**SEA WATER INTRUSION ASSESSMENT**
**and**
**LOWER AQUIFER SOURCE INVESTIGATION**
**of the**
**LOS OSOS VALLEY GROUND WATER BASIN**
**SAN LUIS OBISPO COUNTY, CALIFORNIA**

prepared for the

LOS OSOS COMMUNITY SERVICES DISTRICT

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## EXECUTIVE SUMMARY

The lower aquifer of the Los Osos Valley ground water basin is the principal water supply for the community of Los Osos. Sea water intrusion into this aquifer has been recognized for over 20 years, although the rate and extent of intrusion was never quantified. There has also been uncertainty regarding the main source of recharge to the lower aquifer. Geochemical data suggested the Los Osos Creek valley was the source, while ground water modeling indicated most lower aquifer recharge was from upper aquifer leakage. Resolving these issues are critical to ground water basin management. In 2003, the Los Osos Community Services District obtained a grant from the California Department of Water Resources for a project to assess sea water intrusion and investigate lower aquifer recharge. This report presents the results of the project.

### Project Description and Hydrogeologic Setting

The purpose of the sea water intrusion assessment is to document the historical rate of advance of the sea water wedge and the transition zone, and to establish the current position of these elements within the main aquifer zones of the ground water basin. A monitoring plan has also been developed to assist in observing future changes over time in the rate and extent of intrusion. The purpose of the lower aquifer source investigation is to characterize and quantify lower aquifer recharge from the Los Osos Creek Valley, the upper aquifer, bedrock, and sea water intrusion.

Field work conducted for the project included ground water and surface water sampling, geologic field reconnaissance, deep test hole drilling, geophysics, aquifer testing, and well head elevation surveying. A comprehensive water quality data base was also developed, along with structural and hydrogeologic cross-sections and water level contour maps.

The onshore portion of the Los Osos Valley ground water basin covers approximately 10 square miles. Permeable basin sediments of the Paso Robles Formation and the Careaga Formation extend to depths of up to 700 feet below sea level. Six aquifer zones have been identified in previously published reports. They include the alluvial aquifer in the Los Osos Creek valley, the perched aquifer (Zone A), the transitional aquifer (Zone B), the upper aquifer (Zone C), and the lower aquifer (Zones D and E). A regional clay aquitard averaging 50 feet in thickness separates the upper aquifer from the lower aquifer. Basin-wide ground water production averaged 3,480 acre-feet per year (afy) between 1985 and 2001, with 2,510 afy being drawn from the lower aquifer.

### Sea Water Intrusion Assessment

Sea water is highly concentrated in mineral salts, compared to fresh waters of the Los Osos Valley ground water basin. Less than five percent sea water in a fresh water aquifer can have a significant adverse impact on the potential beneficial uses of the water. The principal criteria for evaluating sea water intrusion are water levels and water quality. According to the Ghyben-Herzberg relation, a fresh water head of approximately 5 feet would be needed to prevent the sea water interface from moving onshore within the upper aquifer. A fresh water head of approximately 9 feet would be required to prevent the sea water interface in lower aquifer Zone D from moving inland, and Zone E would require a fresh water head of approximately 17.5 feet. Currently, only upper aquifer water levels are sufficiently high to prevent sea water intrusion. The occurrence of sea water intrusion in the lower aquifer is indicated by hydraulic pressures below the minimum required to avoid intrusion based on the Ghyben-Herzberg relation, and by a landward hydraulic gradient.

Chloride concentrations define the transition zone between fresh water and sea water, with 250 milligrams per liter (mg/l) chloride representing the leading edge of the transition zone, and 2,500 mg/l chloride representing the trailing edge of the zone. Chloride concentrations in sand spit monitoring wells show increases in lower aquifer salinity of up to 100 percent between the years 1977 and 2005. Evidence of active sea water intrusion in the lower aquifer inland of the bay is shown by elevated chloride concentrations at production wells of up to 800 mg/l. Other water quality constituents, including selected major ion ratios and trace elements, have been used to confirm that the primary source of increasing chlorides in the lower aquifer is sea water. Trends in ion ratios that should accompany sea water intrusion into the lower aquifer, such as increasing chloride-to-bicarbonate, decreasing sodium-to-chloride, and increasing calcium-to-bicarbonate-plus-sulfate ratios have been documented by this study. Deterioration of lower aquifer water quality consistent with sea water mixing has also been documented using plots of bromide-to-chloride versus chloride, strontium-to-chloride versus chloride, and of oxygen-18 versus deuterium.

Conclusions of the sea water intrusion assessment are as follows:

1. The upper aquifer fresh water / sea water interface is relatively stable beneath the Morro Bay sand spit, with a potential for active intrusion during extended drought periods.

2. Sea water intrusion in lower aquifer Zone D has advanced at an average rate of 60 feet per year between 1985 and 2005, and is currently between Pecho Road and Doris Avenue.

3. Sea water intrusion in lower aquifer Zone E has advanced at an average rate of 54 feet per year between 1977 and 2005, and is currently between Broderson Avenue and Palisades Avenue.

**Source of Lower Aquifer Recharge**

Water quality in the lower aquifer, where not impacted by sea water intrusion, is predominantly magnesium-calcium bicarbonate and calcium-magnesium bicarbonate, with an average TDS of 340 mg/l. In the western basin area, sea water intrusion has changed lower aquifer quality from a bicarbonate anion dominance to a chloride anion dominance.

When ground water is pumped out of the lower aquifer, four potential sources of recharge are available for replenishment. These sources are the Los Osos Creek valley, the upper aquifer, bedrock, and sea water.

The creek valley source water is characterized by magnesium-calcium bicarbonate water, with a median total dissolved solids (TDS) concentration of 520 mg/l. The upper aquifer group is generally a sodium-magnesium chloride-bicarbonate water, with a median TDS concentration of 200 mg/l. Ground water quality from bedrock sources is generally magnesium-calcium bicarbonate with a median TDS concentration of 470 mg/l. Sea water has a sodium chloride character and a TDS concentration of close to 36,000 mg/l.

Numerical ground water models constructed for the ground water basin have consistently shown that the main source of recharge to the lower aquifer was leakage through the regional aquitard from the upper aquifer. This was a necessity for calibration, but was in apparent conflict with the water quality associations which correlated the magnesium-calcium bicarbonate lower aquifer water with Los Osos Creek valley water. The conflict has been resolved, and lower aquifer water quality can be closely matched by mixing up to 2.6 parts upper aquifer water with one part creek valley water. The character of the water mixture remains similar to creek valley water because of the greater ionic concentrations present in creek valley water compared to upper aquifer water.

Results of the radiocarbon age-dating of ground water also support the water quality mixing calculations that indicate significant leakage of upper aquifer water into the lower aquifer is occurring. The average age of lower aquifer water becomes younger from east to west (from 4,130 years to 2,210 years before present), which is interpreted to be caused by mixing with younger upper aquifer water.

Recharge to the lower aquifer west of the Los Osos Creek valley under current conditions is estimated to include 910 acre-feet per year of upper aquifer leakage through the regional aquitard, 420 acre-feet per year subsurface inflow from the creek valley, and 560 acre-feet per year of sea water intrusion. Recharge from bedrock is negligible.

Conclusions of the lower aquifer source investigation are as follows:

1. Lower aquifer production west of the Los Osos Creek valley is currently close to 600 acre-feet per year more than the average fresh water inflow. This is confirmed by the evidence of sea water intrusion. The Los Osos Valley ground water basin is currently in an overdraft condition.

2. The upper aquifer is the primary source of fresh water recharge to the lower aquifer, particularly on the west side of the basin. Plans originally developed during the 1980's for treated effluent disposal at higher elevations on the west side of the basin provide a reasonable potential for incidental recharge to the lower aquifer. Nitrates and other conservative constituents of basin return flows present in the upper aquifer will ultimately reach the lower aquifer.

3. Lower aquifer recharge from the southern end of the Los Osos Creek valley into the main basin area where community purveyors operate is restricted by faulting. Artificial recharge projects in the uppermost creek valley would not directly benefit the main basin area, and would require careful positioning of recovery wells with respect to local faulting.

**Recommendations**

The information gained through this project provides a better understanding of the dynamics of sea water intrusion and lower aquifer recharge in the Los Osos Valley ground water basin. These two issues are critical to the future management of water resources. Sea water intrusion is threatening the lower aquifer, which is the primary water supply for the community. Based on the findings and conclusions of this project, it is recommended that:

1. Lower aquifer ground water production be reduced to a level which does not exceed the average annual fresh water recharge to the aquifer. Reductions should be focused primarily on the west side of the basin, where active intrusion is occurring.

2. A basin ground water management plan be configured to mitigate sea water intrusion as a top priority, such as outlined in the July 2005 Draft Water Management Plan for the Los Osos Valley Ground Water Basin (Cleath & Associates). This plan contains a phased approach to basin management, whereby increased utilization of the upper aquifer for ground water supply allows lower aquifer recovery from the excessive draft currently being placed upon it.

3. A sea water intrusion monitoring program be implemented to provide information on the future movement of sea water and the success of mitigation measures. The recommended monitoring program is included in Part 2 of this document.

# PART 1

# PROJECT DESCRIPTION AND HYDROGEOLOGIC SETTING

## INTRODUCTION

In 2003, the Los Osos Community Services District (Los Osos CSD) obtained a grant from the California Department of Water Resources (DWR) for a project consisting of two separate studies; an assessment of sea water intrusion in the ground water basin, and an investigation into the source of lower aquifer recharge. These studies address issues that affect ground water resource management and planning for a sustainable community water supply.

Sea water is highly concentrated in mineral salts, compared to the fresh waters of the Los Osos Valley ground water basin. A relatively low percentage of sea water in fresh water (less than 5%) can have a significant adverse impact on the potential beneficial uses of the water. Sea water intrusion was first documented in deep basin sediments in 1977 (DWR, 1979) and has been affecting water purveyor wells since the mid-1990's.

The purpose of the sea water intrusion assessment is to document the historical rate of advance of the sea water wedge and the transition zone, and to establish the current position of these elements. A monitoring plan has also been developed to assist in observing changes over time in the extent and rate of intrusion. Sea water is currently intruding into the lower aquifer system. Most of the community water supply is produced from the lower aquifer, therefore, understanding the extent and rate of sea water intrusion is critical to protecting the community water supply.

On a broader scope, sea water is just one of several potential sources of recharge to the lower aquifer (though extremely undesirable). The purpose of the lower aquifer source investigation is to characterize these recharge sources. The investigation focuses on lower aquifer recharge from the Los Osos Creek Valley, the upper aquifer, bedrock, and sea water.

One of the key issues to resolve with respect to ground water movement is whether or not a significant amount of the upper aquifer water leaks through the regional aquitard and into the lower aquifer. Upper aquifer leakage through the regional aquitard can potentially carry nitrates and other constituents of concern into the lower aquifer, but without significant recharge from upper aquifer leakage, lower aquifer zones may not be permeable enough to transmit sufficient water from the Los Osos Creek Valley or bedrock sources to sustain community purveyor wells.

## CONDUCT OF WORK

Results of these studies have been combined into a single document, which is organized in three parts. Part 1 includes general information applicable to both studies, including the hydrogeologic setting of the ground water basin and a summary of field investigation activities. Part 2 reports on the sea water intrusion assessment, and Part 3 reports on the lower aquifer recharge investigation.

In December 2004, an Interim Report was prepared that compiled, analyzed, and interpreted available hydrogeologic and water quality information pertinent to sea water intrusion and lower aquifer recharge in the ground water basin. Work from the Interim Report has been incorporated herein, with additional analysis and interpretation of new information collected as part of the project.

The following organizations were contacted and contributed information used in this study:

- United States Geological Survey
- California Department of Water Resources
- California Environmental Protection Agency
- Regional Water Quality Control Board - Central Coast Region
- County of San Luis Obispo
- California Cities Water
- S&T Mutual Water Co.
- Los Osos Community Services District

During this project, Cleath & Associates reviewed over 30 references on information pertinent to basin water resources. Water quality data for close to 1,200 general mineral samples at 110 locations across the basin were compiled and loaded into AquaChem, a database developed by Waterloo Hydrogeologic, Inc., specifically for the analysis of water quality data.

The sea water intrusion assessment involved preparation of hydrogeologic cross-sections, a water level contour map for the lower aquifer, and plan view maps showing water quality relationships. Graphs of trace element and stable isotope data, water level hydrographs and chemographs, and an equivalent fresh water head version of the steady-state basin flow model were also developed for interpreting the rate and extent of sea water intrusion.

The lower aquifer source investigation presents hydrogeologic definition of the basin focused on the structural and water quality characterization of the lower aquifer system. Hydrogeologic cross-sections were developed detailing the aquifer zones through downtown and beneath the Los Osos Creek Valley. A base of alluvial sediments map for the creek valley and a subcrop map of the lower aquifer beneath the alluvial sediments were developed. Piper diagrams and Stiff diagrams were prepared for dozens of wells representing the source water groups. Simulated mixing of general minerals from creek valley and upper aquifer sources was used to investigate the potential for upper aquifer leakage through the regional aquitard.

Field work completed for the sea water intrusion assessment and the lower aquifer source investigation included collecting water samples from 36 wells and three surface water locations, geologic field reconnaissance, test hole drilling, aquifer testing, and re-surveying of selected key monitoring wells. A sea water intrusion monitoring plan is also included herein.

# HYDROGEOLOGIC SETTING

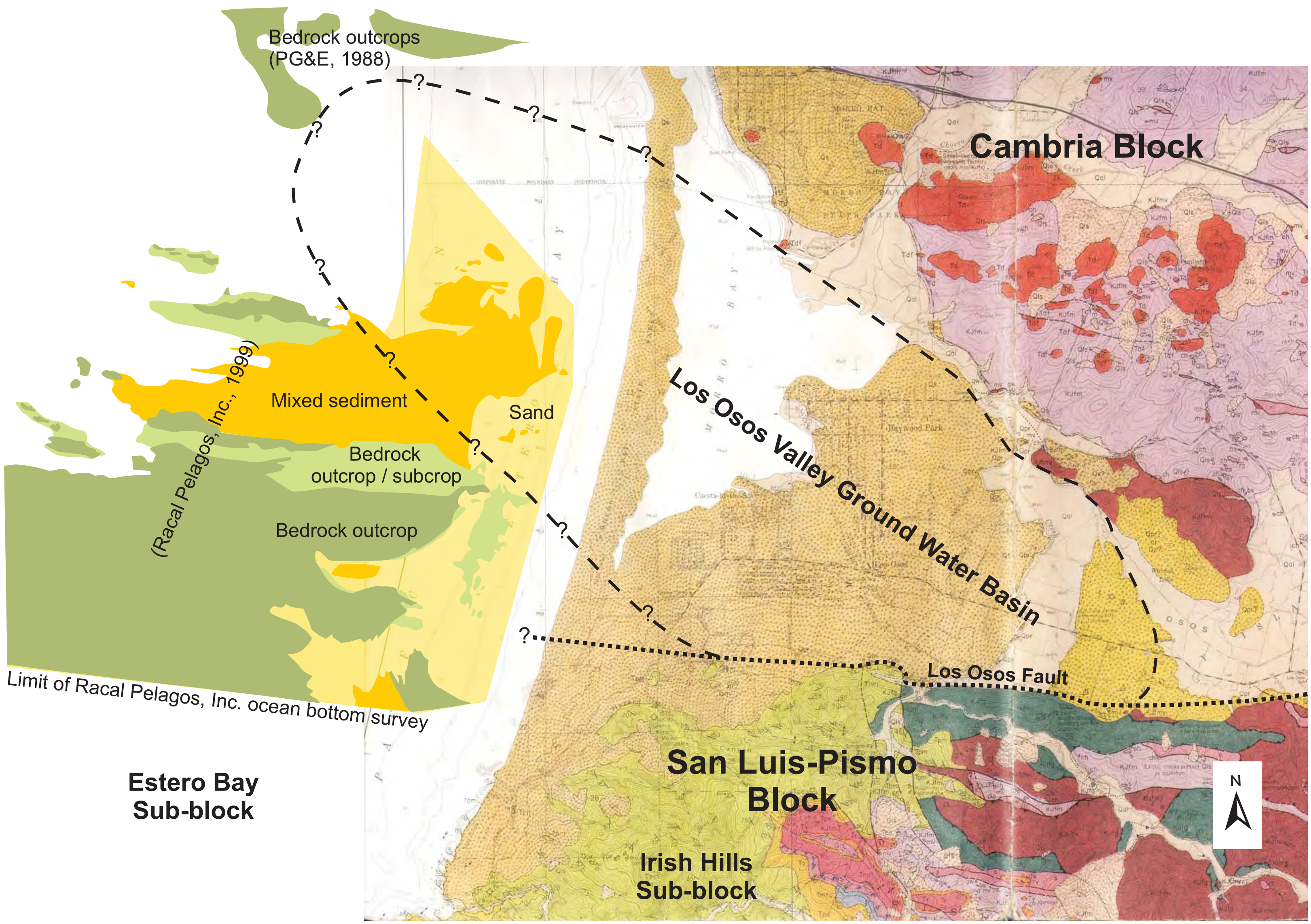
The onshore portion of the Los Osos Valley ground water basin covers approximately 10 square miles, of which approximately 3.3 square miles underlie the bay and sand spit, and 6.7 square miles underlie Los Osos, Baywood Park, and the Los Osos Creek valley. The ground water basin is underlain and bounded by relatively impermeable rocks on the north, east, and south. To the west, the basin is effectively bounded by the sea water/fresh water interface, although basin sediments extend close to three miles offshore. Unconsolidated sediments forming the basin include alluvial deposits, dune sands, the Paso Robles Formation, and the Careaga Formation. The geology of the Los Osos area is shown in Figure 1, and includes offshore mapping. Figure 2 shows the geology of the Los Osos Valley ground water basin.

## Geologic Structure

Formation of the ground water basin was tectonically controlled by the main strand of the Los Osos fault, which forms part of the southern basin boundary (Figures 1 and 2). This reverse fault trends east-west and is considered active near the westerly limits of the City of San Luis Obispo, approximately 10 miles east of Los Osos. The fault offsets basin sediments on the Cambria structural block to the north, with Pismo Formation and Franciscan Formation bedrock of the San Luis/Pismo structural block to the south (Figure 1). Detailed mapping and age-dating of emergent marine terraces disrupted by the Los Osos fault near Montaña de Oro State Park has led to an estimate of coastal uplift of the Irish Hills sub-block (San Luis/Pismo block) at a rate of 0.2 to 0.23 millimeters per year. Uplift of the Irish Hills sub-block relative to the Cambria block is responsible, along with subsidence and erosion in the Los Osos Valley, for the orientation and structural configuration of the basin. Maximum subsidence rates in the basin have been estimated at 0.1 millimeters per year (Lettis and Hall, 1994).

The ground water basin is a synclinal trough, with a southeast-northwest trending fold axis. Dips along stratigraphic horizons on the limbs of the syncline reach approximately 4 degrees, although dips of up to 8 degrees are present near the Los Osos fault zone at the southeast end of the basin. An elevation contour map on the base of permeable sediments is shown in Figure 3. The contact between basin sediments and bedrock is an unconformity, and the synclinal nature of the basin sediments are only partially developed on this surface. Figure 4 shows contours on the base of the upper aquifer. This horizon is conformable to the top of the regional aquitard and illustrated the synclinal structure of the ground water basin sediments.

Faulting along the Los Osos south boundary has encroached into the basin and offset bedrock along at least three planes. The United States Geological Survey (U.S.G.S.) proposed the two parallel faults trending north-northeast and extending into the basin from previously mapped faults in basement rocks south of Bayview Heights (Yates and Wiese, 1988). These parallel faults uplift basin sediments on the east and create a ground water barrier between upper Los Osos Creek and downtown Los Osos. The eastermost parallel fault is interpreted to offset Quaternary sediments with an apparent uplift of close to




Map Geology:

(Onshore)
C.A. Hall, Jr., et al, 1979
Geologic Map of the
San Luis Obispo-
San Simeon Region,
California
U.S.G.S. Map I-1097

(Offshore)
Racal Pelagos, Inc. 1999
Draft Pre-Installation Geophysical
Survey Preliminary Interpretation
Morro Bay, California
Plate 5A

PG&E, 1988
Diablo Canyon Power Plant
Long-Term Seismic Program
Plate 4, Sheet 2

explanation of map symbols
and geologic units attached
seperately

Approximate Basin Limits

Main strand of Los Osos
fault (approximate location)

Scale: 1" = 4000'

Figure 1

Geology
Los Osos Area

DWR Grant Project
Los Osos CSD

Cleath & Associates

# Explanation of Figure 1 Geology

## ONSHORE GEOLOGY

Qal - alluvial deposits

Qs - dune sand

Qls - landslide

Qpr - Paso Robles Fm.

Tpm, Tpe - Pismo Fm.

Td, Tdf - dacite

Tmts - Monterey Fm.

Tv, Top, Tr, To - Obispo Fm.

Kjf(g),(mv),(m) - Franciscan Fm.

s - serpentinite

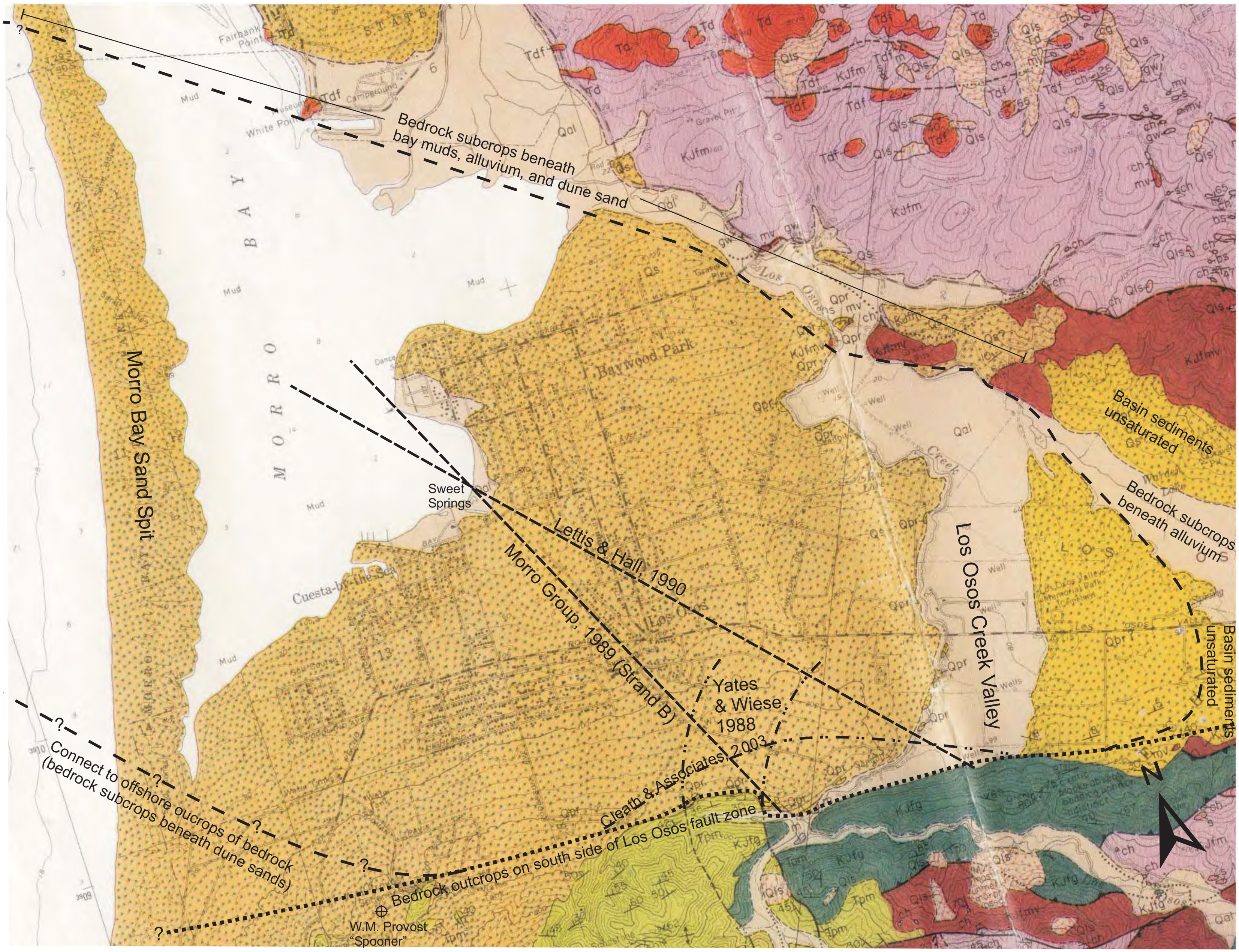
## OFFSHORE GEOLOGY

Rock outcrop - irregular to rough bedrock surface with moderate to high relief.

Rock outcrop/ Subcrop - flat, smooth to low relief locally covered with a thin layer of sediment.

Mixed sediment - Flat bedrock surface or hard-packed sediment covered with coarse-grained sediment.

Sand - Generally restricted to nearshore and in low areas within bedrock exposures.




Map Geology:

C.A. Hall, Jr., et al, 1979
Geologic Map of the
San Luis Obispo-
San Simeon Region,
California
U.S.G.S. Map I-1097

Map Key:

Qal - alluvial deposits
Qs - dune sand
Qls - landslide
Qpr - Paso Robles Fm.
Tpm - Pismo Fm.
Td, Tdf - dacite
Kjf(g),(mv),(m) - Franciscan Fm.

Proposed fault (retained)

Proposed fault (not retained)

Approx. basin limits

Main strand of Los Osos fault (approximate location)

Scale: 1" = 2000'

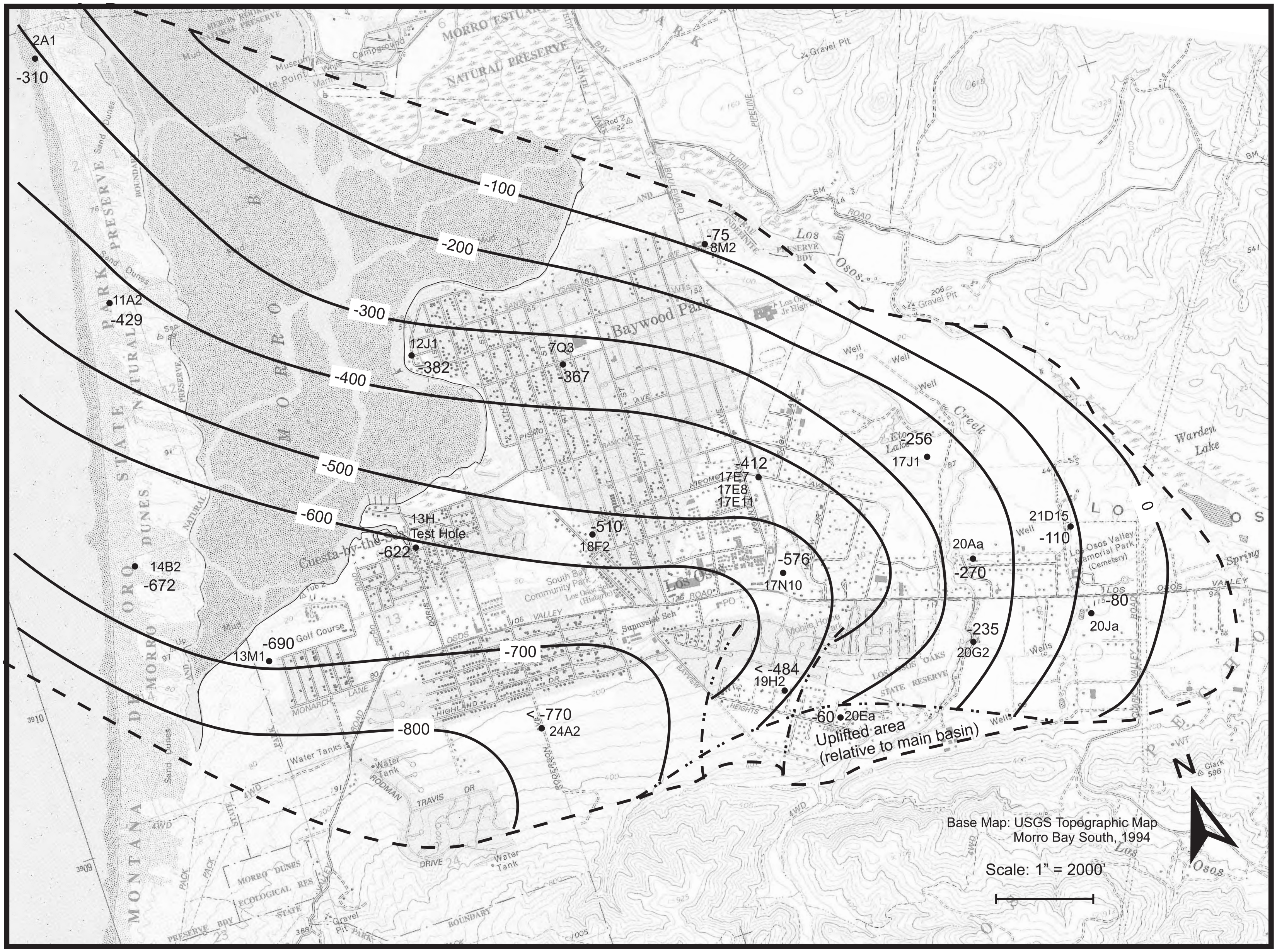
0 2000

Figure 2

Geology
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates




-690
13M1 Well location with data point

-700 Elevation contour on base of permeable sediments in feet above sea level

Buried fault

Approx. basin limits

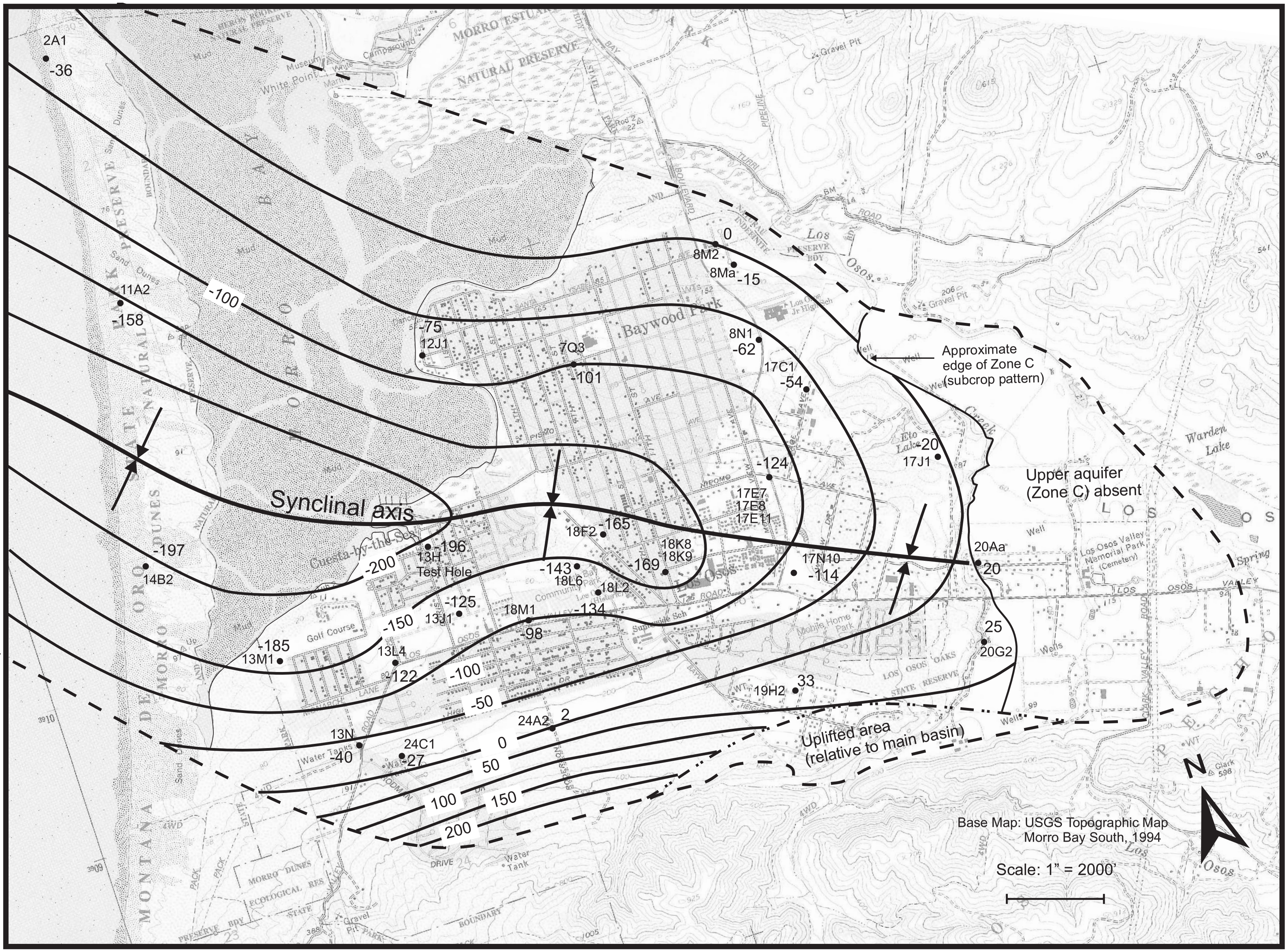
Contour interval = 100 feet

Figure 3

Elevation Contours on
Base of Permeable Sediments
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates




-20
17J1 • Well location with base of Zone C in feet above sea level

-150 Elevation contour on base of Zone C in feet above sea level

Buried fault

Approx. basin limits

Contour interval = 50 feet

NOTE: The base of Zone C is equivalent to the top of the regional aquitard

Figure 4

Elevation Contours on Base of Upper Aquifer (Zone C)
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates

200 feet (geologic cross-section C-C; Appendix A). An east-west trending fault, subparallel to the main strand of the Los Osos fault, has been proposed by Cleath & Associates (2003) and shows an apparent uplift to the south of sediments beneath Bayview Heights by 400-500 feet (geologic cross-section H-H'; Appendix A).

Other faults displacing basin sediments have been proposed by various investigators (Figure 2). The Morro Group (1989) proposed a northwest trending fault, named Strand B of the Los Osos fault zone, between the main Los Osos fault, south of Calle Cordoniz, and Morro Bay (through Sweet Springs). The fault was considered a potential seismic hazard for the former CSA 9 Wastewater Project and was based on electric log correlations, geologic mapping near Calle Cordoniz, vegetation, and springs. Motion on this fault strand was interpreted to be right-lateral. Lettis and Hall (1990, 1994) also proposed a northwest trending fault intersecting Sweet Springs. The motion on this fault was down-to-the-southwest, creating a triangular graben structure between it and the down-to-the-north Los Osos fault. The basis for the alignment was a relatively abrupt change in the depth to the Careaga Formation across the fault, using an assumption that the appearance of marine shells in drilling logs was an indicator for the top of the Careaga Formation. Only the fault strands proposed by Yates and Wiese fault and Cleath & Associates have been retained herein. Further discussion of the proposed faults is provided in Part 3 of this report.

## Aquifer Zone Characterization

In 2003, Cleath & Associates prepared a series of geologic cross-sections interpreting ground water basin structure, based on correlating six discrete horizons across the basin in a series of geologic cross-sections. A revised set of these cross-sections, along with accompanying water level contour maps for aquifer zones identified in the cross-sections, are included in Appendix A and Appendix B.

The six horizons correlated in the cross-sections were selected for their significance with respect to the movement of ground water within the basin. Between these horizons, five aquifer zones were defined, labeled Zone A through Zone E. Zones A, B, and C are designations that had originally been used by Weber, Hayes & Associates (2001) to identify aquifers in downtown Los Osos as part of a service station site investigation report. This nomenclature was adapted for the basin and expanded to include Zones D and E by Cleath & Associates (2003). A sixth aquifer zone also referred to herein is the alluvial aquifer, which lies along the Los Osos Creek valley. A description of these aquifer zones and the regional aquitard is included below. Refer also to cross-sections in Appendix A.

### Alluvial Aquifer

Recent alluvial deposits are interpreted to overlie Paso Robles and Careaga Formation sediments in the Los Osos Creek valley. These alluvial deposits are typically close to 70 feet thick. The base of the alluvial deposits extends to approximately 40 feet below sea level where Los Osos Creek exits the basin through a narrows in the lower creek valley (Figure 2). These general parameters of alluvial thickness and depth for the Los Osos Creek valley are similar to those in Chorro Valley, the other major watershed draining to Morro Bay Estuary.

The Los Osos Creek valley alluvium typically consists of mostly clay with interbedded sand and gravel lenses. A basal sand and gravel unit is also inferred from inspection of drillers logs, although the similarities in lithology with underlying Paso Robles Formation deposits make alluvial sediment interpretation difficult. No pump tests are available for alluvial wells. Active irrigation or private domestic wells may tap the basal gravel in the alluvium, but typically also extend into deeper aquifer zones.

Zone A - Perched Aquifer

The perched aquifer overlies a competent clay at the base of the Older dune sands, beneath a large portion of the central basin area, including Bayridge Estates and Bayview Heights (where it is truly perched), downtown Los Osos, and through portions of Baywood Park. The base of the dune sands is interpreted as an erosional surface, and is an unconformable contact at the top of the Paso Robles Formation. The perched aquifer is unconfined and completely within dune sands, although there are also many areas with saturated dune sands that are not specifically in Zone A. The perching clay outcrops along the banks of Los Osos Creek above an elevation of approximately 80 feet, although more than one perching clay may be involved.

Dune sands are wind-blown deposits. Also referred to as the Baywood fine sand, these deposits typically comprise poorly graded fine to medium-grained clean sand. The dune sands are saturated above the perching clay (Zone A), at lower elevations adjacent to Morro Bay (Zone C), and across Baywood Park (portions of Zones A, B and C). Maximum thickness of the dune sands is estimated at close to 100 feet along the dune ridges in Baywood Park (Cleath & Associates, 2003).

There have been some conflicts in interpretation of the extent and age of dune sand. The DWR (1972) differentiated Older (upper Pleistocene) dune sands in excess of 150 feet thick (extending to the regional aquitard), and limited the Recent dune sands to 25+ feet thick. Brown and Caldwell (1983) also extended Older dune sands to the regional aquitard. The Morro Group (1987, 1989), restricted the extent of Recent dune sand to the sand spit and a few inland areas along the bay. The Morro Group also limited the thickness of Older dune sand by including Paso Robles Formation deposits above the regional aquitard. The U.S.G.S. (Yates and Wiese, 1988), interpreted Recent dune sands as being up to 200 feet thick above the regional aquitard, with the thickest sections attributable to erosion along the coastline during the Upper Pleistocene sea level low.

The interpretation of the Morro Group is adopted herein, with Paso Robles Formation deposits lying between the dune sands and the regional aquitard. The sand spit and some inland dunes along the bay are Recent, while the dune sands elsewhere are probably Older, and in some cases (such as at higher elevations to the south) may be Paso Robles Formation equivalent. The average hydraulic conductivity of the Older dune sand and shallow Paso Robles Formation sand is estimated to range from 70 to 230 gallons per day per square foot (gpd/$ft^2$), based on the first and third quartile of 50 laboratory and field tests from various locations across the basin (Appendix C). The specific yield for these shallow sands is estimated between 20 and 25 percent (DWR, 1958 and Johnson, 1967).

Zone B - Transitional Aquifer

The transitional aquifer is composed of fine sands and silty sands with occasional clayey and gravelly lenses. Zone B is separated from Zone A by a clay and clayey sand aquitard up to 30 feet thick beneath downtown Los Osos. The piezometric head in Zone B lies between the perched aquifer and the uppermost community water supply aquifer.

Water levels in Zone B have been measured up to 16 feet lower than Zone A, and close to 60 feet higher than Zone C at multi-level monitoring wells (Weber Hayes, 2001). These water level differences, along with differences in general mineral water quality, led to the identification of saturated Zone B by Weber-Hayes. Subsequent lithologic correlations between downtown and wells to the north and east placed Zone B within the Paso Robles Formation (Cleath & Associates, 2003). No pumping tests specific to Zone B are available.

Zone C - Upper Aquifer

The upper water supply aquifer, Zone C, overlies the regional aquitard and extends up to the water table, except where overlain by Zones A or B. Zone C is predominantly within Paso Robles Formation deposits, except at lower topographic elevations where dune sands are saturated.

The Paso Robles Formation is composed of unconsolidated sands, gravels, and clays. Gravel clasts are generally composed of Franciscan assemblage rocks, including cherts, metavolcanics, and (hard) sandstone. Shales, quartz, and diabase/dacite, are also commonly logged. The depositional environment has included beach and near-shore marine conditions. As a result, sea shells are occasionally present in the Paso Robles Formation.

West of downtown Los Osos, the upper aquifer Zone C is generally composed of fine to medium grained sands, with relatively few clays or gravels, except one notable basal gravel. In the downtown area, Zone C sediments coarsen, with more fine gravels noted in logs, although interbedded clays are also common.

Pump tests in the main water supply aquifers include tests for Zone C, for Zone C and D combined, for Zone D, for Zone D and E combined, and for Zone C, D, and E combined. Due to lateral differences in aquifer lithology, a test in one area may not necessarily apply to another area. A brief summary of aquifer tests is listed below in Table 1.

**Table 1**
**Constant Discharge Aquifer Test Summary**

| Well ID | Aquifer Zone | Date | Flow (gpm) | Duration | $T^1$ (gpd/ft) | Screen (ft) | $K^2$ (gpd/ft2) |
|---|---|---|---|---|---|---|---|
| 30S/11E-07N1 | C | 12/27/00 | 82 | 8 hours | 3,900 | 28 | 140 |
| 30S/10E-13L | C | 1/16/04 | 85 | 4 hours | 9,000 | est. 60 | 150 |
| 30S/11E-18K3 | C | 7/25/01 | 170 | 24 hours | 9,500 | 64 | 150 |
| 30S/11E-18K9 | C, D | 12/27/00 | 300 | 8 hours | 15,800 | 175 | 90 |
| 30S/11E-17E11 | C, D | 1/2/01 | 190 | 8 hours | 4,600 | 80 | 60 |
| 30S/11E-17N10 | C, D, E | 2/26/01 | 320 | 24 hours | 5,800 | 350 | 17 |
| 30S/11E-07Q3 | D | 1/4/01 | 180 | 24 hours | 7,400 | 40 | 180 |
| 30S/10E-13N | D | 12/7/99 | 150 | 24 hour | 13,200 | 80 | 160 |
| 30S/11E-18M1 | D, E | 8/31/74 | 418 | 6 hours | 10,500 | 130 | 80 |
| 30S/11E-18L2 | D, E | 3/6/86 | 540 | 12 hours | 10,500 | 95 | 110 |
| | | 12/29/00 | 750 | 8 hours | 11,000 | 95 | 120 |
| 30S/11E-18L6 | D, E | 1/18/2005 | 50 | 7 hours | 13,200 | 120 | 110 |
| 30S/11E-19H2 | D | 1/14/2005 | 20 | 12 hours | 6,200 | 100 | 62 |
| 30S/10E-13M1 | E | 1/19/2005 | 50 | 4 hours | 14,200 | 60 | 240 |
| 30S/11E-20Aa | E | 2/1/2005 | 30 | 8 hours | 2,930 | 70 | 42 |

Notes: [1]Transmissivity (T) derived from pumping test and/or recovery data using Cooper-Jacob approximation of the Theis Equation.
[2]Hydraulic conductivity (K) is based on well screen footage, not total aquifer zone thickness, and would generally represent values for the most permeable sand and gravel lenses in the aquifer zone.

Specific yield estimates for aquifer zones would be estimated based on individual lithology, and would typically range from 13% to 20% (Johnson, 1967). Storativity data is scarce in the ground water basin. Where unconfined (portions of Zone C, especially in the west basin), specific yield estimates apply. Where confined, or semi-confined (leaky), values may be several orders of magnitude lower. A review of observation well results for the pumping test conducted at a Zone C well in downtown Los Osos

(30S/11E-18K3) indicated a storativity of 0.0001 for Zone C beneath the perching clay aquitard, a confined aquifer condition (Weber, Hayes & Assoc., 2001).

Regional Aquitard

Individual clay beds in the Paso Robles Formation are generally discontinuous across the basin, with one important exception. A regional aquitard has been recognized since the early 1980's, when Brown & Caldwell (1983) noted differences in water quality above and below the clay. The regional aquitard, also referred to as the AT2 Clay (Morro Group, 1989), ranges from approximately 20 to 80 feet thick, and averages 50 feet thick over 27 locations (Cleath & Associates, 2003). Stringers of gravelly sands may be logged locally within the clay, and some of which are tapped by wells. The regional aquitard is one of the most significant geologic features in the ground water basin and separates the principal upper and lower water supply aquifers (Zone C and D, respectively). The geophysical response of the aquitard to e-logs and natural gamma logs in boreholes provides for aquitard correlation over a large portion of the basin, and also characterizes the aquitard as a layered sequence of two or more discrete clay beds in many areas. The hydraulic parameters of the clay have not been measured directly. Anisotropic hydraulic conductivity values of 0.1 feet per day (0.75 gpd/ft$^2$) horizontal and 0.002 feet per day (0.015 gpd/ft$^2$) vertical are currently used by the steady-state flow model.

Zone D - Lower Aquifer

Below the regional aquitard is lower aquifer Zone D. This is currently the primary source of the community water supply. Zone D is a Paso Robles Formation aquifer zone composed predominantly of sands and gravels.

The lithologic description of Zone D, consisting of interbedded sand, gravel, and clay, does not appear to vary as much as Zone C or Zone E across the basin. Gravel clast composition is predominantly Franciscan Formation detritus (sandstone, chert, metavolcanics) along with siliceous shales and claystones. Shell fragments are noted in Zone D lithology at wells on the sand spit and Baywood Park.

The structure of Zone D is generally conformable with the overlying aquitard, except where displaced by Quaternary faulting in the Bayview Heights area (geologic cross-section C-C'; Appendix A). The aquifer zone averages close to 100 feet thick over the central portions of the basin, thinning toward the east.

Table 1, above, includes results of aquifer tests conducted in Zone D. Hydraulic conductivity ranges from approximately 60 to 180 gpd/ft$^2$ (8 to 24 feet per day) in the main basin area. The results of the U.S.G.S. pumping test in 1986 at well 30S/11E-18L2, with observation well data, indicated a storativity for Zone D and E of 0.0008. This value corresponds to a confined aquifer condition (Yates and Wiese, 1986).

Zone E - Lower Aquifer

The AT3 Clay separates the lower aquifer Zone D from Zone E. This aquitard is typically thinner than the regional aquitard and possibly discontinuous. The two lower aquifer zones differ with respect to salinity near the coast and with respect to permeability in inland areas, warranting the hydrogeologic aquifer distinction.

The contact between the Plio-Pleistocene Paso Robles Formation and the Pliocene Careaga Formation occurs in the middle of Zone E. The Careaga Formation is the lowermost basin hydrostratigraphic unit and has been included for practical purposes with Zone E.

The Paso Robles - Careaga Formation contact is a difficult horizon to track within the basin. This is due to changes in Careaga lithology from east to west across the basin, with possible complications from faulting and/or facies changes. The formation contact is interpreted to be an angular unconformity, based on correlations along a prominent Careaga shell bed.

Correlation between deep basin sediments and the Careaga Formation sandstone has been suggested in prior work (Yates and Wiese, 1988). The Careaga Formation has not been mapped regionally in outcrop, however, and there is considerable variation in what has been tentatively identified as Careaga Formation. The deep basin sediments in the western portion of the basin include much coarser sands and gravels, compared to the finer sands and silty sands in the eastern portion of the basin. Where observed by Cleath & Associates during drilling, the Careaga Formation interval in the eastern basin correlates with the U.S.G.S. (Yates and Wiese, 1988, page 15) description as a "massive, light- to dark-green, fine grained micaceous quartz sandstone, weakly to moderately cemented, locally carrying fossil mollusks." The sand appeared less permeable and finer grained than would normally be associated with the upper Graciosa member of the Careaga Formation, however. The interval could be interpreted to correspond to the lower Cebada member of the Careaga, or (perhaps more likely) as Pismo Formation, which is mapped in the area. In fact, the lithologic descriptor from a U.S.G.S. log for a similar interval (well 30S/11E-19H2) states, "Careaga Formation with a Belleview aspect", referring to a fine-grained sandstone and claystone member of the Pismo Formation.

Coarsening of the deep basin sediments to the west, however, to include sands and gravels with abundant chert and siliceous/porcelaneous shales, could be associated with upper Careaga Formation conglomerate, but could also be part of the overlying Paso Robles Formation. The primary indicators used during correlations to identify the formation contact were a cemented zone and the appearance of white porcelaneous shale clasts, often concurrent with or followed by shells. Available electric logs across the formation contact generally show a spike in resistivity at the cemented zone, although many of the resistivity signatures on east side e-logs are masked by sea water intrusion.

