	---	---	---	32.3	46.7	38
Tuff	---	---	---	2.0	47.0	21

Based on the specific yield estimates from the USGS papers, tentative specific yield values were assigned to the lithologies that showed non-zero volumes in Table BBB. These tentative specific yields are shown on Table 8-5.

Table 8-5
Tentative Specific Yields

	Johnson, 1967	Morris and Johnson, 1967
Soil	14.0%	19.0%
GP	25.0%	28.0%
SP	27.0%	30.0%
CL/GP	14.0%	17.0%
CL/SP	15.0%	18.0%
GW	23.0%	15.0%
SW	26.0%	32.0%
GW/CL	13.0%	15.0%
CL/SW	14.0%	19.0%
GC	14.0%	17.0%
SC	7.0%	7.0%
CL	2.0%	6.0%

Note that the soil lithology was assigned a specific yield based on the specific yield of the CL/SW lithology. Furthermore, the ash and igneous rock specific yields were not modified during this exercise.

Assigning the specific yield values from Johnson (1967) to the various lithologies



results in an effective specific yield of 7.4%. This is quite close to the specific yield of the upper 20 feet of soil as estimated by DWR (1957). Assigning the specific yield values from Morris and Johnson (1967) results in an effective specific yield of 10.9%. This is quite close to the specific yield as estimated by our water balance calculations. These results suggest that the DWR specific yield values are likely too low for the current groundwater storage model. The Morris and Johnson values likely give the closest approximation of groundwater storage gains and losses.

Because of the sensitivity of the groundwater storage model to particular specific yield values, these values should be verified by field tests. As described in Section 8, long term aquifer tests to determine the specific yield of the basin would greatly enhance the value of the groundwater storage model. Of particular interest would be the specific yield of the areas assigned CL and Soil lithologies. These two lithologies constitute almost 70% of the recharged soils during the December 1 1949 to March 31 1950 period.

8.5.2 Calibration Test of Model using Water Balance derived from Land Use Data

Another test of the model was carried out using a small area in the unconfined aquifer zone to develop a correlation between water levels and water storage.

For this test, an area of a little less than a square mile i.e. 5000 ft by 5000 ft was used. The area is located in Township 13N Range 09E Section 16 between Adobe and Kelsey Creeks as shown in red on Figure 8-6.

In this test the volume of the storage zone defined by the decline in water levels over the growing season in 1994 was compared to the estimated net groundwater extraction during the growing season.

The year of 1994 was selected as it was close to the period in which DWR land use data was compiled in 1995 and it was an example of a dry but not drought year (precipitation recorded at Lakeport was 69% of the long term average).



Figure 8-6
Location of Test Area

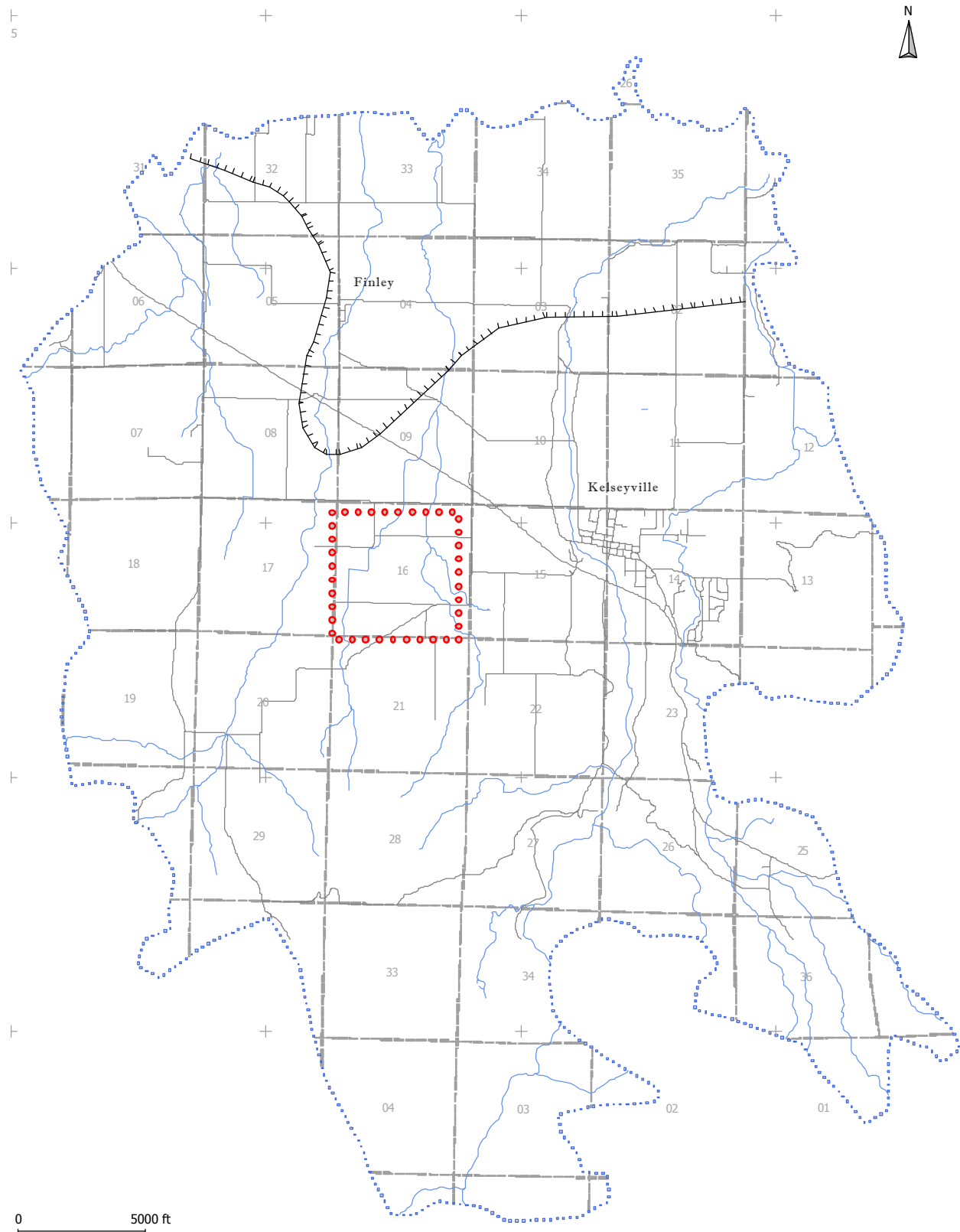




Figure 8-7 Spring water levels are shown on Figure 8-7 and Fall water levels are shown on Figure 8-8. Drawdown during the summer growing season is shown on Figure 8-9. In the area of interest, drawdown ranges from about 10 feet in the South east corner of the area to about 18 feet in the northwest corner.

Land use in the test area based on DWR 1995 data is shown on Table 8-6. The data show that the primary land use is pear and walnut orchards.

Table 8-6
Land Use in Test Area

Irrigated	Area (acres)
iA_Field Crops	8.2
iA_Pasture	9.8
iA_Pears,Apples,Prunes	200.5
iA_Vineyards	39.8
iA_Walnuts	128.4
Non-irrigated	
nA_Walnuts	60.4
nN_Native	21.8
nN_Riparian	9.3
nUrban	95.8
Grand Total	573.9

The estimated water use during the summer of 1994 is shown on Table 8-7. It should be noted that estimated ground water use is based on net water for irrigation use only including an allowance for the urban area. Overall, the estimated net use is estimated to be equivalent to 1.8 ft of water.



Table 8-7
Estimated Ground Water Use in Test Area

Land Use	Area (acres)	Estimated Net Ground Water Use (ac-ft/acre)	Estimated Net Ground Water Use (ac-ft)
Irrigated			
iA_Field Crops	8.2	1.8	14.8
iA_Pasture	9.8	3.3	31.9
iA_Pears,Apples,Prunes	200.5	2.6	516.4
iA_Vineyards	39.8	1.2	46.0
iA_Walnuts	128.4	2.6	330.6
			0.0
Non-irrigated			
nA_Walnuts	60.4		0.0
nN_Native	21.8		0.0
nN_Riparian	9.3		0.0
nUrban	95.8	1.0	95.8
Grand Total	573.9		1035.5

The volumetric analysis of the drawdown zone is shown on Table 8-8 which gives a breakdown of the material types in the drawdown zone based on their lithologic classification. The table shows that the predominant material is Clay.



**Table 8-8
Lithologic Volume Report**

Lithology	Volume (cu. Ft)	Volume (ac-ft)	Percent
Soil	7,930,000	182	3%
GP	20,610,000	473	7%
SP	7,930,000	182	3%
GP/GW	0	0	0%
SC/GP	0	0	0%
SC/SP	0	0	0%
CL/GP	1,760,000	40	1%
CL/SP	0	0	0%
GW	21,170,000	486	7%
SW	1,430,000	33	0%
GW/SC	0	0	0%
GW/CL	0	0	0%
CL/SW	0	0	0%
GC	1,730,000	40	1%
SC	15,200,000	349	5%
CL	238,560,000	5,477	75%
ash	0	0	0%
QPvk	0	0	0%
Kjf	0	0	0%
ub	0	0	0%
Total	316,320,000	7,262	100%

The volumetric analysis of the drawdown zone according to Stratigraphy classifications is shown on Table 8-9. This table shows a fairly even distribution between the C1, A1, C3 and A3 layers. The A layers represent Aquifers and the C layers represent aquitards.

**Table 8-9
Stratigraphic Volume Report**

Stratigraphy	Volume (cu. Ft)	Volume (ac-ft)	Percent
Soil	0	0	0%
C1	57,820,000	1327	18%
A1	90,460,000	2077	29%
C2	4,100,000	94	1%
A2	2,320,000	53	1%
C3	77,260,000	1774	24%
A3	82,190,000	1887	26%
C4	2,170,000	50	1%
Ash	0	0	0%
C5	0	0	0%
Rock	0	0	0%
Total	316,320,000	7262	100%

Comparing the estimated volumes of material in the drawdown zone (7262 acre



ft) and the estimated net ground water extracted (1035 acre ft) provides an overall net specific yield of about 14 %.

The specific yields can be adjusted to bring the volumes into closer agreement. Table 8-10 shows a simple adjustment where the three aquifers A1, A2, and A3 are given specific yields of 25% and the aquitards C1, C2, C3 are given specific yields of 5%. This brings the estimated total water storage utilization to within 90% of the estimated water use.

Table 8-10
Volumes with Trial Adjustment of Specific Yields

Stratigraphy	Volume (cu. Ft)	Volume (ac-ft)	Percent	Trial Specific Yield (%)	Ground Water Volume (ac-ft)
Soil	0	0	0%	15%	0
C1	57,820,000	1,327	18%	5%	66
A1	90,460,000	2,077	29%	25%	519
C2	4,100,000	94	1%	5%	5
A2	2,320,000	53	1%	25%	13
C3	77,260,000	1,774	24%	5%	89
A3	82,190,000	1,887	26%	25%	472
C4	2,170,000	50	1%	5%	2
Ash	0	0	0%	25%	0
C5	0	0	0%	5%	0
Rock	0	0	0%	0%	0
Total	316,320,000	7,262	100%		1,166

8.6 LIMITATIONS OF THE VOLUMETRIC MODEL

The volumetric model can be used to visualize the geology and ground water regime of Big Valley in two and three dimensional space and to perform volumetric calculations on soil deposits and aquifers. The model is a simple volumetric model and is not a more rigorous groundwater flow model.

The model is suitable for use in the unconfined aquifer zones which are important for recharge. The model is not designed to be used in the confined ground water zone or in the Volcanic Ash aquifer. In these zones, changes in water levels in observation wells reflect changes in piezometric head in the well rather than changes in regional water level.

The accuracy of the volumetric model is limited by the accuracy of the information upon which it is based. Development of the data used in the model is based on the relationship between changes in storage, inflow and outflow.

In our case we know the change in water levels at the observation wells with reasonable precision. However what these data are telling us depends on the



groundwater regime and the characteristics of the specific observation well. How deep is it? Which aquifer is it connected to? Does the water level reflect the unconfined water level or the water pressure in a confined zone?

We do not know the inflows and outflows to the basin with any precision. Ground water use is not measured. There are only two active stream gages in the basin and they are both on Kelsey Creek, however, streamgages on small streams are often imprecise due to difficulties in accurately correlating water elevations to discharge. The amount of subsurface inflow from the surrounding mountains and buried springs is also not known and difficult to estimate with reasonable certainty. The amount of underflow to Clear Lake can also only be estimated.

Our knowledge of the subsurface information is based on imprecise information collected from drillers' well logs. What is a blue clay or brown clay to one driller may be a sandy clay or clay with sand and gravel to another. The specific yield of material depends on its gradation which is also difficult to determine from highly disturbed drill cuttings and drilling fluids.

Nevertheless, with these caveats the model can be used to better quantify the amounts of water in the unconfined zones that are important for recharge. Further calibration of the model is desirable to improve its accuracy and usefulness.