The occurrence of marine fossils (shells) is often noted in deep basin sediments, and a prominent shell bed has been correlated within the Careaga Formation. Identification of shells recovered during a 1977 DWR drilling program suggest fossiliferous sediments beneath the Morro Bay sand spit are at least as old as Pleistocene age, except for at well 30S/10E-14B2, where Recent clams and oysters were noted between 97-99 feet, and a clam specimen of Pliocene or older age was reported near the bottom of the hole (680-687 feet depth). Unlike the Pleistocene and Pliocene age determinations, however, the reference to Recent fossils at well 30S/10E-14B2 was not confirmed by the paleontologist's work presented in the DWR report, where fossils suggesting at least Pleistocene age are identified at depths as shallow as 50 feet in the other two sand spit borings (DWR, 1979). A marine facies within the Paso Robles Formation is interpreted to extend along most of the sand spit and into Baywood Park.

There are no pump tests available for wells completed exclusively in the Careaga Formation portion of the Los Osos ground water basin (lower portion of aquifer Zone E). As discussed above, there are both coarser grained and finer grained zones attributed to the Careaga, which would likely have different aquifer parameters. The hydraulic conductivity for the finer grained, massive silty sandstone zone with Pismo Formation characteristics has been estimated based on comparisons between pumping tests at wells 30S/11E-17E11 and 30S/11E-17N10 (Table 1). These two wells, along South Bay Boulevard east of downtown Los Osos, are approximately 2,000 feet apart. Both wells tap productive Paso Robles aquifer zones, but well 17N10 also taps close to 100 feet of the fine-grained Careaga Formation. Assuming the incremental increase in transmissivity measured in pumping tests at 17N10 (compared to 17E11) is attributable to the Careaga Formation, the fine grained silty sandstone is estimated to have a hydraulic conductivity of approximately 7 gallons per day per foot squared (gpd/ft$^2$).

The coarser grained Careaga Formation intervals are lithologically similar to the deep Paso Robles Formation sediments, and are composed of sand and gravel aquifer zones with interbedded clays. No pumping tests are available specifically in Zone E, although pumping tests are available for wells that tap a combination of Zone D and E aquifer zones (30S/11E-18M1 and 18L2; Table 1). E-log comparisons show a typically lower permeability in Zone E sand and gravel zones compared to Zone D.

Adjusting for differences in permeability and screened intervals between Zone D and Zone E aquifers, the hydraulic conductivity of Zone E in the vicinity of wells 18L2 and 18M1 is estimated at 60-90 gpd/ft$^2$, with the overlying Zone D hydraulic conductivity estimated at 129-140 gpd/ft$^2$. Note that these estimates are for discrete aquifer zones only, not aggregate thicknesses of basin sediments.

A specific yield estimate for Careaga Formation materials would be based on lithologic description, as there are no local laboratory or field estimates. The finer-grained, massive sandstone interval in the eastern basin area consists primarily of fine sand and silty sand, and an average specific yield of 10% appears reasonable (between 5% and 15%, based on comparison with specific yield values from U.S.G.S., 1967). The conglomerate interval specific yield is estimated at 15%. Storativity values for Careaga Formation aquifer zones have not been investigated through field studies, and can only be assumed to approximate the storativity for other Paso Robles Formation deep aquifer zones, which is estimated from pumping tests to be approximately 0.0008 in the central portion of the basin (Yates and Wiese, 1986).

Base of Permeable Sediments

Zone E extends to the base of permeable sediments. The base contact is an unconformity and a formation contact, although the general synclinal shape of the basin structure is maintained. The relatively impermeable rocks that underlie and surround basin sediments include primarily Franciscan Formation graywacke, metavolcanics, and mélange in the northern and eastern portions of the basin, and Pismo Formation shales and mudstones in the southwestern portion of the basin. Where sufficiently brittle and fractured, the metavolcanics have a potential for yielding in excess of 100 gallons per minute to a well, but these permeable zones are east of the ground water basin limits, along the Los Osos fault zone on the northern flank of the Irish Hills. The other basement rocks are considered non-water bearing, consisting mostly of soft shales or cemented sandstones and siltstones.

Off-shore Basin Limits

The basin geometry off-shore is not well defined, but there is clearly an abrupt change approximately one mile west of the sand spit. As shown in Figure 1, bedrock outcrops have been mapped on the sea floor and are encroaching into what would otherwise be considered within the off-shore basin area. The mapping technique used offshore was sidescan sonar from an ocean vessel with a resolution sufficient to infer complex folding in shale bedding planes.

## Ground Water Recharge and Movement

The majority of recharge to the Los Osos Valley ground water basin consists of the following elements:

- Direct percolation of precipitation
- Return flow from irrigation and septic system discharges
- Stream seepage from Los Osos Creek
- Subsurface inflow across basin boundaries

Within the basin, individual aquifer zones may receive recharge directly from the above sources, or indirectly through inflow (leakage) from an overlying or underlying aquifer zone. Movement of ground water within alluvial, perched, and upper aquifer zones can be inferred from ground water elevation contour maps included in Appendix B (Cleath & Associates, 2003). Hydrographs for wells representing individual aquifer zones in the basin are included in Appendix D.

Alluvial Aquifer

Ground water in the alluvial aquifer of the Los Osos Creek Valley moves down the valley toward the Morro Bay Estuary. Recharge to the alluvium includes the elements listed above. Subsurface outflow from the alluvium into aquifer Zones C, D and E occurs where these zones subcrop beneath the alluvium.

Alluvial water levels are represented by well 30S/11E-20A2 (Appendix D). During drought years, water levels decline in excess of 10 feet between spring and fall, but typical seasonal fluctuations are closer to 5 feet. Many irrigation wells in the creek valley tap basin aquifers below the alluvium, where water level fluctuations are greater due to seasonal irrigation production (for example, well 30S/11E-21E4; Appendix D).

Zones A, B, and C

The perched aquifer (Zone A) receives recharge from direct percolation of precipitation and return flows from anthropogenic activities. Ground water movement in Zone A is within dune sand, and flow directions are generally northwest to northeast, with relatively steep hydraulic gradients of up to 0.06 ft/ft between Bayview Heights and downtown (parallel to the topographic slope). Flow in the perched aquifer drains to Willow Creek and issues from seeps in the Oaks Preserve and along the banks of Los Osos Creek. To the north and west, the perching clay pinches out, and ground water spills into the upper aquifer (Zone C). A ground water high between downtown Los Osos and eastern Baywood Park separates water moving to the east toward Los Osos Creek from water moving to the west toward the Morro Bay Estuary (Appendix B). In portions of downtown Los Osos and areas to the east, the transitional aquifer (Zone B) receives recharge through leakage from Zone A, and represents an intermediate hydraulic zone between the perched aquifer and the upper (water supply) aquifer.

Recharge to the upper aquifer (Zone C), occurs via the direct recharge sources itemized above, as well as through leakage from Zones A and B. Movement of ground water in Zone C is variable, but generally flows north and west toward the bay, with some easterly flow from Baywood toward Los Osos Creek. There is a pumping depression in downtown Los Osos, that draws water in from surrounding areas. The hydraulic gradients in Zone C range from 0.004 ft/ft to 0.025 ft/ft, and average approximately 0.009 feet of decline in head per foot of distance (Appendix B).

Water levels in Zone A, B, and portions of Zone C generally rose during the rapid development of the 1970's, due to increased recharge from septic return flows. Since the 1970's, seasonal fluctuation and wet period / drought cycles can be seen in these perched and upper aquifer zones, with generally stable levels overall (Appendix D). Of note is the hydrograph for well 30S/10E-14B1, completed in Zone C on the sand spit. This well shows reversed seasonal fluctuations, with higher water levels measured in the fall than the spring. Possible explanations include delayed response to seasonal pumping and/or recharge, or a seasonal fluctuation in local aquifer salinity, although the latter is not suggested from the available water quality data.

Zones D and E

Recharge and movement of ground water in the lower aquifer (Zones D and E) is the subject of the current investigation. Analysis of hydrochemical data has shown that ground water quality from lower aquifer production wells is closer in composition to Los Osos Creek alluvial water than to upper aquifer water (Brown & Caldwell, 1983). In 1988, however, the U.S.G.S. (Yates and Wiese) published a report on the Los Osos Valley ground water basin where the following observations were made based on results of a numerical model of the ground water basin (page 50):

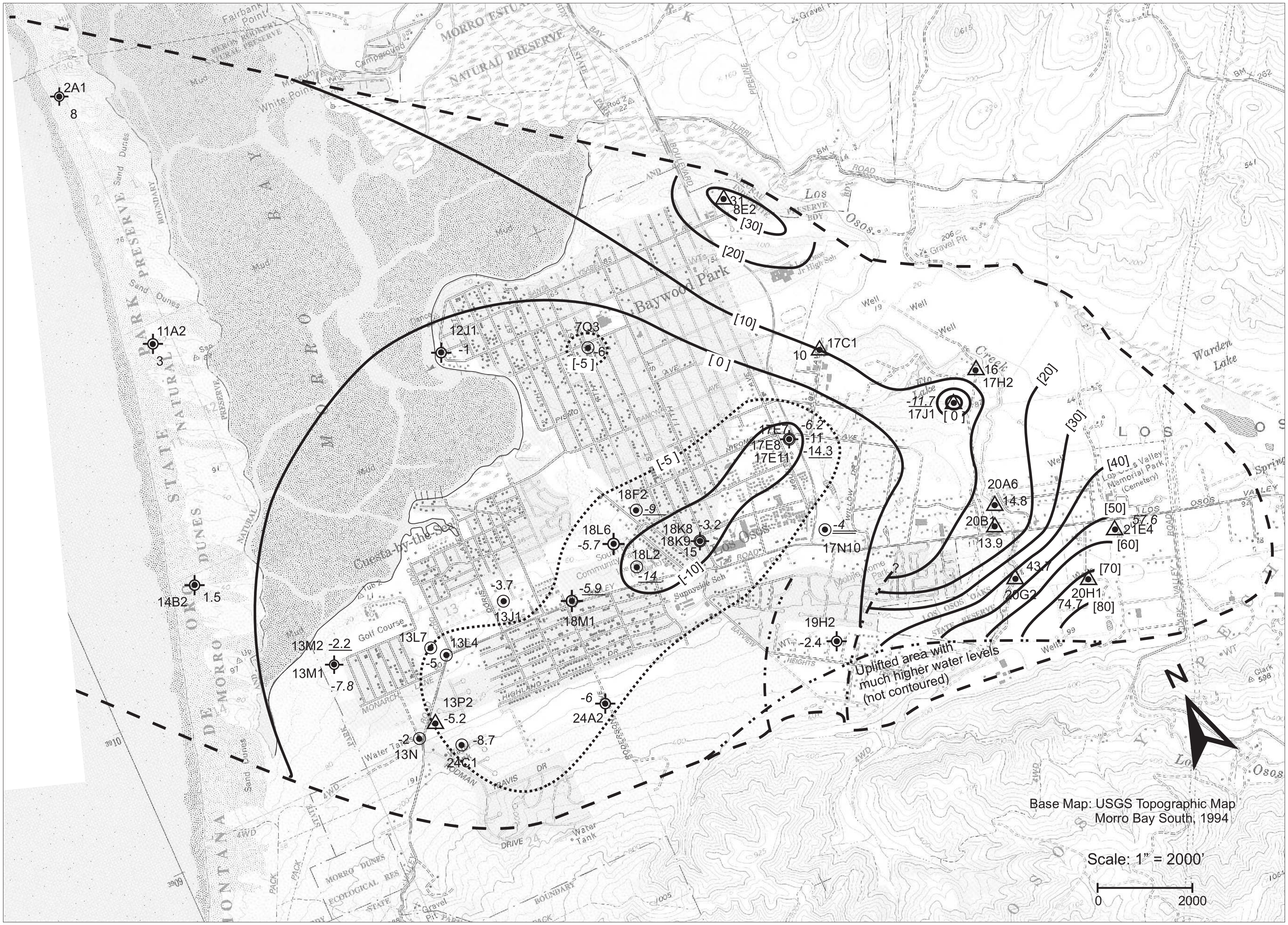
> "The downward head gradients have important long-range water-quality implications. Even in the western part of the basin, where there is an apparently continuous clay layer, model results indicated that a significant amount of recharge to deep strata must come from downward percolation of return flow. Seepage from Los Osos Creek is insufficient to supply present pumping rates, and the absence of widespread seawater intrusion indicates the ocean is also not the principal source of supply. The most likely source is downward percolation of return flow. Although at present only shallow wells have been affected by poor-quality return flow, it is likely the deep wells eventually also would be affected."

A subsequent review of nitrate concentrations over time in deep aquifer production wells showed no historical trend of increasing nitrates in the deep aquifer, while shallow aquifer nitrate concentrations were climbing (Metcalf & Eddy, 1994, Task F). These findings suggest that hydraulic communication between the upper and lower aquifer is significantly restricted by the regional AT2 clay aquitard, despite the U.S.G.S. model findings.

The basin model was later modified by URS Corporation in association with Team Engineering (2000), although the conclusions as to the principal source of recharge to the basin (septic return flows) did not change. The current basin model (Yates and Williams, 2003) also operates with the majority of recharge to the lower aquifer coming from upper aquifer leakage through the regional aquitard.

A lower aquifer ground water elevation contour map for Spring 2001 is shown in Figure 5. Ground water is generally moving toward downtown Los Osos from surrounding areas. The highest ground water elevations are in the Los Osos creek valley, and a hydraulic gradient of up to 0.03 ft/ft is inferred between the upper creek valley and downtown Los Osos. This gradient is relatively steep and suggests significant permeability restrictions, possibly fault-related, as also noted by the U.S.G.S. (Yates and Wiese, 1988).

A large area of the lower aquifer includes ground water elevations below sea level. This condition is a precursor to and a characteristic of sea water intrusion. Water levels in Zones D and E have declined over time in most areas, except the Los Osos Creek valley. These declines took place mostly during the 1970's and early 1980's. Of note, however, are continued declines at monitoring well 30S/11E-19H2 in Bayview Heights (Appendix D).




LEGEND

24A2 Lower aquifer monitoring well

17N10 Lower aquifer purveyor well

21E4 Other lower aquifer well (domestic or irrigation)

normal - Zone D elevation (shallow)
*italic* - Zone E elevation (deep)
*italic* - Zones D, E mixed
normal - Zones C, D mixed
*italic* - Zones C, D, E mixed

[10] Ground water elevation contour in feet above sea level Spring 2001 (some values estimated)

approx. basin limits

buried fault splay

Figure 5

Spring 2001
Ground Water Elevation
Contour Map - Lower Aquifer

DWR Grant Project
Los Osos CSD

Cleath & Associates

The results of the lower aquifer recharge investigation is presented in Part 3 of this report. Sources of recharge considered include subsurface inflow from the Los Osos Creek Valley alluvial deposits, subsurface inflow from bedrock, seawater intrusion, leakage from the upper aquifer through the regional aquitard, and wellbore flow between the upper and lower aquifer.

## Ground Water Production

Production in the Los Osos Valley ground water basin has averaged approximately 3,500 acre-feet per year since 1985, and has been relatively stable due to a 1983 building moratorium. Production for individual aquifer zones, and by user group, is summarized below in Table 2. Estimated annual production for individual aquifer zones between 1982 and 2001 is shown in Figure 6. Purveyor production is based on actual totalizer meter readings, while private domestic and agricultural irrigation production is estimated from land use information. The distribution of ground water production in the basin by aquifer zone for calendar year 2001 is shown in Figure 7.

**Table 2**
**1985-2001 Ground Water Production**
**Los Osos Valley Ground Water Basin**
**(acre-feet per year)**

| Aquifer Zone | Purveyors | | | Private Domestic | Agricultural Irrigation* | 1985-2001 average | 2001 prod. |
|---|---|---|---|---|---|---|---|
| | Cal Cities | LOCSD | S&T | | | | |
| A, B | 0 | 0 | 0 | 40 | 0 | 40 | 40 |
| C, alluvium | 250 | 230 | 50 | 120 | 330 | 980 | 810 |
| D | 820 | 630 | 60 | 40 | 400 | 1950 | 2170 |
| E | 0 | 280 | 0 | 0 | 220 | 500 | 380 |
| Total | 1070 | 1140 | 110 | 200 | 950 | 3470 | 3400 |

Note: *includes 70 afy Sea Pines golf course irrigation. Purveyor production metered. Private domestic production and agricultural irrigation production estimated based on land use.

Purveyor well water production accounts for approximately two-thirds (67%) of the total basin production, with agricultural irrigation at approximately 27%, and private domestic approximately 6% (Figure 6). The active private domestic wells are mostly located outside of the purveyor service areas, and mostly east of South Bay Boulevard. Agricultural irrigation wells are located mostly in the Los Osos

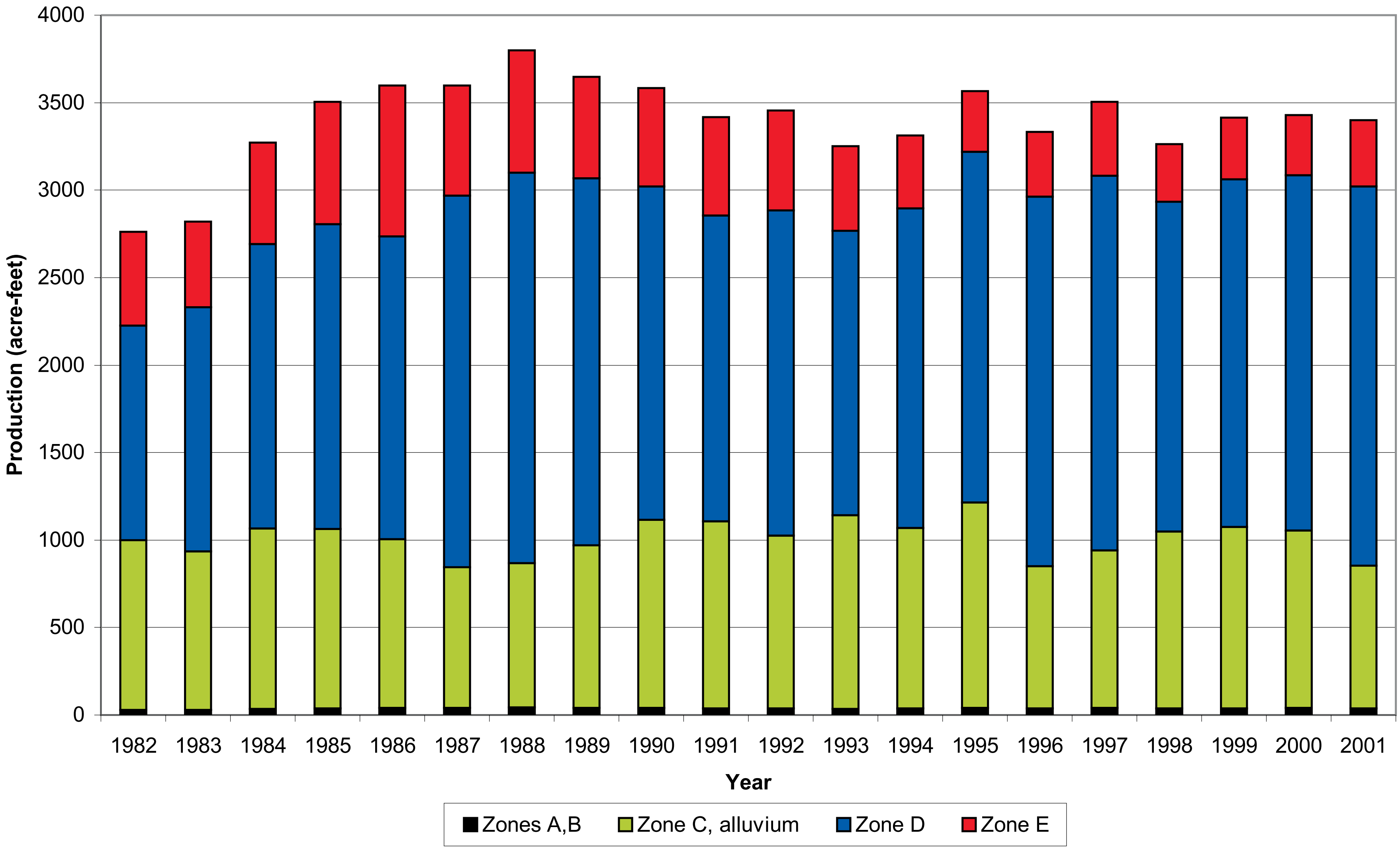



Figure 6
1982-2001 Annual Production
Los Osos Valley Ground Water Basin

DWR Grant Project
Los Ocsc CSD

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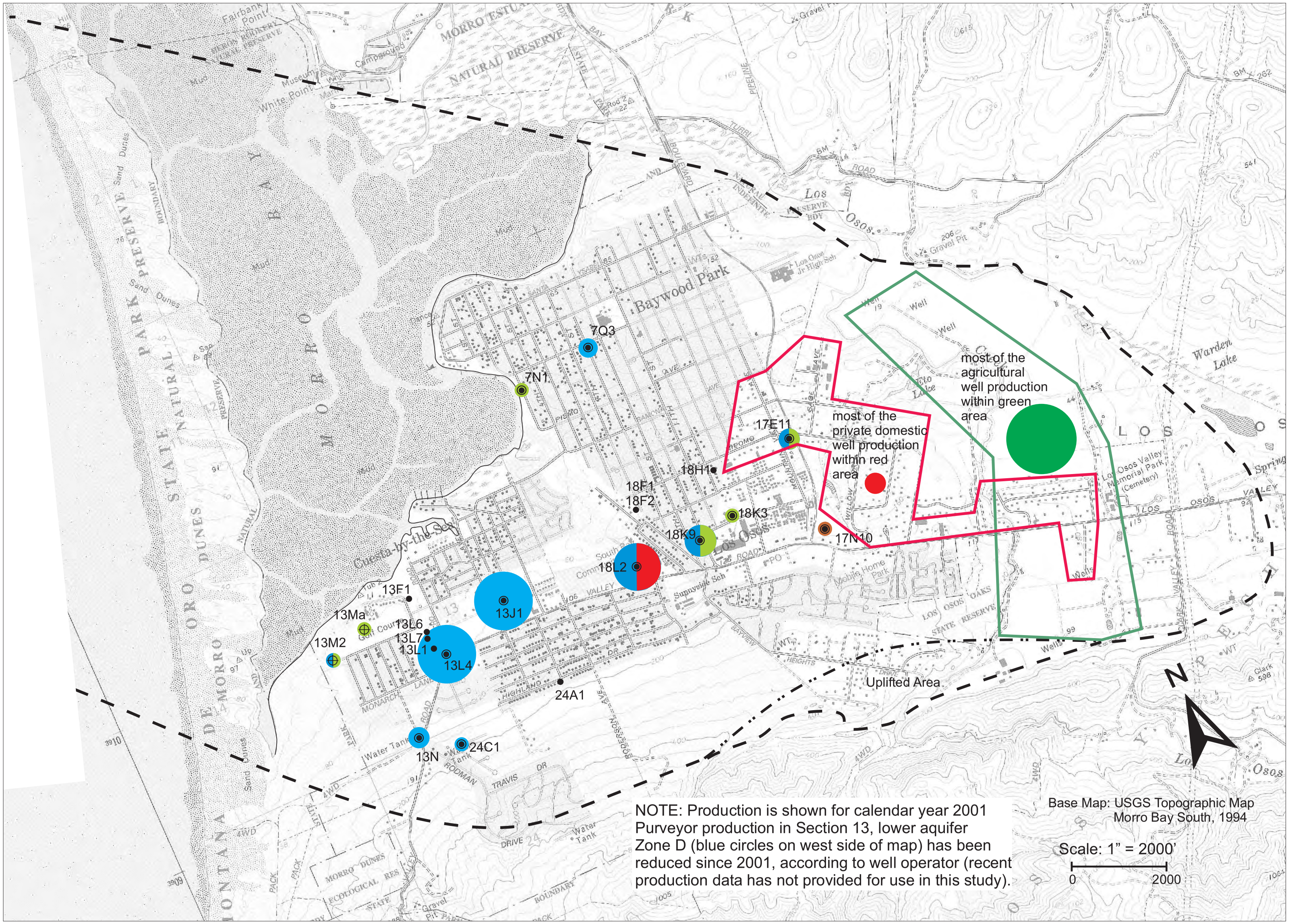



LEGEND

18H1 ● Inactive purveyor well
7N1 ◉ Active purveyor well
13Ma ⊕ Golf course irrigation well

Ground water production in acre-feet per year

10 to 100
101 to 200
201 to 300
301 to 400
401 to 600
601 to 800

Specific Major Well Production:

Zone D
Zone D and E mixed
Zone C and D mixed
Zone C
Zone C, D and E mixed

Generalized Area production:

Zones A, B, C, D and alluvium mixed
Zone C, D, E and alluvium mixed

Figure 7

Ground Water Production
Los Osos Valley
Ground Water Basin
Calendar Year 2001

DWR Grant Project
Los Osos CSD

Cleath & Associates

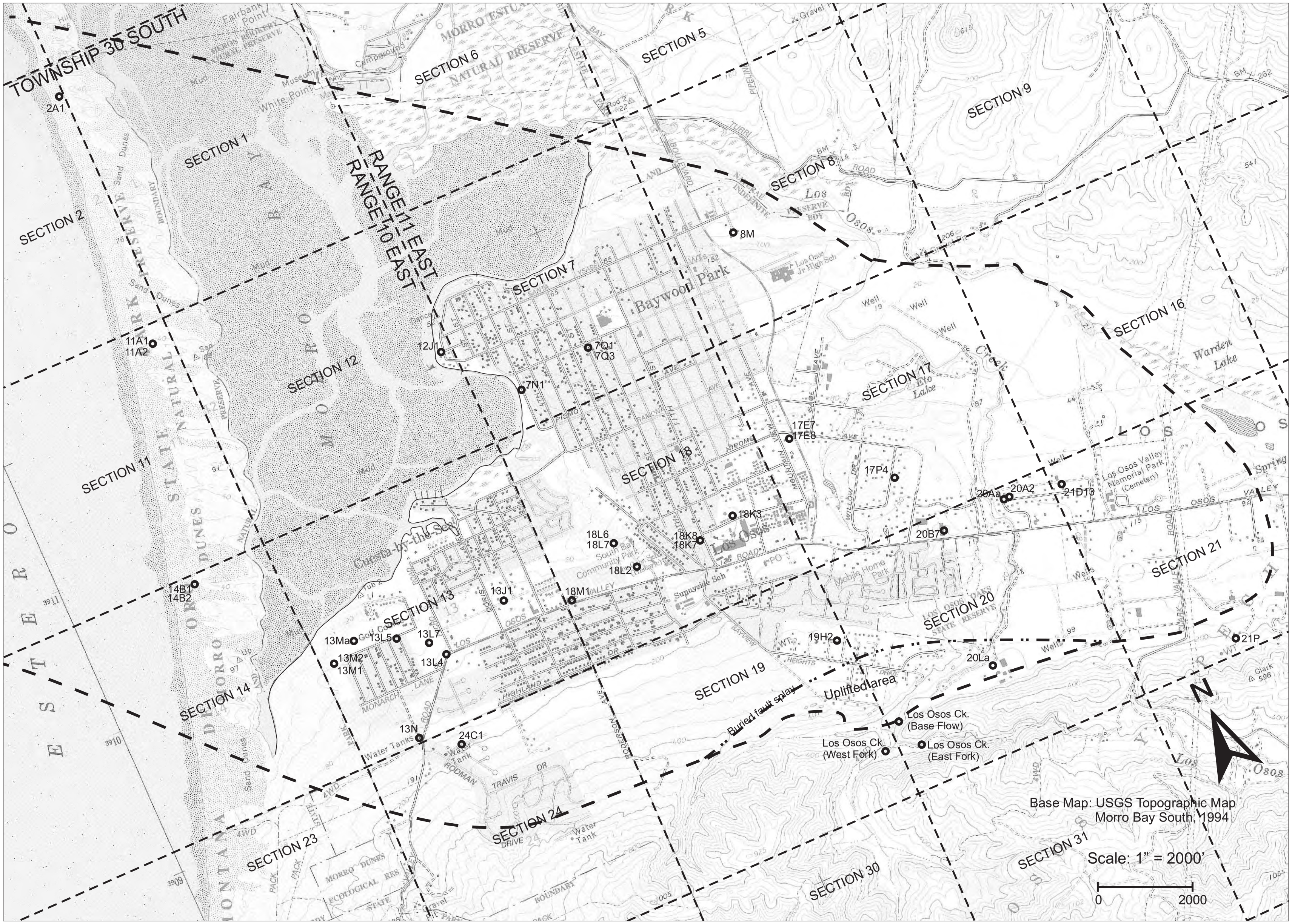
Creek valley. Note that purveyor production from lower aquifer Zone D in Section 13 has been reduced since 2001 (Figure 7).

## FIELD INVESTIGATIONS

Field investigations completed for the project included water sampling, aquifer testing, bedrock reconnaissance, test hole drilling, and geophysical logging. These efforts provide valuable new information on both the extent of sea water intrusion and the sources of lower aquifer recharge.

### Water Sampling

Water samples were collected at 39 locations across the ground water basin, including 20 lower aquifer wells, 11 upper aquifer wells, 4 creek valley wells (2 shallow and 2 deep), 1 bedrock well, and 3 surface water locations. A summary of well construction and aquifer zones tapped at water sampling locations for the sea water intrusion study are included in Table 3. The corresponding information for lower aquifer source investigation water sample locations are included in Table 4. Figure 8 shows sample locations.




LEGEND

7N1 — 2004-2005 Water Sampling Location

approx. basin limits

Section lines

Figure 8

Water Sampling Locations
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

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## Table 3
## Sea Water Intrusion Study Water Sampling Sites

| Well ID | Aquifer Zone | Perforations (depths in ft) | Casing diam. (in) | RP* (ft msl) |
|---|---|---|---|---|
| 30S/10E-2A1 | E | 220-230 | 2 | 15.8 |
| 30S/10E-11A1 | C | 150-160 | 2 | 16.0 |
| 30S/10E-11A2 | D | 234-244 | 2 | 16.1 |
| 30S/10E-12J1 | D | 349-389 | 2 | 8.4 |
| 30S/10E-13J1 | D | 290-406 | 10 | 95.3 |
| 30S/10E-13L4 | D | 240-380 | 14 | 68 |
| 30S/10E-13L5 | C | 26-36 | 2 | 32.6 |
| 30S/10E-13L7 | C, D | 160-300 | 8 | est. 35 |
| 30S/10E-13Ma | C | 128-168 | 10 | 37 |
| 30S/10E-13M1 | E | 477-537 | 6 | 41.2 |
| 30S/10E-13M2 | C, D | 197-227; 262-292 | 6 | 40.71 |
| 30S/10E-13N | D | 260-340 | 8 | 138.5 |
| 30S/10E-14B1 | C | 190-200 | 2 | 16.3 |
| 30S/10E-14B2 | D | 270-280 | 2 | 16.6 |
| 30S/10E-24C1 | D | 250-500 | 10 | 178.3 |
| 30S/11E-7Q3 | D | 230-270 | 10 | 24 |
| 30S/11E-18M1 | D, E | 330-355; 395-415; 465-505; 530-575 | 10 | 106.8 |
| 30S/11E-18L2 | D, E | 350-390; 455-480; 500-530 | 12 | 81 |

NOTE; *RP = reference point elevation in feet above mean sea level.  Some elevations are estimates only.

**Table 4**
**Lower Aquifer Source Investigation Sampling Sites**

| Well ID | Aquifer Zone | Perforations (depths in ft) | Casing diam. (in) | RP* (ft msl) |
|---|---|---|---|---|
| 30S/11E-7N1 | C | 61-83 | 8 | 9.1 |
| 30S/11E-7Q1 | C | 29-46; 54-75 | 8 | 24.0 |
| 30S/11E-8M | C, D | 95-175 | 5 | est. 85 |
| 30S/11E-17E7 | E | 480-490; 500-510 | 2 | 105.85 |
| 30S/11E-17E8 | D | 270-280; 370-380 | 2 | 105.85 |
| 30S/11E-17P4 | C | 90-150 | 6 | 131.47 |
| 30S/11E-20B7 | C | 140-220 | 6 | 135 |
| 30S/11E-18K3 | C | 148-202; 222-232 | 8 | 121.18 |
| 30S/11E-18K7 | C | 180-220 | 2 | 135.74 |
| 30S/11E-18K8 | E | 630-650 | 2 | 135.74 |
| 30S/11E-18L6 | D, E | 355-375; 430-480; 550-600 | 6 | 76.0 |
| 30S/11E-18L7 | C | 180-220 | 2 | 75.8 |
| 30S/11E-19H2 | D | 280-380 | 6 | 256.20 |
| 30S/11E-20Aa | E | 290-360 | 5 | 80 |
| 30S/11E-20A2 | Alluvium | 45-65 | 6 | 76.89 |
| 30S/11E-20La | E | 100-220 | 8 | 140 |
| 30S/11E-21D13 | Alluvium | 35-100 | 6 | 70 |
| 30S/11E-21P | bedrock | 236 feet deep | -- | est. 200 |
| Los Osos Ck. (Base flow) | surface | -- | -- | est. 140 |
| Los Osos Ck. (East fork) | surface | -- | -- | est. 150 |
| Los Osos Ck. (West fork) | surface | -- | -- | est. 150 |

NOTE; *RP = reference point elevation.  Some elevations are estimates only.

**Constituents of Analysis**

All water samples were analyzed for the following constituents:

- General Mineral suite (Na, Mg, Ca, K, Cl, HCO3+CO3, SO4, NO3, EC, TDS, pH, and hardness)
- Silica
- Boron
- Strontium
- Bromide
- Iodide
- $^{18}O$/deuterium

In addition, fourteen of the water samples were age-dated using radiocarbon, and seven were dated using tritium. Sampling protocol included purging a minimum of three casing volumes of water standing in each well, while field parameters (temperature, electrical conductivity, and pH) were monitored to ensure production of aquifer water (sampling procedures in Appendix E). Sample bottle types, sample preservatives, and field sampling techniques were commensurate with the respective analyses.

Laboratory results of water samples are presented in tables in Appendix F. Data interpretation has been incorporated into various discussion within this report.

**Aquifer Testing**

Constant discharge aquifer tests were conducted at four lower aquifer wells, 30S/10E-13M1 (Zone E), 30S/11E-18L6 (Zones D, E), 30S/11E-19H2 (Zone D) and 30S/11E-20Aa (Zone E). Well 30S/10E-13M1, a former U.S.G.S. monitoring well now maintained by Sea Pines Golf Course, was pumped for three hours on January 19, 2005, at an average discharge rate of 50 gallons per minute. The static water level measured 49.3 feet deep prior to pumping. Pumping water levels had declined to 60.7 feet depth by the end of the test (11.4 feet of drawdown). Well 30S/10E-13M1 is screened from 477-537 feet depth. The rate of water level drawdown measured 0.93 feet per log cycle of time over the first 30 minutes of pumping, indicating an aquifer transmissivity of 14,200 gpd/ft, and a hydraulic conductivity of 240 gpd/ft$^2$. Recovery was measured for 30 minutes following pump shut down. Water levels were within 2 feet of original static after 5 minutes recovery.

Well 30S/11E-18L6, a County of San Luis Obispo monitoring well located on Palisades Avenue near the South Bay Community Center, was pumped for seven hours on January 18, 2005, at an average discharge rate of 50 gallons per minute. The static water level measured 88.5 feet deep prior to pumping. Pumping water levels had declined to 106.7 feet depth by the end of the test (18.7 feet of drawdown). Well 30S/10E-18L6 is screened from 355-375 feet, 430-480 feet, and 550-600 feet depth. The rate of water level drawdown measured one foot per log cycle of time over the first four hours of pumping, indicating an aquifer transmissivity of 13,200 gpd/ft, and a hydraulic conductivity of 110 gpd/ft$^2$. A possible boundary condition was observed after approximately 300 minutes of pumping, when the rate of water level drawdown increased to 10.5 feet per log cycle of time, although well interference from pumping at a nearby municipal supply well may also explain the change. Recovery was measured for one hour following pump shut down. Water levels were within 4 feet of original static after 5 minutes recovery.

Well 30S/11E-19H2, a County of San Luis Obispo monitoring well located in Bayview Heights, was pumped for 12 hours on January 14, 2005, at an average discharge rate of 20 gallons per minute. The static water level measured 281.9 feet deep prior to pumping. Pumping water levels had declined to 317.6 feet depth by the end of the test (35.7 feet of drawdown). Well 30S/11E-19H2 is screened from 280-380 feet depth, therefore, the aquifer was being partially dewatered during the test. Recovery was measured for two hours following pump shut down. Water levels were within 5 feet of original static after 4 minutes recovery. The rate of recovery stabilized at 0.83 feet of water level rise per log cycle of time, indicating an aquifer transmissivity of 6,200 gpd/ft, and a hydraulic conductivity of 62 gpd/ft$^2$.

Well 30S/11E-20Aa, a private domestic well located in the Los Osos Creek Valley, was pumped for 8 hours on February 1, 2005, at an average discharge rate of 30 gallons per minute. The static water level measured 68.9 feet deep prior to pumping. Pumping water levels reached 102.6 feet depth at the conclusion of the test (33.7 feet of drawdown). A possible boundary condition was observed after approximately 150 minutes of pumping, when the rate of water level drawdown increased from approximately 2.7 feet per log cycle of time to 6 feet per log cycle of time, although well interference from irrigation pumping may also explain the change. Recovery was measured for two hours following pump shut down. Water levels were within 5 feet of original static after 75 minutes recovery, and the rate of recovery stabilized at 2.9 feet per log cycle. The well is screened from 290 to 360 feet depth (Zone E). Aquifer transmissivity is estimated at 2,800 gpd/ft, with a hydraulic conductivity of 40 gpd/ft$^2$, based on the pumping test results. Aquifer parameter estimates from the two pumping tests have been included above in Table 1 and used to refine estimates of inflow to the lower aquifer from the creek valley. Data from the tests are included in Appendix G.

## Bedrock Reconnaissance

Bedrock surrounding the Los Osos Valley consists of Pismo Formation and Franciscan Formation rocks. The focus of the reconnaissance effort was to evaluate the likelihood of subsurface inflow from bedrock as part of the lower aquifer source investigation. Geologic evidence sited for a Strand B fault splay was also examined during bedrock reconnaissance.

### Bedrock Structure and Lithology

Mapping in the Irish Hills near the drill sites for the W. H. Provost "Spooner" and Gretna Corporation "Maino-Gonzales" oil exploration wells, shows that Hazard Canyon has been incised along an anticline.

The canyon cuts through a thick section of grey and brown, thin- to medium-bedded siliceous shales and claystones, with occasional cherty or porcelaneous appearance. These rocks are mapped by Hall et al (1979) as the Miguelito Member of the Pliocene-age Pismo Formation. Strata in the ridge between Hazard Canyon and the Los Osos fault dip to the northeast at an average of approximately 35 degrees, with northernmost limited exposures suggesting that bedding becomes more convoluted as the Los Osos fault zone is approached. Claystone and siliceous shale in the gravel pit near Pecho Valley Road is nearly flat-lying, while poorly exposed, highly weathered claystone in a road cut along southeastern Rodman Drive, has been mapped with dips to the northeast of as much as 70 degrees (Hall et al, 1979). Such increased deformation immediately above the offset plane would be consistent with a reverse fault.

Lithologic composition is generally siliceous, and locally porcelaneous or cherty, but there is also a predominance of relatively soft claystone interbeds that are not sufficiently hard and brittle to maintain open fractures for ground water flow. The Miguelito shale is not considered a favorable prospect for ground water production, and is generally limited to lower-yielding domestic wells where tapped.

## Los Osos Fault as Ground Water Barrier

In 1952, the oil well test hole W. H. Provost "Spooner" was drilled into sediments south of the Los Osos fault. Interpretation of the test hole notes and e-log indicate that the Los Osos fault acts as a ground water barrier, and that it was penetrated by the test well. Following test well installation and a water shut off test, the well was cleaned out and allowed to stand overnight with perforations open to the formation from 840-1,138 feet depth. Fresh water entered the casing and was measured at 460 feet depth. The elevation of the well reference point was 467 feet above sea level, therefore, water standing in the well overnight had reached a static of close to 7 feet above sea level. Although water levels may have still be rising, they would be consistent with deep ground water basin water levels.

After determining that the lower portion of the cased hole was not productive for oil or gas, a cement plug was installed at approximately 805-827 feet, and a new set of perforations was shot between 704-805 feet depth. This time, the file notes reports that the well produced about 4 barrels (168 gallons) of fresh water overnight. In other words, the test well was artesian (flowing). The "Spooner" well was subsequently capped and turned over to the landowner to be converted to a water well. No further history is known, and the well has not been found.

The static water level in sediments tapped by the test well below 840 feet was close to 7 feet above sea level, while the static water level for the interval tapped from 704-805 feet depth was slightly in excess of 467 feet above sea level. This water level data suggests that the Los Osos fault was penetrated between 805 and 840 feet depth, and that it acts as a barrier to ground water flow. Recharge occurring as deep percolation of rainfall on the south side of the fault cannot drain into the ground water basin, and therefore builds up much greater pressures, consistent with the higher elevations of the surrounding hills.

An e-log is available for the test hole. There is a change in the spontaneous potential and resistivity logs at approximately 830 feet depth, which represent a lithologic change and possibly the fault plane. A lithologic log of the test hole is not available, although a few intervals are described. Interpretation of the Los Osos fault as a ground water flow barrier applies regardless of the exact depths or nature of the lithologic changes in the borehole.

Strand B

Reconnaissance in the ridge crest area to the south and southwest of Calle Cordoniz generally confirms prior mapping by Asquith (1997). Moderately north-dipping Pismo Formation diatomaceous shale exposed on the south flank of the ridge is in part covered by scattered shale gravel which appears to be a lag veneer left from erosion of a Paso Robles Formation remnant. The soft shale outcrops continue east to a drainage swale where the proposed Strand B was mapped. East of the swale there are no bedrock exposures, only relatively loose colluvial soils with fine sand and silt beneath a canopy of oaks. Occasional gravel float suggests Paso Robles Formation, but no definitive exposures were found. The contact between shale and younger deposits appears to follow a southerly vegetative lineament close to the edge of the oaks (including a willow), and not the northwest-southeast alignment suggested by Asquith (1997). Yates and Wiese (1988) have proposed a fault through the same swale (Figure 2). This fault is an extension of one mapped by Hall et al (1979) and trends roughly north-south through the area, in closer agreement with the field observations. A more detailed discussion of Strand B is presented in Part 3.

## Test Hole Drilling

A test hole was drilled on March 1, 2005 at the intersection of Fearn Avenue and Binscarth Road, in Cuesta-by-the-Sea (ground surface elevation estimated at 18 feet above sea level). The test hole was advanced to a total depth of 660 feet, and penetrated the full thickness of basin sediments. The lithologic log, penetration rate log, and geophysical logs are included in Appendix H.

Fine to medium grained dune sands were penetrated to a depth of approximately 30 feet, followed by clayey sands with occasional clay lenses and fine to medium sands through 152 feet depth. A sand and gravel aquifer (base of Zone C) was logged between 152 and 214 feet depth, followed by the regional aquitard, comprised of three discrete sandy clay beds (6, 8, and 10 feet thick), separated by sands and clayey sands through 298 feet. Below the regional aquitard are lower aquifer Zones D and E. Zone D is somewhat atypical, being mostly fine to coarse sand and clayey sands, with a basal gravel interpreted at 378 feet. Zone E is comprised of sand and gravel through the top of the Careaga sandstone at 510 feet depth. Abundant shell fragments were noted beginning at 550 feet depth and continued through the base of permeable sediments, which was logged at 640 feet depth. A dark olive gray clay (no shells) between 640 and 660 feet depth is interpreted as the top of the Pismo Formation shales.

## Geophysical Logging

Geophysical logs performed at the Binscarth Avenue test hole discussed above included spontaneous potential, resistivity (16-inch, 64-inch, and single point), caliper, sonic, natural gamma, and induction (Appendix H). Interpretation of lithology and water quality has been derived from the logs.

Spontaneous (voltage) potential has been used herein, along with the resistivity logs, to interpret changes in formation water salinity with depth. The major clays and the fresh water aquifer zones are correlated using the gamma and resistivity logs. The sonic log measures sound wave velocities adjacent to the borehole, and is used to infer density variations, such as the formation change between Paso Robles Formation and the denser Careaga Formation. The induction log measures formation conductivity and confirms the presence of sea water.

Natural gamma and induction logs were also performed at two existing deep monitoring wells, 30S/10E-13M1 and 30S/11E-18L6. Logging at a third deep monitoring well, 30S/10E-12J1 was unsuccessful due to casing obstructions. The purpose of geophysical logging at existing monitoring wells was to set a baseline for the sea water intrusion monitoring program. These logs are included in Appendix I.

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# PART 2

# SEA WATER INTRUSION

## INTRODUCTION

The first published assessment of sea water intrusion in the Los Osos Valley ground water basin was performed by the Department of Water Resources (DWR) and reported in Bulletin No. 63-6, Sea Water Intrusion: Morro Bay Area (February 1972). This report documented historical sea water intrusion in Recent-age alluvial sediments in the lower Los Osos Creek valley, and in a shallow well tapping a dune sand aquifer adjacent to the bay at Cuesta-by-the Sea. The 1972 report could not evaluate sea water intrusion in the deeper Paso Robles Formation due to a lack of information.

In 1979, the DWR published a report which was the first to address sea water intrusion in the main water supply aquifers. The report, Morro Bay Sandspit Investigation (August 1979), concluded:

"Both [upper and lower] aquifer zones have been intruded by sea water [at the sandspit]. Chloride concentrations in the upper zone indicate that the mixing zone and the toe of the sea water wedge extend landward, but how far landward is not known. The smaller concentration of chloride in the lower zone indicates that it contains more fresh water than does the upper zone. However, because of the thickness of the lower aquifer, the mixing zone and the toe of the sea water wedge could have moved landward for a significant distance."

In 1988, the U.S. Geological Survey published the Hydrogeology and Water Resources of the Los Osos Valley Ground-Water Basin (Yates & Wiese). A brief water quality comparison was made between water samples collected from wells on the Morro Bay sandspit in 1977 and 1986. The findings regarding sea water intrusion were inconclusive, however. According to the report, "The increases in chloride concentration indicate that there may have been a net inflow of seawater during 1977-86. However, there are not enough data to draw firm conclusions."

In July 1989, the DWR published a report titled Geohydrology and Management of Los Osos Valley Ground Water Basin. This report noted that, "The exact location of the sea water-fresh water interface...is still uncertain." One of the recommendations of the 1989 study is that, "The intrusion of sea water be monitored on a regular basis so that its advance can be measured."

At present, sea water intrusion is occurring in the western end of the ground water basin. Water purveyors have been significantly impacted by the increasing salinity. There has been progress on developing basin management strategies to mitigate sea water intrusion, however, there has been no assessment prior to this study of the rate of advance of the sea water wedge, or the position of the zone of mixing.

## MECHANICS OF SEA WATER INTRUSION

Sea water (or salt water) has a density that is 1.025 times greater than fresh water. Near the end of the 1800's, Badon-Ghyben and Herzberg independently used this information to predict that under hydrostatic conditions, for every foot of fresh water above sea level, the sea water interface will be displaced 40 feet below sea level. This became known as the Ghyben-Herzberg relation, and is commonly referenced in discussions regarding sea water intrusion.

The Ghyben-Herzberg relation may underestimate the true depth to the sea water interface, due to the fact that in many cases there is outflow to the ocean. Fresh water outflow voids the assumption of hydrostatic conditions, and results in increasing fresh water pressure head with depth, thus displacing more sea water (lowering the interface) than would otherwise be predicted by a shallow piezometer. For relatively flat hydraulic gradients, however, this difference is small. Conversely, decreasing freshwater pressure head with depth, such as created by pumping conditions, would displace less sea water (raising the interface) than would otherwise be predicted by a shallow piezometer. Any vertical hydraulic gradient or related flow affects the estimate of this hydrostatic relation.

Sea water intrusion typically involves the movement of saline water into fresh water aquifers. Mass transport occurs through the processes of advection, mechanical dispersion, and diffusion. Advective movement of the sea water interface is induced by changes in aquifer pore pressure, normally caused by ground water extraction (or recharge). The sea water interface will move in response to a change in pore pressure toward an equilibrium condition that best satisfies the Ghyben-Herzberg relation. Therefore, in an aquifer where sea water intrusion is actually occurring, the Ghyben-Herzberg relation may not satisfactorily predict the depth of the sea water interface. The Ghyben-Herzberg relation approximates the sea water interface for basin equilibrium, under steady-state conditions, and for relatively flat hydraulic gradients.

Many analytical solutions for modeling sea water intrusion, including those based on the Ghyben-Herzberg relation, also assume that the sea water interface is a sharp boundary, rather than a transition zone. The width of the transition zone can increase significantly during sea water intrusion due to the lengthening (stretching) of the sea water wedge, and to greater hydrodynamic dispersion. Determination of the actual sea water interface location through water level measurements will be affected by the transition zone variation in water density. In addition, the layering and thickness of transmissive zones within an aquifer can further affect the sharpness of the sea water interface.