Figure 8-6
Location of Test Area

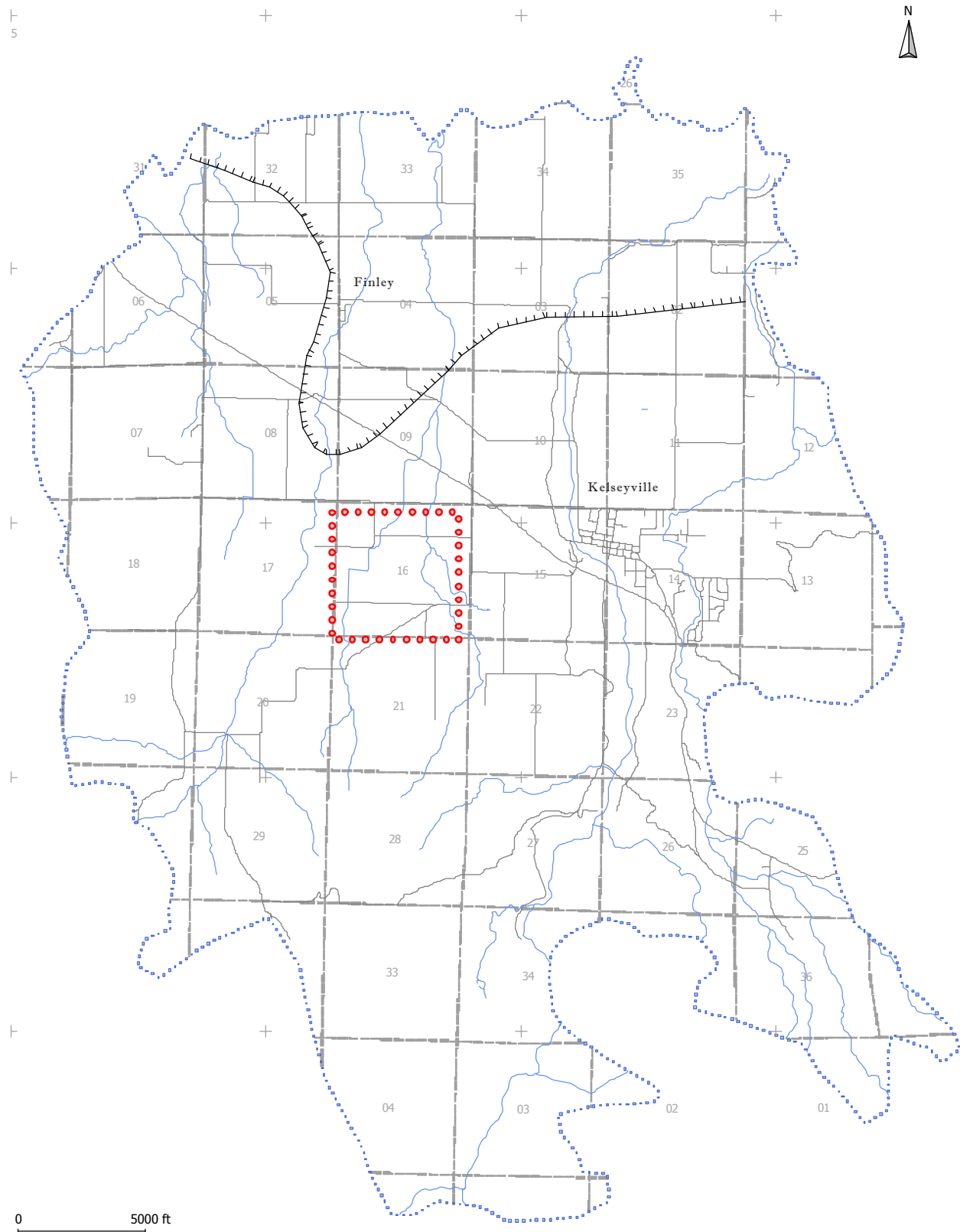




Figure 8-7
Water Levels in Big Valley Basin
Spring 1994

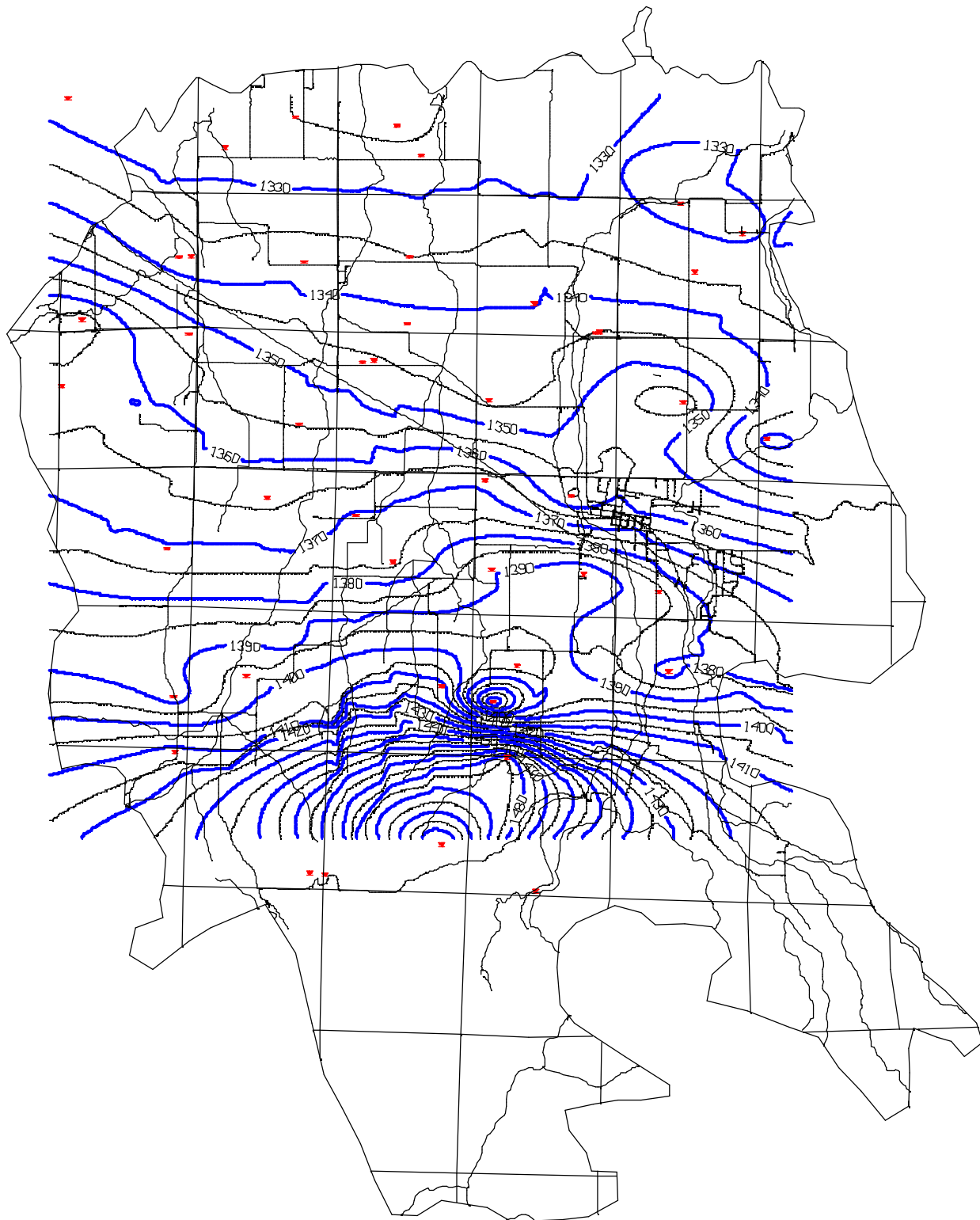




Figure 8-8
Water Levels in Big Valley Basin
Fall 1994

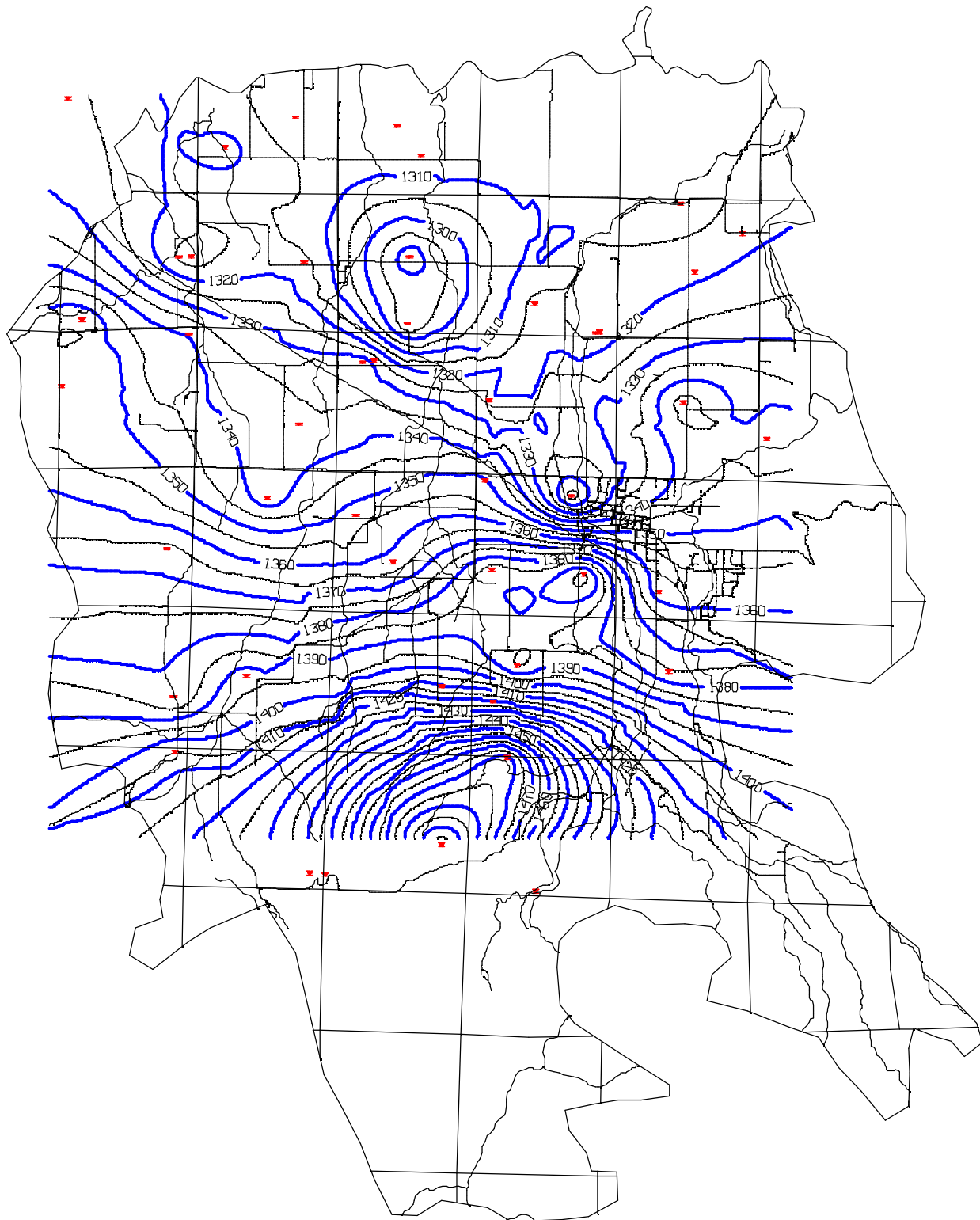
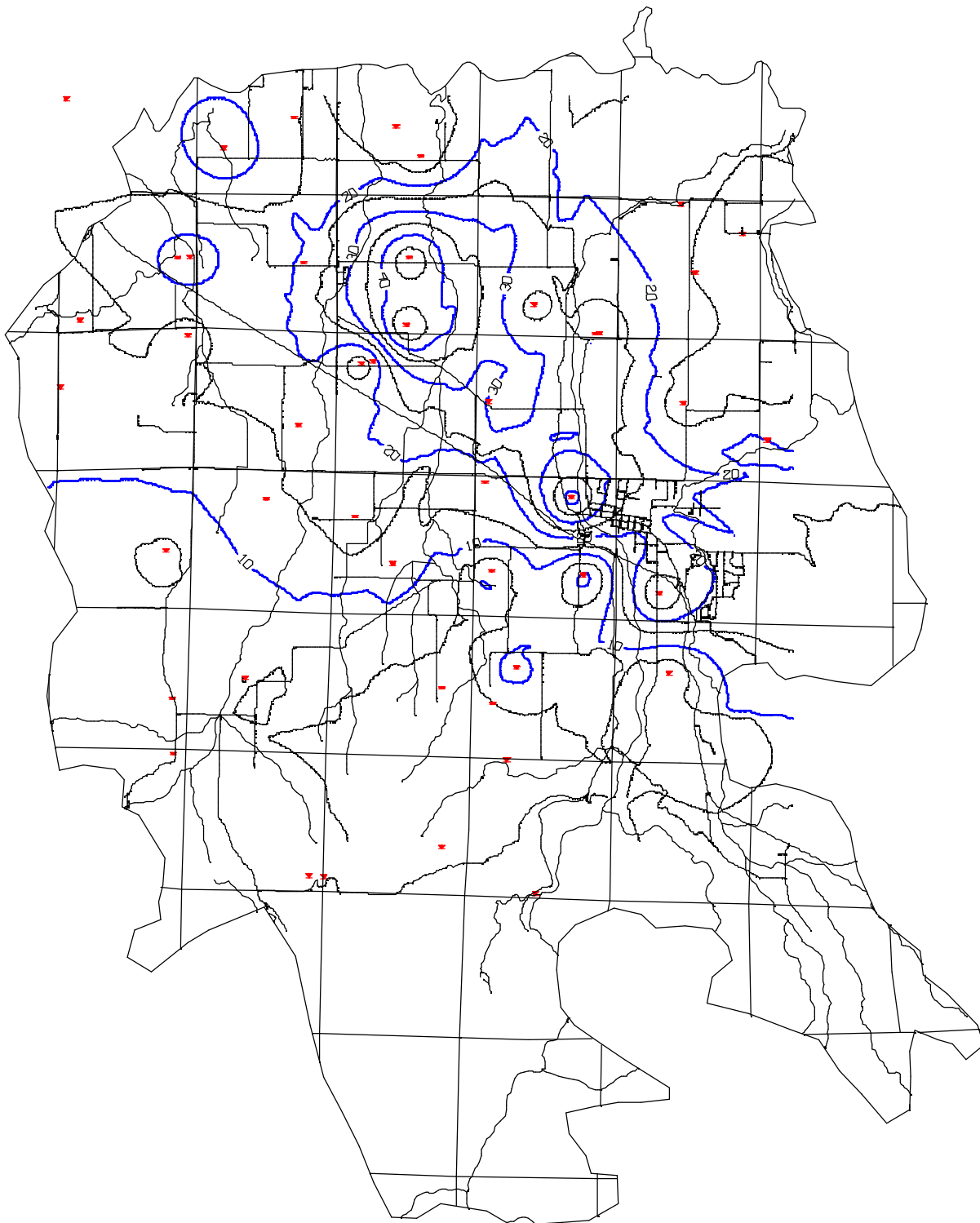




Figure 8-9
Big Valley Basin
1994 Drawdown - Spring through Fall





9. Options for Addressing Overdraft

9.1 INTRODUCTION

This section presents a wide range of options to reduce overdraft of the Basin during drought periods.

Potential benefits include:

- ▶ Elimination of periodic water shortages that impact agricultural production and crop health.
- ▶ Protection of shallow domestic wells from going dry.
- ▶ Protection of ground water quality by reducing intrusion of geothermal water rich in dissolved minerals including iron and boron. This could reduce potential adverse affects of poor water quality on crop yield, operation of drip irrigation systems and municipal water treatment.
- ▶ Reduction of costs to water users for pumping water and deepening wells.
- ▶ Improvement of fish and wildlife habitat and riparian vegetation due to higher water table and higher surface water flows in creeks that are sustained by ground water.
- ▶ Protection from ground subsidence which potentially reduces ground water storage and changes surface drainage patterns.

The following solutions focus on improving the water balance in the Basin by reducing water demand and increasing water supply. As part of the process of planning the future management of the ground water resources of the Basin, the District could select a portfolio of measures for further detailed assessment and implementation.

9.2 POTENTIAL MEASURES TO REDUCE WATER DEMAND

9.2.1 Agricultural Water Management Planning Program

California's population growth and greater awareness of environmental water requirements has increased the pressure to use water more efficiently. Water use efficiency enhancements and conservation measures have become important in balancing water supply and demand and providing demand side flexibility during droughts.

Decreasing agricultural water use is difficult for several reasons. First, California agricultural water use when considered on a broad regional scale, for the most part, is very efficient. Secondly, for most crops, production and yield is directly related to crop water use. A decrease in applied water will often directly decrease yield. The key is management strategies that improve water use efficiency without decreasing yield.



There are technologies and management strategies available that conserve water while maintaining yield and production standards. These technologies and management strategies like improved irrigation scheduling and crop specific irrigation management often not only conserve water, but also save energy used to pump water and decrease growers' costs.

The State of California has instigated programs to improve water use efficiency in both the agricultural and public water supply sectors. The Agricultural Water Management Planning Program provides technical, financial and administrative assistance to water districts throughout the State to develop Water Management Plans and to help implement cost-effective efficient water management practices. Participants in this program may gain assistance to implement water efficiency practices from three lists of potential measures as follows:

LIST A: Practices implemented by all participants

1. Prepare and adopt a Water Management Plan.
2. Designate a Water Conservation Coordinator.
3. Support the availability of water management services to water users.
4. Where appropriate, improve communication and cooperation among water suppliers, water users and other agencies.
5. Evaluate the need, if any, for changes in policies of the institutions to which the water supplier is subject.
6. Evaluate and improve efficiencies of water suppliers' pumps.