When basin ground water development occurs, ground water extractions begin to lower water levels toward a new equilibrium condition. Only when water levels have declined enough to lower pore pressures in the fresh water aquifer adjacent to the sea water interface, can intrusion begin. In cross-section, the sea water interface is a wedge-shape, with the toe of the wedge further inland. This is the natural configuration of the interface because the fresh water head typically decreases toward the ocean, therefore, the corresponding depth to sea water will rise in general accordance with the Ghyben-Herzberg relation. Movement of the interface typically begins at the toe, because it is closer to inland pumping wells, where the aquifer pore pressure reductions are induced.

As the sea water interface moves in response to aquifer pore pressure changes, stratification of the basin sediments by competent aquitards will result in the development of separate interfaces, each of which moves according to the hydraulic conditions for that individual zone.

Sea water can move into a well by lateral intrusion or upconing. Lateral intrusion, as the name implies, involves the lateral movement of the transition zone directly into the perforated interval of a well. If the toe of a sea water wedge moves through the aquifer beneath a pumping well, the rapid decreases in pore pressure surrounding the well may dominate the density differences between salt and fresh water, resulting in upconing of the sea water interface into the well. Seasonal or drought-induced cycles of sea water intrusion are influenced by pumping regimes and precipitation patterns.

## CRITERIA FOR EVALUATING SEA WATER INTRUSION

The principal criteria for evaluating sea water intrusion are water levels and water quality. Pore pressure differences, which control the position of the sea water interface, are measured by comparing water levels in wells. Identifying fresh water, sea water, and mixed water is accomplished through evaluating water quality. Another criterion often used to evaluate sea water intrusion is borehole geophysics, which can provide valuable information on the depth and movement of the sea water interface.

### Water Levels

The sea water interface will move in response to changes in aquifer pore pressure, and will move toward an approximate equilibrium based on the Ghyben-Herzberg relation. Along the axis of the basin syncline between the sand spit and Sea Pines golf course, upper aquifer Zone C is 180 feet deep. According to Ghyben-Herzberg, a fresh water head of approximately 5 feet would be needed to prevent the sea water interface from moving inland in Zone C. At this same location, the lower aquifer Zone D is between approximately 230 and 350 feet below sea level, which would require a fresh water head of approximately 9 feet to prevent the sea water interface from moving inland. Zone E is between approximately 430 and 700 feet below sea level, which would require a fresh water head of approximately 17.5 feet to prevent sea water intrusion. Along the bay near Pasadena Drive in Baywood Park, the respective fresh water heads required by the Ghyben-Herzberg relation to prevent sea water intrusion would be approximately 2.5 feet in Zone C, 5.5 feet in Zone D and 9.5 feet in Zone E.

The water level elevations at the sand spit wells, when first drilled in 1977, were as low as 1.3 feet above sea level in both the upper and lower aquifers. These wells had already been partially intruded by sea water, although much of the sea water mixing beneath the sand spit may have already been in place prior to any basin development.

Zone C hydraulic heads near the bay at Pecho Road have generally been in excess of 5 feet above sea level, based on static water level data from community supply well 30S/10E-13L1 (140 feet deep, drilled in 1955), except between 1989 and 1995, due to the effects of the late 1980's drought. Well 13L1 was placed on standby status in the late 1990's due to increasing nitrate concentrations, and is currently idle. Water levels at well 13L1 have generally been between 8 and 9 feet above sea level in recent years.

Zone C hydraulic heads have historically been in excess of 2.5 feet above sea level along the bay at Pasadena Drive except during severe drought, based on static water level data from community supply well 30S/11E-7N1 (84 feet deep, drilled in 1951). During and following the 1976-77 and 1987-1990 drought periods, static water levels in well 7N1 dropped to below sea level. Water levels in recent years have generally been between 5 and 6 feet above sea level at Well 7N1, which is still in active service.

In 1998, shallow water table monitoring wells were installed at Sea Pines golf course for wastewater discharge monitoring (RWQCB file review for Waste Discharge Order 93-82). Water levels at monitoring well MW3, on the west side of the golf course property, averaged 3.8 feet above sea level between October 2001 and July 2004, which is slightly lower than the hydrostatic requirements of the Ghyben-Herzberg relation (4.5 feet of head) to avoid sea water intrusion through a depth of 180 feet below sea level. As mentioned previously, however, the Ghyben-Herzberg relation would underestimate the depth to the sea water interface under ocean outflow conditions, and while the potential correction is negligible for relatively flat hydraulic gradients, it becomes significant as the outflow face is approached at the bay.

The Zone C sea water interface is currently estimated to be relatively stable onshore, with a potential for active intrusion beneath the sand spit, based on the observed hydraulic pressures and seaward hydraulic gradient. During extended drought periods, however, there is a potential for onshore sea water intrusion in Zone C, although no significant impacts to supply wells have been reported. One example of sea water intrusion near the bay was reported in a shallow well during the 1960's (DWR, 1972). The well (30S/10E-13B2) was only 20 feet deep, however, is interpreted to have been intruded by brackish water from the bay.

The earliest water level information in Zone D near the bay is from well 30S/10E-13L4, drilled in 1977. The first water level reported in May 1977 at this well was equivalent to approximately 7 feet above sea level. Under hydrostatic conditions, this would theoretically maintain fresh water saturated sediments through approximately 280 feet below sea level (Zone D extends to 320 feet below sea level at well 13L4). The e-log of the test hole, however, indicated saline water beginning at approximately 520 feet below sea level. Therefore, either sufficient ocean outflow through the aquifer zones was present in 1977 to maintain an equivalent fresh water head of 13 feet at depth, or active sea water intrusion was occurring by 1977.

Well 30S/10E-12J1, located on Pasadena Drive in Baywood Park, was drilled in 1970 and is screened in Zone E. In November and December of 1970, artesian flows with pressure heads of approximately 10 feet above sea level were reported at the well (DWR, 1972). Under hydrostatic conditions, this would be sufficient head to prevent any movement of the sea water interface through Zone E at this location. Well 12J1 was recorded as flowing for the last time in May 1977. Currently, water levels are approximately one foot below sea level, and there is a hydraulic potential for active sea water intrusion in Zone E beneath the bay.

**Water Quality**

Active sea water intrusion involves the mass transport of dissolved ions. Sea water contains a much greater concentration of mineral salts than fresh water, and when sea water intrudes a potable water supply aquifer, the intruded water becomes non-potable due to the excessive salinity. Increases in fresh water salinity, however, do not necessarily indicate active sea water intrusion, but may be the result of mass loading from other sources of salinity. Distinguishing sea water intrusion as the mechanism for increased salinity is the objective for the water quality evaluation criteria. Due to the possibility of multiple sources and explanations for trends in salinity and ion ratios in ground water, the concurrence of all available hydraulic and water quality criteria should be established when documenting sea water intrusion.

In the transition zone, the mixing of salt water and fresh water is typically accompanied by various ion exchange activities, such that the composition of transition zone water cannot be predicted by a simple mixture of salt water and fresh water. A comparison of selected ratios of ionic concentration between wells or in a time series may be used to identify sea water intrusion as the source of increased salinity.

Chloride

Chloride is a conservative species when dissolved in water, in that it does not readily adsorb to, or otherwise react with, the aquifer matrix. Sea water at the sand spit has 18,500 milligrams per liter (mg/l) chloride, while fresh water in the ground water basin has approximately 60 mg/l chloride. When sea water intrudes, the chloride concentration in fresh water must rise.

Figure 9 presents historical chloride data in lower aquifer Zone D. The figure illustrates changes over time at selected lower aquifer wells, with the estimated historical locations of 250 mg/l and 2,500 mg/l isochlor lines. A level of 250 mg/l chloride was selected to represent the leading edge of the transition zone, corresponding to the maximum recommended chloride concentration for drinking water.

Septic discharges to leach fields are another likely source of increased chlorides in ground water. The general mineral concentrations present in Los Osos septic returns have been characterized by others (i.e. Brown & Caldwell, 1983). Chloride concentrations in septic effluent samples from six representative sites in Los Osos were all reported as less than 100 mg/l and averaged 79 mg/l. Septic system return flows to ground water are not expected to significantly affect the assessment of sea water intrusion, where the impacts, by definition, begin at 250 mg/l chloride.

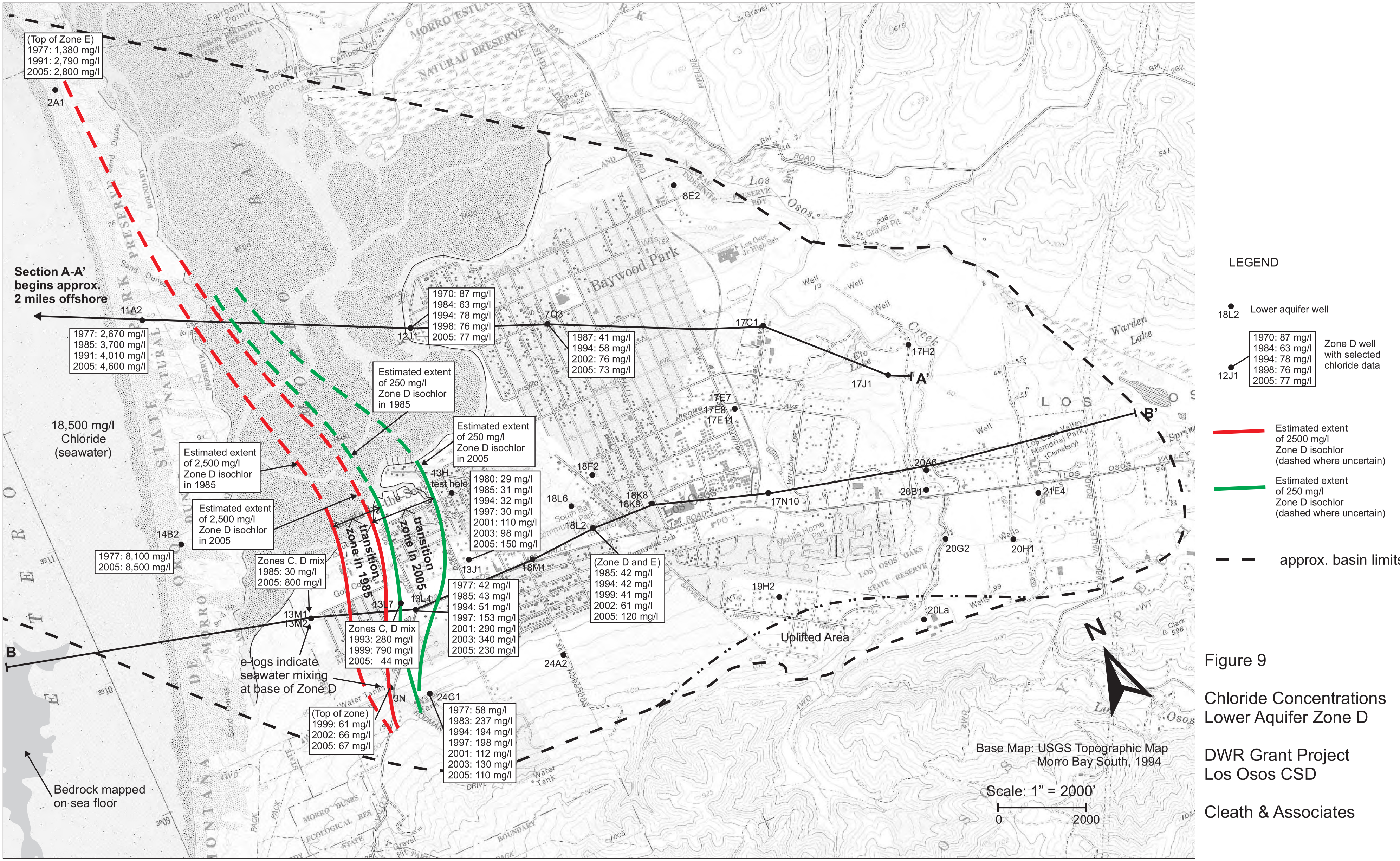



Figure 9

Chloride Concentrations
Lower Aquifer Zone D

DWR Grant Project
Los Osos CSD

Cleath & Associates

Four dates with chloride concentration data are available for some of the sand spit wells: 1977, 1986, 1991, and 2005. Based strictly on chloride concentrations, Zone C was approximately 65 to 85 percent sea water beneath the sand spit in 1977, while Zone D was approximately 14 to 22 percent sea water. The top of Zone E was as low as 7 percent (where it rises near the north edge of the basin), but was probably closer to sea water in composition elsewhere along the sand spit in 1977.

Between 1977 and 2005, chloride concentrations increased in all sand spit wells, with the greatest changes observed in Zones D and E. In Zone D, chloride concentrations increased by over 70%, from 2,670 mg/l in 1977 to 4,600 mg/l in 2005, at well 30S/10E-11A2 (Figure 9). Although chloride concentrations in Zone D well 30S/10E-14B2 only increased from 8,100 mg/l in 1977 to 8,600 mg/l in 2005, an extremely low rate of recovery was noted in this well during purging, compared to well 11A2. A low recovery rate indicates plugging or low formation permeability opposite the screen, and therefore the results of sampling may not be representative of the aquifer zone.

Well 30S/10E-2A1, screened at the top of Zone E on the north end of the sand spit, recorded a doubling of chloride between 1977 and 1991 (1380 mg/l to 2790 mg/l), with little increase since then. This well also had problems with recovery during the recent sampling event. By comparison, chloride concentrations in the Zone C wells increased by approximately 20% between 1977 and 2005. Although rising chloride concentrations alone do not necessarily signify sea water intrusion, other indicators discussed below confirm that sea water intrusion is the likely source of elevated chloride.

The isochlor lines, as drawn, extend farthest inland in Cuesta-by-the-Sea. This is based on the information obtained from the Binscarth Road test hole (13H). Water quality estimates (from the geophysical logs; Appendix H) indicate that the toe of the transition zone is at or very close to the base of Zone D at the test hole. It should be noted that the information obtained from the test hole allows a comparison of water quality with depth, while the water quality information from wells such as 13J1 and 13L4 represent a composite sample from the entire Zone D thickness. Drawing the toe of the transitions zone requires some consideration of the types of data being used (e-logs versus water samples). Sea water intrusion in Zone D appears to be moving faster along the axis of the basin syncline, where the sediments are deepest.

Ion Ratios

Ion ratios compare the concentrations of selected ions in water. The commonly used units for ion ratios are based on molecular weight and charge, and include millimoles per liter (mmoles/l), which corresponds to the number of moles of a constituent dissolved in one cubic meter of water, and milliequivalents per liter (meq/l), which also factors in the ionic valence.

Several major ion ratios involve chloride for evaluating sea water intrusion. The chloride-to-bicarbonate ratio is useful in differentiating sea water intrusion from salinity increases due to other sources (Todd, 1959). Sea water has a much higher concentration of chloride and a lower concentration of bicarbonate than lower aquifer fresh water. When the two waters mix, the ratio of chloride to bicarbonate in the transition zone increases compared to the fresh water value. Figure 10 shows the chloride-to-bicarbonate molar ratio across the ground water basin. A significant increase in the ratio occurs on the west side of the basin, and is one potential indicator of sea water intrusion.

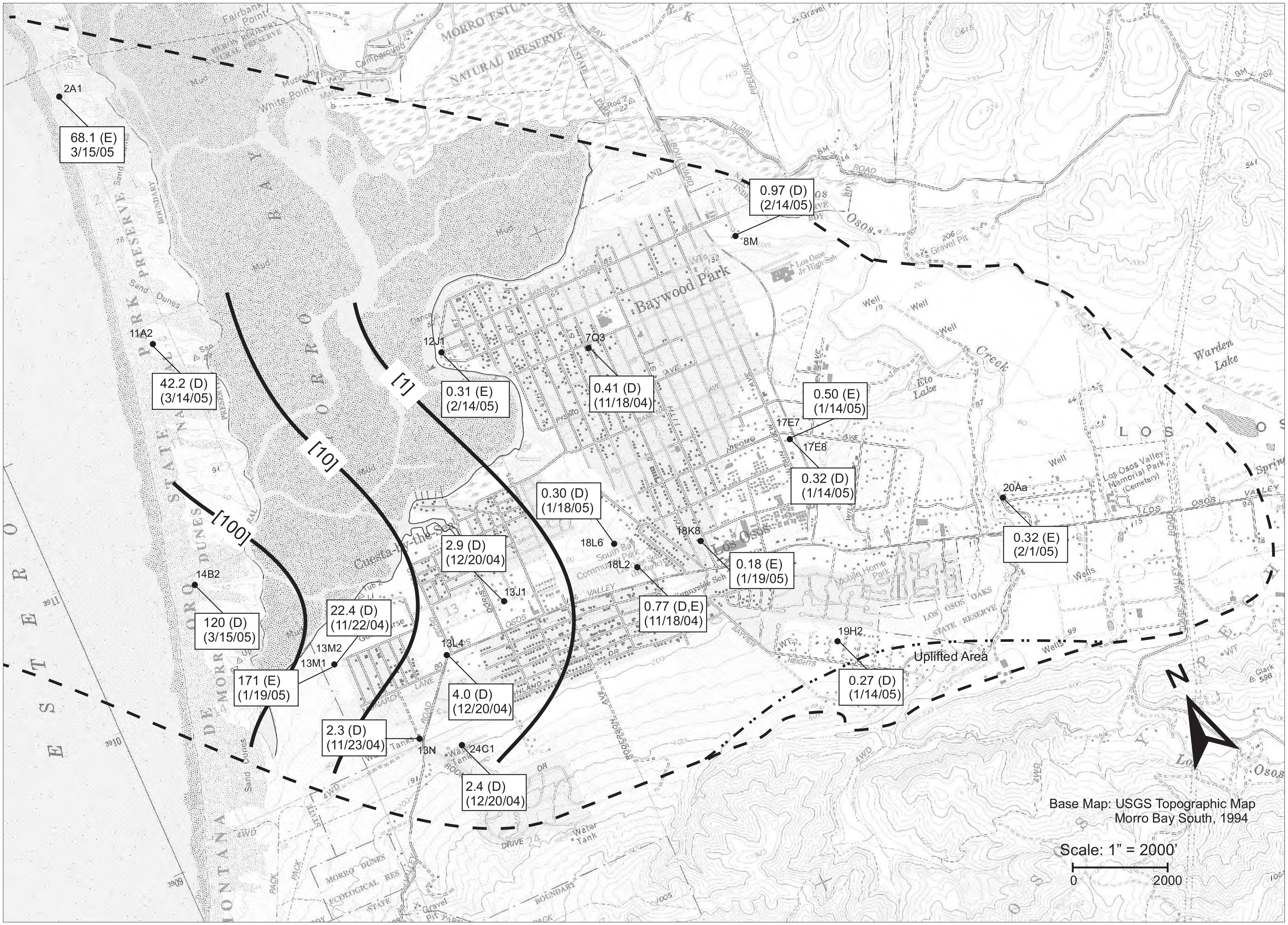
As noted above, trends in ion ratios may result from activities other than sea water intrusion. One possible explanation for affecting bicarbonate ion ratios without sea water intrusion involves leakage from the upper aquifer. The upper aquifer has a lower average bicarbonate concentration than both the lower aquifer and sea water, and a chloride concentration similar to slightly higher than the lower aquifer. Significant upper aquifer leakage could raise the chloride-to-bicarbonate ratio closer to one, but would not be a factor in the exponential increase in the ratio observed in the west basin area.

A second alternate explanation for the increasing chloride-to-bicarbonate ion ratio would be calcite precipitation. Recharge to the lower aquifer from the Los Osos Creek Valley is relatively high in bicarbonate, and conditions for calcite precipitation may exist. The principal changes in the lower aquifer chloride-to-bicarbonate ratio, however, do not occur between the creek valley and downtown Los Osos, as would be expected if calcite precipitation of creek valley recharge were occurring. Therefore, calcite precipitation is not considered significant in the lower aquifer.

Changes in molar ratios involving sodium and calcium during the onset of sea water intrusion illustrate the importance of ion exchange in controlling the geochemistry of the sea water - fresh water mixture. In the Los Osos ground water basin, calcium, magnesium, and bicarbonate ions dominate the lower aquifer water composition. The cation exchange sites in the aquifer sediments, such as clay minerals and organic matter, would have mostly calcium and magnesium cations adsorbed to their surfaces. When sea water intrusion occurs, which is dominated by sodium and chloride ions, some of the sodium cations are exchanged for calcium or magnesium in the aquifer sediments. This process lowers the sodium-to-chloride ratio below sea water values (<0.86 molar) while enriching calcium and magnesium. Eventually, as the potential cation exchange sites are used up, the ratio will begin to rise again toward sea water values (Bear, 1999).

Figure 11 shows the sodium-to-chloride molar ratio for the lower aquifer. Note the reduction in this ratio to below the sea water value in wells on the west side of the basin, particularly in the area of recent intrusion in Zone D between wells 30S/10E-13M2 and 13J1. Active intrusion in the lower aquifer beneath the sand spit is also suggested by the low sodium-to-chloride ratio at well 30S/10E-11A2. Sea water is the only suspected source of salinity in the lower aquifer that would cause the sodium-to-chloride ratio to drop below approximately 0.86 molar.

Other ratios suggested for evaluating sea water intrusion, such as the calcium-to-magnesium ratio, or the calcium-to-bicarbonate-plus-sulfate ratio use the above ion exchange process to map calcium enrichment following sea water intrusion (Bear, 1999). The calcium-to-magnesium ratio is not as useful in Los Osos for mapping calcium enrichment because the magnesium cation in the lower aquifer water is just as




LEGEND

7Q3

0.41 (D)
(11/18/04)

Lower aquifer well (Zones D and/or E) with Chloride-to-Bicarbonate ion ratio (milliequivalents per liter/milliequivalents per liter) and sample date

[1] Estimated line of equal Chloride-to-Bicarbonate ratio for Zone D (milliequivalents per liter/milliequivalents per liter)

approx. basin limits

Figure 10

Chloride-to-Bicarbonate
Ion Ratio
Lower Aquifer

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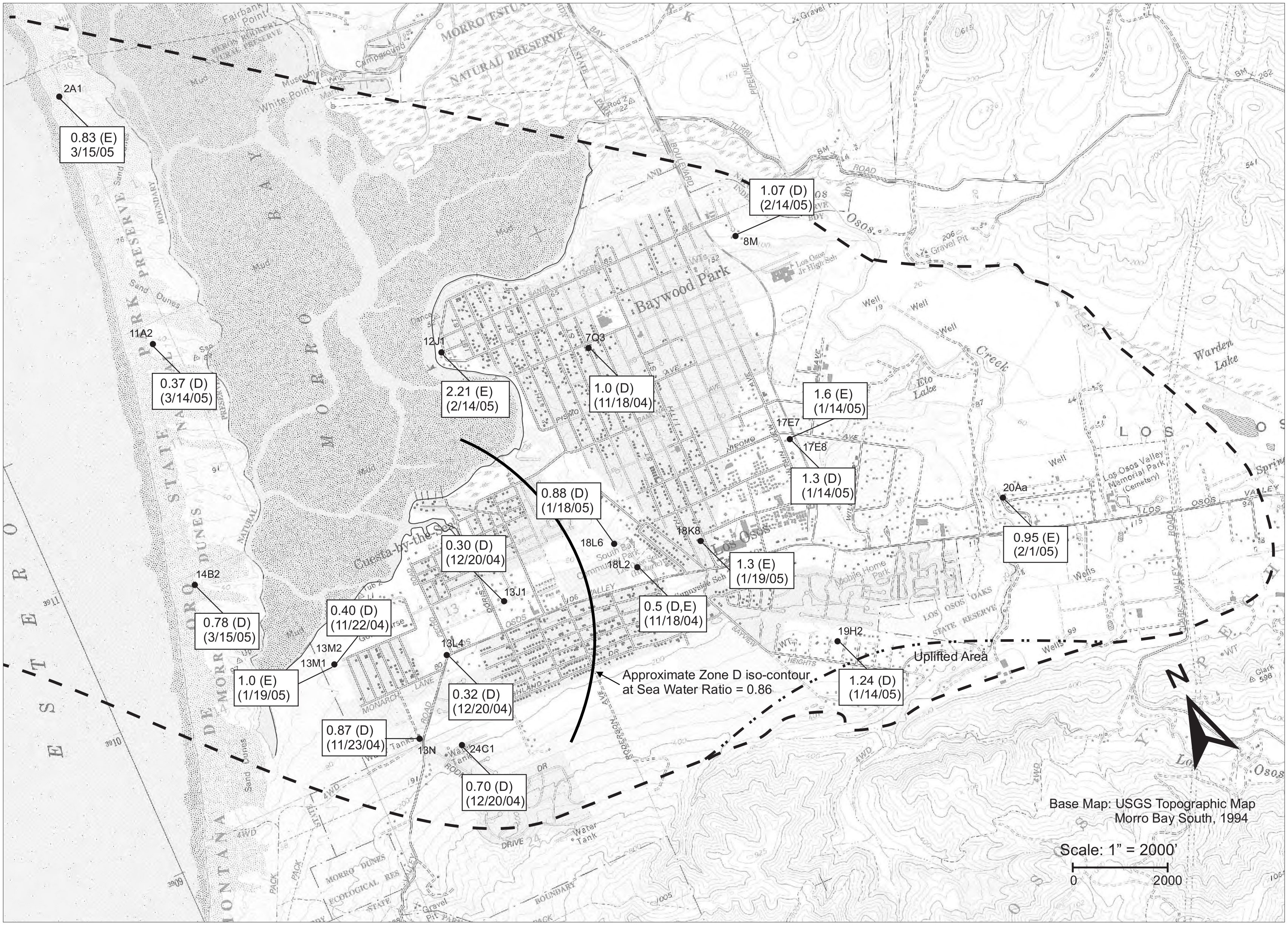


LEGEND

7Q3
1.0 (D)
(11/18/04)

Lower aquifer well (Zones D and/or E) with Sodium-to-Chloride ion ratio (milliequivalents per liter/milliequivalents per liter) and sample date

approx. basin limits

Figure 11

Sodium-to-Chloride
Ion Ratio
Lower Aquifer

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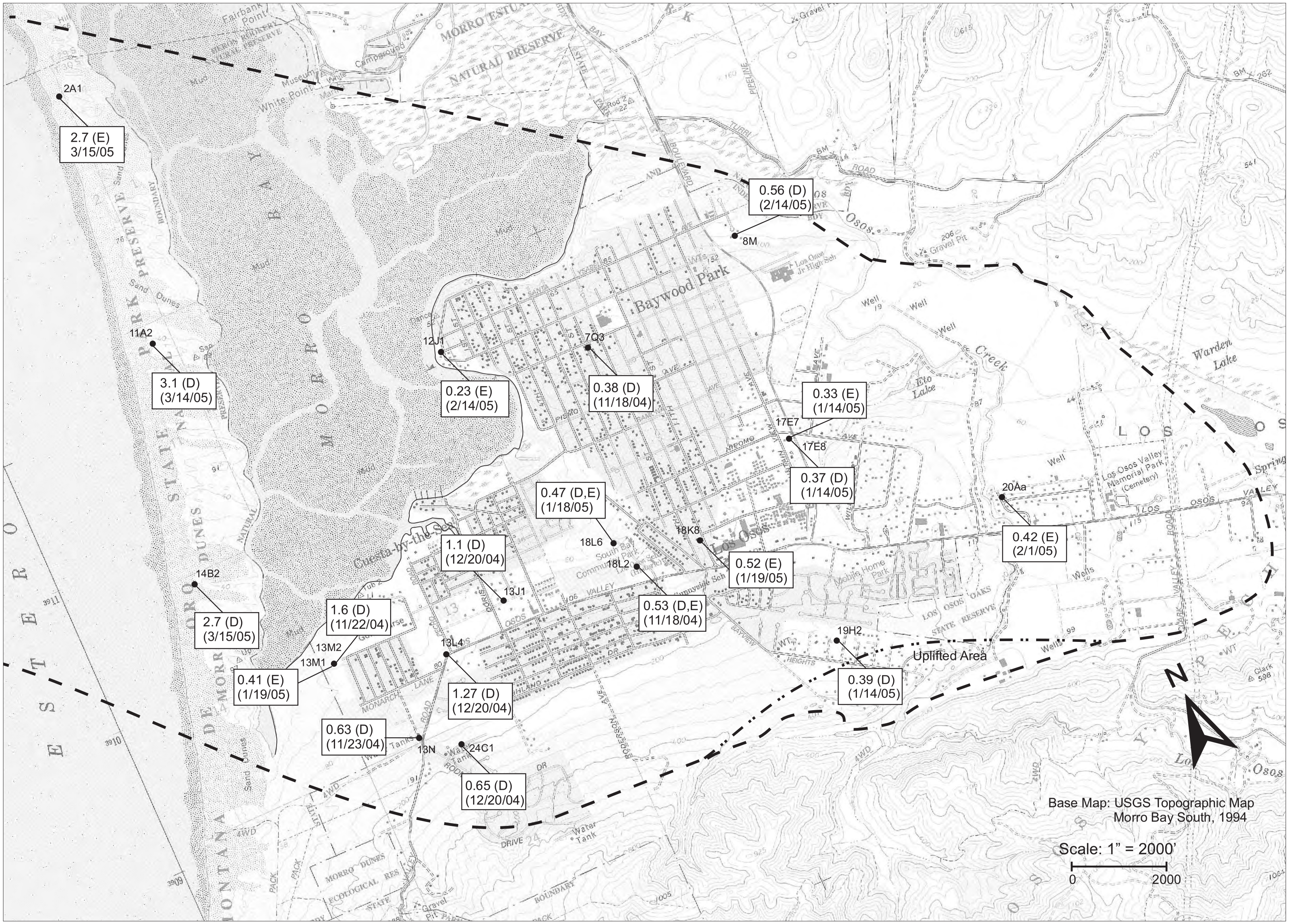
dominant as calcium, and therefore would be adsorbed to the sediments prior to intrusion and would also be enriched, along with calcium, by the exchange with sodium. Once the cation exchange sites are depleted, however, the ratio of calcium-to-magnesium ions will drop, as it approaches equilibrium with sea water (Bear, 1999 *after* Appelo and Postma, 1993).

Figure 12 shows the calcium-to-bicarbonate-plus-sulfate ratio. This data shows the process of calcium enrichment is occurring on the west side of the basin, where the ratios are typically greater than one. Significant upper aquifer leakage would not explain the increase in the calcium-to-bicarbonate plus-sulfate ratio. Possible calcite precipitation in the lower aquifer would also not explain the increasing ratio, since both calcium and bicarbonate would precipitate.

Zone E wells in the ion-ratio Figures 10, 11, and 12 are generally consistent with Zone D, except in the area of sea water intrusion. Well 30S/10E-13M1 is a Zone E well that essentially contains slightly diluted sea water (35,000 mg/l TDS; 17,000 mg/l chloride), and the indicators of a transition zone have come and gone.

Time-series evaluations for selected ion ratios have been performed on six wells in the basin, and results are summarized below in Table 5. The wells were selected based on location and data availability. Graphs of the chloride concentrations and ion ratios are included in Appendix J.




LEGEND

7Q3 — Lower aquifer well (Zones D and/or E) with Calcium-to-Bicarbonate-plus Sulfate ion ratio (milliequivalents per liter/ milliequivalents per liter) and sample date

038 (D)
(11/18/04)

— — approx. basin limits

Figure 12

Calcium-to-Bicarbonate-plus-Sulfate Ion Ratio Lower Aquifer

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**Table 5**
**Ion Ratio Trends**

| Well ID | Long-term trends in lower aquifer ion ratios over time (with approx. beginning year of trend) | | | |
|---|---|---|---|---|
| | Cl/HCO3 | Na/Cl | Ca/($SO_4$+$HCO_3$) | Cl |
| 30S/10E-12J1 | flat (1970+) | variable | flat (1970+) | flat (1970+) |
| 30S/10E-13J1 | incr. (1995+) | decr. (1995+) | incr. (1997+) | incr. (1997+) |
| 30S/10E-13L4 | incr. (1991+) | decr. (1987+) | incr. (1991+) | incr. (1994+) |
| 30S/10E-24C1 | incr. (74-83) | variable | variable (1974+) | variable |
| 30S/11E-7Q3 | incr. (1992+) | decr. (1987+) | incr. (1987+) | incr. (1992+) |
| 30S/11E-18L2 | incr. (2001+) | decr. (2001+) | incr. (2001+) | incr. (2001+) |
| Pattern for Intrusion | increasing | decreasing | increasing | increasing |

Trends in ground water salinity or ion ratios may be caused by factors not related to sea water intrusion. Sea water intrusion is indicated only when all the water quality criteria values and trends agree. The long-term trends in Table 5 suggest some relationships relative to salinity and sea water intrusion, as itemized below:

- Well 30S/10E-12J1 shows some variable trends, the most apparent of which is an increasing Na/Cl ratio between 1987 and 1991, which is the opposite trend typically associated with early stages of sea water intrusion; no sea water intrusion is indicated.

- Wells 30S/10E-13J1 and 13L4 show all the major trends associated with sea water intrusion, and have absolute ratio values consistent with sea water intrusion effects. The onset of ion ratio and chloride trends at 13J1 averaged approximately 5 years behind 13L4. Sea water intrusion is indicated by the data, although the transition zone is not formally shown as extending through well 13J1, because chlorides have remained below 250 mg/l (the threshold used for this study).

- Well 30S/10E-24C1 shows variable trends, the most apparent of which are an increasing Cl/HCO3 and Ca/(SO4+HCO3) ratios between 1974 and 1987, which could be associated with sea water intrusion. Chloride concentrations are also relatively high for lower aquifer water (>100 mg/l, up to 300 mg/l historically), and the sodium-to-chloride ratio average of 0.6 also suggests intrusion. Historical sea water intrusion is suspected, but appears to have stalled or retreated.

- Well 7Q3 has all three ion ratio trends and a chloride trend that could indicate the early stages of sea water intrusion. The absolute ion ratio and chloride values are far below sea water intrusion criteria, however. Sea water intrusion has not reached this well, although precursor trends are developing.

- Well 18L2 has all three ion ratio trends and a chloride trend that suggests the early stages of sea water intrusion. Chloride concentrations recently measured are in excess of 100 mg/l. Sea water intrusion has not reached this well, although precursor trends are definitely established.

Trace Elements

Bromide, iodide, and boron, are trace elements whose ratios with chloride can be used to assess various source waters, including sea water. Other trace elements, including barium, iron, and strontium can have applications in source evaluation and sea water intrusion studies. Laboratory methods and sensitivity can affect data interpretation, due to the relatively low concentrations of trace elements in ground water (generally less than 1 mg/l) and outliers in a data set may or may not be meaningful.

In the Los Osos Valley ground water basin, available trace element data collected prior to this study include boron, barium, and iron. The LOCSD Nitrate Monitoring Program data and historical County database report the boron composition of shallow and deep aquifer water up to 0.2 mg/l (averaging approximately 0.1 mg/l), which is at or close to typical laboratory detection limits, as compared to approximately 4.6 mg/l in sea water. Barium data in Los Osos ground water is limited to purveyor records, which report levels up to 0.22 mg/l (also averaging 0.1 mg/l), compared to 0.03 mg/l in sea water. Dissolved iron data is also available from purveyor records, and is highly variable, with levels ranging from none detected to in excess of 1 mg/l locally in both shallow and deep aquifers, compared to 0.01 mg/l in sea water.

The trace elements selected for water quality analyses in this study included bromide, iodide, boron, and strontium. Results of the trace element analyses support the conclusions reached above using the chloride and ion ratios.

The chloride-to-bromide ratio can distinguish sea water intrusion from hypersaline brines, evaporite-dissolution products, and anthropogenic sources like sewage effluents. Bromine is a conservative solute, like chloride, except in the presence of a high amount of organic matter (Bear et al, 1999).

Figure 13 presents a chloride-to-bromide ratio versus chloride graph for water samples collected during this investigation. Two mixing lines are inferred, one between sea water and upper aquifer water, and the other between sea water and creek valley water (for source investigation purposes). The lower aquifer water samples are scattered across both groups, and labeled individually. Wells in which sea water intrusion is suspected or for which precursor trends have been established, based on chloride and ion ration trends discussed above, are all grouped along or near the sea water mixing lines. Specifically, all the sand spit wells, and wells 13M2, 13L4, 13J1, 24C1, and 18L2 lie between the two major source water

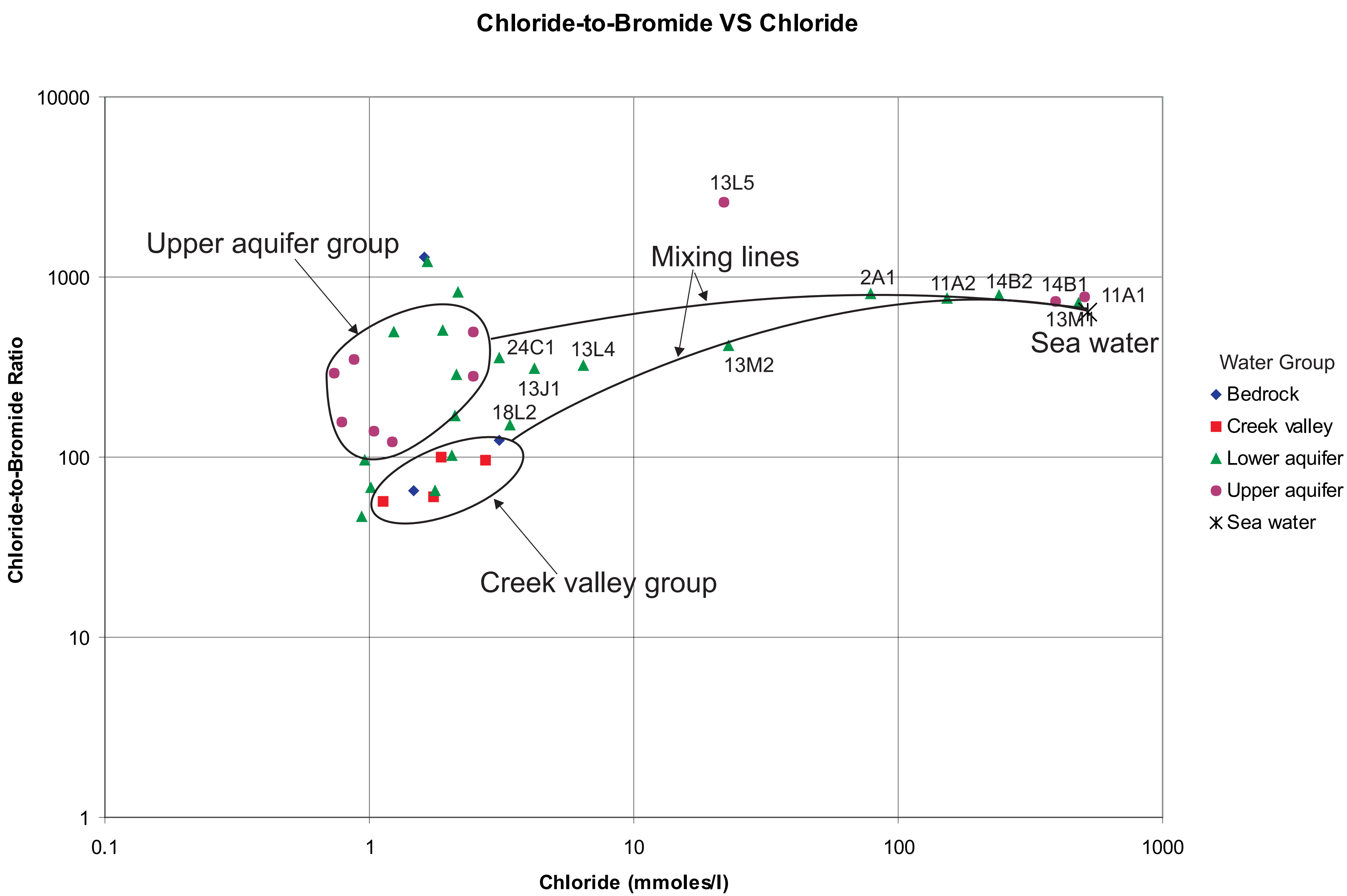


Figure 13
Chloride-to-Bromide versus Chloride

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groups and sea water. Water quality at well 30S/11E-7Q3 in Baywood Park, despite having potential precursor trends in chloride and ion ratios noted above for sea water intrusion, is not associated with the sea water mixing lines, based on the bromide data.

One shallow monitoring well, 30S/10E-13L5, has a high chloride concentration but does not fall along the bromide ratio mixing lines between upper aquifer ground water and sea water shown in Figure 13. This suggests the source of salinity at well 13L5 is not sea water intrusion, but possibly a brine. Given the shallow depth of well 13L5 (36 feet deep), high nitrate concentrations (in excess of 20 mg/l as nitrogen), and a location in close proximity to residences, the most likely source of the elevated salinity would be discharges from one or more residential water softening units. Following regeneration of the softening unit ion exchange resin bed by a sodium or potassium chloride solution, a calcium and magnesium enriched chloride brine is produced. When this brine is discharged to a septic system (rather than collected for off-site disposal), it mixes with other return flows and reaches shallow ground water.

The sodium-to-chloride and calcium-to-bicarbonate plus sulfate ratios for shallow well 30S/10E-13L5 were 0.28 and 4.14, respectively. These values indicate greater ion exchange activity in water from 13L5 than any other water sampled in the basin, and supports a conclusion that return flows from a septic system near well 13L5 contain brine from water softener discharges.

Chloride-to-iodide and chloride-to-boron ratios have also been used to assess sea water intrusion. Reactivity with the aquifer matrix is more likely for these trace elements, under certain geochemical conditions, than for bromide. Just as with the major ions, data interpretation using the trace elements involves an understanding of the composition of the source waters, and the potential reactivity of these elements in the aquifer.

Figure 14 shows the chloride-to-iodide ratio versus chloride for samples collected during this study. There is no significant differentiation within the basin for fresh, non-intruded source waters. Detection limits and laboratory sensitivity appeared to be problematic for iodide. Several reruns of samples were conducted by the laboratory, resulting in the elimination of most, but not all, anomalous outliers (i.e. 30S/10E-2A1). Wells in which sea water intrusion is suspected or for which precursor trends have been established, based on chloride and ion ratio trends discussed above, are all grouped toward or along the sea water mixing line.

Figure 15 shows the chloride-to-boron ratio versus chloride for samples collected during this study. As with the iodide ratio data, there is no significant differentiation using boron ratios within the basin for fresh, non-intruded source waters. In addition, laboratory detection limits and sensitivity were also problematic, with 17 of the 39 water samples reported as non-detected for boron, including wells with sea water intrusion. As a result, the chloride-to-boron versus chloride plot did not prove particularly useful for investigating sea water intrusion for this study. The lack of detectable boron (<0.05 mg/l) in wells known to be intruded by sea water, such as sand spit wells 14B2 (8,500 mg/l chloride) and 11A2 (5,400 mg/l chloride) suggests aquifer matrix interactions may be involved.

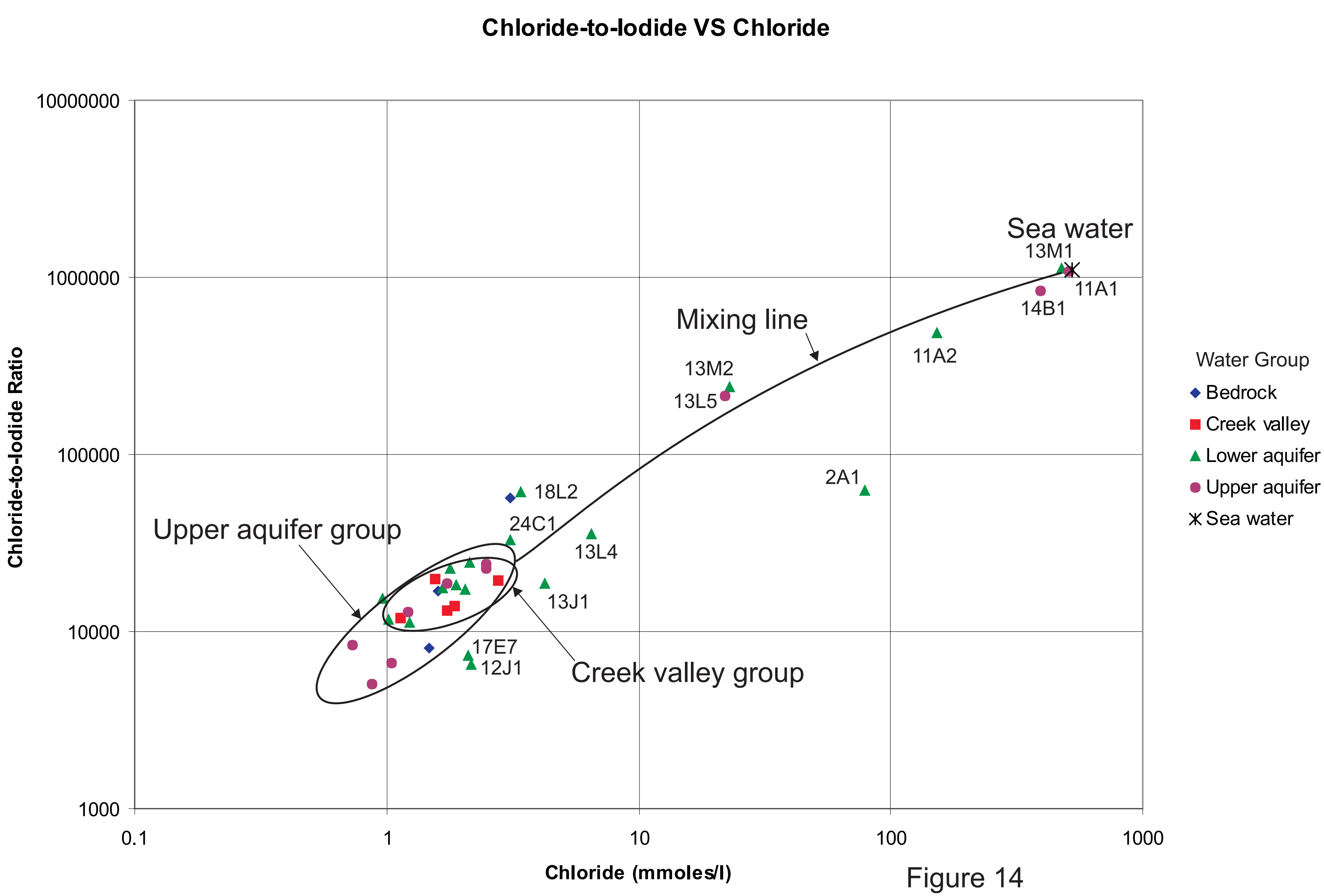


Figure 14
Chloride-to-Iodide versus Chloride

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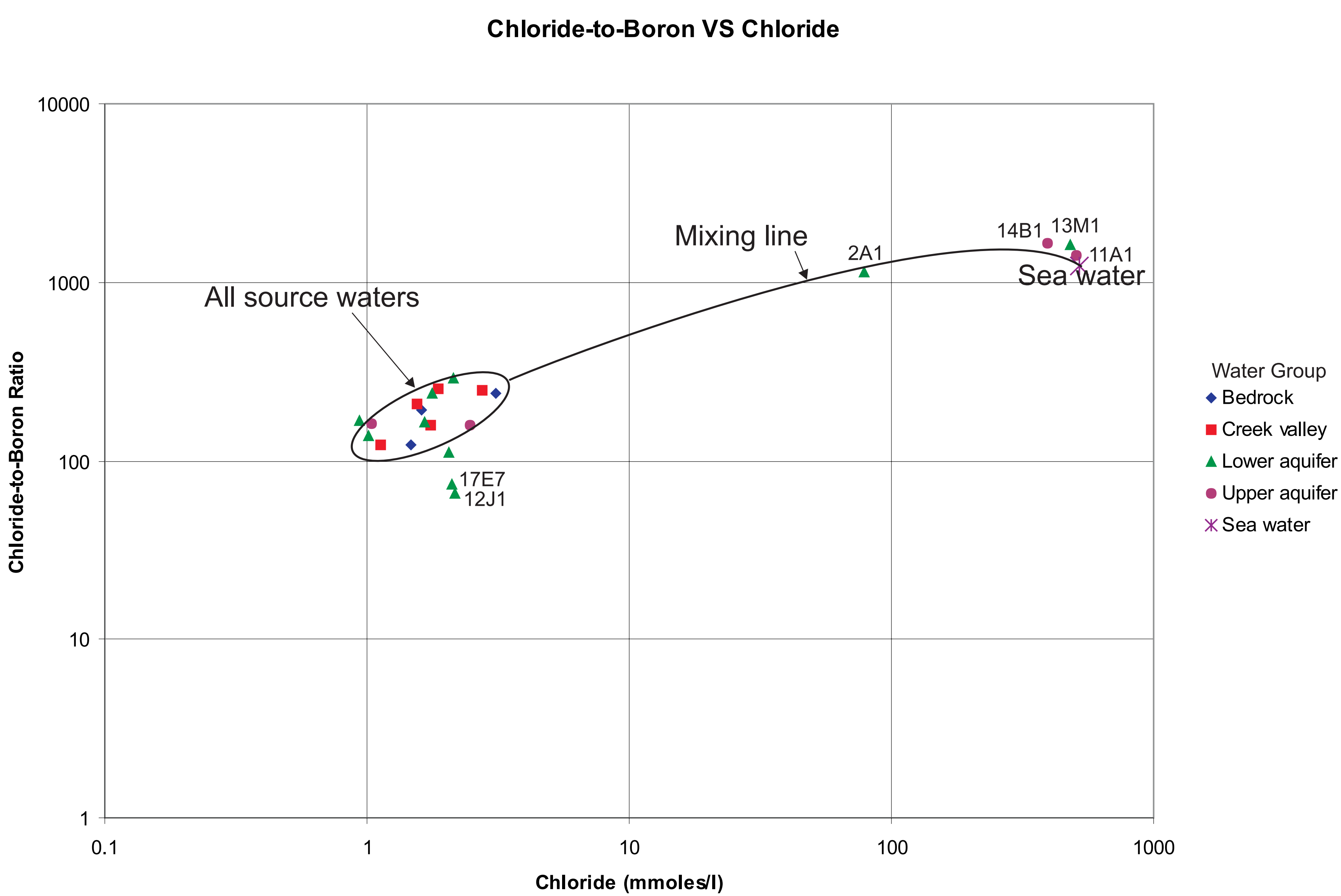


Figure 15
Chloride-to-Boron versus Chloride

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The use of total strontium data for sea water intrusion studies typically involves a comparison with strontium isotope ratios. Total strontium data presented as chloride-to-strontium ratios, however, has proven effective in segregating source waters and evaluating sea water intrusion in the Los Osos valley ground water basin.