LIST B: Conditionally Applicable Efficient Water Management Practices
(selected practices applicable to Big Valley subject to net benefit analysis)

1. Facilitate alternative land use
2. Facilitate use of available recycled water that otherwise would not be used beneficially, meets all health and safety criteria and does not cause harm to crops or soils.
3. Facilitate the financing of capital improvements for on-farm irrigation systems.
4. Optimize conjunctive use of surface and groundwater.

LIST C: Other Efficient Water Management Practices (practices subject to detailed net benefit analysis)

1. Water measurement and water use report.
2. Pricing or other incentives.

The District could consider either participating in this program or adopting some of these water efficiency measures.

Further information about California Department of Water Resources' water use efficiency program is available on the internet at www.owue.water.ca.gov.



9.2.2 Implement a Climate Monitoring Station and Irrigation Scheduling Support

The District could explore joining the CIMIS program and implementing a CIMIS automatic climate monitoring station as part of an Agricultural Water Management Plan. Accurate climate information supported by easy-to-use computational tools for estimating plant evapotranspiration and soil moisture balance can assist growers to more efficiently manage their water use. Reduced water use for irrigation reduces runoff and evaporation losses and also reduces deep percolation losses. With the increased use of "Fertigation" (i.e. application of fertilizer and agricultural chemicals via irrigation systems), better water management can also reduce losses of fertilizer in runoff or deep percolation water and reduce associated impacts to surface and ground water quality.

CIMIS is an integrated network of over 100 computerized weather stations located at key agricultural and municipal sites throughout California. Its purpose is to encourage growers to adopt and use water budget irrigation scheduling so that water is used as efficiently as possible.

Comprehensive, and timely, weather data is collected daily from each weather station. The data is automatically transmitted each night to a computer in Sacramento. Weather data is analyzed for accuracy and stored in the CIMIS database to provide on-demand, localized weather information.

Based on weather data, CIMIS can calculate estimates of the amount of water evaporated from the soil and the amount actually transpired by irrigated grass (transpiration) at the weather station site. Using appropriate crop coefficients and soil data, growers can then calculate the appropriate amounts of water to apply to their crops.

There are no stations in Lake County. The nearest stations are Station 85 (El. 1160 ft.) at Hopland and Station 32 (El. 55 ft.) at Colusa. The Hopland station is probably the most representative of climate conditions in Big Valley; however the intervening Mayacamas Mountains have a significant effect on precipitation. Big Valley lies in the rain shadow of the Mayacamas and Mount Konocti. The average precipitation at Kelseyville is about 23 inches/year whereas average precipitation on the west side of the Mayacamas at Hopland is 37 inches/year at 800 feet elevation and 45 inches/year at 3000 ft.

There is an existing climate monitoring station at Kelseyville that is operated as part of the California Integrated Pest Management Program. It may be possible to reduce the cost of establishing and operating the climate station by participating in the operation of a single station that meets the requirements of both programs. The feasibility of this option would need to be explored with the appropriate resource agencies.

Further information about the CIMIS system is available at www.cimis.water.ca.gov.



9.2.3 Implement Urban Water Efficiency Measures

Although urban water use currently represents a small percentage of water use in the basin, this use is likely to grow with future increase in population. Early implementation of urban best management practices can cost-effectively reduce the rate of growth of water use in urban areas.

The following best management practices could be considered for implementation in urban areas in Big Valley. These measures would need to be facilitated by the Kelseyville and Finley municipal water supply agencies.

1. Conservation coordinator.
2. Large landscape conservation programs & incentives
3. Drought-tolerant urban garden and landscaping programs
4. Water survey programs for single-family residential & multi-family residential customers
5. Residential plumbing retrofit
6. System water audits, leak detection & repair
7. Metering with commodity rates for all new connections and retrofit of existing connections
8. High-efficiency washing machine rebate programs.
9. Public information programs.
10. School education programs.
11. Conservation programs for commercial, industrial & institutional accounts.
12. Wholesale agency assistance programs.
13. Conservation- based water pricing.
14. Water waste prohibition – especially during droughts.
15. Residential ultra low flow toilet replacement programs.

Further information about urban water conservation programs is available at www.calwaterassn.com/conservationManagement.htm.

9.3 POTENTIAL MEASURES TO IMPROVE WATER SUPPLY

There are two approaches to increasing the water supply in the Basin:



- Increase surface water supply
- Increase groundwater supply

9.3.1 Increase Surface Water Supply

The surface water supply can be increased by either importing water from outside the basin or adding storage. Like most areas in California that have a Mediterranean climate, there is a mismatch between surface water availability and water supply demand. When the water needs in Big Valley are highest during mid summer – most of the creeks are dry. Additional water storage helps by carrying over water from the winter to summer and from wet years to dry years.

9.3.1.1 Import surface water

Importing surface water was previously studied in the 1950's. At that time major features of the California Water Plan anticipated diversion of surface water from the Eel River through Clear Lake to the Sacramento Valley. It was anticipated that surplus water from the Eel River could more than meet the probable supplemental water requirements of the Clear Lake area. This project was never implemented.

Importing water from Clear Lake is another option however it would be costly and potentially fraught with water rights issues. Water rights are a major constraint to development of any additional surface water supply in the Clear Lake watershed. Yolo County has pre-1914 rights to store water in Clear Lake in accordance with the Gopcevic Decree. In the Clear Lake watershed, water is available for appropriation from November through mid-April with the caveat that no water is available in years when the elevation of Clear Lake does not reach 7.56 feet as measured at the Rumsey Gage. Therefore at times when water is needed in Big Valley during droughts, there may be no water available for appropriation from Clear Lake. In addition, any water stored in a new reservoir prior to a drought may have to be released on May 1 and would therefore not be available when it is needed most.

9.3.1.2 Reservoir Storage

Notwithstanding water rights issues, additional in-basin reservoir storage could be created by building new reservoirs or increasing the storage of existing reservoirs. The water rights issue might be resolved by compensating Yolo County for any impact on their water rights. Lake County already has a water supply agreement with Yolo County that utilizes this approach.

The District has developed a proposed conjunctive use project that would modify the operation of Highland Springs Reservoir to make an additional 700 acre-feet/year available for ground water recharge in Adobe Creek and an additional 200 acre-ft a year available in spring to enhance fish passage. To address the potential water rights issue, the project includes an allowance to



compensate Yolo County to mitigate water rights impacts. This project is technically feasible and is currently subject to environmental and water rights review processes.

Previous studies in 1967 recommended construction of Kelseyville Reservoir - a multipurpose reservoir on Kelsey Creek for flood control, groundwater recharge and recreation together with a diversion from Kelsey Creek to Adobe Creek. This project was never implemented due to institutional, environmental and cost issues. The proposed reservoir site has a viable resident native trout population which would make obtaining approvals very difficult.

Permitting of surface water storage projects in California is extremely difficult due to environmental constraints. Typical issues include endangered species protection, protection of fish habitat and fish passage, historic preservation, water quality impacts, recreation public trust issues and growth inducing impacts. The cost and time required to complete the permitting process and subsequent legal challenges is uncertain. In relative terms, environmental constraints generally favor enlargement of existing reservoirs or creation of off-stream storage as opposed to new conventional reservoirs created by impounding streams. However, the outcome of the permitting process is often driven by project-specific issues, competing interests and a myriad of other factors which surface during the project review process.

No comprehensive assessment of potential off-stream storage sites in Big Valley has been carried out. There are many small private impoundments scattered across the Basin and there appear to be many more sites with suitable topography for small off-stream reservoirs. If the District wishes to further explore the feasibility of off-stream storage, the first step would be to carry out an inventory of available sites and rank them according to technical, environmental and cost factors.

9.3.1.3 Investigate In-Lieu Use of Surface Water for Frost Control

Water sprinklers have become the primary method of frost control on pears and grapes replacing smudge pots and elevated air circulation fans. This has substantially improved air quality in Big Valley on chilly spring nights but has also increased the demand on the basin's ground water resources.

On a cold night when temperatures dip below freezing, sprinklers are turned on in the early hours of the morning and run for several hours. Typical water use is in the order of one half inch/night for Grapes and one inch/night for Pears, depending on temperature conditions.

Most growers build small ponds which are used to store pumped groundwater water for frost control. A typical water storage pond will carry about 5 to 10 acre feet of water.

The timing and amounts of water used in any year depend on climate and



specifically minimum temperatures. Use could occur sporadically or be concentrated into an extended cold snap. Some of the water applied for frost control would be lost to evaporation and surface runoff, some will be used by the crop and some may percolate back into the groundwater basin.

For planning purposes, we estimate that under normal conditions a little less than one half of the total water used for frost control will return to the ground water system resulting in an estimated net average consumptive demand of about 4000 acre -feet/year.

Use of water for frost control during spring reduces ground water levels at a time when there may be surface water available in creeks that could be used in lieu of groundwater.

Riparian water users could reduce their groundwater use by either taking water directly from creeks or by direct infiltration basins located in shallow alluvium near the banks of the creek. Furthermore, early season deep percolation of water used for frost control would help to spread the surface water over the aquifer replacing normal recharge from precipitation.

Further investigation of frost control practices and conjunctive use of surface water for frost control could lead to reduced ground water demand and improved ground water levels. The first step would be to inventory water use for frost control and investigate the feasibility of in- lieu use of surface water by riparian property owners

9.3.2 Ground Water

Increasing the ground water supply that can be sustained without overdraft requires that recharge be increased. There are several potential ways of increasing recharge as follows:

9.3.2.1 Enhancing Natural Recharge from Streams

In previous studies this was identified as the most promising recharge option. This natural recharge system is already in place and is not so susceptible to clogging since it gets flushed out each year during storms. Its productivity is limited by the time duration of the surface water supply and the relationship between water levels in the stream versus the adjacent aquifer.

Recharge enhancement measures include upstream conjunctive -use storage to regulate the surface water supply and detention structures which also regulate streamflow and increase the hydraulic gradient between the stream and the aquifer.

Kelsey Creek is a major source of stream recharge. Some potential ways to increase Kelsey Creek recharge are as follows:

Previous studies have investigated upstream storage including the Kelseyville



(Pomo) Dam on Kelsey Creek. This project was never implemented for a number of institutional and environmental reasons and it is probably less likely that it could be implemented today – given the ongoing controversy regarding development of surface water storage projects in California.

Nevertheless, from a water resources planning standpoint, some alternatives to this project which could be kept in mind are:

- Small dam with bottom sluice on Kelsey Creek in the volcanic ridge narrows (SE ¼ Sec 34) allowing seasonal impoundment in the upstream broad valley (NE ¼ Section 3) (This would flood several homes and may well be subject to the same hitch spawning run constraints as the downstream detention structure.)
- Dam 60 to 80 feet high in mouth of upper canyon of Kelsey Creek approximately at the boundary of Sections 9 and 10. The storage opportunity is limited by the steep narrow canyon so only about 1000 acre-feet of storage possible. No residences but still potential problem with fish passage.

Another option is to improve the effectiveness of the Kelsey Creek Detention Structure operations for recharge. This would involve devising a solution to the restrictions on timing of water and retention imposed by hitch spawning.

- Upstream
 - Fish ladder
 - Low gradient channel
 - Trap and lift fish over dam
 - Hydraulic elevator,
- Downstream
 - Monitor fish return and hatching.
 - Release of water at intervals timed for optimum return to Clear Lake.

Install one or more either permanent (e.g. Rubber Dam), or renewable gravel berm, additional “slow outflow” detention structures in channel of Kelsey Creek between existing structure and Kelseyville.

The Adobe Creek Conjunctive Use Project previously described in Section 9.3.1.2 is designed to modify operation of Highland Springs Reservoir to enhance recharge from Adobe Creek.

Although Adobe Reservoir is much smaller than Highland Springs Reservoir, modification of its operation to better regulate the flashy runoff in Adobe Creek may also be feasible and could be further investigated.



A detention structure could be built on Adobe Creek at the downstream end of the unconfined aquifer zone in the vicinity of the Merritt Road crossing. The structure could be a low profile rubber dam, or flap gate structure that would only be needed in dry winters to aid the recharge process.

It is understood that the county has already proposed a detention structure for Adobe Creek which was not pursued due to potential problems with fish passage. Some of the suggestions made in the previous discussion relative to the Kelsey Creek structure may apply.

9.3.2.2 Spreading Basins

Artificial recharge by the spreading method consists of increasing the surface area of infiltration by releasing water from the source to the surface of a basin, pond, pit or channel. Only phreatic (unconfined) aquifers can be recharged by the spreading method. Clogging is also a problem that affects their performance. In Big Valley, spreading basins may be feasible at old gravel pits or on idle bottomland in the unconfined aquifer zones. Potential issues include feasibility of surface water diversions to spreading areas, impacts of higher water table on agriculture and other land use/environmental issues. Nevertheless spreading basins may be useful in improving the water balance in localized areas in the Basin.

9.3.2.3 Injection Wells

Injection wells have the ability to recharge deep or confined aquifers and also have the advantage of being physically compact. Cost and potential need for pre-treatment of recharge to address water quality concerns are potential issues. The productivity of the volcanic ash aquifer may benefit from injection of surface water during drought periods when recharge diminishes, however the costs of drilling and maintaining injection wells may preclude this option.

9.3.2.4 Land Management Practices

Land management practices focus on increasing recharge by reducing surface runoff and evapotranspiration losses, and increasing infiltration. This can be accomplished by leveling land to reduce runoff, vegetation control to reduce evapotranspiration losses and tilling the soil to increase permeability.

Soils in Big Valley are generally of low permeability over considerable depth and there are drainage and high water table problems in several areas near Clear Lake. The feasibility of facilitating land management practices to increase recharge would therefore need to be carefully evaluated.

Urbanization of agricultural lands has the potential to decrease natural recharge due to increases in surface runoff due to increases in the areas of impervious surfaces and installation of storm water drainage systems.



9.3.2.5 Enhance Recharge of “Volcanic Ash” Aquifer

Investigate recharge schemes as outlined on pages VI -6 and VI -10 of the 1967 report.

Investigate aquifer properties of “Volcanic Ash” Kelsey Tuff bed, in order to evaluate whether it is feasible, beneficial, and economic to recharge this aquifer and whether there is some threshold level of extraction from this aquifer beyond which either or both yield is permanently diminished, or water quality degrades.

The investigation could at simplest involve a long-term pumping test preferably from a well with a good log and if possible another non pumping well in the vicinity that is also screened in the volcanic ash. Water samples would be collected at set intervals and analyzed to detect any change in mineral quality with continued extraction.

A more elaborate test could involve installation of a staged piezometer system with the piezometers below, within, and above the ash layer in the vicinity of the pumped well.

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10. Findings & Recommendations

10.1 INTRODUCTION

The purpose of this study is to provide updated information needed for planning and management of the ground water resources of Big Valley. This section presents findings and recommendations of the study.

10.2 FINDINGS

10.2.1 Geology

The Big Valley groundwater regime exists within the sequence of the late Pleistocene to recent age alluvial and lacustrine basin fill deposits that occupy the Big Valley subunit of the Clear Lake Basin.

The Big Valley Basin fill sequence comprises two major units, the Kelseyville Formation, and the younger floodplain, channel, terrace, and lacustrine deposits.

The Kelseyville Formation was deposited by ancestral Kelsey, Adobe, Highland and other creeks flowing across floodplains or into the Big Valley arm of the Pleistocene Clear Lake, depending on the fluctuations in lake level. The fine-grained floodplain and lake deposits include many horizons of fine volcanic ash, and at least one 2 to 5 foot thick layer of Lapilli tuff, referred to in geologic literature as the Kelsey Tuff and by a well driller as the "volcanic ash aquifer".