Figure 16 shows the chloride-to-strontium ratio versus chloride for samples collected during this study. As with the bromide ratio data discussed previously, two mixing lines are inferred, one between sea water and upper aquifer water, and the other between sea water and creek valley water. The lower aquifer water samples are scattered across both groups, and labeled individually. Those wells in which sea water intrusion is suspected or for which precursor trends have been established, based on chloride and ion ratio trends discussed above, are all grouped along or near the sea water mixing lines. The sand spit wells, and wells 13M2, 13L4, 13J1, 24C1, and 18L2 lie between the two major source water groups and sea water. Well 30S/11E-7Q3 in Baywood Park is not associated with the sea water mixing lines.

Collectively, the trace elements analyses confirm the ion ratio findings that sea water intrusion is the source of increased salinity in lower aquifer wells on the west side of the ground water basin. The trace element data also confirms ion ratio findings that sea water intrusion does not appear to have reached Baywood Park (wells 30S/10E-12J1 and 30S/11E-7Q3).

## Isotopes

Analysis of seawater intrusion using a variety of isotopes has been performed in other coastal basins. Radioactive isotopes such as tritium and carbon-14 (radiocarbon), can be used for age-dating water and thereby assist in defining potential sources of recharge.

Carbon-14 dating of water is based on the assumption that the principal source of carbon (as bicarbonate) during the initial ground water recharge process is dissolved carbon dioxide from atmospheric and soil-plant interactions. Once the recharge water percolates into the aquifer, the ratio of carbon-14 to carbon-12 changes through radioactive decay, and the apparent age of the water can be estimated by measuring this ratio. Other sources of carbon in ground water, such as dissolution of carbonate from the aquifer matrix, can alter the ratio. Sea water bicarbonate can also alter the radiocarbon isotope ratio when mixing with ground water.

Tritium is a hydrogen isotope that was released into the atmosphere in relatively large quantities during atomic bomb testing in the 1950's and 1960's. Tritium dating of ground water can be used to differentiate recently recharged ground waters (since the 1950's) from older water. Results of age-dating for basin waters are detailed in the lower aquifer source investigation portion of this study. The reported age of basin waters range from post-bomb (<50 years old) in shallower Zone C wells, to over 7,000 years old in deep Zone E wells. Zone D wells were generally between 2000 and 4000 thousand years old.

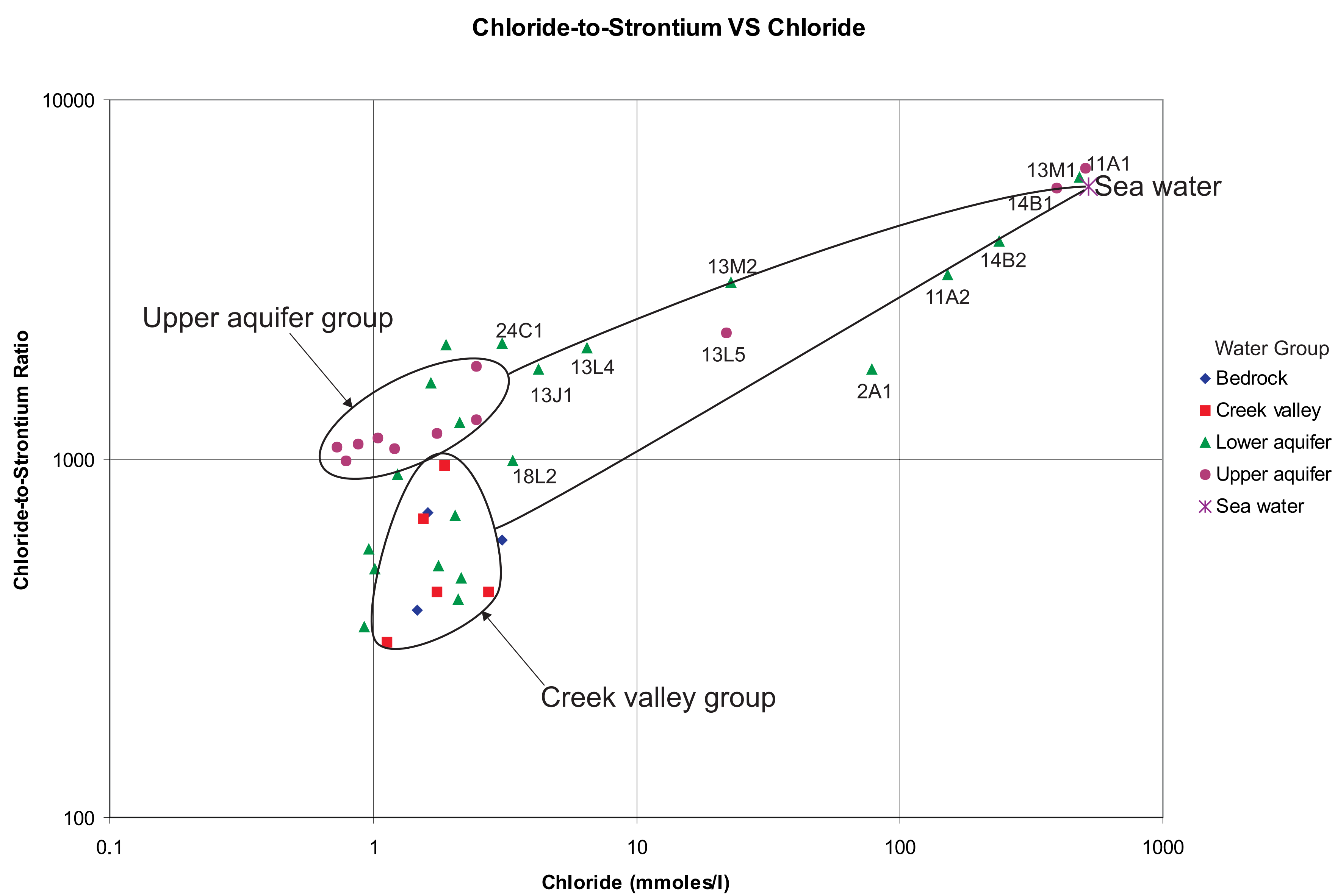


Figure 16
Chloride-to-Strontium versus Chloride

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Stable isotopes such as oxygen-18 and deuterium, delta boron-11, and strontium 86/87, may be used to distinguish end-members for evaluating sea water-fresh water mixtures (Bear et al, 1999; Land et al, 2004). As with the major ions and trace elements, interpretation of isotope data requires certain assumptions that may or may not apply to the study area being evaluated. These interpretive tools are best applied as part of a multi-level approach, where conclusions based on one set of results can be supported, refined, or refuted by another set. There were no stable isotope data available for ground water in the Los Osos valley ground water basin prior to this study.

The oxygen-18 versus deuterium isotope ratio of ground water samples collected during this project are shown in Figure 17. Only the sand spit wells, and the highly saline Zone E well 30S/10E-13M1 are noticeably separated from the main cluster of samples, being isotopically heavier due to mixing with sea water.

Comparison of the percent sea water based on chloride anions to the percent sea water based on the deuterium and oxygen isotopic composition yields a reasonable match for samples with greater than 20% sea water (mixture estimates are within 10% in four out of five samples). This confirms that sea water is the source of salinity for the isotopically heavy samples. Further interpretation of stable isotope data is detailed in the lower aquifer source investigation portion of this study.

**Geophysical Logs**

Geophysical logs can be used to detect changes in formation water salinity with depth. If geophysical logs are periodically run in the same hole, changes in formation water salinity may also be tracked over time. Logging performed for the sea water intrusion assessment includes analysis of formation water salinity with depth and also over time at three locations within the ground water basin. The primary logs used herein for assessing water quality changes are the resistivity and induction logs. Gamma logs are also useful as control for depth alignment when two logs from the same hole are compared.

As mentioned previously, besides the Binscarth Road test hole, natural gamma and induction logs were also run at two existing deep monitoring wells, 30S/10E-13M1 and 30S/11E-18L6 (Appendix I). Logging at a third deep monitoring well, 30S/10E-12J1 was unsuccessful due to casing obstructions. The purpose of geophysical logging at existing monitoring wells was to set a baseline for the sea water intrusion monitoring program.

The e-log signature of the Binscarth Road test hole indicated increasing salinity with depth. A sharp increase in salinity is observed in the induction log between 460 and 490 feet depth, and is interpreted as the fresh water - sea water interface. Estimates of water quality with depth, based on the geophysical logs, are summarized in Appendix H. The transition zone (>250 mg/l chloride) is estimated beginning in the lower portion of Zone D (between 300-350 feet depth), and the fresh water - sea water interface (>2,500

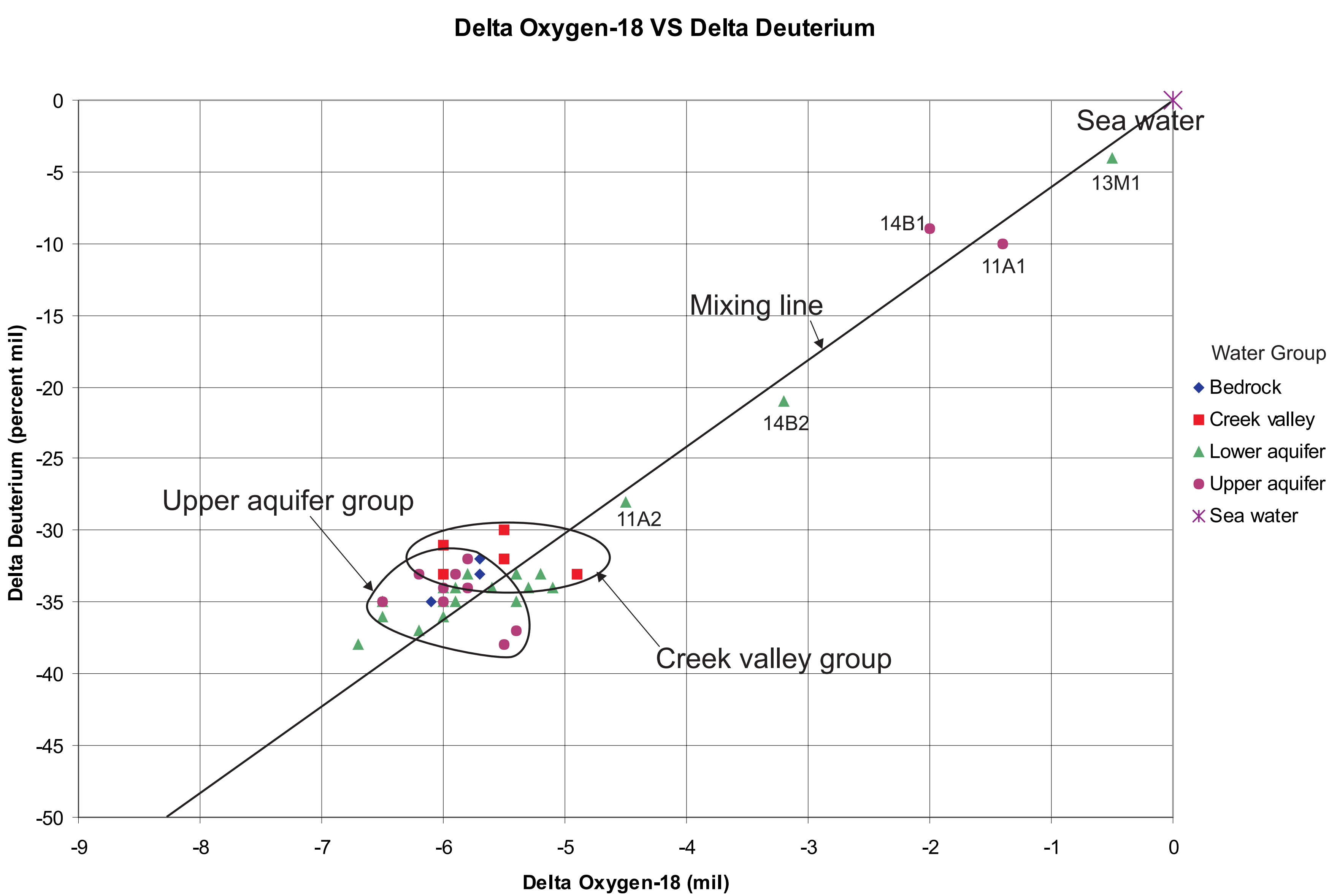


Figure 17
Oxygen-18 versus Deuterium

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mg/l) is estimated to begin in Zone E at approximately 460 feet depth, close to the base of the Paso Robles Formation.

Well 30S/10E-13M1 is completed in Zone E at Sea Pines golf course, and is approximately 90% sea water. Comparison of the gamma logs between the original March 1985 test hole and the recent March 2005 identified a two-foot offset between the logs, and this correction was applied prior to comparing the resistivity logs (resistivity data for the March 2005 log was created as a reciprocal of the induction log). The overall resistivity signature in the 2005 log is subdued, compared to the 1985 log. This is due primarily to the fact that the borehole fluid in the 2005 log is of much greater salinity than the fluid during drilling. Pertinent observations from the geophysical log comparison at well 30S/10E-13M1 are as follows (Figure 18):

- In the 1985 log, permeable aquifers in Zone D, centered at 268 and 285 feet depth, show greater resistivity than a less permeable zone between them, centered at 275 feet depth, which is normal for fresh water aquifers. The 2005 log shows the relationship has been reversed, with a lower resistivity opposite the permeable zones, compared to the less permeable zone in between. This reversal would be explained by sea water intrusion, and is confirmed by the water analyses from adjacent irrigation well 30S/10E-13M2, in which chloride concentrations have risen from 30 mg/l in 1985 to 800 mg/l in 2005.

- The base of the transition zone (>2,500 mg/l chloride) may be inferred as the point where resistivity flat lines close to zero ohm-meters. This point was at approximately 360 feet depth in 1985, but has risen to approximately 320 feet depth in 2005.

Well 30S/11E-18L6 is a deep monitoring well at the north end of Palisades Avenue. An induction and natural gamma log was also performed in March 2005 and compared to the prior geophysical log of this hole in May 1985. The comparison does not show any clear signs of sea water intrusion, although the well was obstructed below 550 feet depth (soft bottom, suggesting the casing collapsed or has filled in with sediment). Precursors of sea water intrusion have been detected at production well 30S/11E-18L2, approximately 550 feet south-southwest of 18L6.

## EXTENT OF INTRUSION

Hydrogeologic cross-sections A-A' and B-B' (Figures 19 and 20) illustrate the approximate locations of the sea water interface and transition zone (cross-section alignments are shown on Figure 9). The actual slope of the interface is uncertain, although it is assumed to be steeper in the upper aquifer (Zone C) where hydraulic heads are generally above the Ghyben-Herzberg threshold for intrusion, than in the lower aquifer zones.

The transition zone is defined herein as the area where chloride concentrations range from 250 to 2,500 mg/l. The following information on transition zone position for each aquifer zone is itemized with

# Well 30S/10E-13M1

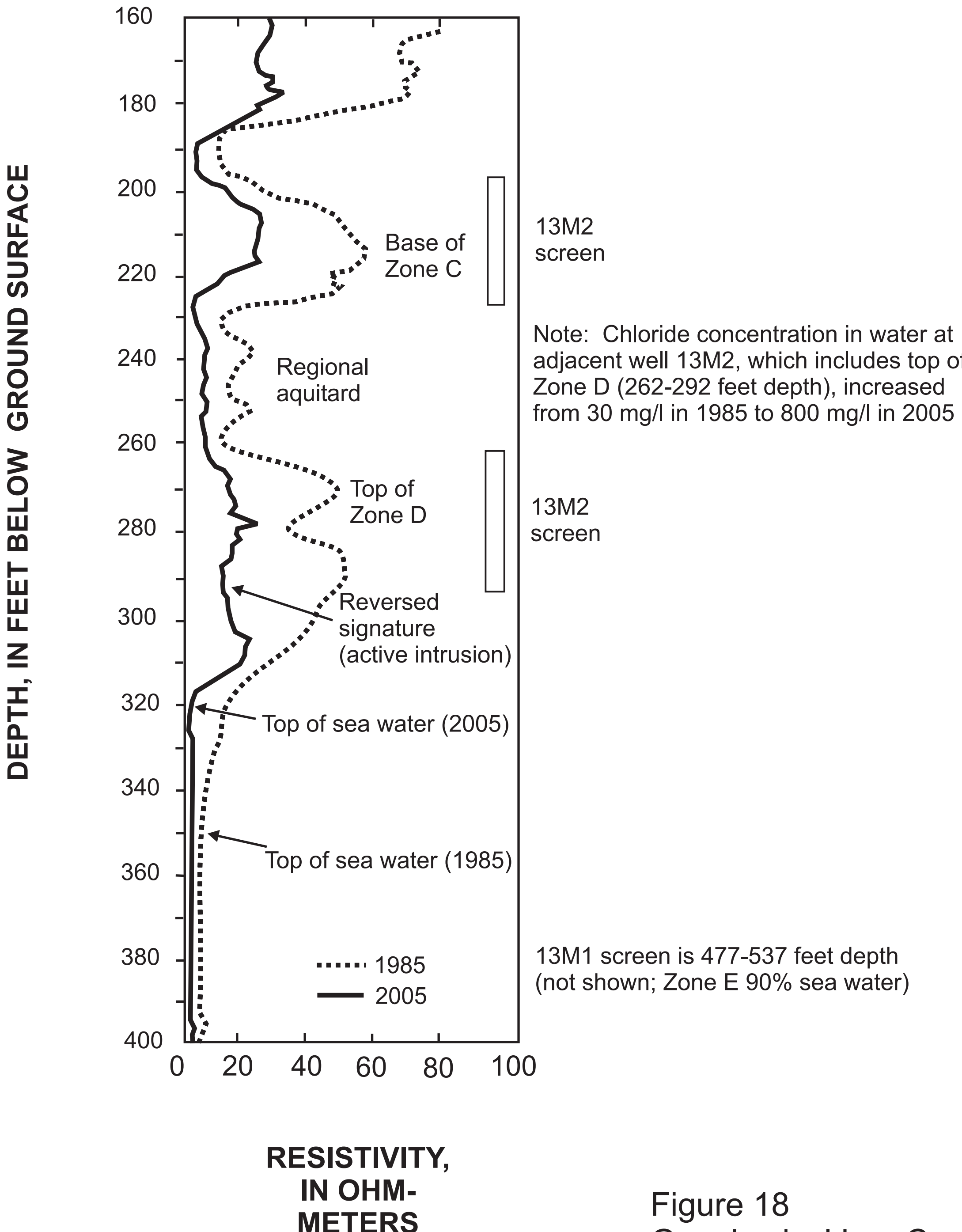


Figure 18
Geophysical Log Comparison
at 30S/10E-13M1

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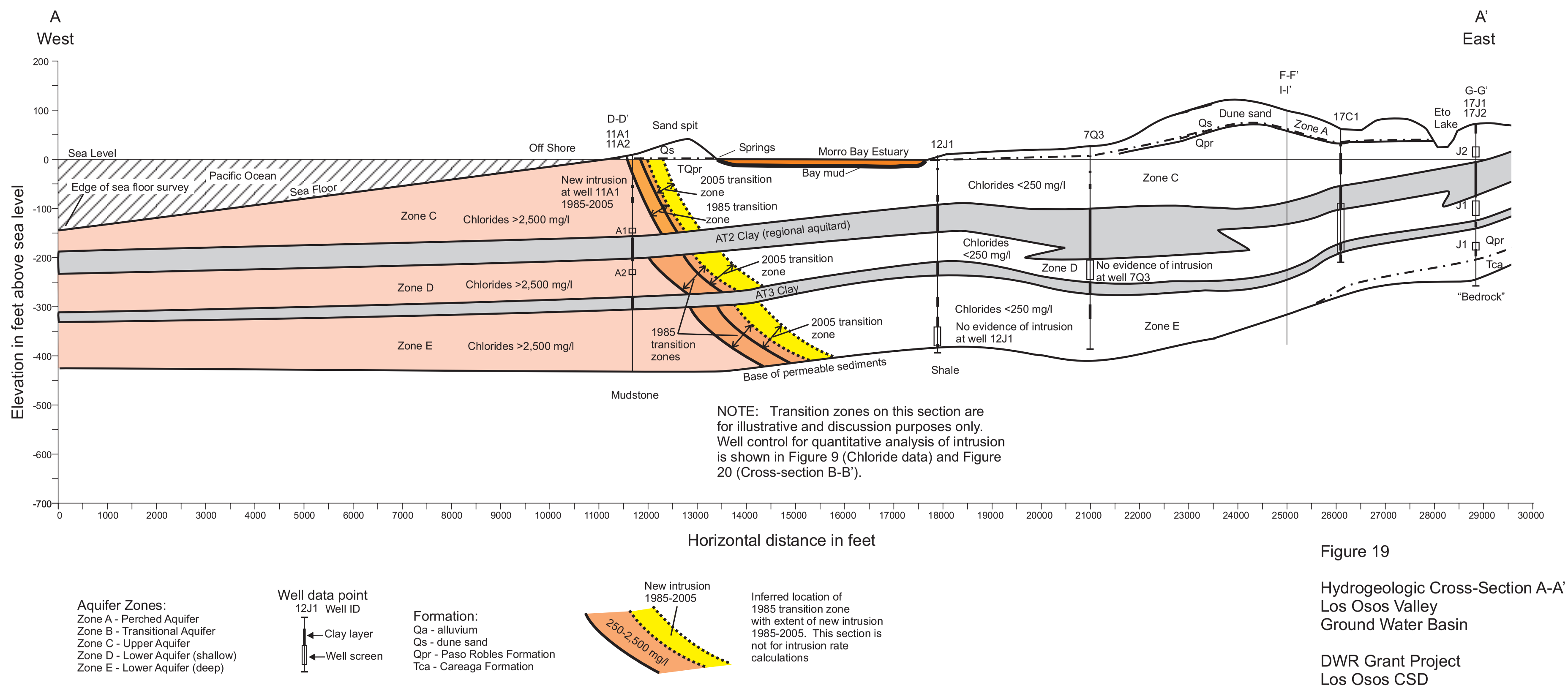


Figure 19

Hydrogeologic Cross-Section A-A'
Los Osos Valley
Ground Water Basin

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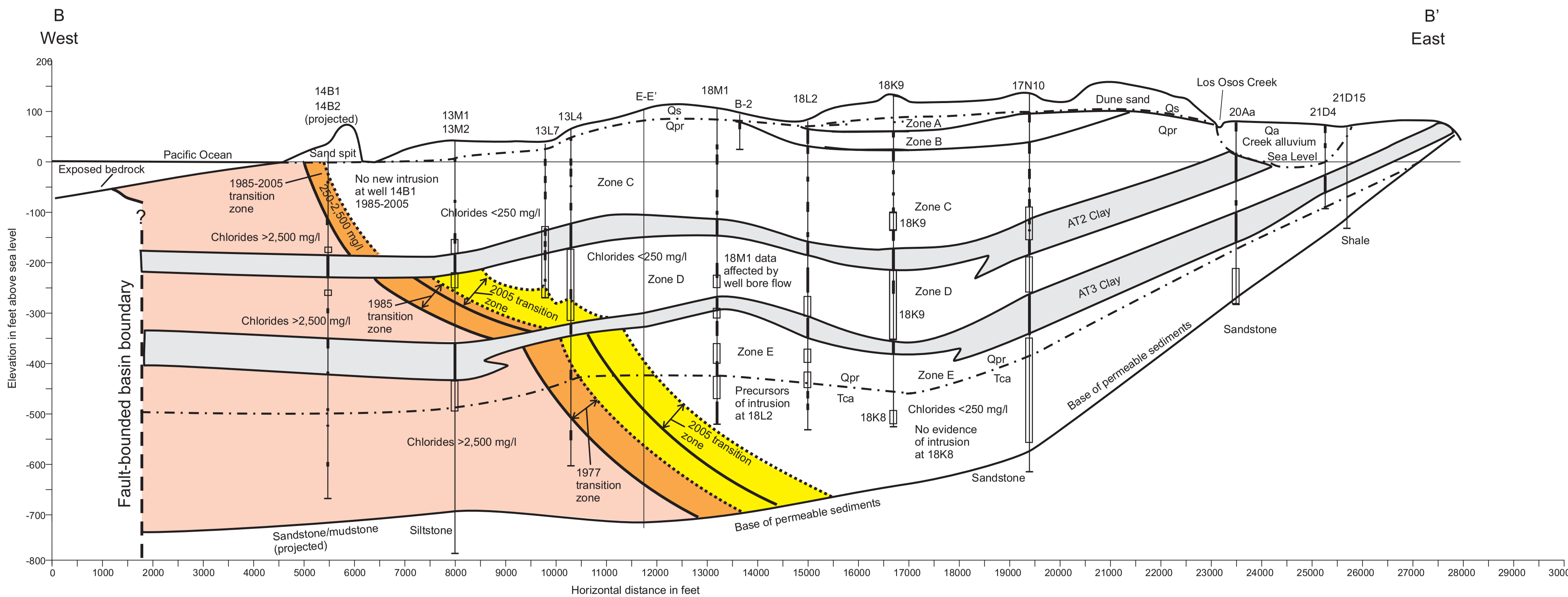



Figure 20

Hydrogeologic
Cross-Section B - B'
Los Osos Valley
Ground Water Basin

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reference to cross-section B-B' (Figure 20), to facilitate review and comparison. A summary of sand spit analytical data is also included in Appendix K for reference.

**Zone C Transition Zone**

- In 1985-86, the transition zone for Zone C was constrained between 30S/10E-14B1 (14,000 mg/l chloride) and 30S/10E-13M2 (bottom of Zone C and top of Zone D well completion, with 30 mg/l chloride).

- Hydraulic heads above sea level and ocean outflow in Zone C are considered sufficient to avoid sea water intrusion, except during extended drought. Chloride and TDS data for sand spit wells 11A1 and 14B1 between 1977 and 2005 indicate stable to slightly increasing salinity. These wells are already in excess of 75 percent sea water.

- No evidence of active sea water intrusion inland of the bay is present, based on a review of chloride concentrations and ion ratios between 1988 and 2003 at Zone C well 30S/10E-13F1, and a 2005 analysis from well 30S/10E-13Ma, located within 600 feet of the bay.

Although active sea water intrusion inland of the bay is not suspected in Zone C, there are shallow monitoring wells that have been indirectly, though significantly affected by sources of salinity (Well 30S/10E-13L5, and Sea Pines shallow monitoring well MW3). Chloride concentrations close to 400 mg/l and major ion ratios over time are all indicative of sea water intrusion beginning at well 13L5 in 1994. Chloride concentrations at MW3 rose from 130 mg/l in July 1998 to over 300 mg/l in January 2000, and remain over 300 mg/l in 2004. However, wells 30S/10E-13L5 and MW3 are 37- to 40-foot deep, non-pumping observation wells screened 15 feet into the water table (less than 10 feet below sea level). With ground water elevations above sea level, no sea water intrusion would be expected at the shallow water table.

The explanation for the increases in salinity at well 30S/10E-13L5 has been presented earlier following the discussion on chloride-to-bromide ratios. The chloride-to-bromide ratio for this well does not plot along the fresh water - sea water mixing line, and the sodium-to-chloride and calcium-to-bicarbonate plus sulfate ratios indicate greater calcium enrichment through ion exchange activity than any other water sampled in the basin. Additional data, such as elevated nitrates and proximity to residences, suggests that the increases in salinity at well 13L5 are due to return flows from a septic system near the well that contains brine from water softener discharges.

Well MW3 was constructed to monitor for water quality degradation attributable to treated wastewater discharges from a nearby treatment plant. The chloride concentrations in 13L5 were observed to spike prior to construction of the treatment plant, and chloride concentrations at MW3 have exceeded the concentrations in the wastewater discharge. MW3 is immediately adjacent to irrigated turf, and the suspected source of high salinity at this well is due to irrigation with high chloride water from a well that has been subject to relatively recent sea water intrusion. The irrigation well, 30S/10E-13M2, is used by the golf course and is screened at the bottom of Zone C and the top of Zone D (not to be confused with adjacent well 13M1, which is a Zone E well with very high chlorides). The transition zone is interpreted to have moved through this well within the last 10 years, and chlorides are currently at 800 mg/l.

**Zone D Transition Zone**

- In 1985-86, the transition zone for Zone D was constrained between 30S/10E-14B2 (8,700 mg/l chloride) and partially through 30S/10E-13M1. Evidence of intrusion is not present in a 1985 water sample from the top of Zone D at nearby 13M2, but e-log response for 13M1 shows transition zone intrusion at base of Zone D beginning at close to 300 feet below sea level. Further east, there is no evidence of intrusion as of 1985 at base of Zone D in well 30S/10E-13L4.

- Inland hydraulic heads below sea level and ocean inflow in Zone D are conditions for sea water intrusion.

- On the sand spit, where insufficient hydraulic head is present to avoid intrusion, chloride and TDS data for sand spit well 30S/10E-11A2 between 1977 and 2005 indicate steady increases in salinity over time, while sand spit well 14B2 shows lesser increase (Appendix K).

- Evidence of active sea water intrusion inland of the bay since 1985 is present in a review of chloride concentrations and ion ratios at Zone D wells 30S/10E-13L4, 13L7, 13J1, and 18L2. The 250 mg/l chloride threshold was exceeded at 13L7 in 1993, and at 13L4 in 2001. Although chlorides were much lower at 13L7 during the 2005 sampling event, the concurrent appearance of elevated nitrates indicates the sample from 13L7 was not representative of lower aquifer water. Downward leakage of upper aquifer water inside the well casing is suspected due to several years of relative inactivity.

- Geophysical logs from the test hole drilled on Binscarth Road (30S/10E-13H) suggest that the transition zone is very close to the base of Zone D at that location.

- Sea water intrusion does not appear to be active in Zone D beneath Cabrillo Estates, based on water quality data from well 30S/10E-24C1. Chloride concentrations have been in overall decline for the last 20 years, and are currently at 110 mg/l. There has also been a steady increase in nitrate concentrations at well 24C1 over the last 20 years, suggesting significant leakage from the upper aquifer is occurring.

**Zone E Transition Zone**

- In 1985-86, Zone E sea water intrusion appears to have extended further inland than in Zone D. Water quality data from 1985 at Well 30S/10E-13M1 shows the top of Zone E to have approximately 90 percent sea water. The e-log for well 30S/10E-13L4 shows transition zone water beginning at approximately 480 feet depth, based on erratic activity of the spontaneous potential, and the sea water - fresh water interface beginning at approximately 560 feet depth, based on the resistivity and induction logs.

- Well 30S/11E-18M1 is located approximately 3,000 feet east of 30S/10E-13L4, and is ideally situated for detecting the leading edge of sea water intrusion. Water quality results for 18M1 from 1982 showed no evidence of sea water intrusion. A 2005 water sample collected from well 18M1, however, contained elevated nitrates (10 mg/l as nitrogen) and had an upper aquifer water character, despite purging approximately 1.3 acre-feet of water from the well immediately prior to sampling. The problem with well 18M1 is over 20 years of inactivity. Upper aquifer leakage through the annular space has created an upper aquifer plume surrounding the well.

- Well 30S/10E-12J1 (cross-section A-A'; Figure 19) shows no geochemical evidence of sea water intrusion based on chloride and ion ratios over time between 1982 and 1998.

- Geophysical logs from the test hole drilled on Binscarth Road (30S/10E-13H) indicates Zone E has been intruded, with the sea-water interface beginning at approximately 480 feet depth.

- Chemographs of ion ratios over time at well 30S/10E-18L2 shows the arrival of sea water intrusion precursor trends in 2002.

The e-log responses referred to above as indications of the transition zone at well 30S/10E-13M1 and 13L4 consisted of relatively abrupt decreases in resistivity within permeable sections of the test hole, and changes in the spontaneous potential activity. Indications of the presence of intruded zones in Zone D and E based on e-logs were recognized by the Morro Group (1989).

## AVERAGE RATE OF INTRUSION (1985-2005)

Active intrusion in Zone C is not considered likely, given that hydraulic heads in this zone have not declined over time, and generally remain above the threshold for intrusion established by the Ghyben-Herzberg relation. Hydraulic heads in the Zone C sand spit wells (30S/10E-11A1, 14B1) have not declined over time, although they were slightly below the Ghyben-Herzberg relation threshold during the early 1990's. High chloride concentrations in these sand spit wells (14,000+ mg/l) indicate sea water intrusion has occurred in the past, but evidence for recent intrusion is mixed. Chloride concentrations at well 14B1 have not increased since 1985, but have increased at well 11A1.

The movement of two intrusion fronts have been tracked in Zone D, corresponding to the leading and trailing edges of the transition zone. The available geochemical data indicate that the toe of the transition zone had moved past well 30S/10E-13L4 by 2001 (290 mg/l chloride), but had not yet reached 13J1 (110 mg/l chloride). The 2004-2005 data collected for this study demonstrates that the transition zone has also passed through well 13M2 (800 mg/l chloride) and continues to advance toward well 13J1 (150 mg/l chloride) and the 13H test hole (estimated between 190 mg/l and 260 mg/l chloride). A recent sample from well 13L4 detected chlorides slightly below the transition zone threshold (230 mg/l), and this is interpreted to be due to a significant drop in production since 2001. Although the transition zone may become thinner at Well 13L4 during periods of lower production, the advance of the toe continues in 2005 toward 13J1.

Based on the interpreted positions of the 250 mg/l isochlor lines shown in Figure 9, the maximum inland advance of the transition zone over the last 20 years (1985-2005) would be approximately 1,200 feet, or 60 feet per year (0.16 ft/day). Precursor trends appear to be moving through the basin ahead of the transition zone at a faster rate, while the sea water - fresh water interface is trailing the transition zone at a slower rate. Comparisons discussed previously between chloride and major ion ratios over time at wells 30S/10E-13L4 and 13J1 suggest a lag time averaging 5 years between the onset of precursor trends at the two wells. The distance between the wells perpendicular to the isochlor fronts is approximately 1,000 feet, which would correspond to an average rate of 200 feet per year (0.55 ft/day). The advance of the fresh water - sea water interface, based on the movement of the 2,500 mg/l isochlor by up to 900 feet over the last 20 years, is estimated at only 45 feet per year (0.12 ft/day).

The rate of sea water intrusion in lower aquifer Zone E may be estimated based on data from geophysical logs. A comparison between the interpreted position of the transition zone in 1977 and 2005 is shown in Figure 20. Data from the Binscarth Road (13H) test hole was projected along onto the section along a line parallel to the Zone D isochlors. The resulting estimated rate of sea water intrusion in Zone E is 1,500 feet over 28 years, equivalent to 54 feet per year (0.15 ft/day).

The above estimated rates of intrusion apply only to the area and are averaged over the time period evaluated, and would not apply to other areas or time periods. The rate of intrusion is typically not uniform over time, but varies seasonally according to pumping cycles, and is accelerated during drought periods. Progressive ground water storage depletion over time may also increase the rate of intrusion.

The estimated sea water intrusion rate of 50 to 60 feet per year in the Los Osos Valley ground water basin is much lower than that measured in the pressure aquifers of the Salinas Valley, where sea water intrusion moved inland up to 2 miles between 1985 and 2001, an average rate of 660 feet per year (MCWRA, 2001). Sea water intrusion rates in the Oxnard Plain of Ventura County have been estimated at between 70 and 1,100 feet per year (0.2 to 3 ft/day) based on tritium and carbon-14 data (Izbicki et al, 1992) and approximately 400 feet per year (1.1 ft/day) based on a reinterpretation of chloride source data using oxygen isotopes (Izbicki, 1992).

## SEA WATER INTRUSION MONITORING PROGRAM

The purpose of the sea water intrusion monitoring program is to provide additional data for improving the estimates presented herein concerning the rate and extent of sea water intrusion in the lower aquifer. The program would also continue to monitor selected sites over time, to assist in planning, implementing, and evaluating future sea water intrusion control measures.

### Monitoring Frequency

Sea water intrusion is a relatively slow process. The recommended frequency of water quality and geophysics monitoring is once every three years, preferably in October, before the onset of seasonal rains. Water level monitoring, however, would be critical to model calibration, and should be performed in April and October of every year.

### Constituents of Analysis

The work performed for this study has shown that the general mineral water quality suite is satisfactory for characterizing and identifying sea water intrusion in the Los Osos Valley ground water basin. Trace elements and isotope data have confirmed the conclusions reached using only general mineral data. Therefore, general minerals are the recommended water quality constituents of analysis for the sea water intrusion monitoring program.

The recommended geophysical logs to be run every three years are electromagnetic induction and natural gamma. The induction log serves to chart changes in formation water salinity over time throughout the entire cased hole, while the natural gamma provides elevation control for matching the induction logs between different years. The constraint on induction logging is that the well casing must be plastic, and not metallic.

### Reporting

Reports on the status of sea water intrusion would be generated every three years, following the water sampling events. The reports would include ion ratio and chloride chemographs, water level hydrographs, side-by-side geophysical log illustrations, tabular presentation of water level and water quality data, and data interpretation, including maps revising the extent of intrusion, as appropriate.

### Monitoring Locations

Several of the existing wells where sea water intrusion monitoring would be recommended are community water supply wells. These wells are already monitored regularly for water levels and at least every three years for general minerals. Data from these wells should be gathered for interpretation and report preparation, with no additional monitoring activity required. The purveyor wells to be included in the monitoring program are shown in the following table.

**Table 6**
**Purveyor Wells included in Sea Water Intrusion Monitoring Program**

| Well ID | Location | Aquifer Zone | Depth (ft) | Perforations (depths in ft) | Casing diam. (in) | Monitoring Tasks* |
|---|---|---|---|---|---|---|
| 30S/10E-13J1 | Rosina Dr. | D | 406 | 290-406 | 10 | (none) |
| 30S/10E-13L4 | Pecho Rd. | D | 390 | 240-380 | 14 | (none) |
| 30S/10E-13N | Pecho Valley Rd. | D | 350 | 260-340 | 8 | (none) |
| 30S/10E-24C1 | Rodman Dr. | D | 500 | 250-500 | 10 | (none) |
| 30S/11E-7Q3 | 8th Street | D | 290 | 230-270 | 10 | (none) |
| 30S/11E-18L2 | Palisades Dr. | D, E | 550 | 350-390; 455-480; 500-530 | 12 | (none) |

*NOTE: Monitoring tasks at purveyor wells would be performed by purveyors - sea water intrusion program activities would only involve gathering information for the report.

Recommended locations for sea water intrusion monitoring at non-purveyor wells are shown in Table 7 below. These wells would be monitored specifically for the program.

**Table 7**
**Sea Water Intrusion Monitoring Program Wells**

| Well ID | Location | Aquifer Zone | Depth (ft) | Perforations (depths in ft) | Casing diam. (in) | Monitoring Tasks |
|---|---|---|---|---|---|---|
| 30S/10E-2A1 | Sand spit #2 | E | 230 | 220-230 | 2 | sample, level |
| 30S/10E-11A1 | Sand spit #1 | C | 160 | 150-160 | 2 | sample, level |
| 30S/10E-11A2 | | D | 244 | 234-244 | 2 | sample, level |
| 30S/10E-12J1* | Pasadena Dr. | D | 394 | 349-389 | 2 | sample, level |
| 30S/10E-13M1 | Howard | E | 550 | 477-537 | 6 | geophysics, level |
| 30S/10E-13M2 | Howard | C, D | 292 | 197-227; 262-292 | 6 | sample, level |
| 30S/10E-14B1 | Sand spit #3 | C | 200 | 190-200 | 2 | sample, level |
| 30S/10E-14B2 | | D | 280 | 270-280 | 2 | sample, level |
| 30S/11E-18L6* | Palisades | D, E | 600 | 355-375; 430-480; 550-600 | 6 | geophysics, sample, level |

*NOTE: Well 12J1 has a bent casing which obstructs placement of a sampling pump or geophysical logging tools. This monitoring location is critical, and a replacement well in the vicinity is recommended (with a Zone D and Zone E piezometer). Well 18L6 was obstructed at 550 feet depth with a soft bottom. Removing the sediment from the bottom 50 feet of this well is recommended.

## New Monitoring Well Construction

Two new monitoring locations are considered necessary. One location would near the existing well 30S/10E-12J1 in Baywood Park. Well 12J1 provides samples for Zone E, but cannot be used to assess Zone D, due to obstructions in the casing that prevent the use of geophysical tools. Purveyor well 30S/11E-7Q3 has shown some precursor trends of sea water intrusion in Zone D, but they are not definitive. A replacement well for 12J1 is recommended, and would include a Zone D and Zone E piezometer. A multi-piezometer monitoring well is also recommended in Cuesta-by-the-Sea. The test hole drilled along Binscarth Road during this study was instrumental in defining the current sea water intrusion front, and a monitoring well near that location, such as at the Lupine Street pump station lot, is needed. The well would include Zone C, D, and E piezometers.

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# PART 3

# SOURCE OF LOWER AQUIFER RECHARGE

## INTRODUCTION

The purpose of the lower aquifer source investigation is to characterize the primary recharge sources for the lower aquifer, which is the principal water supply aquifer in Los Osos. Understanding the mechanisms for recharge to the lower aquifer is a critical part of ground water basin management. The investigation will focus on four source areas: recharge from the Los Osos Creek Valley, leakage from the upper aquifer through the regional aquitard, subsurface inflow from adjacent and underlying bedrock, and sea water intrusion.

## STRUCTURAL DEFINITION OF LOWER AQUIFER SYSTEM

The lower aquifer system comprises aquifer zones lying beneath the regional (AT2 clay) aquitard. A structural interpretation of the location and continuity of the regional aquitard is critical to an analysis of recharge to the lower aquifer. Specifically, identification of lower aquifer wells is required for the analysis of recharge, from a perspective of both water quality and water levels.

Separation of the ground water basin into an upper and lower aquifer system was first proposed by the DWR (1979, page 2) for water-bearing sediments beneath the sand spit, and later extended to the basin as a whole by Brown & Caldwell (1983, page 4-8). The dual aquifer-system approach to assessing ground water basin issues was refined by the Morro Group (1987) in the Environmental Impact Report (EIR) for the County Services Area No. 9 Wastewater Treatment Facilities. The 1987 EIR, along with the Final Supplemental EIR (Morro Group, 1989), presented a structural definition of the aquifers and proposed a system of nomenclature that included aquifers AF1 through AF4 and aquitards AT2 through AT4.

Not all investigators supported the dual aquifer-system approach. In 1988, the U.S.G.S. report recognized continuous clay layers in two areas but characterized the basin as an aquifer system which is homogeneous with vertically anisotropic hydraulic conductivity.

A brief recap of the historical interpretation of the AT2 clay structure is presented below, along with the current interpretation. This recap is provided primarily for background information, but also serves a practical purpose, due to the continuing evolution of basin structural interpretation. Alternative interpretations, rather than being permanently discarded, have occasionally been reincorporated into current opinion.

### East Side

Brown & Caldwell (1983, cross-section A-A', page 4-9) and the Morro group (1987, cross-section A-A', page V-9) interpreted the regional aquitard as subcropping beneath Older dune sands west of Los Osos Creek. The Morro Group (1989, cross-section F-F', page B-5) also showed the aquitard outcropping along the west bank of Los Osos Creek, upstream of Los Osos Valley Road. A concurrent investigation by the U.S.G.S. (Yates and Wiese, 1988, cross-section A-A', pages 8, 9, and 16) identified and correlated continuous clay layers in two areas, one layer up to 20 feet thick between Los Osos Creek and downtown Los Osos, and the other layer 50 to 80 feet thick west of the north-south extension of Ninth Street.

A lower aquifer water level contour map for Fall 1984 was prepared based on the above historical interpretation by the Morro Group (1987 EIR, Volume II, Figure C-3.4). This map showed deep aquifer water levels below sea level from the coast through Ferrell Avenue. East of Ferrell Avenue, lower aquifer water levels were shown above sea level and increasing in elevation up to the invert level of the Los Osos Creek channel. Many of the wells on the east side of Ferrell Avenue used for preparation of the Fall 1984 lower aquifer water level contour map, however, have since been reinterpreted as upper aquifer wells.

In the mid 1990's, the Morro Group prepared cross-sections for Metcalf & Eddy (unpublished) and a map of elevation contours on the base of the regional aquitard (EDA and Morro Group, 1997) that differed from the original 1987 EIR interpretation. Specifically, the perching clay that extends from Bayview Heights though downtown Los Osos was interpreted as separate from the regional aquitard. It was recognized that the perching clay (AT1 clay) outcrops along the banks of Los Osos Creek, while the regional aquitard subcrops further to the east beneath the creek valley alluvium. In fact, the perching clay had been previously studied during development of Bayridge Estates and correlated with the outcrops along Los Osos Creek (Wiese, 1974).

In 2001, Weber, Hayes & Associates investigated the perched aquifer beneath a portion of downtown Los Osos, and identified three discrete hydraulic zones, which they named Zones A, B, and C. The work by Weber, Hayes & Associates confirmed the existing interpretation regarding the depth of the perching clay, and the nomenclature for the aquifer zones was expanded by Cleath & Associates (2003) to include Zones D and E. The current interpretation of the regional aquitard structure on the east side, including the creek valley, is shown in Figure 21 (Detail of Hydrogeologic Cross-Section B-B').

**Los Osos Creek Valley**

A main source of recharge to the lower aquifer has historically been considered to be Los Osos Creek and the creek valley sediments. The Morro Group (1987, 1989) focused on the upper creek valley as the most likely location for recharge from stream seepage, with supporting evidence from possible fracture conduits along the Los Osos fault near the juncture of Strand A and Strand B, from ground water mounding in the upper creek valley area, and from the former structural interpretation of the regional aquitard as absent east of the creek. Stream seepage had been measured in the upper creek valley during portions of 1986, and was estimated to average 1.1 acre-feet per day.