The Kelseyville Formation is present throughout the Big Valley area but is exposed only in the Central and Western upland areas where it has been uplifted over the Big Valley fault. The principal water yielding units within the Kelseyville Formation are the A-3 and the volcanic ash aquifers.

The younger floodplain, channel, terrace, and lacustrine deposits are mainly present beneath the northern floodplain margin of the Valley between Highway 29 and Clear Lake, and beneath the Adobe Creek floodplain as far south as a confluence of Highland Creek. This sequence contains two sections of predominantly alluvial deposits that are partly overlain, and probably separated at depth, by sections of predominantly lacustrine deposits. The alluvial deposits sections form the A1 and A2 aquifers in the northern floodplain area. The A1 aquifer extends southward beneath the Adobe Creek floodplain.

The channel of Kelsey Creek south of Kelseyville is eroded into and directly floored by strata of the Kelseyville Formation, which provides little opportunity for recharge. From the vicinity of Kelseyville north towards Clear Lake, Kelsey Creek flows within a relatively wide channel underlain by highly permeable coarse sand and small gravel alluvium. This channel reach of Kelsey Creek provides the principal recharge to the A1 and A2 aquifers of the northern Big Valley area. The recharge occurs via direct percolation of surface flow and from



underflow within the channel alluvial section.

10.2.2 Land Use

Land use data last compiled in 2001 indicates the following distribution of land use in Big Valley.

**Table 10-1
Summary of Land Use**

Land Use (2001)	Acres	Percent
Agricultural	10,403	43 %
Native	10,352	43 %
Urban	1,554	6 %
Unclassified	1,919	8 %
Total	24,227	100 %

Based on DWR Provisional Land Use Data (2001)

Approximately one half of the basin is undeveloped. The primary use of developed lands is for growing pears, walnuts and wine grapes.

Recently the total area of irrigated lands in Big Valley has declined about 13% from 9603 acres in 1995 to 8317 acres in 2001 due to a downturn in the economics of the local fruit growing industry.

10.2.3 Estimated Water Use

The estimated net average consumptive use of ground water based on land use data, estimated rates of water use, and estimates of return flows to the ground water basin is shown on Table 10-2:

**Table 10-2
Estimated Average Net Consumptive Use of Ground Water**

Use	Amount (Ac-ft)	Percent
Irrigation	12957	74 %
Frost Control	4056	23 %
Urban	600	3 %
Total	17613	100%

Agricultural irrigation and frost control accounts for about 97% of estimated consumptive use of ground water in the basin.

10.2.4 Ground Water Aquifers and Recharge

Most accessible groundwater in Big Valley is contained in three main, somewhat diffuse alluvial aquifers and in one mostly deep, thin layer of volcanic ash lapilli tuff.



The most widespread alluvial aquifer, the A1 aquifer, is present beneath the northern Big Valley floodplain and the floodplain of Adobe Creek. Recharge from Adobe Creek and lower Kelsey Creek is directly into this aquifer. The northern margin of the A1 aquifer is partly confined by overlapping fine-grained deposits from higher strands of Clear Lake.

A second, lower alluvial aquifer, the A2 aquifer, underlies but is separated by an aquitard layer from, the A1 aquifer in the northern Big Valley floodplain area, but is not present beneath the Adobe Creek floodplain. Recharge of the A2 aquifer is mainly by downward percolation from the A-1 aquifer and underflow from the Kelseyville Formation.

Ground water serving the Central and the Western Upland areas is extracted from the A3 and volcanic ash aquifers in the Kelseyville Formation. The A3 aquifer is recharged by some direct percolation from the upland surface and by underflow from Kelsey Creek and from the A-1 aquifer under the Adobe Creek floodplain. The path of recharge to the volcanic ash aquifer is not well understood.

10.2.5 Ground Water Levels

The Lake County water level database contains water level data for 88 wells in Big Valley. The water level data were collected between June 1948 and April 2002. Earlier water level data were collected semi-annually or quarterly. Beginning in approximately 1992, some water level data were collected monthly. At present, monthly water level data are collected from approximately 16 wells in Big Valley

The groundwater basin returns to a relatively full condition during average years. The basin's capacity, however, is not replenished during dry years, suggesting that without expanded recharge capabilities, extended droughts may have serious consequences on water supplies.

Maps of groundwater surface contours show that the general groundwater flow direction is from the surrounding mountains towards Clear Lake. The general flow pattern is interrupted by pumping depressions that become more pronounced during the irrigation season. Data from the extreme droughts of 1975-77 and 1987-92 show a large cone of depression near Finley in the confined aquifer zone and a smaller steeper cone near the base of the Central Highlands. Extreme drawdowns in 1987-92 were deeper than the drought of 1975-77.

Experience with extreme hydrologic events such as droughts in California tells us that as more time passes, the magnitude and duration of extreme drought events experienced in Big Valley will surpass the extreme events of record in 1976-77 and 1987-92. Depending on the levels of water use during future more severe droughts, water levels in the Basin may be drawn down below historic minima. Existing water quality and supply problems during drought periods may reoccur and new problems may arise.



10.2.6 Ground Water Quality

Discreet areas of the Big Valley basin are experiencing progressive groundwater quality degradation from inflow and mixing of geothermal waters. This is evident in wells 13N-09W-12M01, 13N-09W-02K02, 13N-09W-09F02, and 13N-09W-17A01.

The water quality degradation from geothermal waters is ongoing. This suggests that locally, wells are not receiving adequate freshwater recharge from rainfall or percolation.

Large portions of the Big Valley basin are experiencing a rise in nitrates and nitrate levels are approaching regulatory limits in parts of the Big Valley basin.

Some residents have complained that groundwater quality worsens during droughts. Unfortunately, insufficient data are available to definitively correlate water quality changes with groundwater elevations. It is a reasonable to assume that water quality worsens when there is insufficient recharge, however. This correlation between insufficient recharge and worsening water quality is evident in the few wells that are currently impacted by geothermal waters. The actual water level that triggers inflow of poor water quality is unknown, however.

10.2.7 Volumetric Model

The volumetric model developed in this investigation is a simple volumetric model and not a more rigorous groundwater flow model. It can be used to visualize and analyze the geology and ground water regime of Big Valley, and to perform volumetric calculations on soil deposits and the amounts of water stored in unconfined aquifers. The model is suitable for use in the unconfined aquifer zones which are important for recharge operations. The model is not designed to be used in the confined ground water zone or in the Volcanic Ash aquifer. In these zones, water levels reflect piezometric head in the aquifer that is hydraulically connected to the observation well rather than changes in regional water level.

Further calibration of the model is desirable to improve its accuracy and usefulness. The data used in development of the model could be used to further develop a full ground water flow model; however limitations in water inflow and outflow data may limit the accuracy and utility of a more complex model.

10.3 RECOMMENDATIONS

Big Valley Ground Water Basin is an important asset to Lake County. Although there is sufficient ground water recharge in most years to replenish ground water extracted for irrigation and municipal supply, the basin experiences overdraft during drought periods. During these periods, ground water extraction exceeds the natural ability of the basin to annually recharge from precipitation and infiltration from creeks and streams in the basin.



In average water years, drawdowns are typically in the range of 10 to 20 feet; however drawdown of the water table can reach up to 50 to 60 feet during drought periods. This trend poses a number of potential problems during future drought periods which may be more severe than those already experienced:

- ▶ Water shortages during droughts that may impact agricultural production.
- ▶ Drying up of shallow wells used for irrigation and domestic water supply.
- ▶ Deterioration in ground water quality due to greater intrusion of geothermal water rich in dissolved minerals including iron and boron,
- ▶ Additional costs to water users for pumping water and deepening wells.
- ▶ Drying up of creeks due to lowered water table which impacts fish, wildlife and riparian vegetation.
- ▶ Ground subsidence which potentially reduces groundwater storage and changes surface drainage patterns.