In 1988, the U.S.G.S. report considered seepage from Los Osos Creek to be a major natural source of recharge to the basin as a whole (upper and lower aquifers were not distinguished in the report), although the net basin recharge from the creek was negligible, due to outflow seepage. The upper creek valley was recognized as the area where seepage occurred based on the 1986 measurements, however, a major

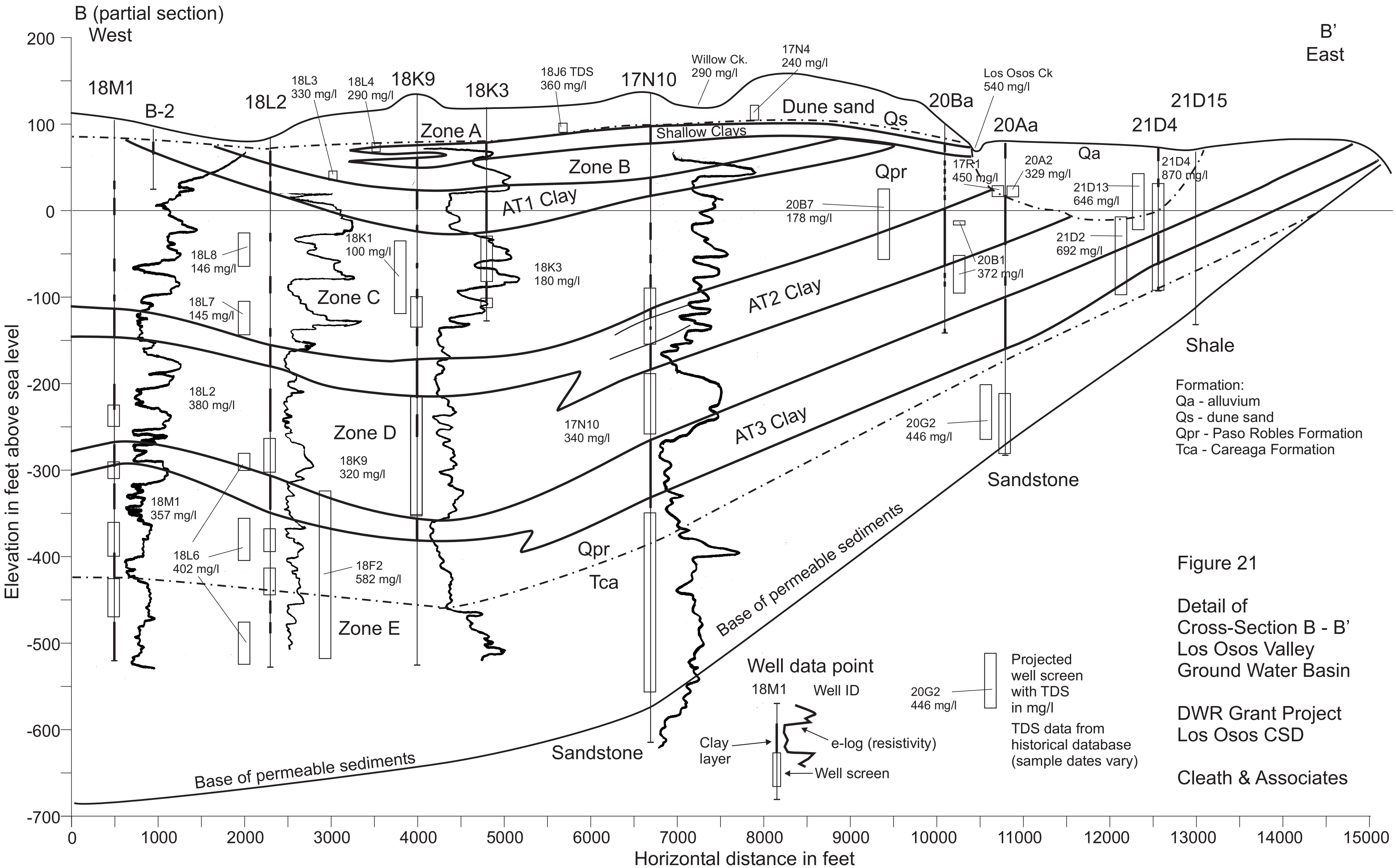



Figure 21

Detail of
Cross-Section B - B'
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates

problem existed for ground water movement from the upper creek valley to the west. The ground water mound in the upper creek valley was so high, compared to water levels at deep monitoring well 30S/11E-19H2 to the west, that a barrier to flow was inferred. The most likely barrier was the extension of a fault that has been mapped by Hall intersecting the Los Osos fault south of Bayview Heights (Figure 2).

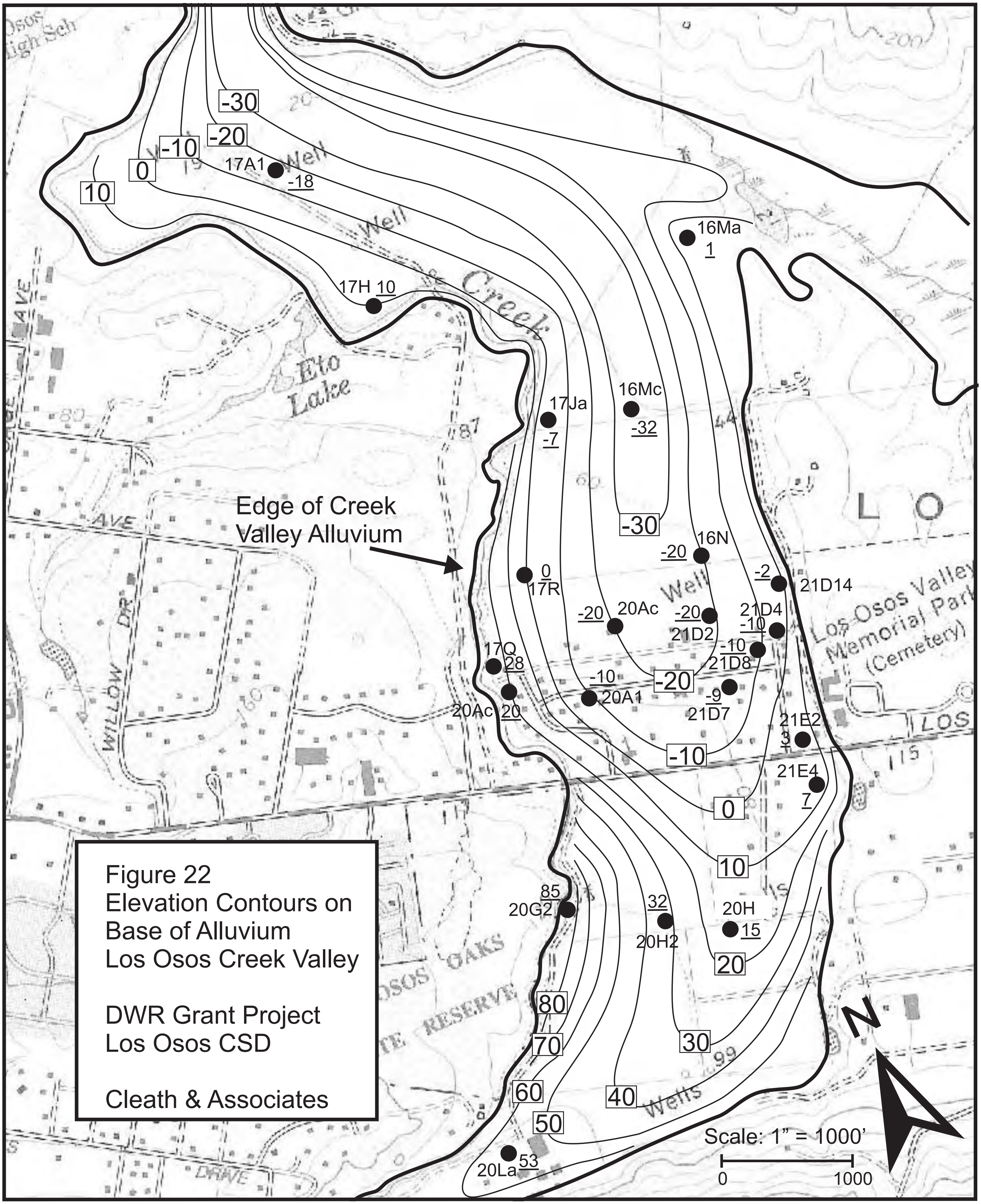
With the revised correlation of the regional aquitard in the mid-1990's to a lower horizon on the east side, direct hydraulic communication between upper Los Osos Creek and the lower aquifer was no longer possible. This, together with the permeability restriction to the west, effectively isolated Los Osos Creek from recharging anything but the relatively shallow Holocene alluvial sediments, which is the current interpretation.

The presence of a buried fault beneath Bayview Heights is indicated by a sharp rise in bedrock between wells 30S/11E-19H2 and 30S/11E-20Ea, located 1,000 feet apart (cross-section H-H'; Appendix A). Shale bedrock is logged in well 20Ea (Bayview Heights) at approximately 100 feet below sea level, which is at the same elevation that shale bedrock is logged beneath the upper Los Osos Creek Valley to the east, at well 30S/11E-20L. The buried fault is interpreted to trend east to west, subparallel to Strand A of the Los Osos fault (cross-sections F-F', H-H', and G-G'; Appendix A). A pair of buried faults beneath Bayview Heights along the trend projected by the U.S.G.S. in 1988 have also been incorporated into the current structural interpretation, based on geological field reconnaissance along the basin southern boundary and on ground water flow considerations discussed above.

Recharge to the lower aquifer beneath the creek valley would occur primarily where the aquifer subcrops beneath alluvial sediments, with additional recharge from leakage through portions of the regional aquitard that extend beneath the valley. Figure 22 shows elevation contours on the base of alluvial sediments in the Los Osos Creek Valley, based on well logs. Figure 23 shows the subcrop map for the lower aquifer beneath the alluvial sediments, based on well logs and structural projection.

**Southern Boundary**

No detailed assessment of structure at the southern basin boundary was presented in early studies, other than the characterization of the boundary as a fault contact with the Los Osos fault (Brown & Caldwell, 1974). The first structural maps extending to the south boundary were presented in the Morro Group 1987 Wastewater Facilities EIR and 1989 Supplement, which showed the AT2 clay rising toward the south-southeast above Highland Drive at a dip of approximately 6 to 9 degrees (similar to the topographic slope). Based on this geometry, the lower aquifer would come into contact with Pismo Formation deposits across the Los Osos fault. By comparison, in the 1988 U.S.G.S. report, the dip on the <u>base</u> of the Paso Robles Formation is approximately 20 degrees on the south limb of the basin syncline and rises to ground surface along the ridge upslope of Highland Avenue (Geologic cross-section B-B', Figure 5 in Yates and Wiese, 1988).




Base Map: U.S.G.S. Topographic Map
Morro Bay South
Map Scale: 1 inch = 1,000 feet

32 ● 20H2 Well with base of alluvium in feet above sea level

40 Elevation contour on base of alluvium in feet above sea level

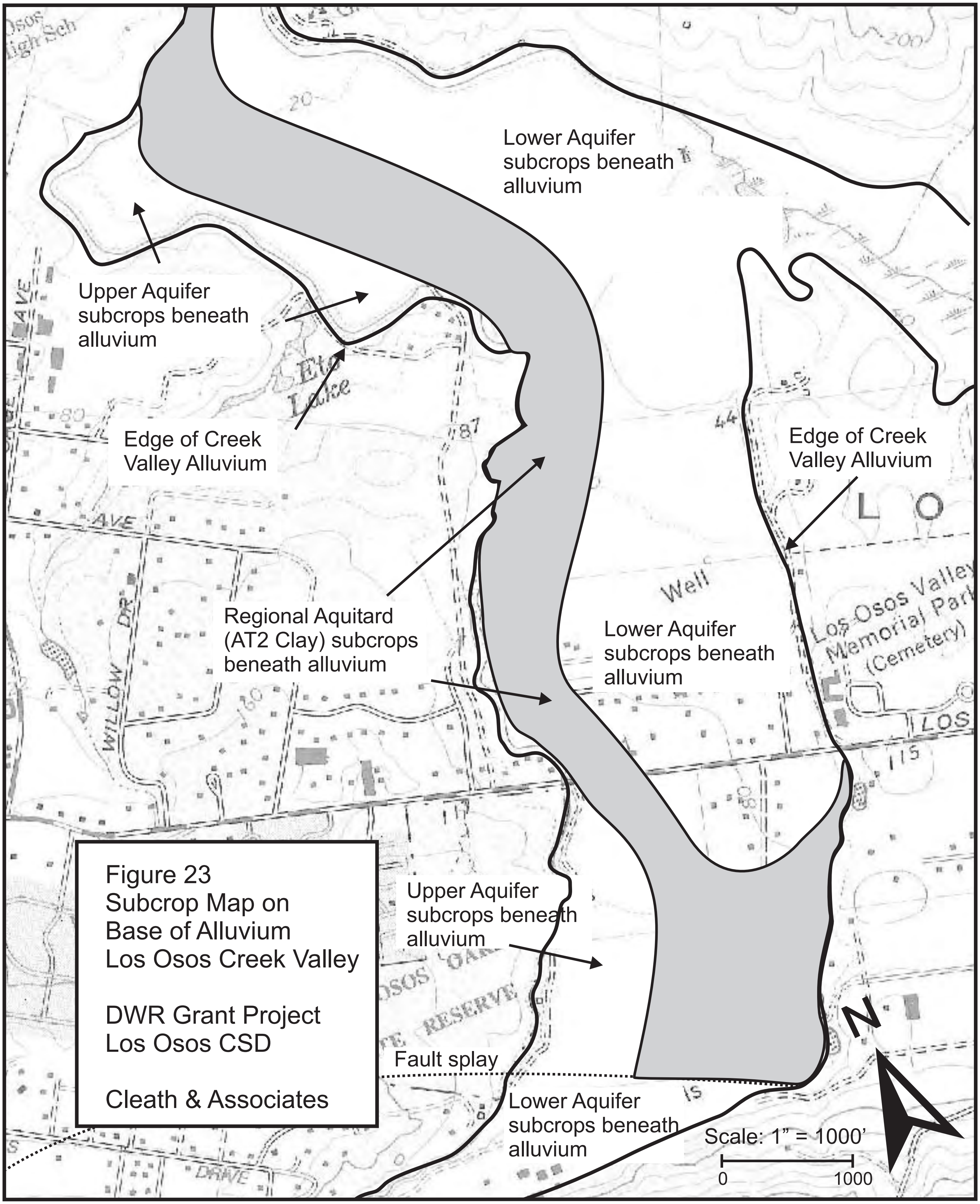



Figure 23
Subcrop Map on
Base of Alluvium
Los Osos Creek Valley

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A revised structural interpretation developed by the Morro Group in the mid-1990's brought the AT2 Clay closer to ground surface on the south, subcropping beneath Older dune sands along the ridge upslope of Highland Avenue. This interpretation used data from shallow soil borings drilled by Pacific Geosciences (1985), and resulted in an average dip of 12 degrees for the AT2 clay upslope of Highland Avenue. A similar dip was also inferred for the AT2 clay to the east, upslope of Bayview Heights Drive (Figure C3-4 in EDA and the Morro Group, 1997).

In May 2000, Cleath & Associates supervised a series of test holes upslope of Highland Avenue that indicated the dip of the regional aquitard was sub-parallel to the topographic slope of approximately 4 degrees (Cleath & Associates, 2000). Correlation between the regional aquitard and the shallow clays from Pacific Geoscience borings further upslope was not considered likely at the time, based on an inspection of surface geology. Projection of the regional aquitard at the steeper angle (17 degrees) required for the correlation would result in outcropping of the clay upslope of Pacific Geoscience soil boring SB2. Paso Robles Formation outcrops showing through the looser dune sands in the vicinity were composed of mostly firm reddish brown sand. A relatively competent clay with embedded angular shale gravel was observed along the Los Osos fault zone itself, and while this may be the AT2 clay, its close proximity with the fault zone increases the likelihood that it is either an unrelated gouge or an isolated remnant. The current interpretation of the basin structure along the southern boundary, therefore, is similar to that originally described by the Morro Group in 1987 and 1989, with the regional aquitard close to 200 feet below ground surface, rising sub-parallel to the topographic slope until its contact with the fault.

## Intrabasinal Faults

There have been five faults proposed within the ground water basin limits (Figure 2). Faulting often creates ground water flow barriers, which are of particular interest to this investigation. It should be noted that while this investigation includes some critical review of selected portions of prior work, it could not have arrived at the present interpretation without the significant contributions of these prior investigators.

### Lettis and Hall

A northeast-southwest trending intrabasinal fault was proposed by Lettis and Hall based on the interpretation of depth to bedrock from borehole data (PG&E, 1988; also referenced herein as Lettis and Hall, 1990). The 1990 analysis included a southwest-northeast geological cross-section through the fault, with a down-to-the-southwest dip-slip motion. Current interpretation of the borehole data differs in from that presented by Lettis and Hall. In particular, the top of the Careaga Formation had been correlated as the top of shell-bearing zones, which resulted in a 380-foot rise in the contact with the Paso Robles Formation between well 30S/11E-18L6 (formerly GS-2) and 30S/10E-12J1 (formerly MBO-5). These shell-bearing horizons do not correlate, however, and the relatively shallow appearance of shell fragments (135 feet depth) at well 30S/10E-12J1 and others is not considered Careaga, but a near shore facies of the

Paso Robles Formation, which is also the interpretation presented by the U.S.G.S. (Yates & Wiese, 1988). Borehole correlations by Lettis and Hall for the top of the Careaga for two other wells (30S/11E-17J1 and 20G2) on the up-thrown side of the proposed fault are also much shallower than either the U.S.G.S. or Cleath & Associates interpretation. As noted by the Morro Group (1989), the documentation for the intrabasinal fault proposed by Lettis and Hall included no corroborative evidence such as springs, photo lineaments, or topographic features. Given that key borehole lithologic correlations are considered incorrect, this fault has been removed from structural representations of the basin.

The Morro Group

Correlation of the regional aquitard across the basin in 1983 (Brown & Caldwell) and 1987 (Morro Group) was not detailed, and did not include faulting. By 1988, however, results of the U.S.G.S. deep well drilling program were available and one cross-section prepared in the EIR Supplement (Morro Group, 1989), oriented through the Palisades area, showed a fault with an apparent downward vertical displacement of approximately 80 feet between wells 30S/11E-18L6 (north end of Palisades Avenue) and 30S/11E-18F2 (Ferrell Avenue). The new fault was labeled Strand B (Figure 2) of the Los Osos fault, and represented a potential seismic hazard.

Subsequent east side correlation of the AT2 clay to a lower horizon in the mid-1990's by the Morro Group resulted in a greater apparent vertical displacement across the Stand B fault. In 1997, the apparent displacement was estimated to be 150-200 feet (down to the east), and was associated with up to 1,500 feet of right-lateral slip, although the possibility of alternative explanations of the sense of movement of the fault was noted (D. O. Asquith, 1997, page 13 and Figure III-5).

Cleath & Associates' current interpretation of the regional aquitard correlation does not include Strand B (cross-section B-B' detail, Figure 21), based on an evaluation of water quality, pumping tests, and lithologic/electric resistivity log (e-log) data. Water quality above and below the horizon selected as the regional aquitard is significantly different, supporting the e-log correlation as shown in Figure 21, which does not include a Stand B offset. Above the regional aquitard, total dissolved solids in Zone C are less than 200 mg/l. Below the aquitard, total dissolved solids in Zone D are above 300 mg/l, and generally above 400 mg/l in Zone E. The character of the waters are also different, with the lower aquifer being a predominantly calcium-magnesium bicarbonate water and the upper aquifer predominantly a sodium bicarbonate-chloride water.

As discussed in Part 1 of this report, bedrock reconnaissance by Cleath & Associates along the ridge crest south of Calle Cordoniz confirmed a contact between Pismo Formation shale and younger sediments (possibly Paso Robles Formation). This contact was mapped previously by the Morro Group as Strand B, although it appears to be aligned roughly north-south, rather than northwest-southeast. Mapping by Hall et al (Figure 2) also shows a north-south trending fault between Pismo Formation shale and Paso Robles Formation sediments in this area.

Regardless of the specific orientations of the formation contacts and faulting south of the ridge crest, the entire Bayview Heights area is interpreted by Cleath & Associates to lie within an uplifted portion of the basin (cross-section H-H'; Appendix A). Faulting along the basin margin in this uplifted area should be considered localized, unless strong evidence for projection into the basin interior exists. In the case of Strand B, evidence cited included abrupt changes in shallow ground water levels, a large willow thicket along the alignment, Sweet Springs, and lithologic correlations in boreholes (Morro Group, 1989, 1990, 1997).

The lithologic correlations have been revisited by Cleath & Associates (Figure 21 and various cross-sections in Appendix A). Abrupt changes in shallow water levels are attributed to the termination of a shallow perching clay layer. The willow thicket is an indicator of shallow water. There are other large willow thickest above the perching clay, notably along Willow Creek.

Sweet Springs has been studied in some detail (Morro Group and Tenera Environmental Services, 1990). A spring located at the easterly end of two ponds appears to contribute significantly more flow, and more consistent flow, than other springs to the west (even after accounting for the old artesian well which also flows into the east pond). One possible explanation offered was that the east pond spring was being fed by groundwater on the east side of Strand B. Perhaps the explanation is simpler. As noted by the Morro Group, there is a greater hydraulic gradient and a larger drainage area flowing toward the main Sweet Spring than toward the springs in the marsh to the west. Furthermore, since the east spring area has been developed by excavation of the pond site, it is able to flow at a greater and more consistent rate than the other springs.

With respect to lower aquifer ground water movement, if Strand B could create a significant restriction to flow in the upper aquifer, it should also restrict ground water movement in the lower aquifer. The U.S.G.S. conducted a pump test between three deep wells (30S/11E-18L2, 18L6, and 18F2; page 16 of Yates and Wiese,1988). An apparent anomaly was noted during the tests, whereby pumping well 30S/11E-18F2 produced approximately six times as much drawdown at observation well 30S/11E-18L6 than observed when pumping well 30S/11E-18L2. All three wells tap roughly the same aquifer zones, discharge rates at the pumping wells were within 10 percent of each other, and no other deep wells were pumping in the vicinity. Restricted flow from a fault barrier would not explain the anomaly, which appeared localized between wells 18L2 and 18L6 (both west of the proposed Strand B fault).

Cleath & Associates reviewed the unpublished report available for the pumping test conducted at well 30S/11E-18L6 (Yates and Wiese, 1986). The report notes the anomalous reduction in interference at well 18L6 due to pumping well 18L2 occurred only on the day of the test, whereas the interference had been much greater when observed in the months prior to the test. This suggested a problem with the test, rather than local hydrogeology. The most plausible explanation is that, on the day of the test, the observation well monitoring equipment was inadvertently placed in well 18L7 or well 18L8, which are aquifer Zone C piezometers within the same borehole as 18L6. In fact, the aquifer test and design implementation report incorrectly states that the Palisades well (18L6) is a 2-inch diameter observation well. Well 18L6 is actually a 6-inch diameter observation well, whereas wells 18L7 and 18L8 are 2-inch diameter wells. As a check, Cleath & Associates monitored water levels in well 18L7 while pumping well 18L6 during water sampling activities for this project. Water levels in well 18L7 well dropped by 2 feet, which is exactly the amount of interference reportedly observed in well 18L6 during the 1986 pumping test. This drop is interpreted as a borehole effect, rather than actual drawdown across the regional aquitard separating Zone C from Zones D. The conclusion is that there is probably no subsurface flow restriction between well 18L2 and 18L6, nor has one been identified between 18F2 and these wells (i.e. no evidence for Strand B from the pumping tests).

In conclusion, there is geologic evidence for faulting along the south edge of the basin in the area where Strand B is shown branching off of the main Los Osos fault strand. The potential fault contact does not appear to be aligned specifically with proposed Strand B, however, and has been connected by others with a fault unrelated to Strand B. Evidence cited for Strand B along its alignment in the basin interior has been reinterpreted without recourse to faulting, and no barrier to flow has been identified in the lower aquifer. Therefore, Strand B has been removed from structural representation of basin sediments.

Yates and Wiese

Yates and Wiese (1988) proposed two parallel faults trending north-northeast and extending into the basin from previously mapped faults in basement rocks south of Bayview Heights (Figure 2). These parallel faults uplift basin sediments on the east and create a ground water barrier between upper Los Osos Creek and downtown Los Osos. The easternmost of these two faults enters the basin at the same location as proposed for Strand B, along the ridge crest area south of Calle Cordoniz.

Extension of these parallel faults is consistent with several key observations. Geologic mapping along the basin southern boundary by Hall et al (1979) shows Pismo Formation in fault contact with the Paso Robles Formation where the easternmost parallel fault enters the basin (Figure 2). The north-south alignment of the fault in this area is consistent with field reconnaissance observations. Offset of the Los Osos fault main strand by inferred motion of the parallel faults would be right-lateral, which is suggested by the surface mapping of the easternmost parallel fault. This implies that the easternmost parallel fault has incurred Quaternary displacement, providing the mechanism for a hydraulic barrier to flow in the lower aquifer between the upper creek valley and Bayview Heights. The westernmost parallel fault does not affect Quaternary sediments, as no evidence of right-lateral displacement on the Los Osos fault is apparent where intersected.

Both Cleath & Associates (2003) and the Morro Group (1989) have prepared cross-sections between wells 30S/11E-19H1 (Bayview Heights) and 30S/11E-20G2 (upper creek valley) that do not show any vertical displacement above bedrock. A review of these sections shows that vertical offset below the base of the regional aquitard by the easternmost parallel fault would not be unreasonable, and would resolve several issues as discussed above. The Yates and Wiese (1988) interpretation of the parallel faults, including

Quaternary movement of the easternmost strand has been included in the structural representation of basin sediments.

## CHARACTERIZATION OF SOURCE WATERS

Source waters for lower aquifer recharge may be divided into four basic groups, based on the structural definition outlined above. The four source groups are Los Osos Creek valley, upper aquifer, bedrock, and sea water. A summary of water group type and median TDS is presented below in Table 8. Water quality data graphics are in Appendix L through P. Well locations, according to township, range and section, are shown in Figure A1 (Appendix A).

**Table 8**
**Characterization of Water Groups**

| Source Group | Dominant Water Type | Median TDS |
|---|---|---|
| Los Osos Creek Valley | Magnesium-Calcium Bicarbonate | 524 mg/l |
| Upper Aquifer Group (Section 13) | Sodium-Magnesium Chloride-Bicarbonate | 280 mg/l |
| Upper Aquifer Group (Section 7) | Sodium-Magnesium Chloride-Bicarbonate | 180 mg/l |
| Upper Aquifer Group (Section 17) | Sodium-Magnesium Chloride-Bicarbonate | 230 mg/l |
| Upper Aquifer Group (Section 18) | Sodium Chloride-Bicarbonate | 180 mg/l |
| Bedrock | Magnesium-Calcium Bicarbonate | 470 mg/l |
| Sea Water | Sodium Chloride | 36,300 mg/l |
| Lower Aquifer Group (Range 11E) | Magnesium-Calcium-Sodium Bicarbonate | 364 mg/l |
| Lower Aquifer Group (Range 10E) | Highly variable due to sea water intrusion | |

Note: Characterization based on representative data sets as discussed in text.

### Los Osos Creek Valley Group

The Los Osos Creek valley source group includes surface water in Los Osos Creek, alluvial ground water in the valley sediments, and ground water in the aquifers directly beneath the alluvial deposits. Data for this group is represented by water samples from 11 well locations and three surface water locations.

The creek valley group is characterized by magnesium-calcium bicarbonate water. The two exceptions are a sample collected in 1970 from 30S/11E-21E1, which contained magnesium chloride water, and a sample collected in 1985 from well 30S/11E-20G2, which contained sodium bicarbonate water. Well 21E1 is 143 feet deep and taps lower aquifer zones on the east side of the creek valley, and well 20G2 is 370 feet deep and taps the base of lower aquifer Zone E adjacent to Los Osos Creek, approximately 1,000 feet upstream of Los Osos Valley Road.

Some sample locations have multiple data sets, in which case a representative sample date was selected for each location. These representative samples are shown in a Piper diagram and Stiff diagrams in Appendix L (Figures L1 through L4). Los Osos Creek surface water quality at three locations is shown in Figure L5. The quality is very consistent as the flow enters the alluvial valley through a point just above the confluence with Eto Creek Downstream of the confluence, there are increases in the relative proportions of sodium and chloride, and a reduction in TDS (from 505 mg/l to 400 mg/l), indicative of upper aquifer mixing. A Box and Whisker plot showing total dissolved solids (TDS) for the representative sample group is included (Figure L6). The average TDS of creek valley group water is approximately 520 mg/l.

**Upper Aquifer Group**

The upper aquifer water quality data group consists of close to 30 wells in Zone C across the basin. Many sample locations have multiple data sets, in which case a representative sample date was selected for each location. To facilitate data presentation and interpretation, the upper aquifer group water quality has been characterized by section. Four sections have been represented, 30S/10E-13, 30S/11E-7, 30S/11E-17, and 30S/11E-18. Water quality graphics for the Upper aquifer group are in Appendix M (Figures M1 through M14)

<u>Section 13 (T30S/R10E)</u>

Section 13 upper aquifer (Zone C) water quality may be characterized as generally sodium-magnesium chloride-bicarbonate in character. The exceptions (wells 13B2 and 13H) are shallow wells. Median TDS of the section group is approximately 290 mg/l.

<u>Section 7 (T30S/R11E)</u>

Section 7 upper aquifer water quality may be characterized as generally sodium-magnesium chloride-bicarbonate in character. Median TDS is below 200 mg/l, although the sample set is limited to four wells. Two of the wells, 7Q1 and 7N1, are given two points, one representing historical values (1960's), and the other a recent value. Water quality at both wells have remained similar in character over time, although well 7Q1 has had a notable increase in TDS, as with many other upper aquifer wells.

Well 7N1 has long been considered an anomalous well, having provided excellent water quality from Zone C for decades from a shallow depth (perforated from 56-84 feet) without any significant influence from increasing salinity over time in the general vicinity, such as observed at nearby 7Q1. Despite having been grouped with deep aquifer wells by Brown & Caldwell (1983; Figure 5-1, page 5-20), well 7N1 is definitely a Zone C well, based on regional lithologic correlations, water quality (TDS below 200 mg/l), and water levels (consistently above sea level). Despite its shallow depth, well 7N1 taps the bottom of Zone C, which is rising on the north limb of the syncline (cross-section H-H'; Appendix A). The aquifer zone is protected by a thick clay lens associated with the bay, which is less than 100 feet away. Water moving toward well 7N1 is likely heavily controlled by permeability. That is, the well may tap a (Paso Robles Formation) buried stream channel or other permeable lens that preferentially draws water in only from the deepest parts of Zone C, which have yet to been affected by wastewater return flows. By comparison, nearby well 7Q1 (75 feet deep), does not penetrate the deepest portion of Zone C, which extends to the top of the regional aquitard at 125 feet depth.

Section 17 (T30S/R11E)

Section 17 upper aquifer water quality may be characterized as generally sodium-magnesium chloride-bicarbonate in character. Median TDS of the section group is approximately 230 mg/l. This section contains the highest proportion of private domestic wells in the basin, most of which tap Zone C, compared to other sections.

Section 18 (T30S/R11E)

Section 18 upper aquifer water quality may be characterized as generally sodium-chloride bicarbonate in character. The bicarbonate anion appears more prevalent in the lower portion of the aquifer. Median TDS of the section group is approximately 180 mg/l, the lowest of any current Zone C section group.

**Sea Water**

The water quality characteristics of sea water are assumed to be relatively constant. Sea water has a sodium chloride character, with a TDS of close to 36,000 mg/l. As a source water, sea water greatly impairs an aquifer's beneficial use, and recharge causing the movement of sea water inland is considered intrusion. Sea water intrusion is the focus of study in Part 2 of this report. A Piper diagram and Stiff diagram for sea water are included in Appendix N.

## Bedrock Group

Water quality information on bedrock wells near the Los Osos Valley ground water basin is sparse. Only one bedrock well was available for sampling during this study (other data in the group are either from samples prior to this study or surface flows). The well sampled during this study, 30S/11E-21P, taps the Franciscan Formation on the south side of the Los Osos Valley. The character of bedrock water in this well is magnesium-calcium bicarbonate, similar to base flows of surface water from the Clark Valley portion of the Los Osos Creek watershed. The TDS is also similar to upper Los Osos Creek surface flows, at 540 mg/l. Differentiation between Franciscan Formation and Pismo Formation water quality may be expected due to the differences in matrix composition. The base flow from the west fork of Los Osos Creek, which drains Pismo Formation sediments, has a calcium bicarbonate-sulfate character with a TDS of 830 mg/l.

Evidence for an increase in the sulfate anion concentration in bedrock compared to other source groups is also suggested at wells 30S/10E-12J1 and 30S/11E-18F2, which tap lower aquifer zones immediately above shale bedrock and have elevated sulfate and TDS values. Piper and stiff diagrams for available bedrock group water quality are included in Appendix O.

# LOWER AQUIFER WATER CHARACTERIZATION

The lower aquifer system includes aquifer Zones D and E. For the source investigation, characterization of water quality in terms of location and changes over time has been provided, where available. Some of the wells included in the lower aquifer group (17E11, 17K9, and 17N10) include screened intervals in Zone C, however, the bulk of production in these wells is interpreted to come from the lower aquifer. Piper and Stiff diagrams for lower aquifer wells are in Appendix P. Chemographs for selected lower aquifer wells are in Appendix Q.

## Western Basin Area (Range 10 East)

In the western basin area (Range 10E), sea water has influenced water quality to the extent that the character of the water has changed over time from a bicarbonate anion dominance to a chloride anion dominance. This change has been documented in Part 1. The Piper diagram for the lower aquifer group also shows wells in the western basin area that have been influenced by sea water intrusion (Figure P1, Appendix P).

Water quality is sodium chloride near the sand spit and transitions to a calcium-magnesium chloride farther east. TDS concentrations in Lower aquifer Zone D beneath the sand spit averaged 11,350 mg/l in 1985, but currently ranges from 250 mg/l to 660 mg/l across most of the west side (highest TDS in Section 13). The character of lower aquifer Zone D water in Section 13 prior to sea water intrusion was magnesium-sodium bicarbonate to magnesium-calcium bicarbonate, with TDS levels averaging 221 mg/l.

**Eastern Basin Areas (Range 11 East)**

The lower aquifer water quality in Range 11 East is predominantly magnesium-calcium bicarbonate to calcium-magnesium bicarbonate. The median TDS of the lower aquifer group in Range 11 East is approximately 364 mg/l.

One exception is well 30S/11E-8E2, which is near the mouth of Los Osos Creek and has a sodium-chloride character. This is an area where the deep aquifer rises close to ground surface. The water quality at well 8E2 appears to come from the upper aquifer, based on the sodium chloride character and the level of nitrates (22 mg/l).

**Time Series**

Water quality changes over time in lower aquifer wells not subject to sea water intrusion are a key component in source investigation. One monitoring well (30S/10E-12J1) and several Los Osos CSD purveyor wells have data sets spanning many years. Changes in quality over time at each of these wells is discussed below (chemographs attached in Appendix Q).

<u>30S/10E-12J1</u>

Monitoring well 12J1 along Pasadena Drive in Baywood Park taps the lowermost portion of Zone E. The data set spans 28 years, although there is a data gap between 1971 and 1982. Water quality is magnesium-sodium bicarbonate-sulfate, which is not representative of the lower aquifer, creek valley or the upper aquifer groups. Well 12J1 has a high TDS (750 mg/l). A increase in the molar ratio of the sulfate anion, along with TDS, is also noted in lower aquifer well 30S/11E-18F2, which taps the same aquifer zones as 12J1 at the basin bottom. It appears that the elevated sulfate and TDS is derived from bedrock influence. No significant overall change in water quality over time is observed at well 30S/10E-12J1, although some short-term trends and fluctuations are noted (Figures Q1 and Q2, Appendix Q). Nitrate is generally non-detected.

<u>30S/11E-7Q3</u>

Well 30S/11E-7Q3 is a municipal production well in Baywood Park. This well has shown a steady change in water quality over time (1987-2002). The TDS has risen from 308 mg/l in 1987 to 430 mg/l in 2002, with a steady increase in all general mineral constituents. Nitrate (as nitrogen), which had been first reported above the 0.44 mg/l detection limit in 1994, was detected on several occasions in 1998, as high as 3 mg/l. Since 2000, nitrate has generally remained below the detection limit, although the last available analysis from 2003 reports 1.6 mg/l. Figures Q3 and Q4 (Appendix Q) show the changes over time in various major ion constituents. These changes will be further discussed with lower aquifer recharge below.

<u>30S/11E-18F2</u>

The data set for well 18F2, a former municipal production well, only spans five years (1982-1987). Notable trends involve increases in sulfate and calcium over time. TDS also increases slightly, and is generally elevated compared to most lower aquifer wells. As mentioned above, 18F2 water quality appears to represent the deepest zones in the aquifer, based on correlation with 12J1 and wells in the eastern Los Osos Creek valley. Nitrate was reported below the detection limit of 0.4 mg/l in four out of six available analyses, and at 0.9 mg/l in 1985, and 0.4 mg/l in 1989. Figures Q5 and Q6 (Appendix Q) show the changes over time in various major ion constituents.

<u>30S/11E-18L2</u>

Well 18L2 is a municipal production well with a 1982-2002 water quality data set. The water quality is typical lower aquifer quality, with magnesium-calcium bicarbonate water, and a TDS close to 400 mg/l. No significant overall change in major ion water quality over time has been observed at well 30S/11E-18L2, although some short-term trends and fluctuations are noted. Of note, however, are increasing nitrate concentrations at well 18L2 since first detected in 1989. Nitrate levels still remain typically below 2 mg/l (Figure Q7, Appendix Q). Figures Q8 and Q9 (Appendix Q) show the changes over time in various major ion constituents.

## LOWER AQUIFER RECHARGE

When ground water is pumped out of the lower aquifer, four potential sources of recharge are available to replenish that water. These sources are sea water intrusion, subsurface inflow from bedrock, subsurface inflow from the creek valley, and leakage through the regional aquitard from the upper aquifer. The structural definition of the basin, water quality characterization, and water level information presented above are some of the tools used for investigating the sources of lower aquifer recharge. A ground water model, being a dynamic expression of the hydrologic budget, may also be used to estimate items of inflow or outflow. Flow model estimates for individual budget items, however, should be checked using another methodology whenever possible.

Note that subsurface inflow from the Los Osos Creek valley is defined herein as a source of recharge to the lower aquifer. Actually, as shown in Figure 21 and Figure 23, the lower aquifer is present beneath the creek valley, where it receives recharge from bedrock and from recent alluvial deposits. Evaluating the creek valley as a single source of recharge to the main basin area, however, is considered of greater practical use for community water purveyors and basin ground water management than performing estimates of recharge within the creek valley itself. The community purveyor wells lie west of the creek valley, and sea water intrusion, which is one of the issues of greatest concern to ground water basin management, is largely controlled by purveyor production.

**Sea Water**

The occurrence of sea water intrusion in the basin has been documented in Part 2 of this report. Sea water is a virtually unlimited, but highly undesirable, source of recharge to the basin. The estimated extent of intrusion of the transition zone in lower aquifer Zone D between 1985 and 2005 covers approximately 160 acres in plan view (Figure 9; movement of 2,500 mg/l isochlor). The average thickness of Zone D in this area is approximately 140 feet. Assuming an aquifer zone porosity of 30 percent, the volume of water in the intruded area of Zone D is roughly 6,720 acre-feet, equivalent to 340 acre-feet per year of fresh water impacted by intrusion. This volume calculation assumes the transition zone has advanced uniformly, and the slope of the sea water wedge has not changed.

Less than 50 acre-feet of sea water would be needed to raise the chloride concentration in 340 acre-feet of lower aquifer fresh water to above 2,500 mg/l. The recently intruded area is not the only place salinity has increased, however. There has also likely been an incremental increase in salinity west of the intruded area, requiring much more than 50 acre-feet of sea water. If the entire concentration gradient between fresh water and salt water had moved inland uniformly, and there had been no change in ground water storage or leakage from the overlying aquifer during the 1985-2005 period, the amount of sea water recharging Zone D could also be approximated by dividing the volume of water intruded by the number of elapsed years, as in the preceding paragraph.

The average annual volume of sea water inflow to the lower aquifer is difficult to quantify because of variations in ground water salinity over space and time. Much of the salinity data for the lower aquifer is from production wells, which tend to draw in sea water along permeable pathways, by-passing finer-grained strata where ground water may remain relatively fresh. The broad zone of mixing in the basin indicates that the mass transport of salts in solution is also significantly affected by dispersion and diffusion. As relatively heavy pumping at inland wells brings sea water in more quickly by advection along the most permeable zones, mixing by dispersion and diffusion is increased. Therefore, the actual sea water recharge can be much less than the average annual volume of water impacted by new intrusion.

Two methodologies were used to estimate the annual volume of recharge from sea water intrusion. The first method was analytical, based on hydraulic gradient, aquifer permeability, and aquifer thickness. The second method used the steady-state ground water basin model. Both methods convert saline water pressures to their equivalent fresh water heads.

Analytical Method

Darcy's law is an empirical law that can be used to calculate the discharge rate of water through a cross-sectional area of an aquifer, based on the hydraulic conductivity and hydraulic gradient perpendicular to the area. The basic equation is $Q = KiA$, where Q is flow, K is the hydraulic conductivity, *i* is the hydraulic gradient, and A is the cross-sectional area. The direction of flow is from higher to lower pressure head.

The cross-sectional area used for the calculation is along geologic cross-section D-D' (Appendix D-D'), which runs along the sand spit. The cross-section was broken into two segments, and outflow for each segment in Zone D and Zone E were calculated (see Appendix R). The hydraulic gradient calculations are based on the Spring 2001 ground water elevations in Figure 5. All hydraulic heads were adjusted to their equivalent freshwater heads according to the average depth of the aquifer and relative salinity at each location. A total of 210 acre-feet per year of sea water intrusion was estimated for aquifer Zone D, and approximately 290 acre-feet per year of sea water intrusion for aquifer Zone E. The total volume of sea water intrusion in the lower aquifer is estimated to average 500 afy, based on the analytical method.

Steady-State Ground Water Flow Model

The steady-state ground water flow model is a MODFLOW numerical model of the Los Osos Valley ground water basin developed by Yates and Williams (2003) and Cleath & Associates (2003, 2004). An equivalent fresh water head version of the steady state model was used to evaluate the amount of recharge from sea water intrusion over the balanced hydrologic period. In this model version, general head boundaries were used at the ocean, with the sea water levels in each aquifer set to their equivalent fresh water heads, based on the Ghyben-Herzberg relation. The model was then recalibrated. Documentation on the equivalent freshwater head version of the steady state model is included in Appendix S.

Following steady state flow model recalibration, water began flowing across the ocean boundary into the lower aquifer. The simulated 1999-2001 steady-state ocean boundary inflow was approximately 200 afy in Zone D and 420 afy in Zone E (620 afy combined). The range of sea water inflow, based on the two methods used herein, is between 500 and 620 acre-feet per year. Both methods indicate a greater amount of intrusion is occurring in Zone E, compared to Zone D.

**Bedrock Sources**

Subsurface inflow from bedrock sources is currently interpreted to be a minor source of lower aquifer recharge, except in the creek valley. Water levels near the south basin boundary in two key lower aquifer monitoring wells (30S/10E-24A2 and 30S/10E-19H2) are below sea level. At well 24A2, water levels have stabilized at between 5 and 10 feet below sea level. At well 19H2 in Bayview Heights, water levels have been rapidly declining from several years, and are in excess of 20 feet below sea level.

Bedrock inflow is likely to be negligible because of low permeability, except where geologic units are brittle and highly fractured. Sediments mapped on the south side of the Los Osos fault (west of the creek valley) consist of the Miguelito member of the Pismo Formation (Figure 1), a marine claystone and siltstone with generally poor water yielding characteristics, which has been confirmed by field reconnaissance. Bedding planes in the Miguelito are also oriented east-west, sub-parallel to the basin boundary and main Los Osos fault trend, which (along with the fault itself) further restricts the movement of ground water to the north into the basin.

On the northeast side of the basin is the Franciscan Formation mélange, which is a chaotic mixture of various rock types. Outcrops along Turri Road near the bay are comprised of relatively soft shale and are not good water-bearing materials. Materials in the mélange that are brittle and could be suitable for maintaining fracture porosity and ground water flow are typically isolated blocks surrounded by impermeable materials.

The local bedrock type with the best potential for subsurface recharge to basin sediments are the Franciscan Formation metavolcanics. These rocks border the north east side of the creek valley and are found along the Los Osos fault zone at the southeast corner of the basin (Figure 2). Where fractured by faulting along the Los Osos fault zone, the metavolcanics have provided yields in excess of 100 gallons per minute to wells (on the south side of the Los Osos Valley). Along the northeast side of the creek valley, metavolcanic rock is probably not fractured. Graywacke sandstone is also mapped along the Los Osos fault in the creek valley, where it has fracture permeability.

The southeastern creek valley is the most likely place for subsurface bedrock inflow, due to the combination of more brittle rock types and faulting. Lower aquifer water levels along the south basin boundary are much higher in the creek valley than in other areas to the west. Well 30S/11E-20G2, for example, taps lower Zone E and underlying fractured Franciscan bedrock, and maintains water levels close to 50 feet above sea level. Although sulfate is not elevated at well 20G2, the sodium bicarbonate water quality is unlike any other creek valley group or lower aquifer group well. According to the U.S.G.S. (Yates and Wiese, 1988, page 29), water from the uppermost Franciscan basement rocks flowed into the borehole at 20G2 during drilling. The water quality in another well (30S/11E-21P) tapping only Franciscan bedrock, however, is different from 20G2 quality and very similar to the quality of Los Osos Creek base flow. Nevertheless, the shallow water levels in lower aquifer wells and the drilling report from well 20G2 suggest inflow from bedrock may be significant in the creek valley. The U.S.G.S. estimated that underflow from fractured Franciscan rocks might amount to several hundred acre-feet per year recharge to the basin, although it was assumed to be negligible (no reason given).

The amount of subsurface inflow from bedrock in the creek valley cannot be directly measured. Estimates based on water quality mixing calculations would not be appropriate, since recharge from stream flow is of similar quality. Estimating inflow based on cross-sectional areas, hydraulic gradients, and permeability through the basin boundaries is also not feasible with existing information.

Bedrock inflow is one of the hydrologic budget items incorporated into the steady-state ground water flow model. A total of 140 afy of bedrock inflow from the southeast (Clark Valley) boundary was used in the model to improve calibration of upper creek valley water levels. This is not an unreasonable value, although without an independent analytical analysis, this value is not necessarily meaningful. Using a ground water flow model as the sole method of quantifying a specific element of inflow or outflow can be misleading, since the same calibration or model scenario result may often be achieved with very different combinations of specific inflow and outflow budget values.

As noted previously, recharge to the lower aquifer beneath the basin area west of the creek valley is of greater practical use to community water purveyors and ground water basin management than recharge within the creek valley itself. In fact, subsurface calculations of inflow from the creek valley accounts for the contributions of all recharge sources within the creek valley.

### Inflow from Creek Valley

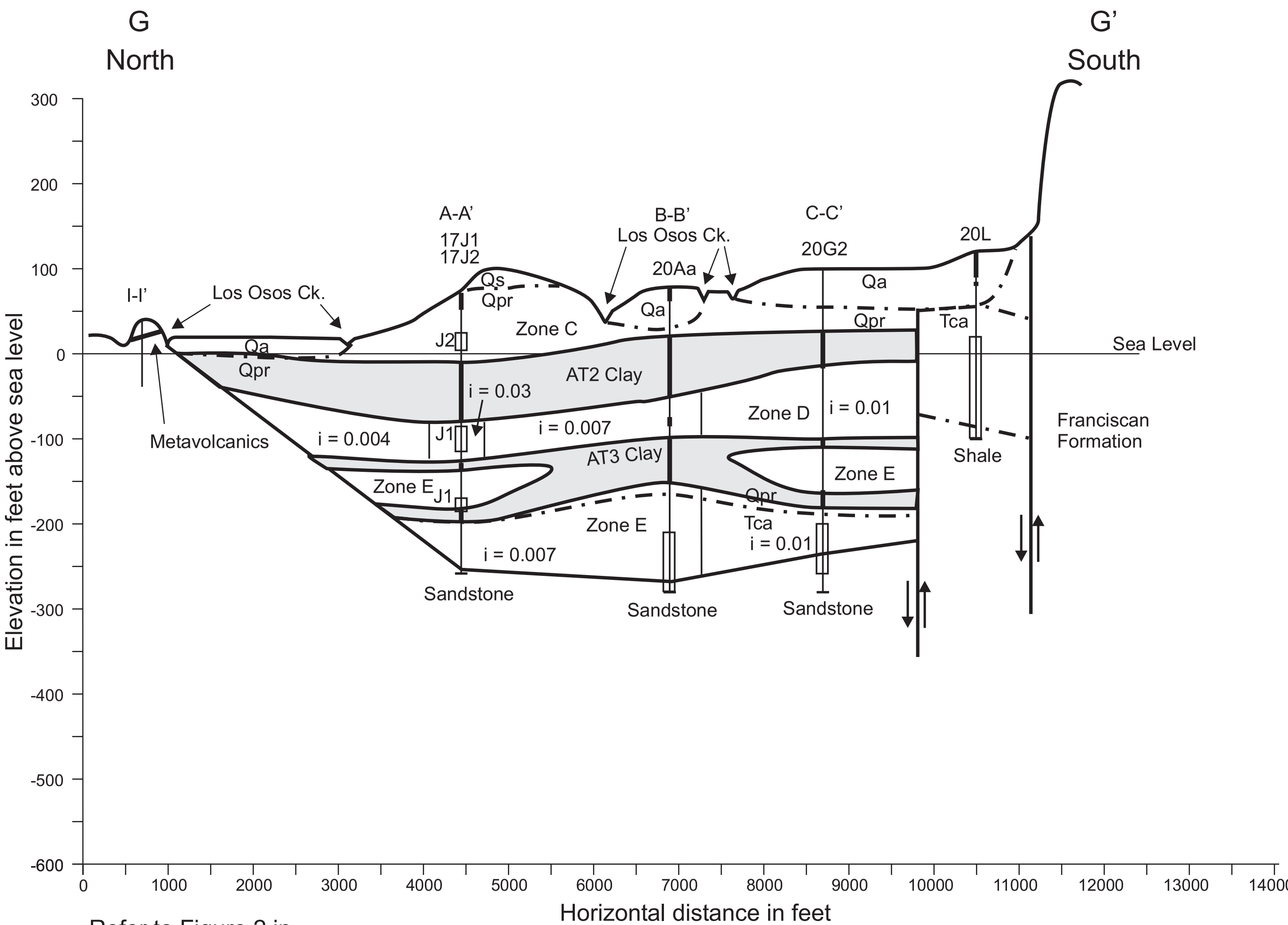
As with sea water intrusion, recharge to the lower aquifer from the creek valley has been estimated using two methodologies, one based on hydraulic gradient, aquifer permeability, and aquifer thickness, and the other using the steady-state ground water basin model.

#### Analytical Method

Cross-section G-G' (Figure 24; modified version of G-G' in Appendix A) presents the width and thickness of the main aquifer zones along the west side of the creek valley. The width of the Zone D aquifer is approximately 7,300 feet, with an average thickness of 50 feet. The Zone E aquifer is estimated to be 6,000 feet wide and average 90 feet thick. Lower aquifer hydraulic gradients through the west side of the creek valley, based on Spring 2001 water levels (Figure 5), are estimated at 0.01 ft/ft in the upper creek valley, 0.007 ft/ft in the central creek valley, and 0.004 ft/ft in the lower creek valley, although the gradients are inferred to increase to 0.03 ft/ft in the immediate vicinity of irrigation well 30S/11E-17J1 in the lower creek valley (reaches shown in Figure 24).

The hydraulic gradient for upper creek valley outflow (0.01 ft/ft) is a lower gradient than actually contoured in Figure 5 for the G-G' cross-section alignment, but is considered more representative for the recharge calculation. The much higher contoured gradient of 0.03 ft/ft to the west suggests a permeability
restriction for outflow, such as a fault. Since the available permeability (hydraulic conductivity) data from pumping tests represents the aquifer zones, the hydraulic gradient used for the calculation should also represent the aquifer zones, rather than a boundary condition. In this case, the average hydraulic gradient in the lower aquifer west of the upper creek valley is closer to 0.01 ft/ft.

Two pumping tests were performed during this study to help refine estimates of hydraulic conductivity. A pumping test for a creek valley well completed in Zone E (30S/11E-20Aa resulted in an hydraulic




Refer to Figure 2 in
Appendix A for cross-section
alignment

Aquifer Zones:
Zone A - Perched Aquifer
Zone B - Transitional Aquifer
Zone C - Upper Aquifer
Zone D - Lower Aquifer (shallow)
Zone E - Lower Aquifer (deep)

Well data point
20G2 Well ID
Clay layer
Well screen

Formation:
Qa - alluvium
Qs - dune sand
Qpr - Paso Robles Formation
Tca - Careaga Formation

i = 0.01
Approximate
hydraulic gradient
(ft/ft) perpendicular
to section

Figure 24

(Modified) Hydrogeologic
Cross-Section G-G'
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates

conductivity estimate of 42 gpd/ft (5.6 ft/day). The second pumping test was performed at a Zone D well in Bayview Heights (30S/11E-19H2), where the hydraulic conductivity of the aquifer tapped by the well was estimated to be 62 gpd/ft (8.3 ft/day). The resulting estimated subsurface flow from the creek valley into lower aquifer zones to the west is approximately 470 acre-feet per year (afy).

Steady-State Ground Water Flow Model

The equivalent freshwater head version of the steady-state model was also used to evaluate subsurface flow from the creek valley into lower aquifer zones to the west. Simulated the lower aquifer subsurface outflow flow from the creek valley at close to 370 afy.

The estimated average annual volume of subsurface flow from the creek valley into lower aquifer zones to the west, based on the two methods described above, is between 370 and 470 acre-feet per year. A greater amount of creek valley inflow is occurring in Zone D, compared to Zone E.

## Upper Aquifer Recharge

Numerical ground water models constructed for the Los Osos Valley ground water basin have consistently shown that the principal source of recharge to the lower aquifer was leakage through the regional aquitard from the upper aquifer. This was a necessity for calibration (Yates and Wiese, 1988, page 50; and Cleath & Associates independent analysis of URS 2000 transient model code and Yates and Williams 2003 steady-state model code), but was in apparent conflict with the water quality associations which correlated lower aquifer water with Los Osos Creek Valley water (Brown & Caldwell, 1983). A closer look at the data, however, suggests that the apparent conflict does not really exist.

Major Ions

Piper diagrams presented by Brown & Caldwell (1983) compared the relative proportion of general mineral constituents, but not the actual concentrations. What has not been mentioned in prior work is that, although the character of the lower aquifer water is similar to Los Osos Creek Valley water, the actual degree of mineralization is significantly higher in the creek valley than in the lower aquifer.

The median TDS of the creek valley water group is approximately 520 mg/l. Background TDS in the lower aquifer (in east side areas without sea water intrusion), however, is only 370 mg/l. A reduction in TDS in the lower aquifer west of the creek valley would most likely be due to dilution by upper aquifer leakage, which has a median TDS of approximately 210 mg/l on the east side. Precipitation of bicarbonate could also lower TDS values, however, the all the major ions and anions in the lower aquifer are reduced west of the creek valley, and not just bicarbonate.

Based on the TDS values alone, the lower aquifer water salinity could be achieved with an approximate 50:50 mix of upper aquifer group and creek valley group water. More importantly, due to the much higher salinity of the creek valley group, a mixture of upper aquifer water and creek valley water produces water with lower aquifer character, even at relatively high proportions of upper aquifer water.

Two simulated mixtures of upper aquifer group water and creek valley group water have been optimized to best fit the composition of lower aquifer water, one mixture for the east side aquifers in Baywood Park, and the other for the west side aquifer near Pecho Road. On the east side, well 30S/11E-7Q1 represents the upper aquifer group, while 30S/11E-7Q3 represents lower aquifer group. On the west side, well 30S/10E-13F1 represents the upper aquifer group, while well 30S/10E-13L4 represents the lower aquifer group. Los Osos Creek water represents the creek valley group. The water quality samples from each area were selected to represent background (pre-development) conditions, prior to the effects of sea water intrusion or wastewater return flows. The Los Osos Creek water quality sample used is representative of the base flows entering the creek valley. Tables 9 and 10 presents the two optimized mixtures, and Figures 25 and 26 show the end members and mixture plotted on Piper diagrams.

**Table 9**
**Source Mixture for Historical Conditions - Baywood Park**

| Parameters | Sources | | Product | |
|---|---|---|---|---|
| | Los Osos Creek (Creek Valley) | 30S/11E-7Q1 (Upper Aquifer) | 30S/11E-7Q3 (Lower Aquifer) | Optimized Mixture |
| Sample mixture | 56% | 44% | (target) | (result) |
| Sample date | 6/1/1995 | 8/2/1960 | 8/12/1987 | |
| TDS (mg/l) | 540 | 154 | 332 | 370 |
| Bicarbonate (mg/l) | 363 | 34 | 265 | 218 |
| Chloride (mg/l) | 48 | 31 | 43 | 40 |
| Sulfate (mg/l) | 59 | 7 | 25 | 36 |
| Calcium (mg/l) | 57 | 9 | 34 | 36 |
| Magnesium (mg/l) | 50 | 8 | 30 | 32 |
| Sodium (mg/l) | 33 | 43 | 47 | 38 |

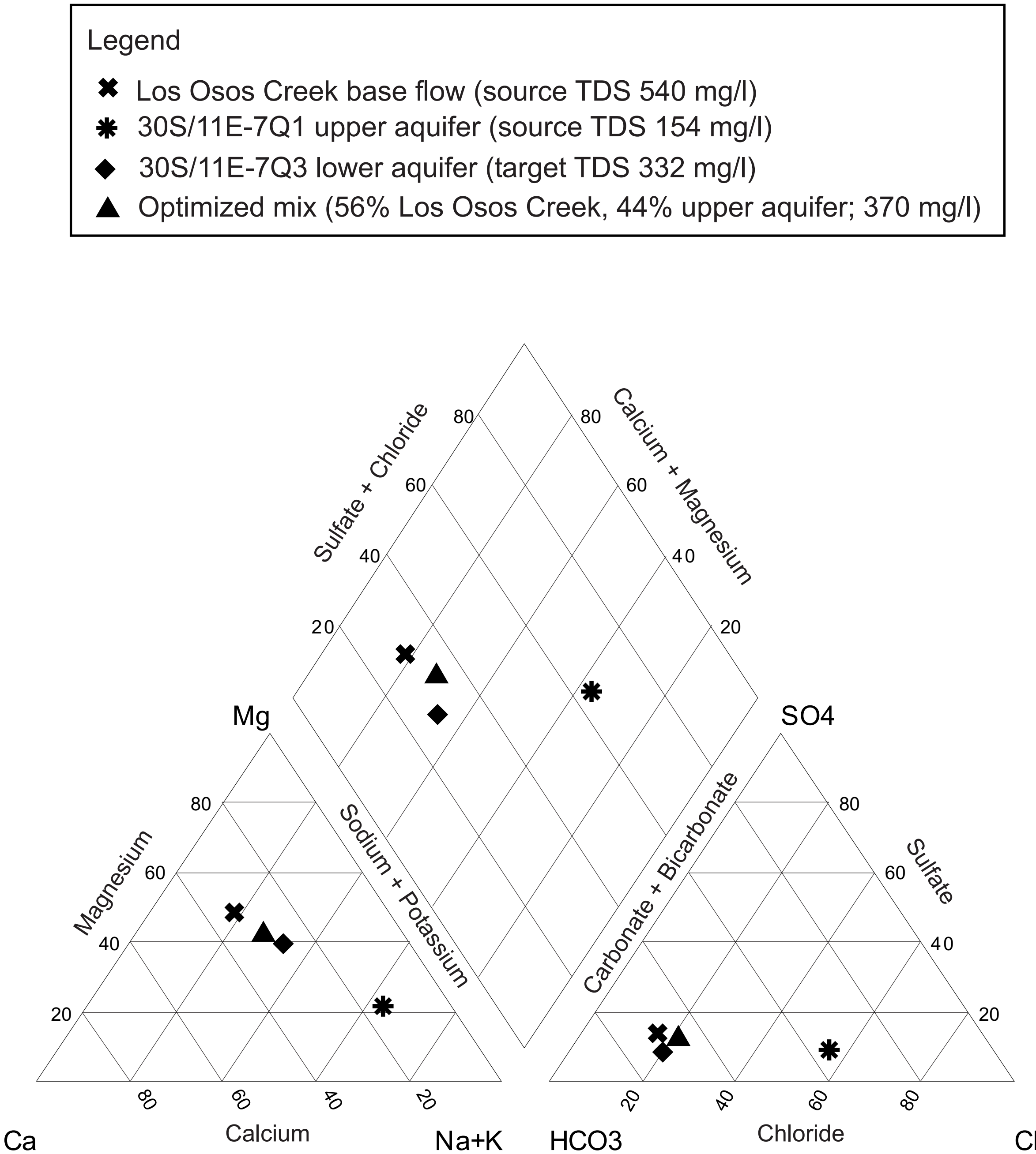



Figure 25
Optimized Source Mixture
East Side (Baywood Park)

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Legend

- ✖ Los Osos Creek base flow (source TDS 540 mg/l)
- ✱ 30S/10E-13F1 upper aquifer (source TDS 124 mg/l)
- ◆ 30S/11E-13L4 lower aquifer (target TDS 212 mg/l)
- ▲ Optimized mix (28% Los Osos Creek, 72% upper aquifer; TDS 232 mg/l)

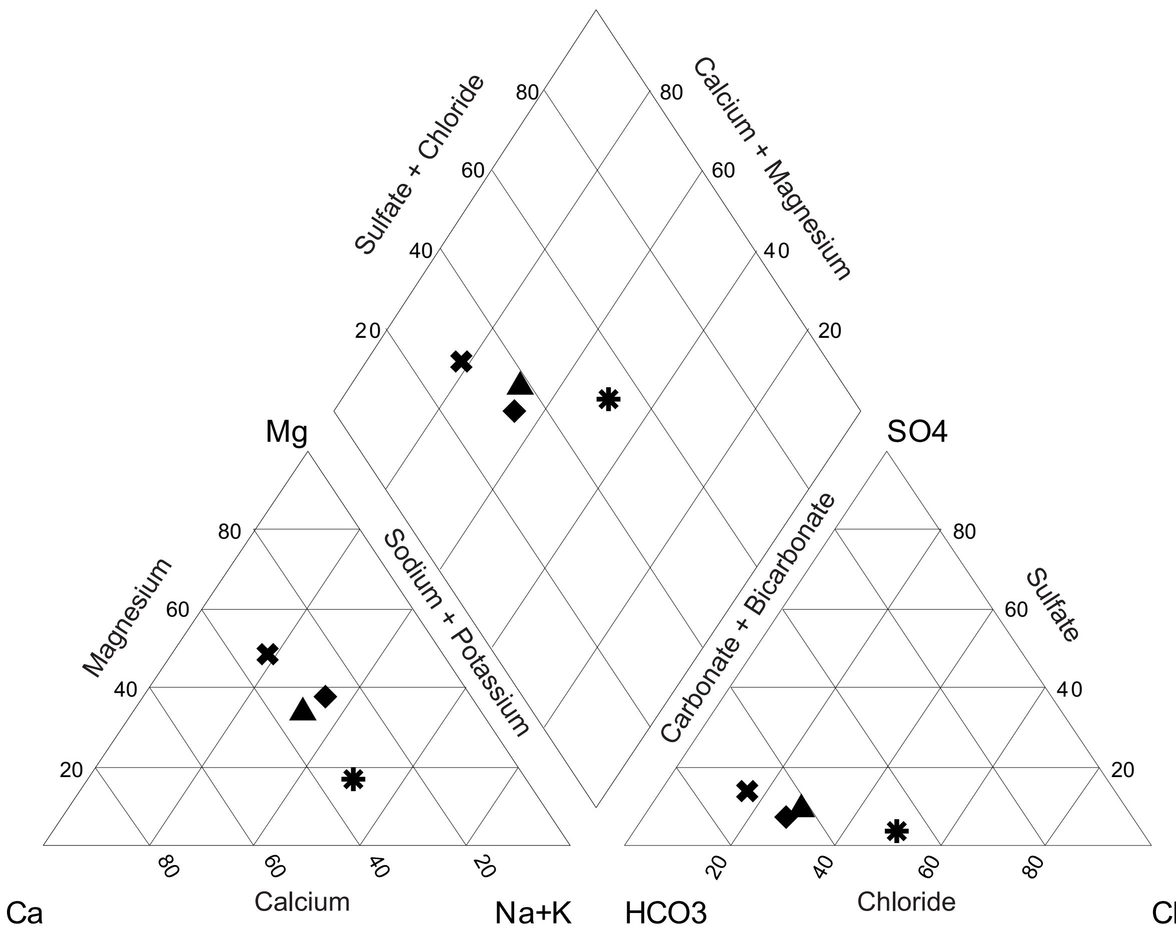


Figure 26
Optimized Source Mixture
West Side (Pecho Road)

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**Table 10**
**Source Mixture for Historical Conditions - Pecho Road**

| Parameters | Sources | | Product | |
|---|---|---|---|---|
| | Los Osos Creek (Creek Valley) | 30S/11E-13F1 (Upper Aquifer) | 30S/11E-13L4 (Lower Aquifer) | Optimized Mixture |
| Sample mixture | 26% | 74% | (target) | (result) |
| Sample date | 6/1/1995 | 7/8/1988 | 1/8/1981 | |
| TDS (mg/l) | 540 | 124 | 212 | 232 |
| Bicarbonate (mg/l) | 363 | 50 | 167 | 131 |
| Chloride (mg/l) | 48 | 31 | 39 | 35 |
| Sulfate (mg/l) | 59 | 3 | 15 | 18 |
| Calcium (mg/l) | 57 | 14 | 20 | 25 |
| Magnesium (mg/l) | 50 | 5 | 16 | 16 |
| Sodium (mg/l) | 33 | 25 | 27 | 27 |

Tables 9 and 10 show that the west side optimized mixture requires a greater ratio of upper aquifer water to creek valley water than the east side mixture, to simulate lower aquifer water quality. This greater proportion of upper aquifer water on the west side would be expected, because the west side wells are farther from the creek valley, allowing more leakage to occur.

The Piper diagrams in Figures 25 and 26 show that the optimized mixtures plot close to the respective target lower aquifer water samples. It should be noted that the simulated mixtures assume no aquifer or aquitard matrix interactions. It is possible that the regional aquitard affects the quality of water moving from the upper to lower aquifers through ion exchange activity.

Table 11 below presents a mixing simulation for the median water quality values of the upper aquifer, creek valley, and lower aquifer groups. The optimized mixture of 40% creek valley group water and 60% upper aquifer water is a good overall match for the water quality in the lower aquifer. The Piper diagram for the mixing calculation is shown in Figure 27.

Legend

- ✖ Creek valley water group average (source TDS 524 mg/l)
- ✱ Upper aquifer water group average (source TDS 200 mg/l)
- ◆ Lower aquifer water group average (target TDS 310 mg/l)
- ▲ Optimized mix (40% creek valley, 60% upper aquifer; TDS 330 mg/l)

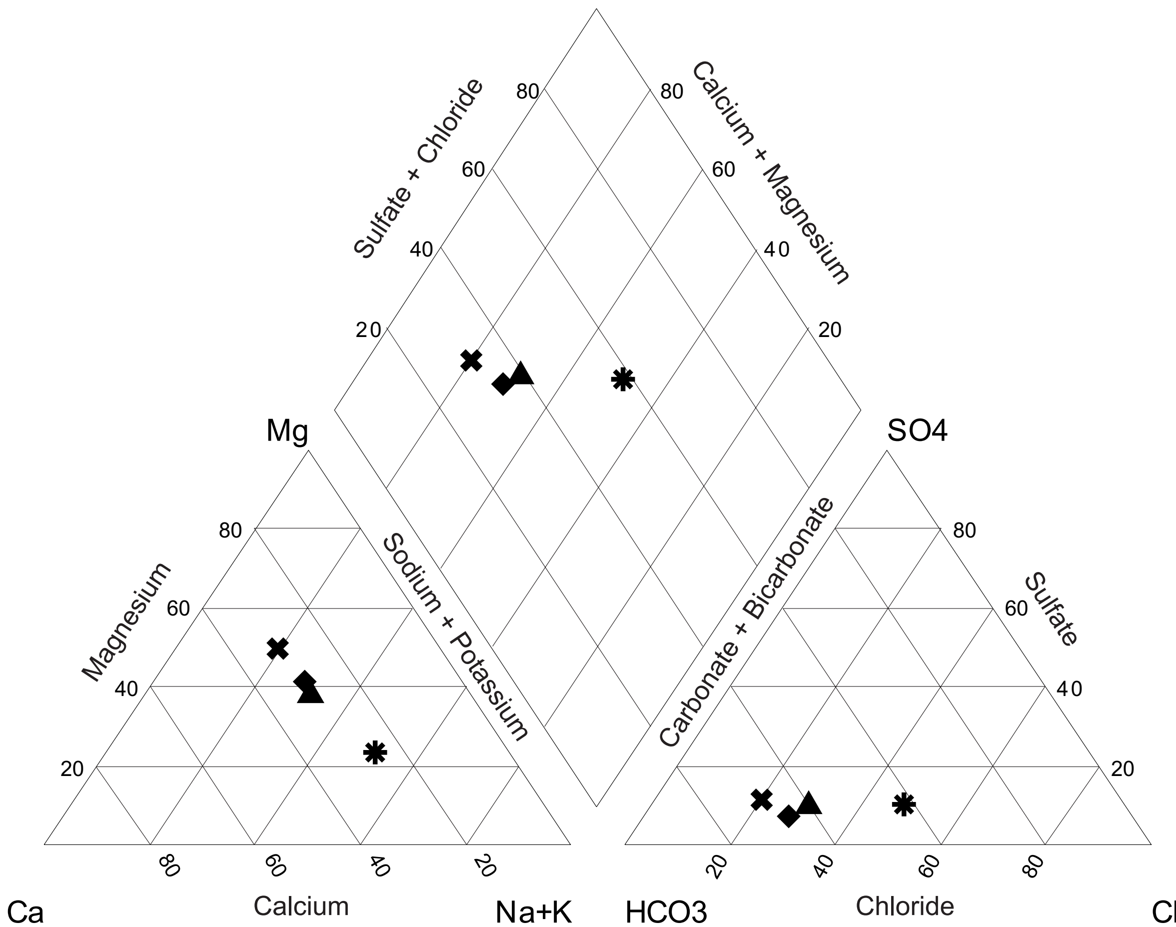


Figure 27
Optimized Source Mixture
Basin Average

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**Table 11**
**Source Mixture for Basin Average**
**West of Los Osos Creek Valley**

| Parameters | Sources | | Product | |
|---|---|---|---|---|
| | Creek Valley | Upper Aquifer | Lower Aquifer | Optimized Mixture |
| Sample mixture | 40% | 60% | (target) | (result) |
| Number of locations | 19 | 32 | 15 | |
| TDS (mg/l) | 524 | 200 | 310 | 330 |
| Bicarbonate (mg/l) | 363 | 71 | 208 | 188 |
| Chloride (mg/l) | 62 | 47 | 50 | 53 |
| Sulfate (mg/l) | 50 | 14 | 20 | 28 |
| Calcium (mg/l) | 57 | 18 | 31 | 34 |
| Magnesium (mg/l) | 56 | 10 | 26 | 28 |
| Sodium (mg/l) | 41 | 40 | 33 | 40 |

Note that many of the sample locations used in the basin average source mixture had multiple samples, many of which varied in quality over time. Where quality did not vary significantly, a representative sample for the location was selected based on visual inspection of a Piper diagram. Where quality varied over time, the earlier data was used, which minimized the effects of sea water intrusion and septic returns.

Trace Elements

Data for bromide, iodide, boron, and strontium have been presented earlier in Part 2 (Figures 13 through 16). The plots show how the constituent concentrations in the water pumped from lower aquifer wells east of downtown are moving along the mixing lines toward sea water. The chloride-to-bromide versus chloride plot (Figure 13) and chloride-to-strontium versus chloride plot (Figure 16) also show a spatial separation between the creek valley and upper aquifer water groups. Lower aquifer water quality in these figures are generally scattered across and between these two main source groups, or within the wedge-shaped area formed by the mixing lines with sea water.

The trace element results support a three-component source for lower aquifer recharge (creek valley/bedrock inflow, upper aquifer leakage, and sea water intrusion). Bedrock water quality as shown is typically close enough to the creek valley quality to preclude meaningful separation of these groups using the trace element data, except for one bedrock group sample, 30S/11E-21P, located in Franciscan

Formation metavolcanics southeast of the Los Osos Creek valley. This is the only bedrock well which was accessed during the investigation (the other group representatives are surface base flow from the watershed outside the basin). Some lower aquifer water quality results plot near the trace element ratios for well 21P, but not with consistency (different wells on different plots). Bedrock inflow to the southern creek valley is indicated by other factors, however, as discussed earlier.

Stable Isotopes

The ratios of oxygen-18 and deuterium in precipitation are dependant on climatic factors and, in coastal settings, the distance of precipitation events from the coast. These ratios are expressed in delta notation as units per mil. The per mil concentration of stable isotopes in sea water is the baseline, and is subtracted from other measured sample values to produce the reported delta value. Therefore, in delta notation, sea water is zero units per mil.

Evaporation off the ocean introduces stable isotopes into meteoric water. All other things being equal, the stable isotopes will be more concentrated in earlier precipitation events than later precipitation events from the same storm system. As storm systems coming off the ocean travel inland, the concentration of stable isotopes in precipitation will lessen with increased distance traveled. Therefore, when the sea water baseline is subtracted, the resulting delta notation values for precipitation will become progressively more negative, or lighter.

The ratio of oxygen-18 and deuterium isotopes of ground water samples collected during this project have been shown previously in Figure 17. Except for those water samples with significant salinity (due to sea water intrusion), other samples from the various source water groups, including surface waters in Los Osos Creek, have a significant overlap in relative oxygen-18 and deuterium concentrations. This is not surprising, since the watershed is relatively small, with respect to size and movement of winter storm systems.

An expanded-scale version of the oxygen-18 and deuterium isotopes plot is shown in Figure 28. Of note is that the creek valley, upper aquifer, and lower aquifer groups are shifted progressively downward along the delta deuterium axis, with one exception. Water collected from the base of the upper aquifer zone (wells 30S/11E-7N1 and 30S/11E-18K7) exhibits even lower delta deuterium values than most lower aquifer wells. The implication is that a matrix interaction is occurring with the deuterium (hydrogen) anions in the vicinity of the regional aquitard, or that significantly different climatic conditions were present during the last 10,000 years (based on the oldest carbon-14 age dates for lower aquifer water). Progressive global warming has occurred since the last ice age at the close of the Pleistocene. In either case, the stable isotope data does not offer a satisfactory means of evaluating the sources of recharge to the lower aquifer.

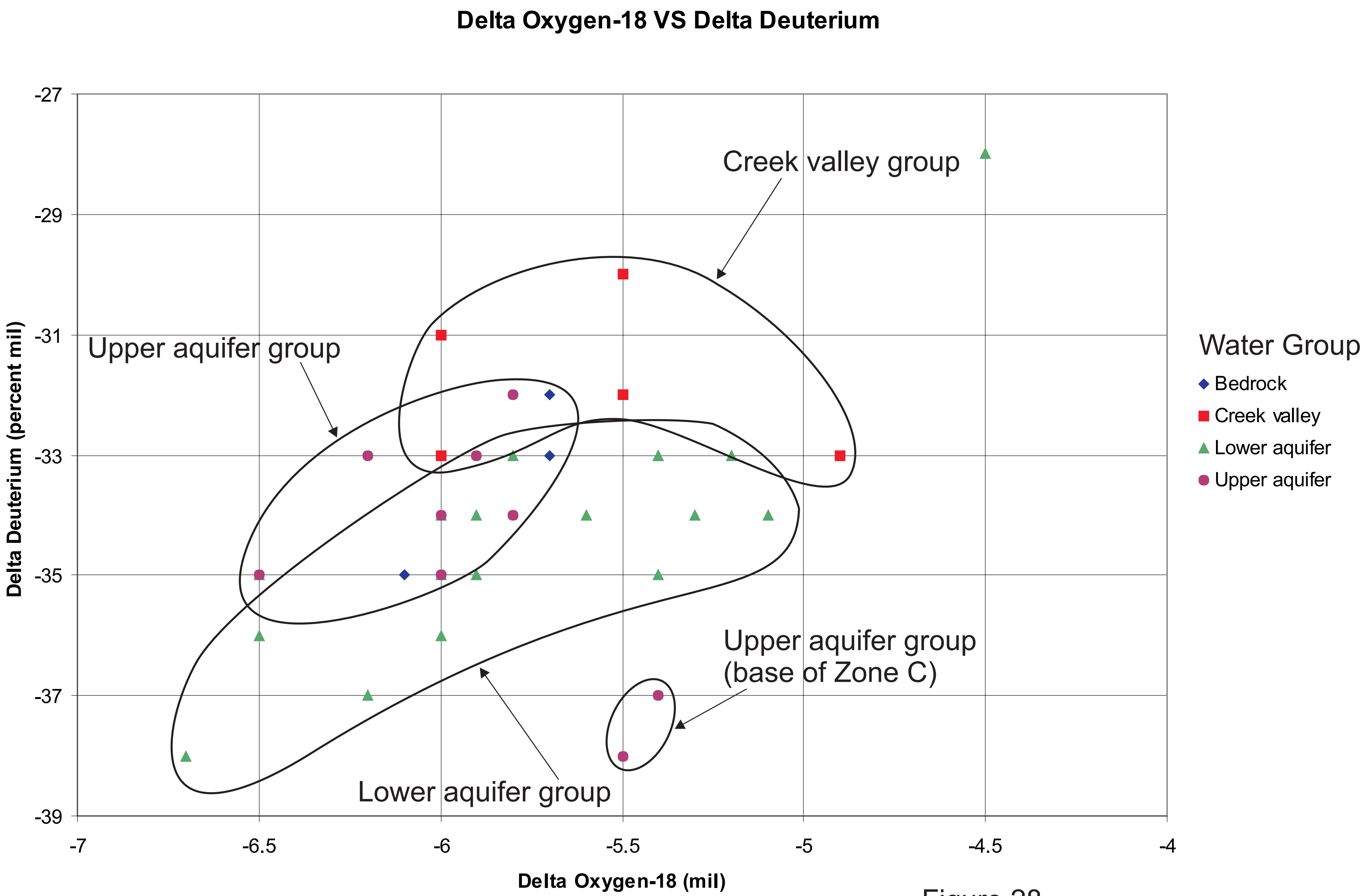


Figure 28
Oxygen-18 versus Deuterium
at Expanded Scale

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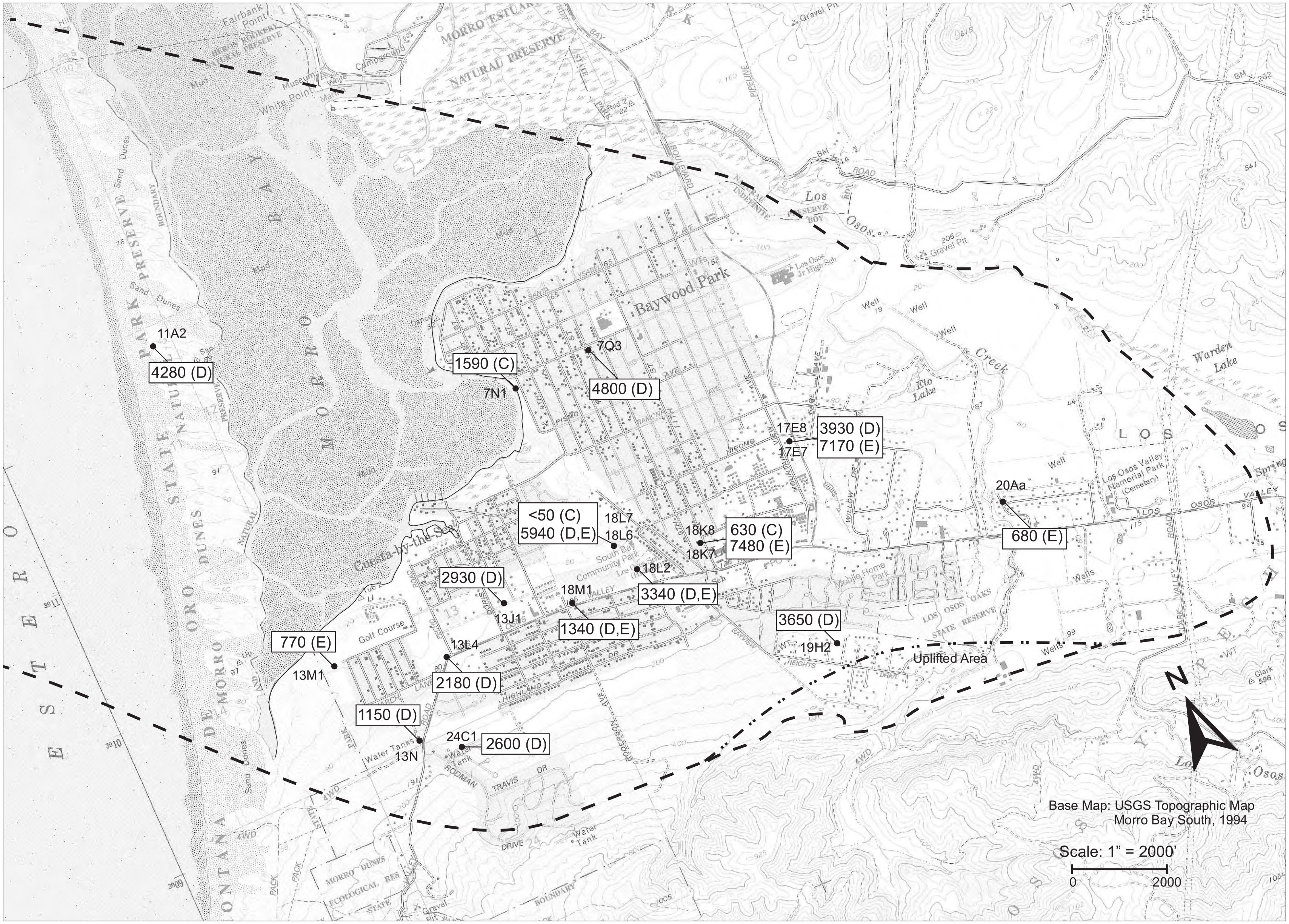
Radiocarbon

As previously noted, carbon-14 dating of water is based on the assumption that the principal source of carbon (as bicarbonate) during the initial ground water recharge process is dissolved carbon dioxide from atmospheric and soil-plant interactions. Once the recharge water percolates into the aquifer, the ratio of carbon-14 to carbon-12 changes through radioactive decay, and the apparent age of the water can be estimated by measuring this ratio.

The radiocarbon age is only an approximation of the absolute age. For the purposes of this investigation, the relative radiocarbon ages are sufficient for data interpretation. Figure 29 shows the radiocarbon ages of ground water samples collected from upper and lower aquifer wells in the basin. Results are also summarized in Appendix F, and in Table 12.




LEGEND

7Q3 4800 (D) Water sample location with radiocarbon age in years before present (rounded) and aquifer zone

approx. basin limits

Figure 29

Radiocarbon Age
of Ground Water

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**Table 12**
**Radiocarbon Age of Ground Water Samples**

| Well ID | Aquifer Zone | Radiocarbon Age (years before present) |
|---|---|---|
| 30S/11E-7N1 | Upper Aquifer (Zone C) | 1,594 +/-39 |
| 30S/11E-18L7 | Upper Aquifer (Zone C) | modern (<50) |
| 30S/11E-18K7 | Upper Aquifer (Zone C) | 634 +/- 36 |
| 30S/10E-11A2 | Lower Aquifer (Zone D) | 4,279 +/-48 |
| 30S/10E-13J1 | Lower Aquifer (Zone D) | 2,927 +/-39 |
| 30S/10E-13L4 | Lower Aquifer (Zone D) | 2,183 +/-43 |
| 30S/10E-13N | Lower Aquifer (Zone D) | 1,151 +/-45 |
| 30S/10E-24C1 | Lower Aquifer (Zone D) | 2,595 +/-41 |
| 30S/11E-7Q3 | Lower Aquifer (Zone D) | 4,796 +/-50 |
| 30S/11E-17E8 | Lower Aquifer (Zone D) | 3,933 +/-39 |
| 30S/11E-19H2 | Lower Aquifer (Zone D) | 3,651 +/-39 |
| 30S/11E-18L2 | Lower Aquifer (Zone D, E) | 3,340 +/-30 |
| 30S/11E-18L6 | Lower Aquifer (Zone D, E) | 5,937 +/-46 |
| 30S/11E-18M1* | Lower Aquifer (Zone D, E)* | 1,338 +/-45* |
| 30S/10E-13M1* | Lower Aquifer (Zone E)* | 765 +/-58* |
| 30S/11E-17E7 | Lower Aquifer (Zone E) | 7,166 +/-49 |
| 30S/11E-18K8 | Lower Aquifer (Zone E) | 7,484 +/-59 |
| 30S/11E-20Aa | Lower Aquifer (Creek Valley) | 681 +/-37 |

*NOTE: The two marked samples are excluded from averages calculations. See text for details.

Two general observations are readily apparent from the radiocarbon age-dating. First, that the water becomes older with increasing depth. Second, that lower aquifer water is generally younger on the west side of the basin, compared to the east side. These observations are summarized below in Table 13.

**Table 13**
**Average Radiocarbon Age of Ground Water by Aquifer Zone**

| Aquifer Zones | Average Radiocarbon Age (years before present) |
|---|---|
| Zone C | 750 |
| Zone D | 3,190 |
| Zone D/E mix | 4,640 |
| Zone E | 7,330 |
| East Side Zone D | 4,130 |
| West Side Zone D | 2,210 |

The average age of water samples collected from upper aquifer Zone C wells was 750 years before present (ybp). The average age of water samples collected from lower aquifer Zone D wells was 3,190 ybp. Water from wells screened in both lower aquifer zones D and E had an average radiocarbon age of 4,640 ybp. Ground water collected from Zone E, the deepest part if the basin, had an average age of 7,330 ypb.

Lower aquifer Zone D water averages 4,130 ybp on the east side of the basin (excluding the creek valley), and 2,210 years old on the west side (excluding the sand spit). Lower aquifer water was reported at 681 ybp beneath the creek valley, and 4,279 ybp beneath the sand spit. Water at the base of Zone C is also older on the east side compared to the west side.

There are two wells with reported ground water ages that have been excluded from the average age calculations. Well 30S/10E-13M1 is a Zone E well screened from 436 to 496 feet below sea level containing 90 percent sea water. The age of water sampled from this well was reported at 765 ybp. Sea water from the ocean typically has a radiocarbon age of 400-500 ybp (due to ocean residence time), making the reservoir-corrected age of the sea water at well 13M1 less than 300 ybp. By contrast, Zone E fresh water is over 7,000 ybp.

The second well excluded from average age calculations was 30S/11E-18M1. Water from this lower aquifer (Zone D and E) well was reported to be 1,338 ybp, while the average age for other mixed Zone D and E wells was 4,640 ybp. As mentioned previously, the 2005 water sample collected from well 18M1 also contained elevated nitrates (10 mg/l as nitrogen) and had an upper aquifer water character, despite having pumped approximately 1.3 acre-feet of water from the well immediately prior to sampling. Upper aquifer leakage through the annular space has created an upper aquifer plume surrounding the well over the last 20 years of inactivity.

Results of the radiocarbon age-dating support the general mineral data that indicate significant leakage of upper aquifer water is occurring. The average age of Zone D water becomes younger west of downtown Los Osos, which is interpreted to be caused by mixing with upper aquifer water. Assuming an average age of 4,100 ybp for lower aquifer water entering the west side of the basin from the east side, and modern water in the east side upper aquifer (<50 ybp), a mixture of close to 46 percent Zone C (west side) water and 54 percent Zone D (east side) water would produce the age measured in Zone D (west side) water.

Unlike the general mineral data, there are no prior age-dated samples to compare the current data set to, and changes over time in the age of upper aquifer water due to development can alter the mixture estimates. As the assumed average pre-development age of upper aquifer water on the west side increases, so does the amount of leakage required to bring the mixture of upper an lower aquifer water to 2,200 years old.

Of note is the relatively young age of lower aquifer water in the creek valley, reported at 681 ybp. This age was measured in a well screened in the lowest part of the basin near Los Osos Creek. Less than a mile to the west, at South Bay Boulevard, lower aquifer water in Zone D was 3,930 ybp, and the deepest basin water was 7,170 ybp.

There are a few possible explanations for the dramatic change in lower aquifer water age between the creek valley and South Bay Boulevard. One possibility is that the Yates and Wiese parallel faults (at least the easternmost one, which displaces Quaternary sediments) continues across the basin west of the creek valley, effectively cutting off the majority of subsurface flow from the valley to the main basin area. Another possibility is that the lower aquifer water in the creek valley water was much older prior to agricultural development of the valley, and has seen a dramatic change in age over the last 50 years due to pumping extractions which have induced recharge from younger alluvial water. A third possible explanation is that there is sufficient wellbore flow in the well sampled (30S/11E-20Aa) to affect the age analysis. This deep well serves a private residence where outdoor irrigation is provided by a separate, shallow well, therefore the well has a relatively low demand placed upon it, such that even a small amount of constant leakage through the annular space from above could have a significant effect on the water quality. Water quality characteristics at well 20Aa include the presence of nitrates (2.4 mg/l as nitrate), also indicating shallow water influence, and confirming the relatively young ground water age.

The lower aquifer is effectively boxed in between bedrock walls, the Los Osos fault zone, and the ocean. Prior to the onset of development, and associated ground water extractions by deep wells, there was a much longer residence time for water in the lower aquifer (thousands of years). Yates and Williams (2003) estimated the current residence time for lower aquifer water (beneath the 2,100 acre prohibition zone) at 268 years, based on extractions averaging 1,690 acre-feet per year between 1998-2001 and an onshore storage volume of 452,000 acre-feet. Before any pumping, therefore, the natural flushing of water in the lower aquifer was much less than 1,690 acre-feet per year, and also limited to specific areas based on permeability. In fact, permeability remains an important part of ground water movement, residence time, and flushing.

Upper aquifer well 30S/11E-7N1 is 83 feet deep and has been in continual service to the LOCSD since the 1950's. Despite its shallow depth, correlation with nearby deep well 30S/10E-12J1 indicates that well 7N1 taps the base of Zone C (cross-section H-H', Appendix A). The age of water from well 7N1 was reported at 1,594 years old. Clearly, permeability factors within Zone C dominate ground water movement at this well, causing recharge to flow toward the well laterally from a considerable distance, rather than from above, where younger water (and high nitrates) predominate.

Tritium

As described earlier, Tritium is a hydrogen isotope that was released into the atmosphere in relatively large quantities during atomic bomb testing in the 1950's and 1960's. Tritium dating of ground water can be used to differentiate recently recharged ground waters (since the 1950's) from older water. The results of the tritium analysis in the Los Osos ground water basin are presented in Table 14.

**Table 14**
**Tritium Results**

| Well ID | Aquifer | Sample Date | Tritium Units | Error (eTU) |
|---|---|---|---|---|
| 30S/11E-7N1 | Zone C | 1/19/05 | 0.15 | 0.09 |
| 30S/11E-18L7 | Zone C | 1/13/05 | 3.04 | 0.10 |
| 30S/10E-13L4 | Zone D | 3/3/05 | 0.07 | 0.09 |
| 30S/10E-13J1 | Zone D | 3/3/05 | 0.13 | 0.10 |
| 30S/10E-13N | Zone D | 11/23/04 | 1.20 | 0.09 |
| 30S/11E-7Q3 | Zone D | 3/1/05 | 0.08 | 0.09 |
| 30S/11E-18L2 | Zone D, E | 3/1/05 | 0.38 | 0.09 |

Tritium was measured in all the samples, although two of the samples were less than the margin of error (one standard deviation), which would be effectively a non-detection. Two other samples contained trace amounts of tritium, and only two samples exceeded 1 TU.

The results of the tritium tests indicate that modern recharge (<50 years old) has reached portions of the base of Zone C and Zone D. Since tritium has a half-life of only 12.32 years, equivalent to a decay rate of 5.626% per year, it dissipates relatively quickly in the subsurface, and the older, "submodern" ground water would be essentially tritium free. Natural production of tritium in the subsurface, except where uranium or lithium rich rocks are present, is negligible, and in most aquifers would be close to or less than the 0.1 detection limit. Therefore, even a trace of tritium in water would likely be an indicator of some modern recharge. The greatest concentration of tritium is at well 30S/11E-18L7, which is a monitoring well at the base of Zone C along Palisades Avenue, only a few hundred feet from lower aquifer water supply well 30S/11E-18L2, where tritium was also detected.

Tritium is essentially a tracer, and confirms that upper aquifer leakage into the lower aquifer is occurring, but cannot quantifying the leakage with a single data set. The tritium data does suggest that modern recharge is moving downward at a slower rate on the east side, compared to the west side. In fact, no modern recharge was detected in the lower aquifer at well 30S/11E-7Q3, and was found at trace amounts at the base of Zone C in Section 7 wells (Baywood Park). This is consistent with the radiocarbon data, where the water in Zones C and D in Section 7 was older than west side ages for corresponding zones.

Leakage Estimate

The major ions analysis indicates that between the two dominant fresh water sources of recharge to the lower aquifer, creek valley inflow contributes approximately 40 percent of the composition and leakage from the upper aquifer about 60 percent. Using the hydrogeologic cross-section calculation for creek valley inflow of 470 afy, the corresponding amount of upper aquifer leakage to balance water quality would be 700 afy.

The steady state model estimates creek valley inflow at 370 afy, and upper aquitard leakage west of the creek valley at 920 afy, which is a greater proportion of upper aquifer leakage than estimated by the water quality balance. A shift in the proportion of creek valley inflow compared to upper aquifer leakage would be expected following the onset of ground water development. Declines in lower aquifer water levels due to ground water pumping and increases in upper aquifer water levels from return flows would increase the amount of upper aquifer leakage over time, therefore the 60 percent contribution of upper aquifer leakage to creek valley inflow is considered a minimum value under post-development conditions.

As previously mentioned, average residence time for water in the lower aquifer was measured in the thousands of years prior to the onset of development. Nevertheless, even the pre-development water quality balance is considered to be primarily between creek valley inflow and upper aquifer leakage. The Quaternary sediments comprising the lower aquifer are estimated to predate the Wisconsin Glacial Stage (>60,000 years before present), which was the last low sea-level stand. This is based on the amount of folding observed in basin sediments, which is correlated primarily by control on the regional aquitard.

Basin geologic cross-sections in Appendix A (i.e. F-F', H-H', or I-I') show the top of the regional aquitard at the synclinal axis to be 150+ feet (46+ meters) lower in elevation than the corresponding horizon near the edges of the basin. This folding has been in response to relative uplift of the Irish Hills and subsidence in the basin. The maximum rate of uplift measured by dating marine terraces at Montaña de Oro has been established at 0.2 to 0.23 millimeters per year, and the maximum rate of basin subsidence at 0.1 millimeters per year, for a maximum relative vertical displacement within basin sediments of 0.33 millimeters per year (Lettis and Hall, 1994). These rates of displacement would require at least 140,000 years to fold the regional aquitard to its present condition. The lower aquifer underlies this aquitard, and is even older. Ground water ages measured in the lower aquifer are Holocene, therefore, connate water has been replaced by recent sources of recharge.

Wellbore Flow

Flow of ground water between the upper and lower aquifer through inactive wells west of the creek valley has the potential to make a significant contribution to the lower aquifer recharge. There are 30 wells known to penetrate the regional aquitard beneath the main basin area (most wells in the basin are private domestic wells completed in the upper aquifer). Of these 30 lower aquifer wells, eight have mixed-aquifer completions, with screened intervals above and below the regional aquitard. Five of these mixed-aquifer wells are active, and are pumping from both aquifers. One of the three inactive mixed-aquifer wells has a down hole packer to separate the two screened intervals, leaving only two wells (30S/10E-13L7 and 30S/11E-18F1) as potential conduits for cross-aquifer flow through the well casing.

Cross-aquifer flow through the annular space is possible at 19 of the 30 wells penetrating the regional aquitard (11 wells have deep seals or plugs opposite the regional aquitard). Of these 19 wells, 11 are active, leaving eight inactive wells with a potential for cross-aquifer flow through the annual space (active wells remove any cross-aquifer flow that they induce).

The average nominal casing diameter of the eight inactive wells is 10 inches, with a borehole diameter of 20 inches, for a cross-sectional area of 1.6 square feet in the annual space (between the casing and the borehole wall). The hydraulic conductivity of gravel pack materials is estimated at 15,000 gpd/ft$^2$ (2,000 ft/day). The vertical gradient through the annular space would vary across the basin, but is assumed to average close to 0.4 ft/ft, based on a head differential of 20 feet across the approximate 50-foot regional aquitard. These values would result in an annual flow of up to 10 acre-feet between the upper and lower aquifer through an average inactive borehole.

The potential recharge through the casings of the two inactive mixed-aquifer wells discussed above could be several times greater than for annular space alone. Overall, the amount of recharge from wellbore flow at inactive wells between the upper and lower aquifer could be on the order of 200 afy. Wellbore flow is a relatively recent component of lower aquifer recharge, and is probably not fully accounted for by the water quality balance for leakage discussed above.

Hill Method

Cleath & Associates (2005) used the Hill method to estimate the average annual recharge to the lower aquifer. The Hill method, developed by R.A. Hill for ground water investigations in Arizona and Southern California, compares the annual production to the annual change in ground water level (Todd, 1959). When the method assumptions are satisfied, data from individual years will plot along a straight line. The point where the line intercepts the zero annual change in water level represents an equilibrium between the elements of recharge and discharge, and is an independent check of the other methods used in this investigation for lower aquifer recharge. The assumptions in the Hill method are that the water supply to the basin is reasonably constant and should approximate the long-term mean supply.

A plot of annual production versus average annual change in water levels is shown in Figure 30 for the balanced hydrologic base period from water years 1986 through 1999 (14 years). This period includes drought and wet cycles, with a cumulative departure from the mean precipitation of less than 3 inches. Five key wells were used to determine the average annual change in lower aquifer water levels for the basin:

- 30S/10E-12J1
- 30S/10E-13P2
- 30S/11E-17J1
- 30S/11E-18M1
- 30S/11E-19H2

The water level data were plotted using a 3-year moving average to smooth out annual variations in supply. The best-fit straight line intercepts the point of zero change in water level at approximately 1,890 afy. The distribution of data points above and below the zero intercept suggests a dynamic equilibrium has been reached. Note that the average water levels in the lower aquifer at this particular dynamic equilibrium are below sea level, another indicator of sea water intrusion.