Since the amount of near -surface ground water storage in the basin is limited, the following portfolio of potential solutions focus on improving the water balance in the Basin during drought periods by reducing water demand and increasing water supply.

10.3.1 Recommended Options for Addressing Overdraft

The following ground water supply management options are recommended for further consideration by the District in developing an overall plan for managing the ground water resources of Big Valley. These options are discussed in further detail in Chapter 9.

10.3.1.1 Implement an Agricultural Water Management Plan

The State of California has instigated programs to improve water use efficiency in both the agricultural and public water supply sectors. The Agricultural Water Management Planning Program provides technical, financial and administrative assistance to water districts throughout the State to develop Water Management Plans and to help implement cost-effective efficient water management practices.

Examples of these practices are as follows:

- Designate a Water Conservation Coordinator.
- Support the availability of water management services to water users.
- Improve communication and cooperation among water suppliers, water users and other agencies.



- Facilitate alternative land use
- Facilitate use of available recycled water
- Facilitate the financing of capital improvements for on-farm irrigation systems.
- Optimize conjunctive use of surface and groundwater.
- Water measurement and water use reporting.
- Conservation pricing or other economic incentives to increase demand flexibility.

As part of this plan, the District could also explore joining the CIMIS program and implementing an automatic climate monitoring station. The program provides accurate climate information and water management data so that growers can more efficiently manage their water use.

10.3.1.2 Implement Urban Water Efficiency Measures

Although urban water use currently represents a small percentage of water use in the basin, this use is likely to grow with future increase in population. Early implementation of urban best management practices so that they are built in to new infrastructure can cost-effectively reduce the rate of growth of urban water use.

The following best management practices could be considered for implementation in urban areas in Big Valley. These measures would need to be facilitated by the Kelseyville and Finley municipal water supply agencies.

- Designate a Water Conservation Coordinator.
- Large Landscape Conservation Programs & Incentives
- Drought-tolerant urban garden and landscaping programs
- System Water Audits, Leak Detection & Repair
- Metering with Commodity Rates for All New Connections and Retrofit of Existing Connections
- Water Survey Programs for Single-Family Residential & Multi-Family Residential Customers
- Conservation Programs for Commercial, Industrial & Institutional Accounts.
- Residential Plumbing Retrofit



- High-Efficiency Washing Machine Rebate Programs.
- Residential Ultra Low Flow Toilet Replacement Programs.
- Public Information and school education programs.
- Conservation- Based Water Pricing.
- Water Waste Prohibition – especially during droughts

10.3.1.3 Increase Surface Water Supply

The most promising options appear to be:

- Adobe Creek Conjunctive Use Project,
- In-lieu use of surface water for frost control,
- Off-stream storage.

The proposed Adobe Creek Conjunctive Use project is currently undergoing environmental and water rights permitting reviews.

Further investigation of frost control practices and conjunctive use of surface water for frost control could lead to reduced ground water demand and improved ground water levels. The first step would be to inventory water use for frost control and investigate the feasibility of in- lieu use of surface water by riparian property owners.

There are many small private impoundments scattered across the Basin and there appear to be many more sites with suitable topography for small off-stream reservoirs. If the District wishes to further explore the feasibility of off-stream storage, the first step would be to carry out an inventory of available sites and rank them according to technical, environmental and cost factors.

10.3.1.4 Increase Ground Water Recharge

The most promising measures appear to be:

- Enhancing natural ground water recharge from streams.
- Spreading basins

Upstream storage on Kelsey Creek could improve recharge in lower Kelsey Creek however environmental constraints may preclude construction of on-stream surface water storage. Off-stream storage may be feasible and could be explored further. The proposed Adobe Creek Conjunctive Use Project would enhance recharge on Adobe Creek.

Detention structures regulate streamflow and increase the hydraulic gradient between the stream and the aquifer. The effectiveness of the Kelsey Creek Detention Structure is severely limited by environmental constraints designed to maintain fish passage. If the fish passage problem could be solved through



installation of a fish ladder or elevator then the recharge may be enhanced.

A detention structure at the downstream end of the Adobe Creek unconfined zone in the vicinity of the Merritt Road crossing would also help the recharge process. The structure could be a low profile rubber dam, or flap gate structure that would aid the recharge process. It is understood that the county has already proposed a detention structure for Adobe Creek which was not pursued due to potential problems with fish passage. Some of the suggestions made in the previous discussion relative to the Kelsey Creek structure may apply.

Artificial recharge by the spreading method consists of increasing the surface area of infiltration by releasing water from the source to the surface of a basin, pond, pit or channel. In Big Valley, spreading basins may be feasible at old gravel pits or on idle bottomland in the unconfined aquifer zones. Potential issues include feasibility of surface water diversions, impacts of higher water table on agriculture and other land use/environmental issues. Nevertheless spreading basins may be useful in improving the water balance in localized areas in the Basin.

10.3.2 Recommended Ground Water Monitoring and Studies

The following ground water studies are recommended to support the ground water management:

10.3.2.1 Improve the current water level monitoring program.

The District currently collects water levels from wells throughout Big Valley on a monthly schedule. This program is effective, but could be improved somewhat.

The District should first define clear goals for the water level monitoring program. Goals may include ideas such as collecting data for the groundwater storage model, estimating the stream – groundwater interactions, or estimating well interference effects.

Based on the stated goals, the County should reassess the current set of wells used in the monitoring program, and modify the set of wells in order to better focus on the stated goals.

10.3.2.2 Expand the current water quality monitoring program.

The water quality monitoring program should be carried out in coordination with the water level monitoring program. As with the water level monitoring program, the District should first define clear goals for the water quality monitoring program. This water quality monitoring program may be used to further define the areal extent of various compounds, track the migration of compounds over time, or develop a relationship between water level and concentrations.

A set group of wells should be identified for the water quality monitoring



system, and a sampling schedule should be implemented for each well. The sampling schedule should be adequate to define background water quality, as well as changes over time and changes with water levels.

10.3.2.3 Investigate the aquifer properties including confinement of the A1-A2 aquifer system in the confined zone of Northern Big Valley.

Install a staged piezometer array in the vicinity of a suitable test pumping well with a good log and suitable screened intervals. Determine effect of long-term pumping on piezometric head in both aquifer and aquitard layers.

10.3.2.4 Investigate Enhanced Recharge of “Volcanic Ash” Aquifer

Investigate aquifer properties of “Volcanic Ash” Kelsey Tuff bed, in order to evaluate whether it is feasible, beneficial, and economic to recharge this aquifer and whether there is some threshold level of extraction from this aquifer beyond which either or both yield is permanently diminished, or water quality degrades.

The investigation could at simplest involve a long-term pumping test preferably from a well with a good log and if possible another none pumping well in the vicinity that is also screened in the volcanic ash. Water samples would be collected at set intervals and analyzed to detect any change in mineral quality with continued extraction.

A more elaborate test could involve installation of a staged piezometer system with the piezometers below, within, and above the ash layer in the vicinity of the pumped well.

10.3.2.5 Develop Estimates of Hydrogeologic Parameters

The groundwater storage model relied on a number of uncertain hydrogeologic parameters, including hydraulic conductivity and specific yield. A series of aquifer tests throughout Big Valley would help define these parameters. Aquifer tests could be performed on existing production wells, however it will likely be necessary to install monitoring wells or piezometers to adequately define the hydrologic parameters. This data could further shed light on the interactions between the ash aquifer and the overlying sediments.

10.3.2.6 Monitor Land and Water Use Practices in the Basin

The District should maintain an updated water balance for the Basin. Periodic updating of land use data and water use information should be carried out to help keep the water balance current and to identify any significant trends.