Not coincidentally, the average annual production from the lower aquifer during the 1986-1999 base period used in the Hill method was approximately 1,900 afy. A review of water level hydrographs for the key wells identified above indicate losses to ground water in storage beneath Bayview Heights, but the rest of the basin appeared relatively unchanged.

## Conclusions

Various independent lines of research have been used in this investigation to resolve questions regarding the sources of lower aquifer recharge to the Los Osos Valley ground water basin. What has emerged is a relatively consistent picture of the recharge dynamics. Upper aquifer leakage is the primary component of recharge to the lower aquifer. Sea water intrusion dominates subsurface inflow from the west, and creek valley inflow dominates subsurface inflow from the east. Recharge from bedrock is minor.

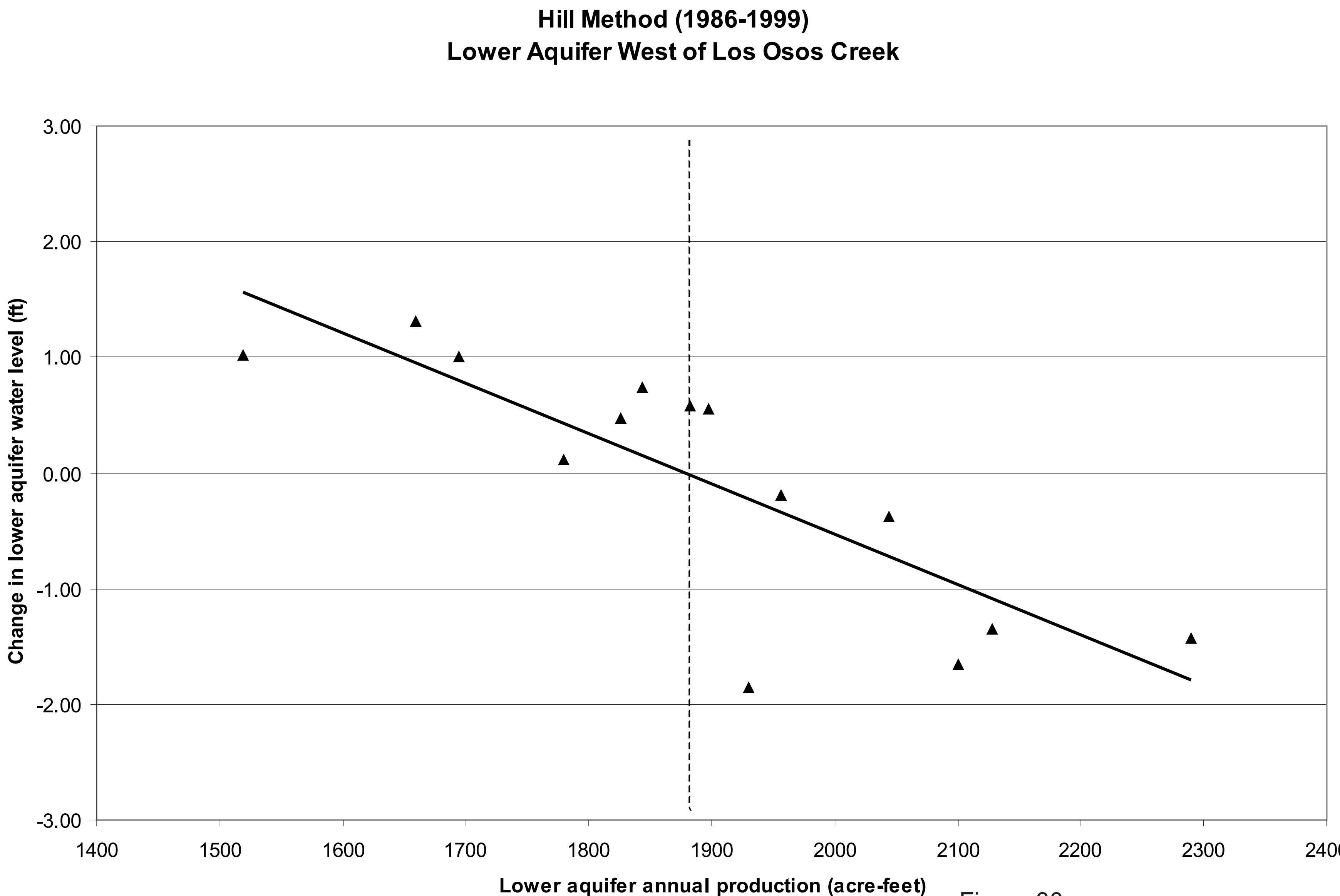


Figure 30
Hill Method (1986-1999)
Lower Aquifer West of Los Osos Creek

DWR Grant Project
Los Osos CSD

Cleath & Associates

The best estimate for total average annual recharge to the lower aquifer (including sea water intrusion) based on the results of the methodologies used is 1,890 afy . The amount of sea water intrusion occurring is estimated at 560 afy (average of analytical and model results), leaving 1,330 afy of fresh water recharge.

The individual components of fresh water recharge are estimated to be 420 afy creek valley inflow (average of analytical and model results), and 910 afy upper aquifer leakage (post-development condition, including inactive wellbore flows). A summary of the best estimates for sources of recharge to the lower aquifer west of the Los Osos Creek valley is summarized below in Table 15.

**Table 15**
**Sources of Recharge to the Lower Aquifer**
**West of the Los Osos Creek Valley**

| Source of Recharge | Estimated Recharge (acre-feet per year) |
|---|---|
| Sea Water Intrusion | 560 |
| Bedrock | Negligible (except in Creek Valley) |
| Inflow from Creek Valley | 420 |
| Upper Aquifer Leakage | 910 |
| Total | 1,890 afy (1,330 fresh water) |

There are at least three significant conclusions based on this source investigation. First, much more fresh water is being pumped from the lower aquifer than is being replenished. Lower aquifer production west of the creek valley in year 2000 was approximately 1,950 acre-feet, or 620 acre-feet more than the average fresh water inflow. This is also confirmed by the evidence of sea water intrusion.

Second, the upper aquifer is the primary source of recharge to the lower aquifer, particularly on the west side of the basin. This conclusion indicates that plans originally developed during the 1980's for treated effluent disposal at higher elevations on the west side of the basin provide a reasonable potential for incidental recharge to the lower aquifer. This also indicates that nitrates and other conservative constituents of basin return flows will ultimately reach the lower aquifer.

Third, lower aquifer recharge from the uppermost reaches of the creek valley into the main basin area where community purveyors operate is restricted by faulting. This conclusion has implications relative to the management of creek valley water resources. For example, artificial recharge projects in the uppermost creek valley would not directly benefit the main basin area, and would require careful positioning of recovery wells with respect to localized faulting.

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# SEA WATER INTRUSION ASSESSMENT
# and
# LOWER AQUIFER SOURCE INVESTIGATION
# of the
# LOS OSOS VALLEY GROUND WATER BASIN
# SAN LUIS OBISPO COUNTY, CALIFORNIA

prepared for the

LOS OSOS COMMUNITY SERVICES DISTRICT

with grant funding provided by the

CALIFORNIA DEPARTMENT OF WATER RESOURCES

## APPENDICES

October 2005

CLEATH & ASSOCIATES
1390 Oceanaire Drive
San Luis Obispo, California 93405

## Appendix A

**Geologic Cross-Sections**
**from Cleath & Associates (2003)**
**Revised October 2005 for DWR Grant Study**


LEGEND

17N10 Ground Water Well

approx. basin limits

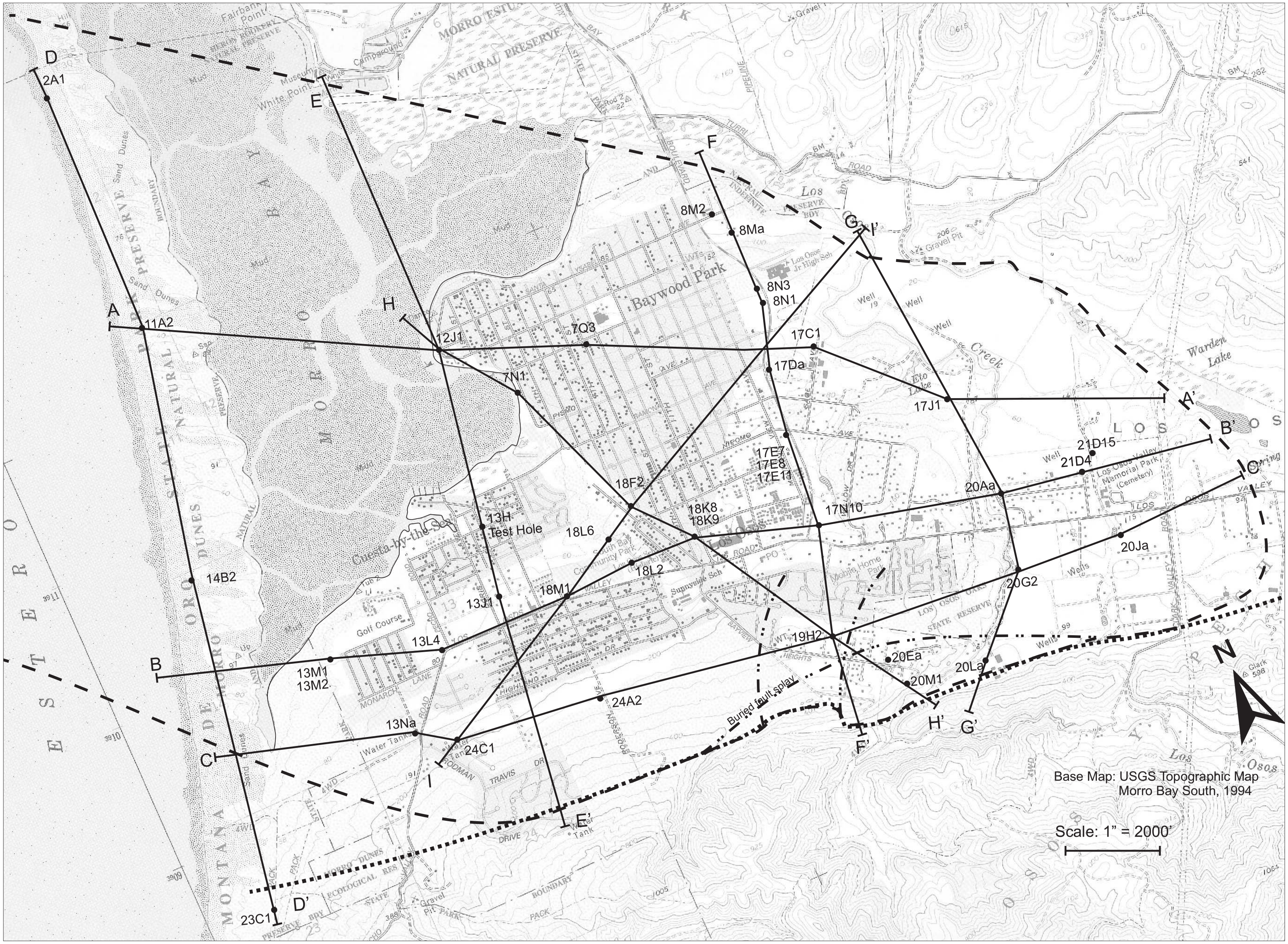
Note: Not all of the known well locations in basin are shown. Most shown have logs, water levels and/or water quality information used in basin studies.

Figure A1

Well Locations
Los Osos Valley
Ground Water Basin

DWR Grant Project
Los Osos CSD

Cleath & Associates




LEGEND

A A' Cross-section orientation

Approx. basin limits

Main strand of Los Osos fault (approx. location)

Figure A2

Geological Cross-Section Orientations

Los Osos Valley Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

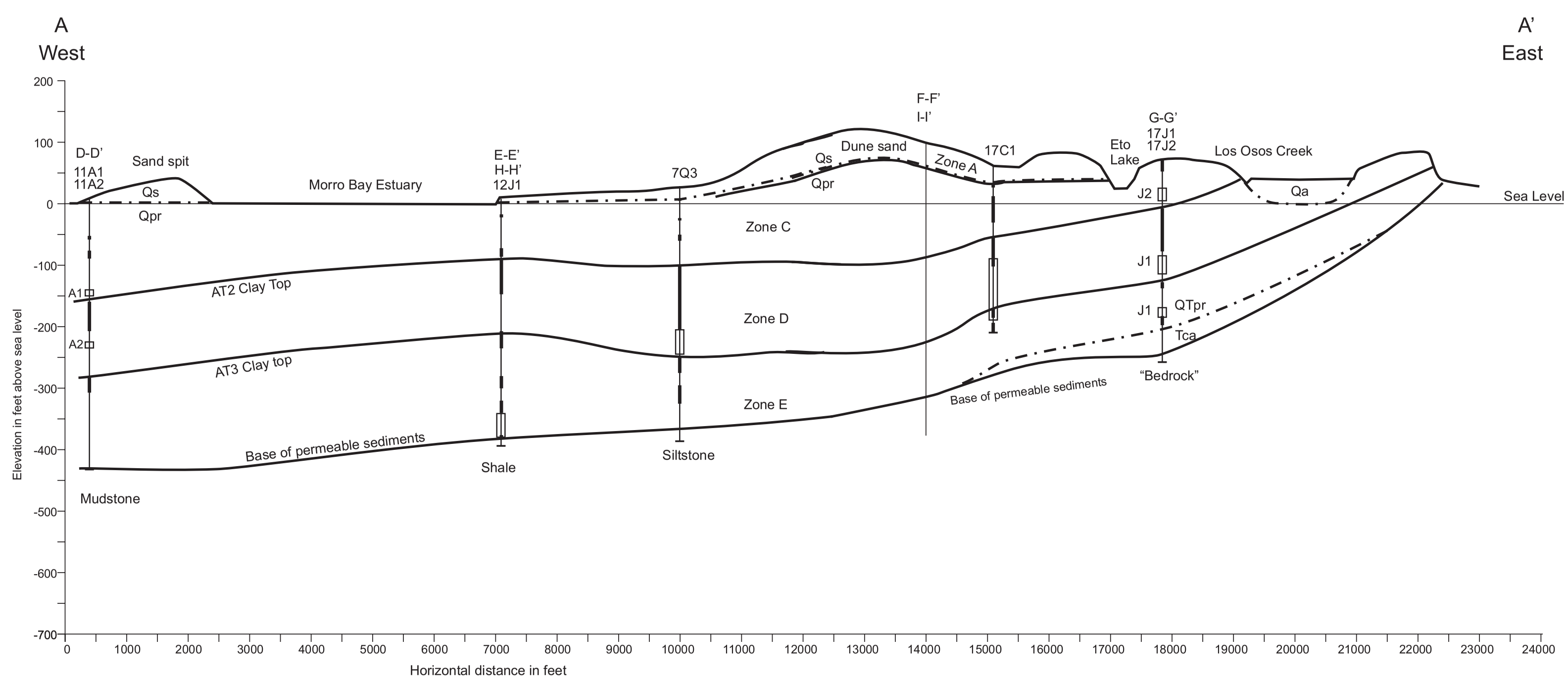



Figure A3

Cross-Section A-A'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

Aquifer Zones:
Zone A - Perched Aquifer
Zone B - Transitional Aquifer
Zone C - Upper Aquifer
Zone D - Lower Aquifer (shallow)
Zone E - Lower Aquifer (deep)

Well data point
12J1 Well ID
Clay layer
Well screen

Formation:
Qa - alluvium
Qs - dune sand
Qpr - Paso Robles Formation
Tca - Careaga Formation

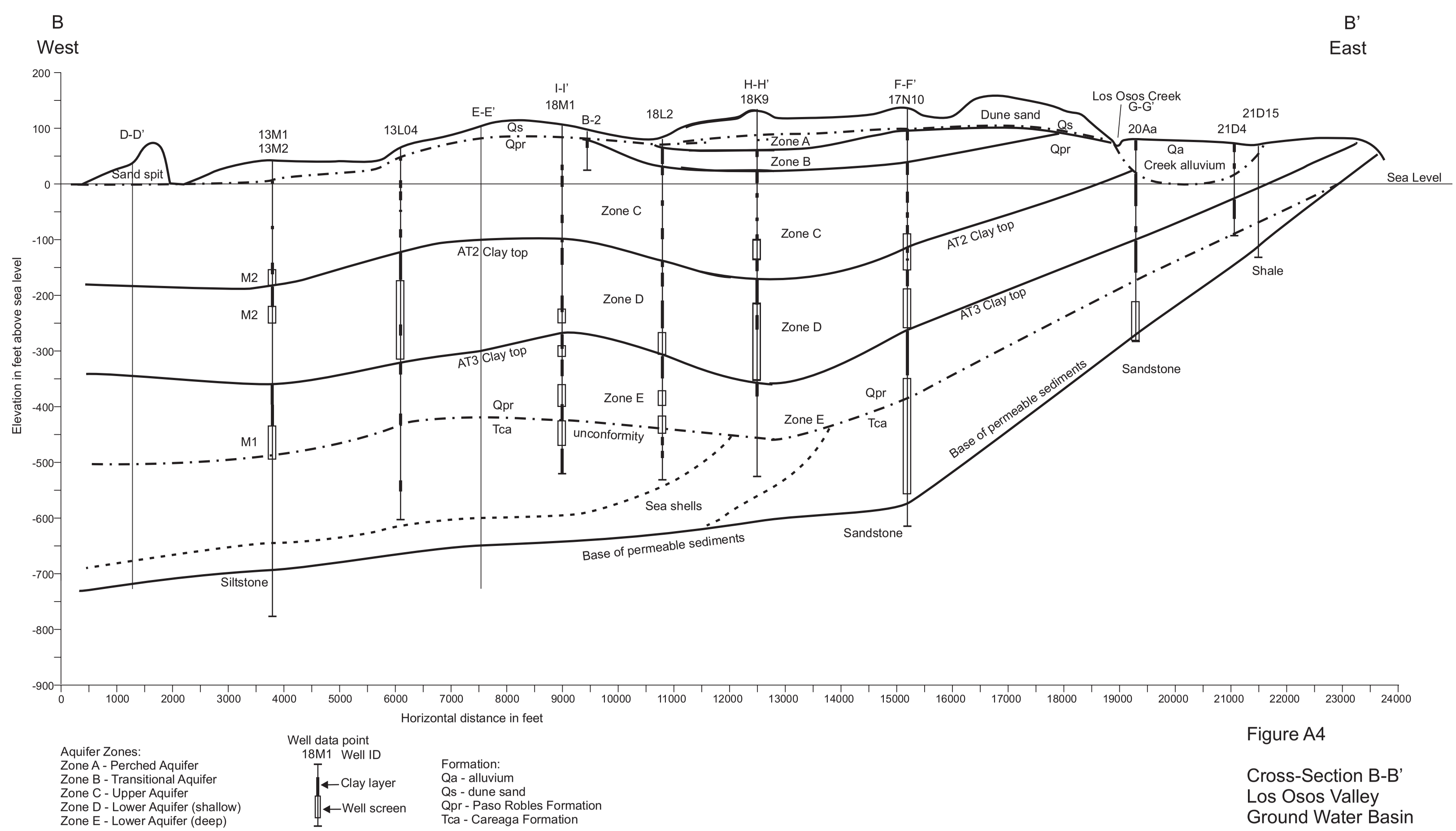



Figure A4

Cross-Section B-B'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

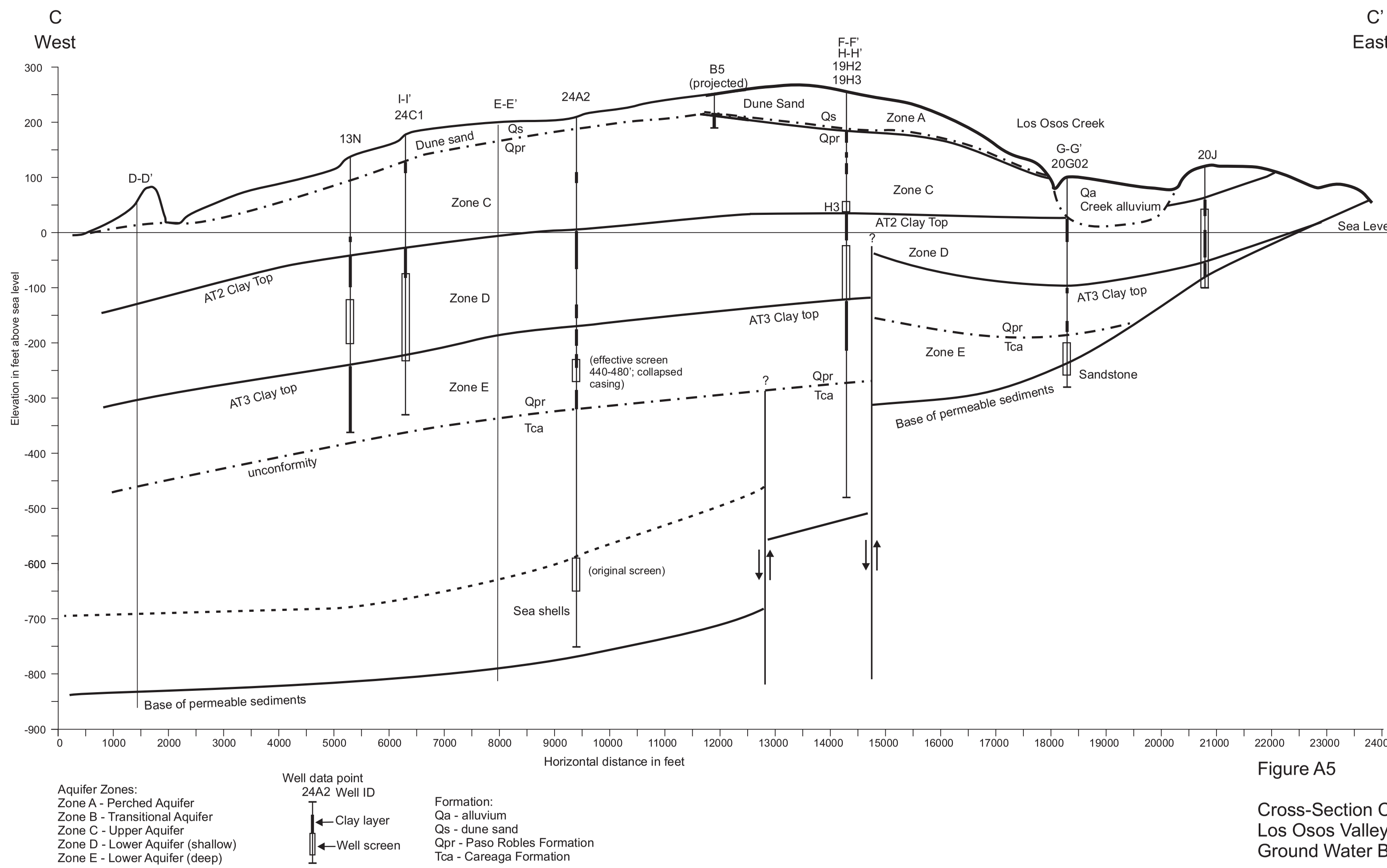



Figure A5

Cross-Section C-C'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

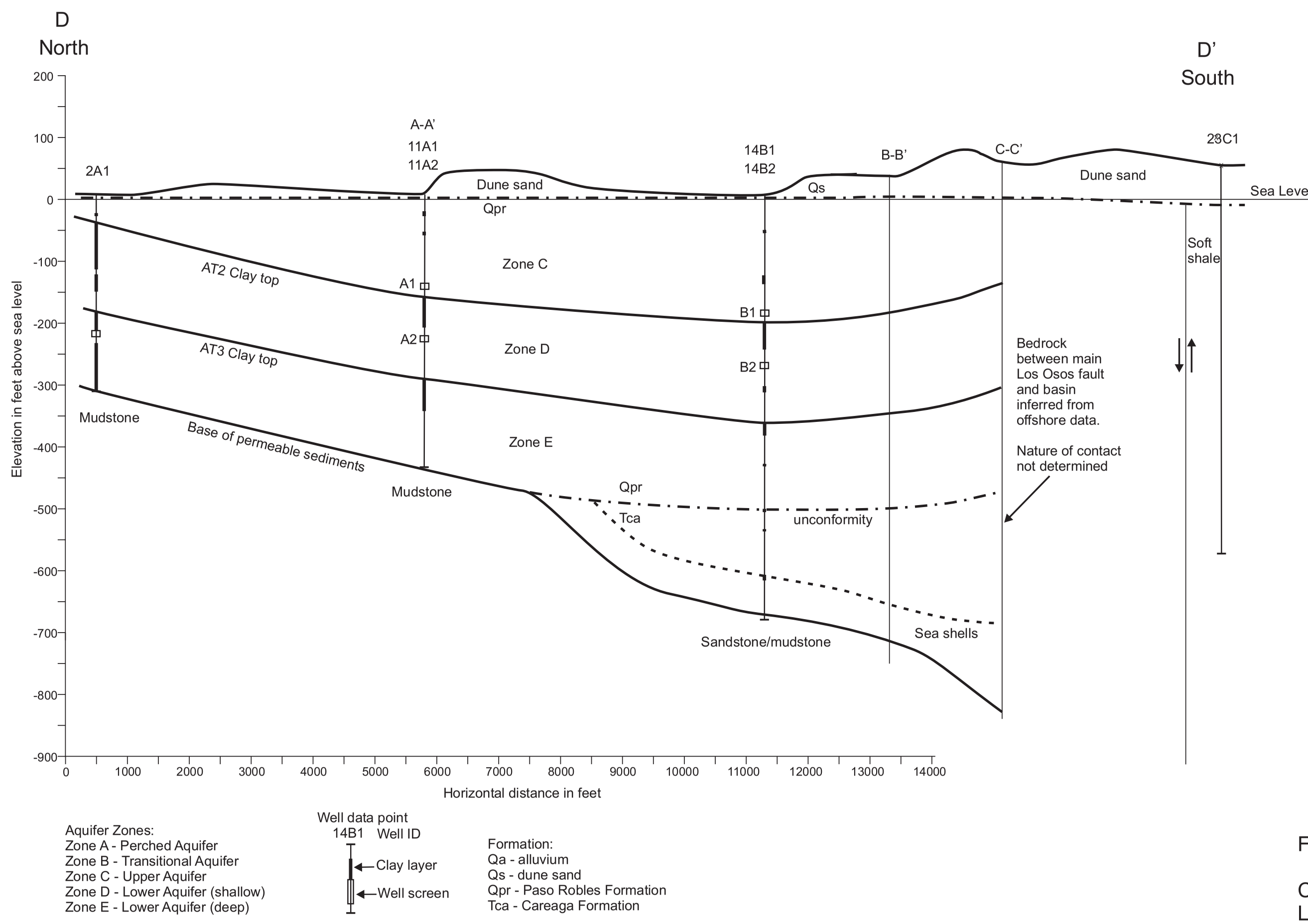



Figure A6

Cross-Section D-D’
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

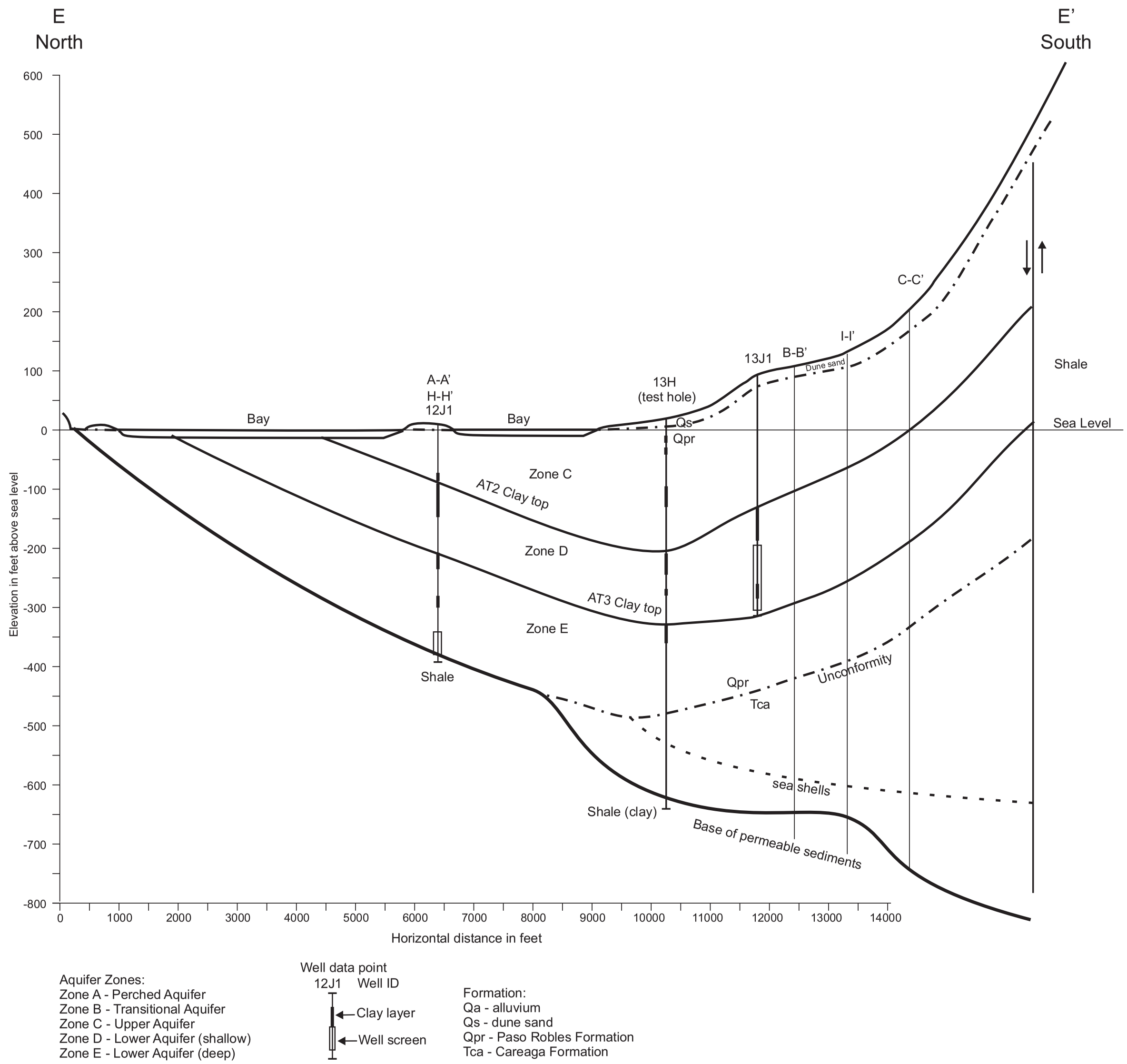
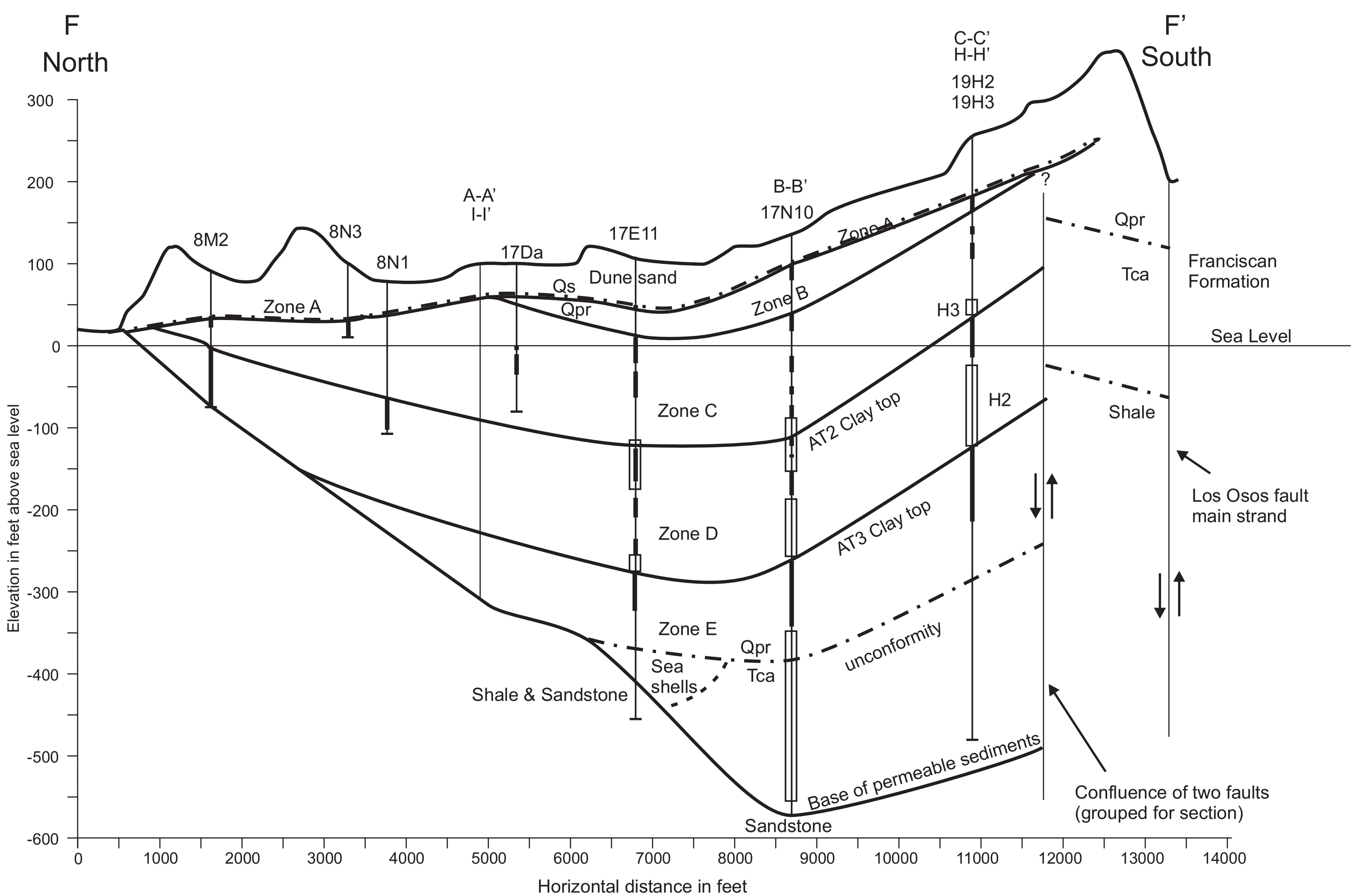



Figure A7

Cross-Section E-E'
Los osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates




Aquifer Zones:
Zone A - Perched Aquifer
Zone B - Transitional Aquifer
Zone C - Upper Aquifer
Zone D - Lower Aquifer (shallow)
Zone E - Lower Aquifer (deep)

Formation:
Qa - alluvium
Qs - dune sand
Qpr - Paso Robles Formation
Tca - Careaga Formation

Figure A8

Cross-Section F-F'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

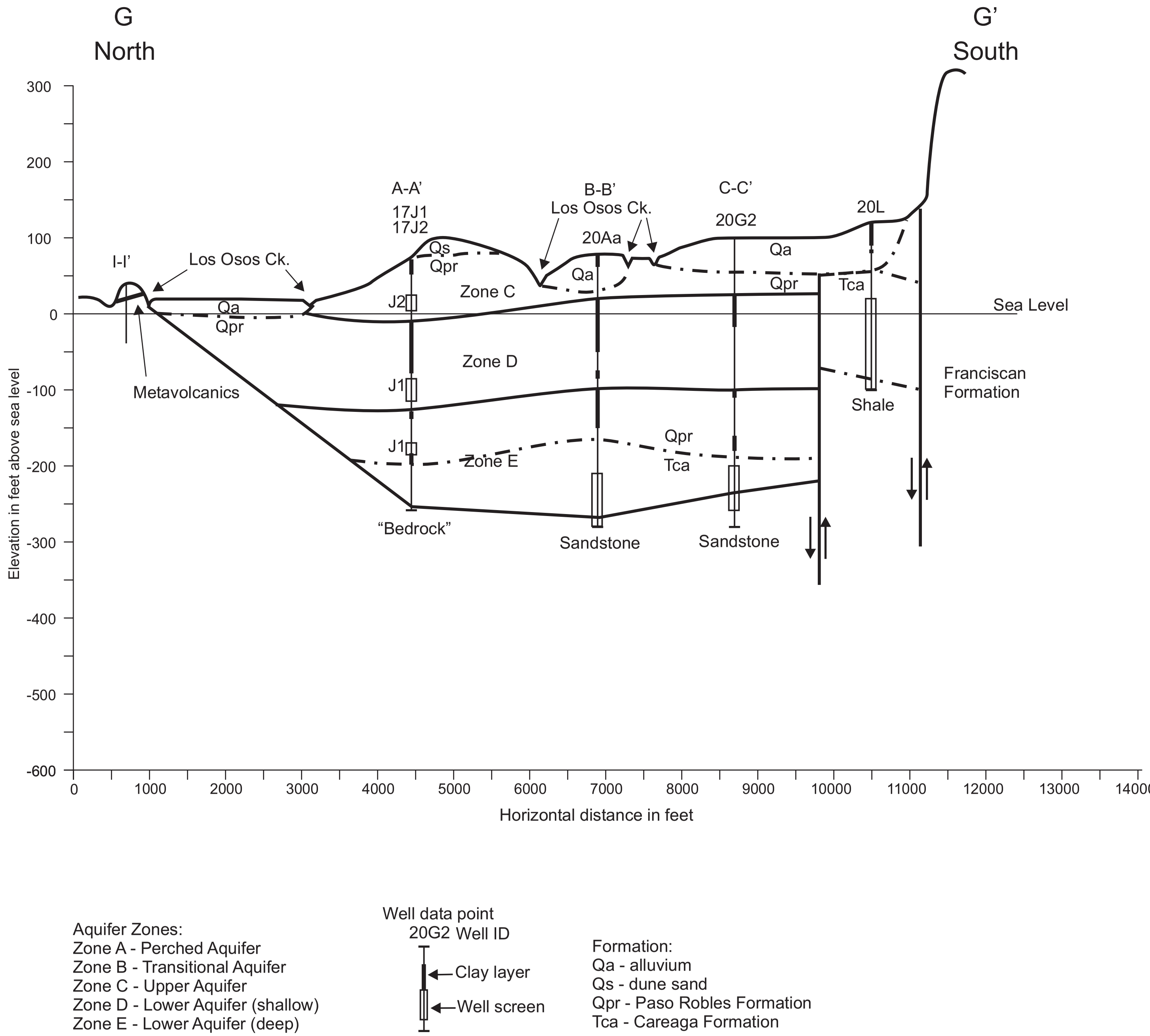



Figure A9

Cross-Section G-G'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

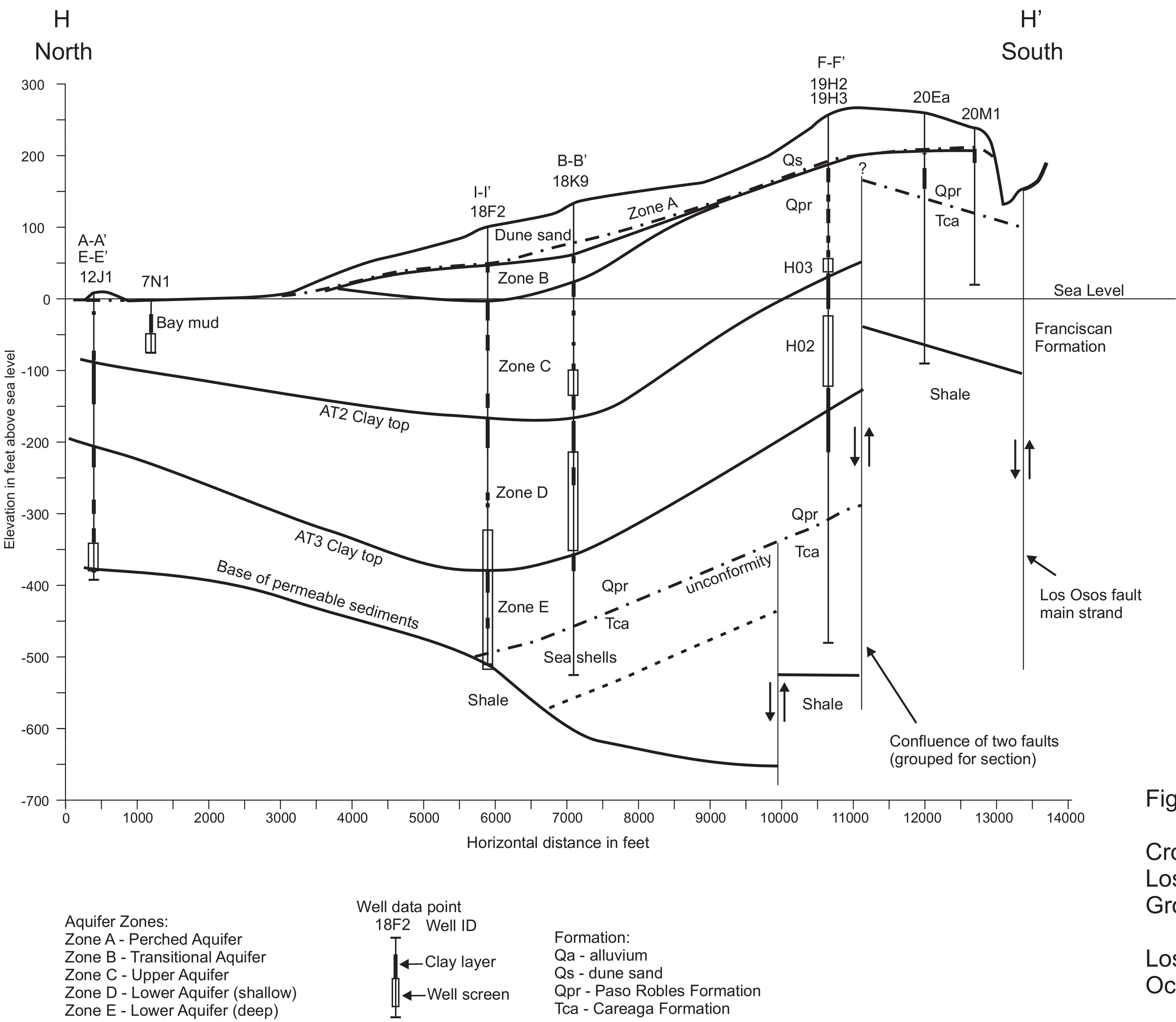



Figure A10

Cross-Section H-H'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

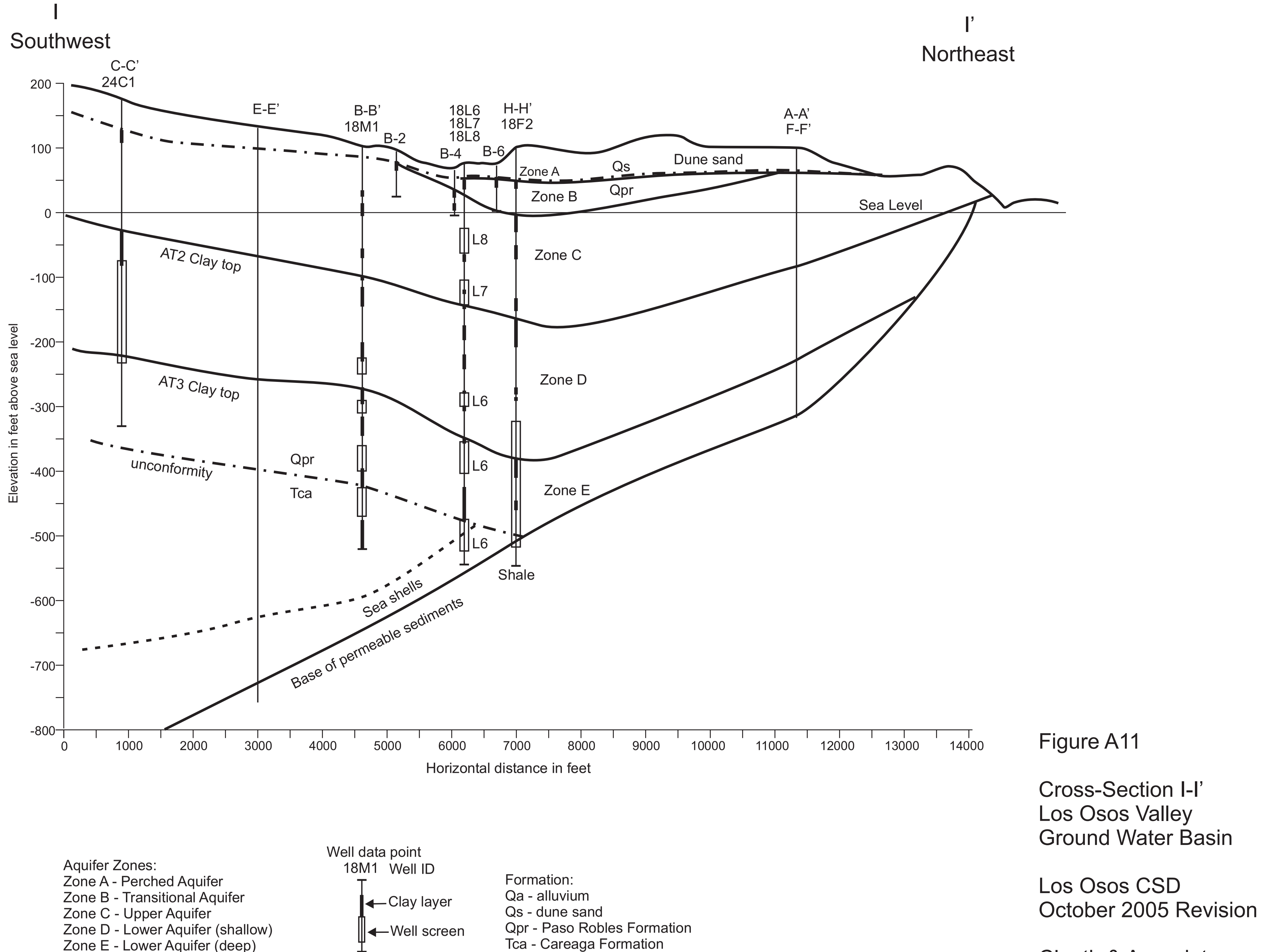



Figure A11

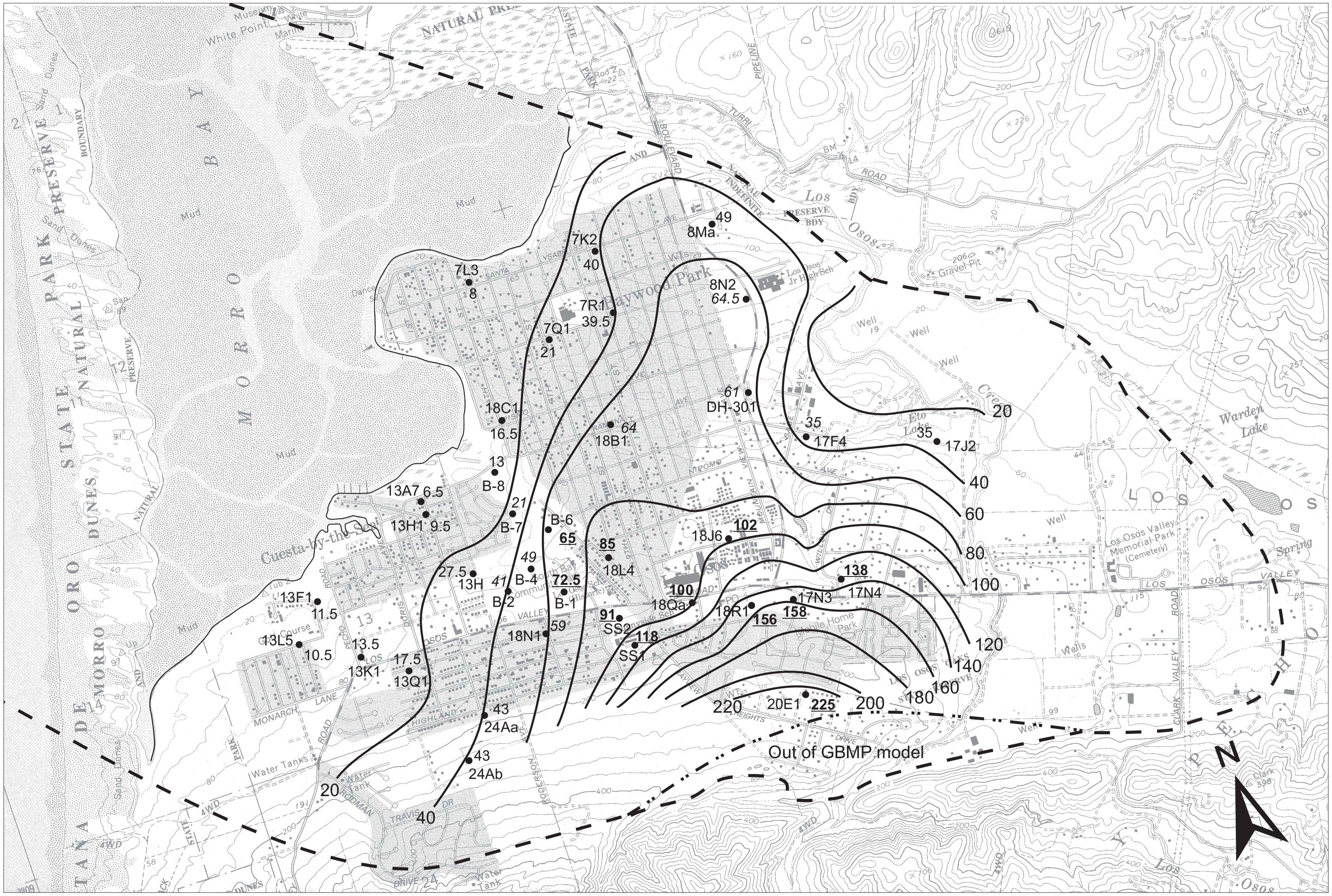
Cross-Section I-I'
Los Osos Valley
Ground Water Basin

Los Osos CSD
October 2005 Revision

Cleath & Associates

# Appendix B

## Water Level Contour Maps
## from Cleath & Associates (2003)




Base Map: USGS Topographic Map
Morro Bay South, 1994

Scale: 1" = 2000'

**bold** - Zone A elevation only
*italic* - Zone A and B elevation
normal - Zone A, B and C elevation

60 Ground water elevation contour in feet above sea level

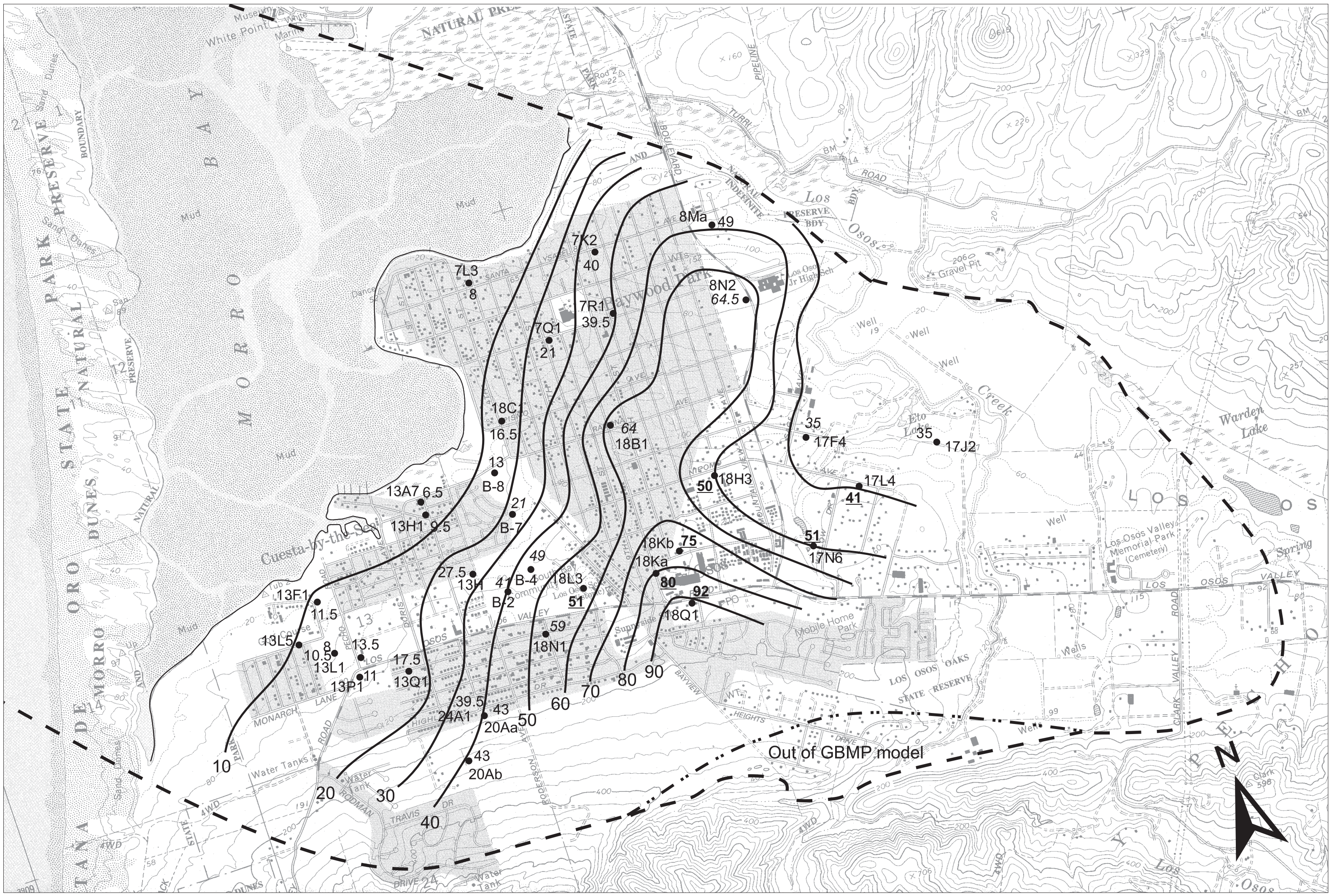
Approx. basin limits

Figure B1

Ground Water Elevation Contours
Perched Aquifer (Zone A)
Steady-State Conditions (1999-2000)
Los Osos Valley Ground Water Basin

Los Osos CSD

Cleath & Associates




Base Map: USGS Topographic Map
Morro Bay South, 1994

Scale: 1" = 2000'

**bold** - Zone B elevation only
*italic* - Zone A and B elevation
normal - Zone A, B and C elevation

60 Ground water elevation contour in feet above sea level

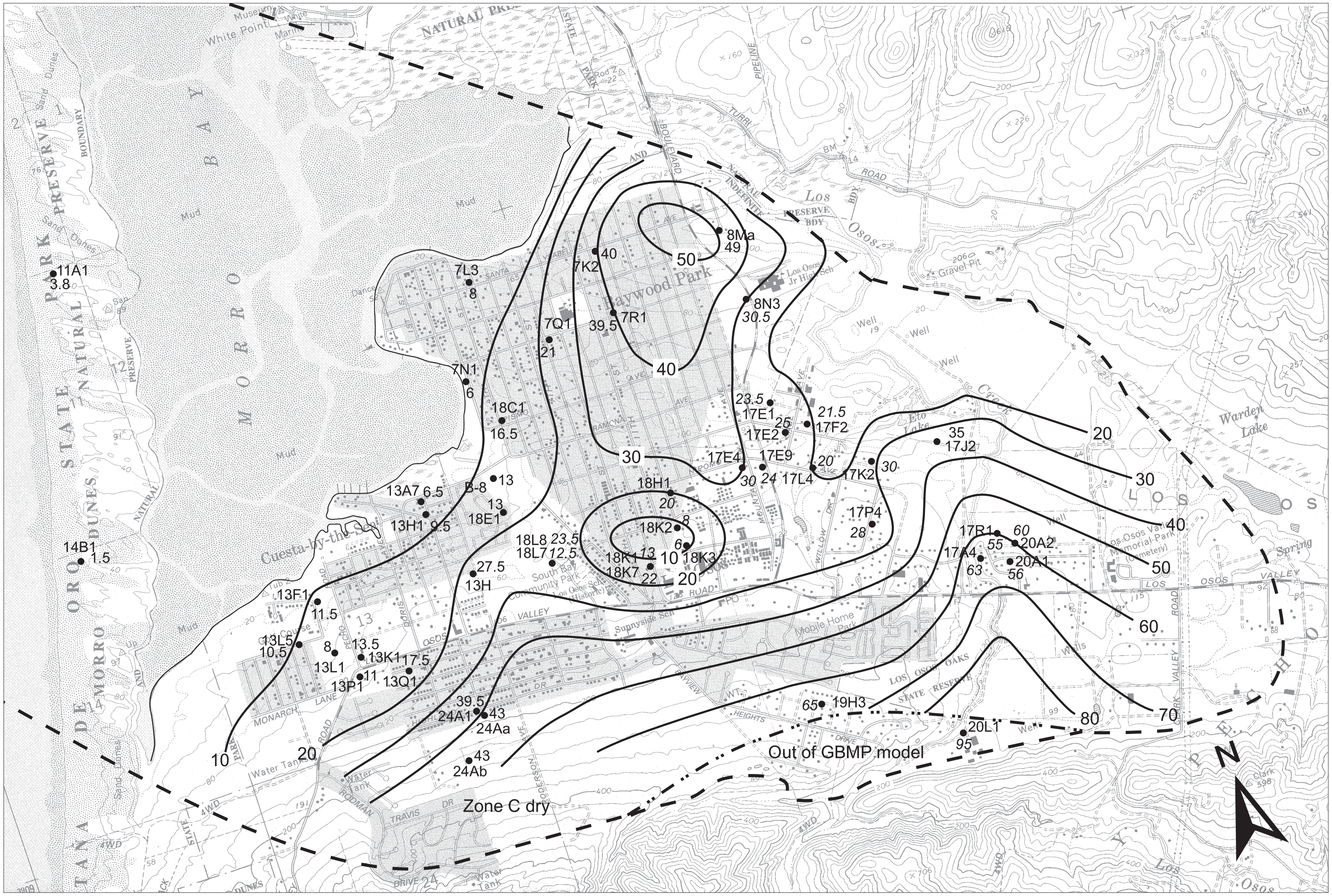
Approx. basin limits

Figure B2

Ground Water Elevation Contours
Transition Zone Aquifer (Zone B)
Steady-State Conditions (1999-2000)
Los Osos Valley Ground Water Basin

Los Osos CSD

Cleath & Associates




Base Map: USGS Topographic Map
Morro Bay South, 1994

Scale: 1" = 2000'

*italic* - Zone C elevation only
normal - Zone A, B, and C elevation

60 Ground water elevation contour in feet above sea level

Figure B3

Ground Water Elevation Contours
Upper Supply Aquifer (Zone C)
Steady-State Conditions (1999-2000)
Los Osos Valley Ground Water Basin

Los Osos CSD

Cleath & Associates

# Appendix C

## Summary of Prior Laboratory Testing for Soil Permeability

Summary of Shallow Permability Data - Los Osos

| Boring ID | depth (ft) | data source | type | soil | Permeability All K (cm/s) | Sand K (ft/day) | Sand K (gpd/ft2) |
|---|---|---|---|---|---|---|---|
| DH-1 | 35 | M&E, 1996 | lab test | fine sand w/silt | 4.05E-04 | | |
| DH-4 | 20 | M&E, 1996 | lab test | fine sand | 1.76E-03 | 5 | 37.4 |
| DH-4 | 50 | M&E, 1996 | lab test | fine sand | 1.68E-03 | 4.8 | 35.9 |
| DH-5 | 21 | M&E, 1996 | lab test | fine sand | 1.34E-03 | 3.8 | 28.4 |
| DH-5 | 50 | M&E, 1996 | lab test | clayey sand | 1.41E-05 | | |
| DH-8 | 35 | M&E, 1996 | lab test | fine sand | 7.58E-04 | 2.1 | 15.7 |
| DH-8 | 49 | M&E, 1996 | lab test | fine sand | 1.23E-03 | 3.5 | 26.2 |
| Basin 1 | surface | M&E, 1996 | field test | fine sand | 0.011289 | 32 | 239.4 |
| Basin 4 | surface | M&E, 1996 | field test | fine sand | 0.016228 | 46 | 344.1 |
| Basin 5 | surface | M&E, 1996 | field test | fine sand | 0.00635 | 18 | 134.6 |
| | | | | | | | |
| DH 101 | 1 | Fugro, 1997 | lab test | sand | 0.0047 | 13.3 | 99.5 |
| DH 102 | 1 | Fugro, 1997 | lab test | sand | 0.0018 | 5.1 | 38.1 |
| DH 103 | 2 | Fugro, 1997 | lab test | sand | 0.0037 | 10.5 | 78.5 |
| DH 104 | 2 | Fugro, 1997 | lab test | sand | 0.0048 | 13.6 | 101.7 |
| DH 111 | 2 | Fugro, 1997 | lab test | sand | 0.0065 | 18.4 | 137.6 |
| DH 113 | 2 | Fugro, 1997 | lab test | sand | 0.004 | 11.3 | 84.5 |
| DH 116 | 2 | Fugro, 1997 | lab test | silty sand | 0.0002 | | |
| DH 117 | 2 | Fugro, 1997 | lab test | sand | 0.0016 | 4.5 | 33.7 |
| DH 201 | 4 | Fugro, 1997 | lab test | sand | 0.0026 | 7.4 | 55.4 |
| DH 201 | 35 | Fugro, 1997 | lab test | sand | 0.0018 | 5.1 | 38.1 |
| DH 202 | 15 | Fugro, 1997 | lab test | sand | 0.0033 | 9.4 | 70.3 |
| DH 203 | 3 | Fugro, 1997 | lab test | sand | 0.0012 | 3.4 | 25.4 |
| | | | | | | | |
| B-2 | 30 | CFS, 2000 | lab test | SP | 2.60E-02 | 73.7 | 551.3 |
| B-2 | 79 | CFS, 2000 | lab test | SP-SM | 3.80E-03 | | |
| B-3 | 10 | CFS, 2000 | lab test | SP-SM | 1.50E-04 | | |
| B-7 | 10 | CFS, 2000 | lab test | SP | 9.10E-03 | 25.8 | 193 |
| | | | | | | | |
| B1 (18J06) | 10 | B&C, 1983 | lab test | sandy clay | 1.27E-06 | | |
| B3 (13L05) | 34 | B&C, 1983 | lab test | clayey sand | 1.13E-05 | | |
| B4 (13Q01) | 14 | B&C, 1983 | lab test | fine-med sand | 0.01 | 28.3 | 211.7 |
| B5 (18B1) | 20 | B&C, 1983 | lab test | fine-med sand | 0.01 | 28.3 | 211.7 |
| B10 (7K2) | 19 | B&C, 1983 | lab test | medium sand | 0.02 | 56.7 | 424.1 |
| B12 (18N01) | 24 | B&C, 1983 | lab test | medium sand | 0.01 | 28.3 | 211.7 |
| B13 (8N3) | 25 | B&C, 1983 | lab test | medium sand | 0.02 | 56.7 | 424.1 |
| | | | | | | | |
| DH-401 | 9 | Fugro, 2004 | lab test | SM | 0.017 | 48.2 | 360.5 |
| DH-402 | 19 | Fugro, 2004 | lab test | SP | 0.01 | 28.3 | 211.7 |
| DH-403 | 19 | Fugro, 2004 | lab test | SP | 0.012 | 34 | 254.3 |
| DH-404 | 14 | Fugro, 2004 | lab test | SP-SM | 0.005 | | |
| DH-405 | 14 | Fugro, 2004 | lab test | SP | 0.004 | 11.3 | 84.5 |
| HP-1 | 14.5 | Fugro, 2004 | lab test | SP | 0.014 | 39.7 | 297 |
| HP-1 | 34.5 | Fugro, 2004 | lab test | SP | 0.019 | 53.9 | 403.2 |
| HP-1 | 44.5 | Fugro, 2004 | lab test | SP | 0.02 | 56.7 | 424.1 |
| HP-2 | 44 | Fugro, 2004 | lab test | SP | 0.013 | 36.9 | 276 |

Summary of Shallow Permability Data - Los Osos (Continued)

| | | | | | Permeability | | |
|---|---|---|---|---|---|---|---|
| | | | | | All | Sand | Sand |
| Boring ID | depth (ft) | data source | type | soil | K (cm/s) | K (ft/day) | K (gpd/ft2) |
| L-1 | 4.5 | Fugro, 2004 | field test | SP | 0.006 | 17 | 127.2 |
| L-2 | 4.5 | Fugro, 2004 | field test | SP | 0.003 | 8.5 | 63.6 |
| P-1 | 4.5 | Fugro, 2004 | field test | SP | 0.008 | 22.7 | 169.8 |
| P-7 | 4.5 | Fugro, 2004 | field test | SP | 0.011 | 31.2 | 233.4 |
| P-12 | 4.5 | Fugro, 2004 | field test | SP | 0.005 | 14.2 | 106.2 |
| P-16 | 5 | Fugro, 2004 | field test | SP | 0.01 | 28.3 | 211.7 |
| P-17 | 4.5 | Fugro, 2004 | field test | SP | 0.004 | 11.3 | 84.5 |
| P-23 | 4.5 | Fugro, 2004 | field test | SP | 0.008 | 22.7 | 169.8 |
| P-26 | 4.5 | Fugro, 2004 | field test | SP | 0.003 | 8.5 | 63.6 |
| P-3W2 | 4.5 | Fugro, 2004 | field test | SP | 0.005 | 14.2 | 106.2 |
| P-3W3 | 4.5 | Fugro, 2004 | field test | SP | 0.011 | 31.2 | 233.4 |
| P-SP1 | 4.5 | Fugro, 2004 | field test | SP | 0.004 | 11.3 | 84.5 |
| P-SP2 | 4.5 | Fugro, 2004 | field test | SP | 0.005 | 14.2 | 106.2 |
| S | 3.5 | Fugro, 2004 | field test | SP | 0.007 | 19.8 | 148.1 |
| S | 4 | Fugro, 2004 | field test | SP | 0.009 | 25.5 | 190.7 |

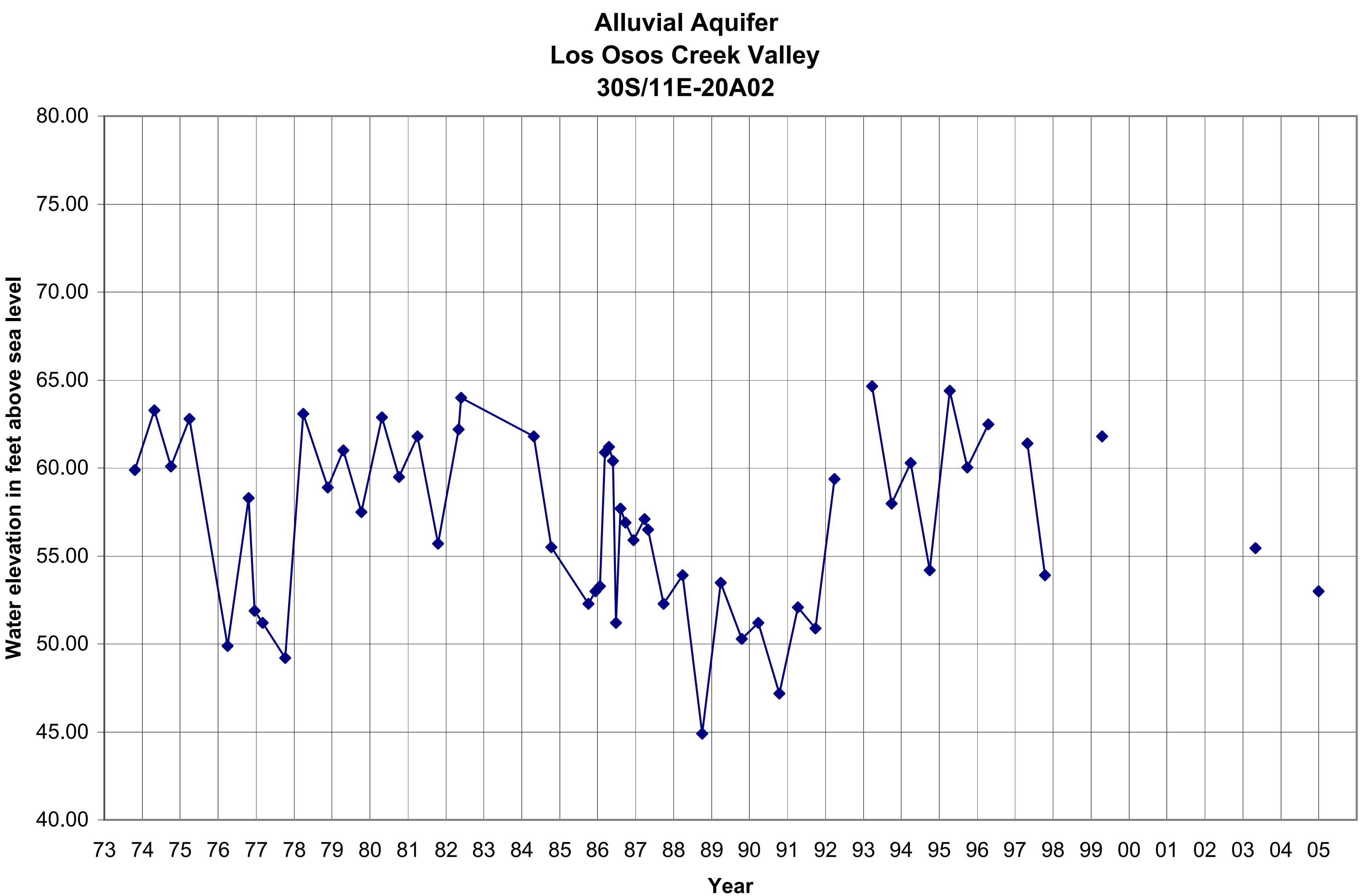
| AVERAGE FOR SAND ONLY | | |
|---|---|---|
| | K (ft/day) | K (gpd/ft2) |
| 1st quartile | 9.4 | 70.3 |
| 3rd quartile | 31.2 | 233.4 |

**References:**

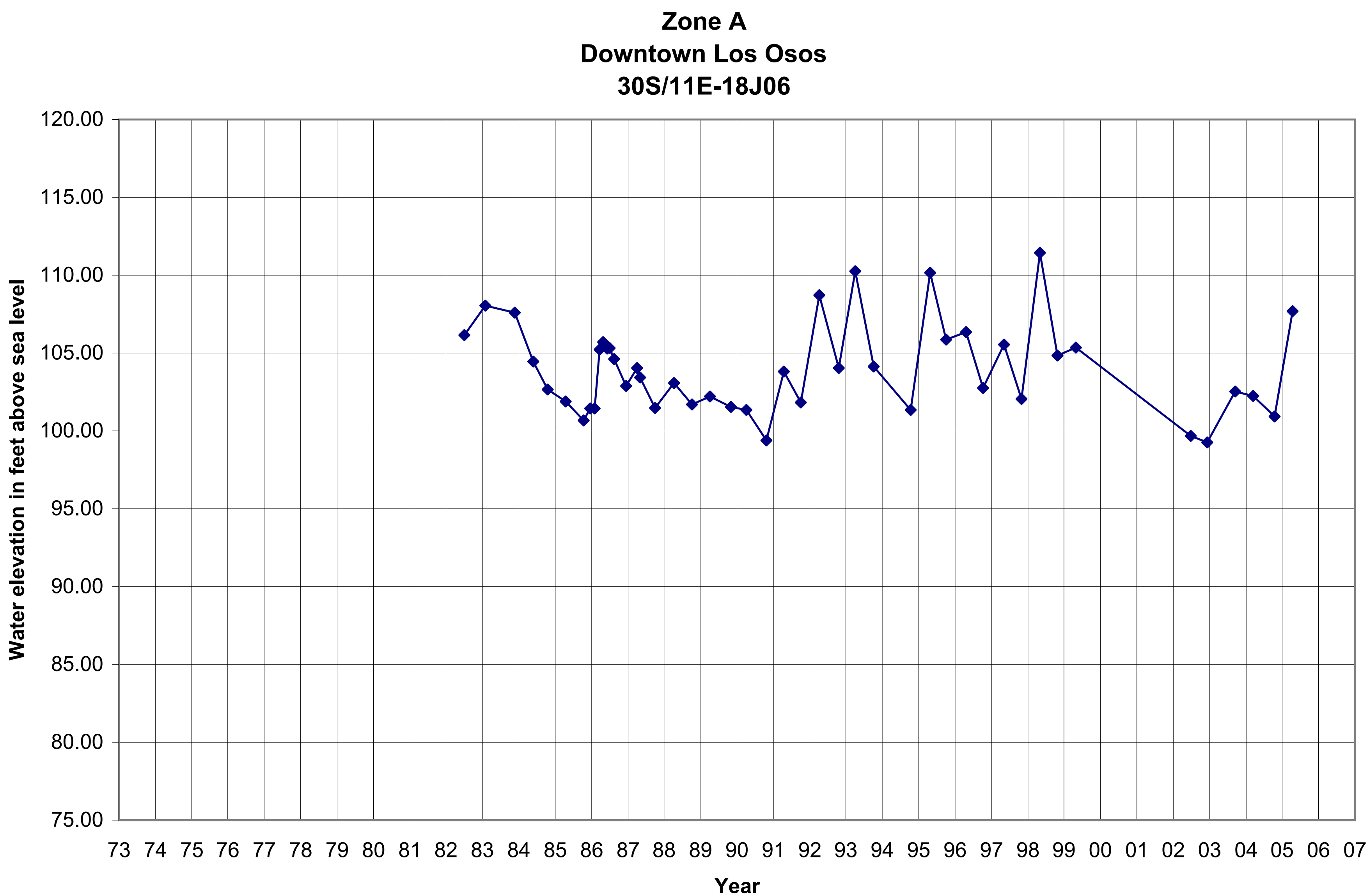
Brown & Caldwell, 1983, Los Osos - Baywood Park Phase I Water Quality Management Study, Vol.II
Metcalf & Eddy, 1996, Hyrologic Evaluation of the Proposed Broderson Recharge Site, Los Osos
Fugro, 1997, Draft Geotechnical Engineering Report, Los Osos Wastewater Project, San Luis Obispo
Fugro, 2004, Geotechnical Report, Los Osos Wastewater Project, LOCSD, San Luis Obispo County

# Appendix D

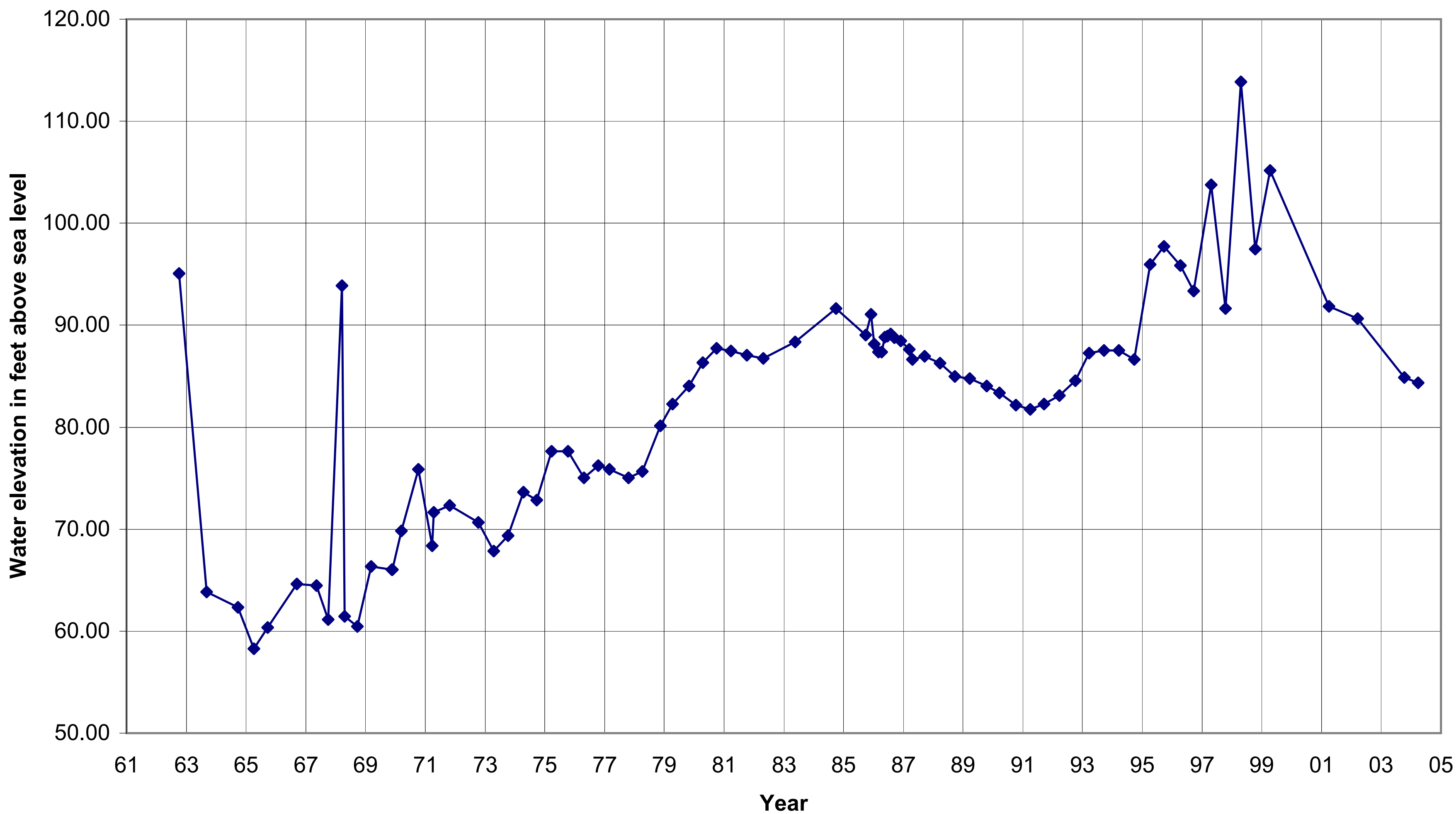
# Representative Hydrographs

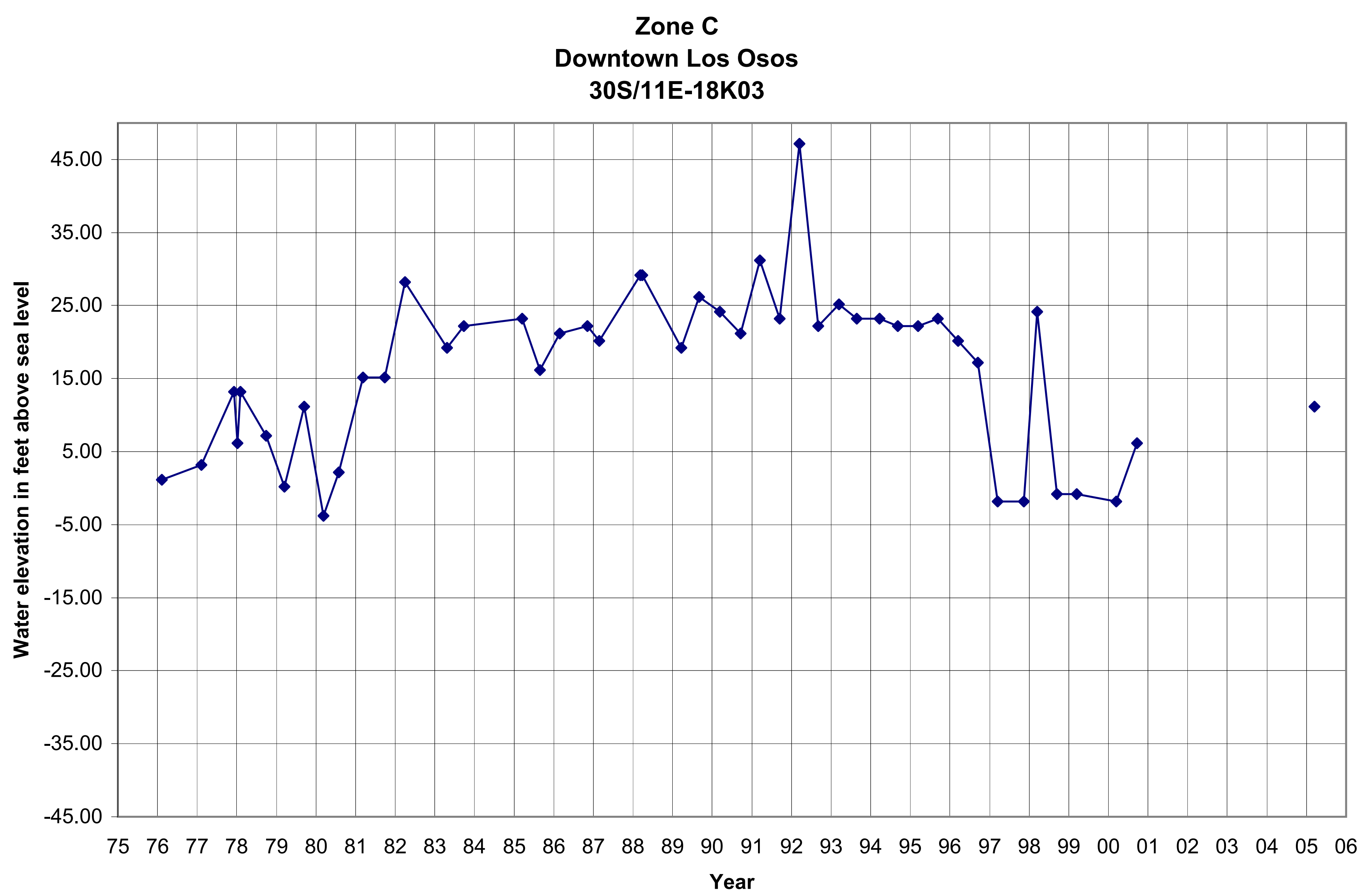


Alluvial Aquifer
Los Osos Creek Valley
30S/11E-20A02
Water elevation in feet above sea level
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05
Year

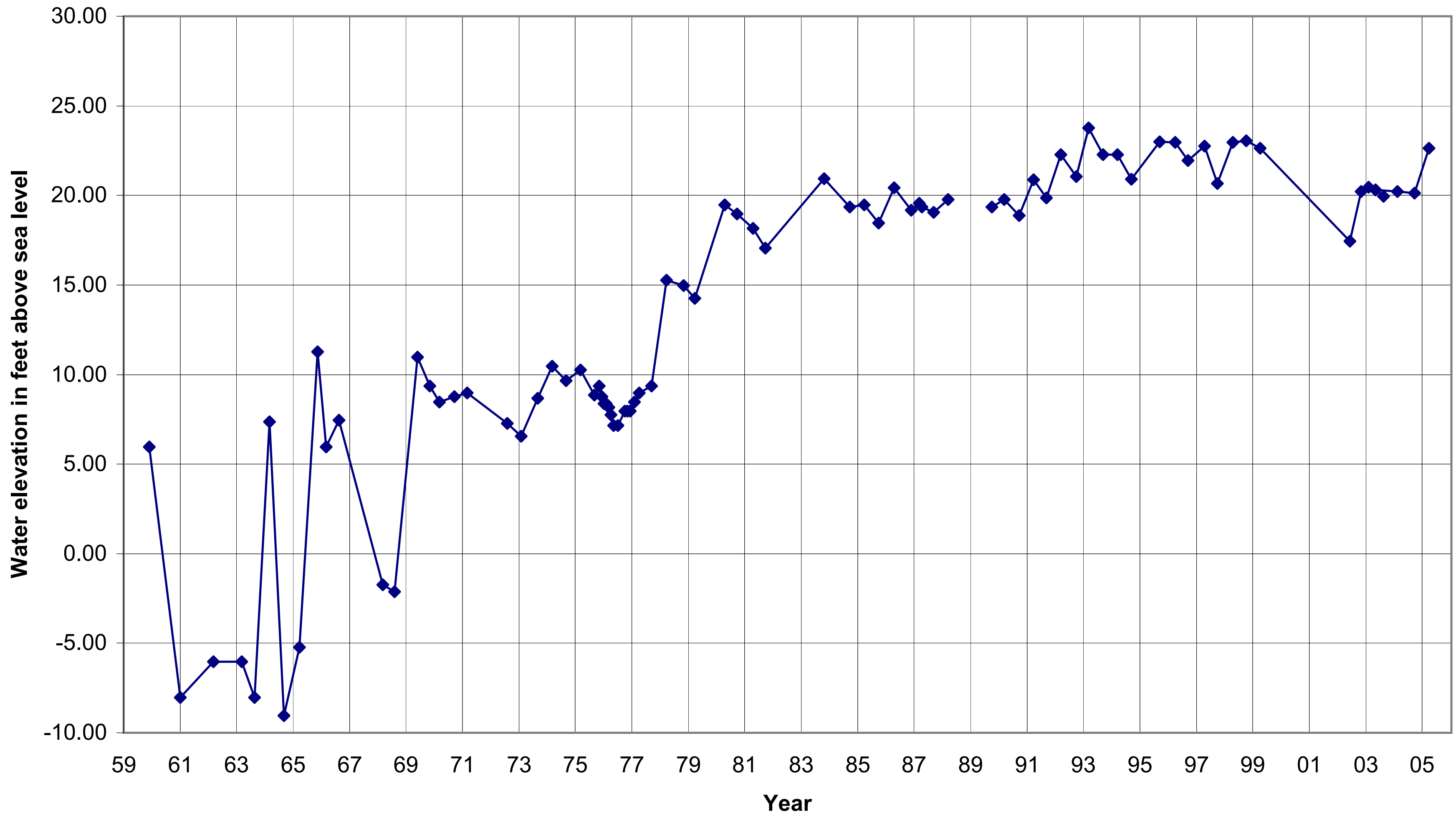

Zone A
Downtown Los Osos
30S/11E-18J06
Water elevation in feet above sea level
120.00
115.00
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07
Year

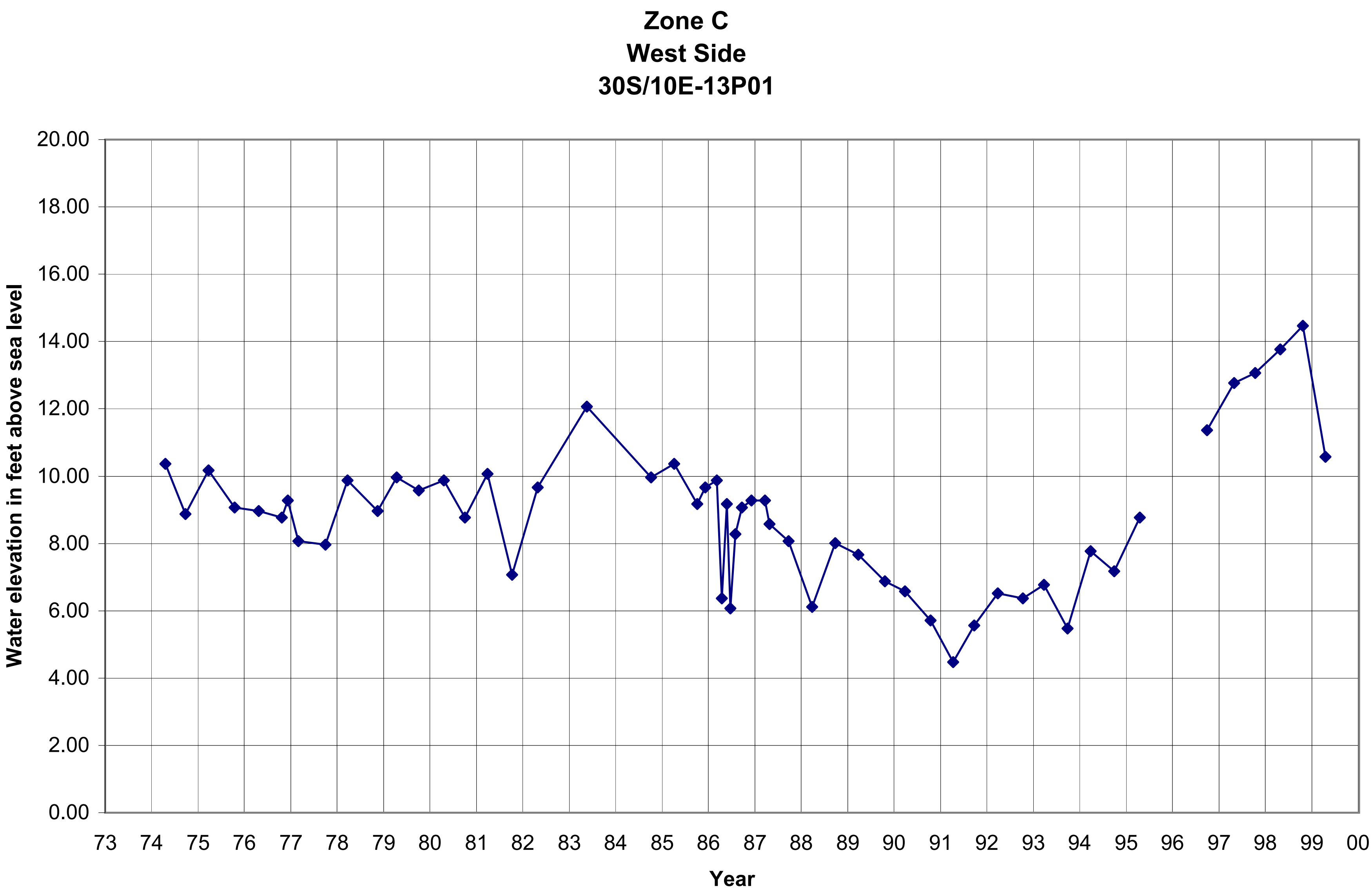
## Zone B
## 30S/11E-18Q01
## Downtown Los Osos



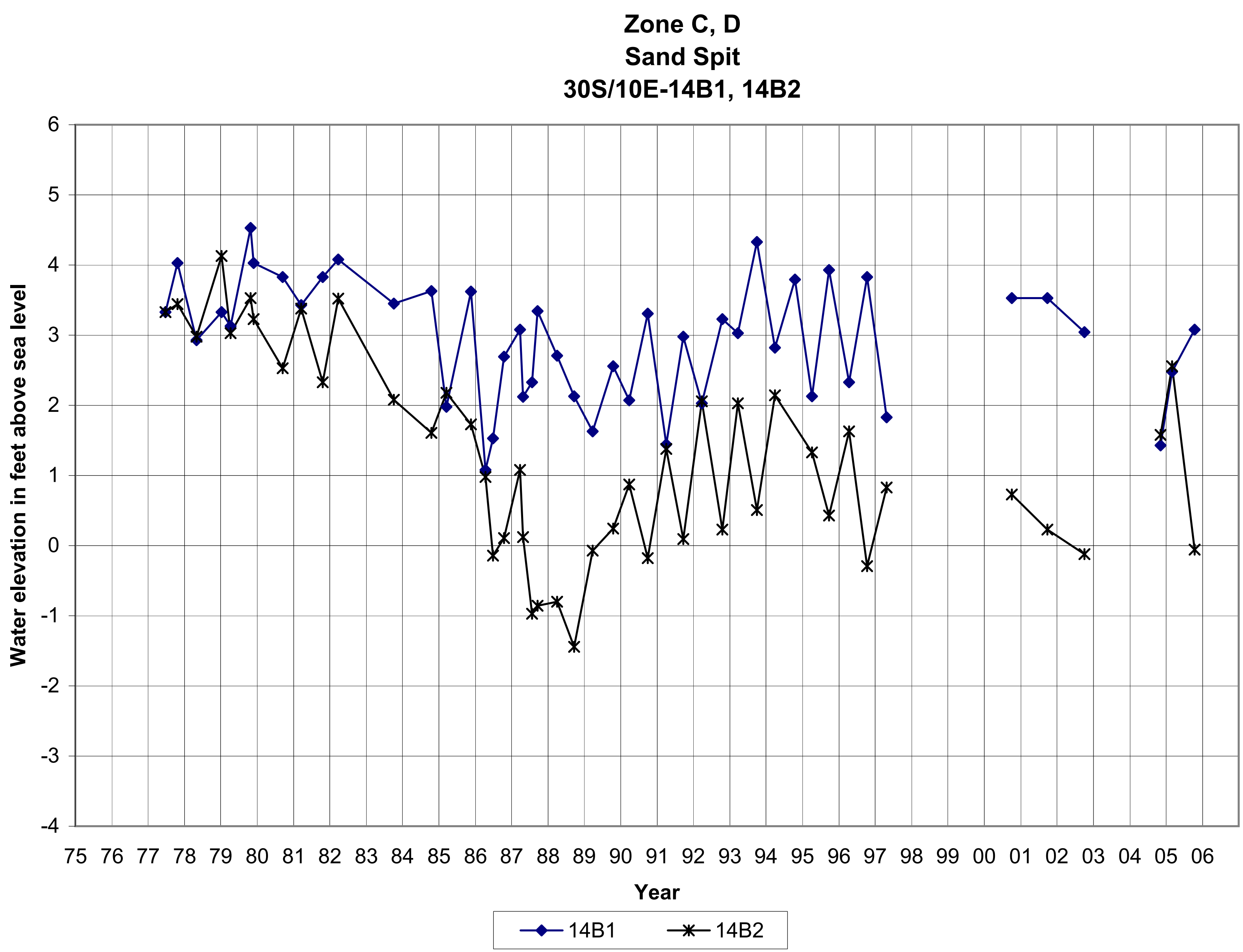

Zone C
Downtown Los Osos
30S/11E-18K03
Water elevation in feet above sea level
45.00
35.00
25.00
15.00
5.00
-5.00
-15.00
-25.00
-35.00
-45.00
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
Year

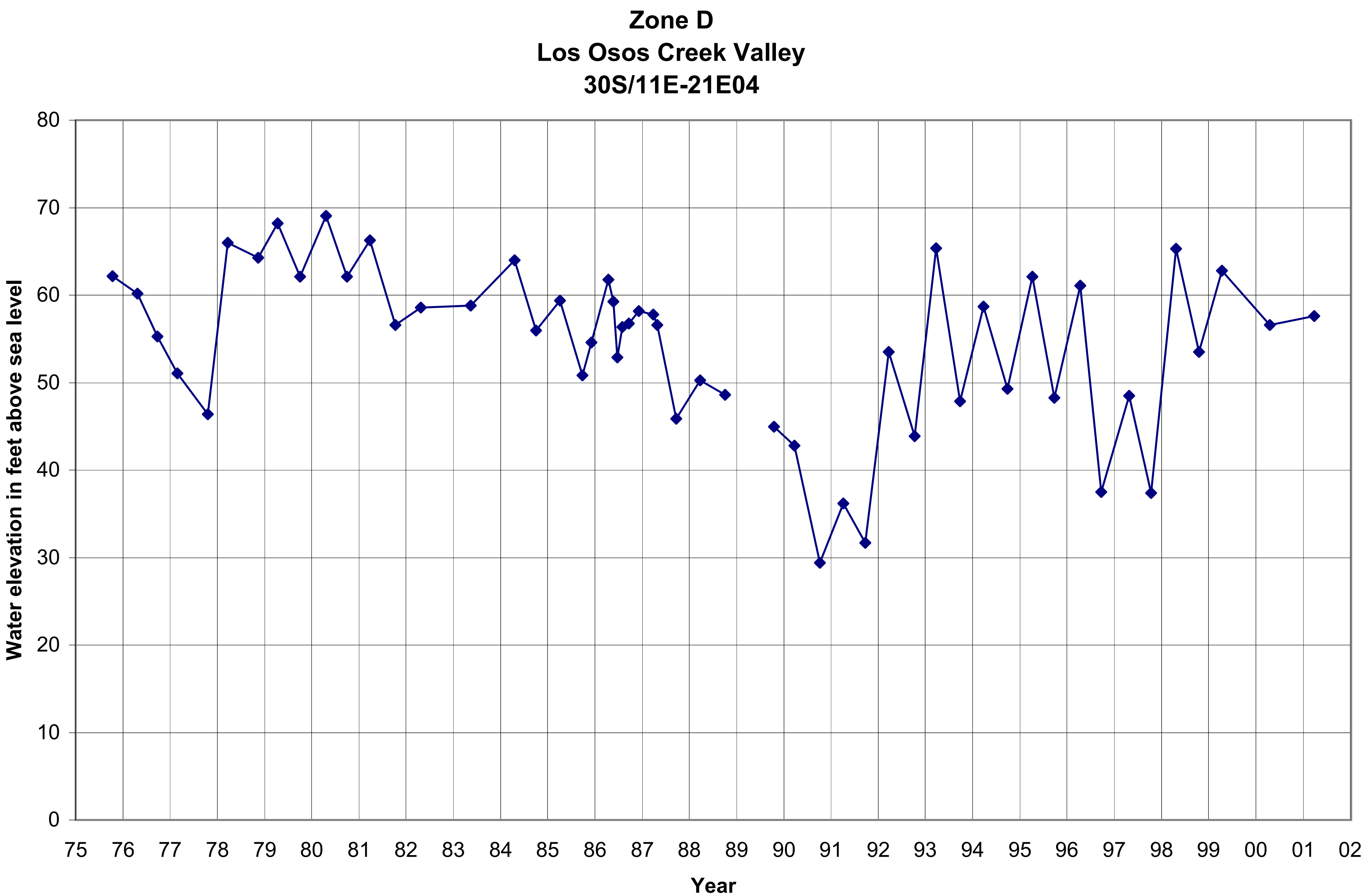
Zone C
Baywood Park
30S/11E-07Q01





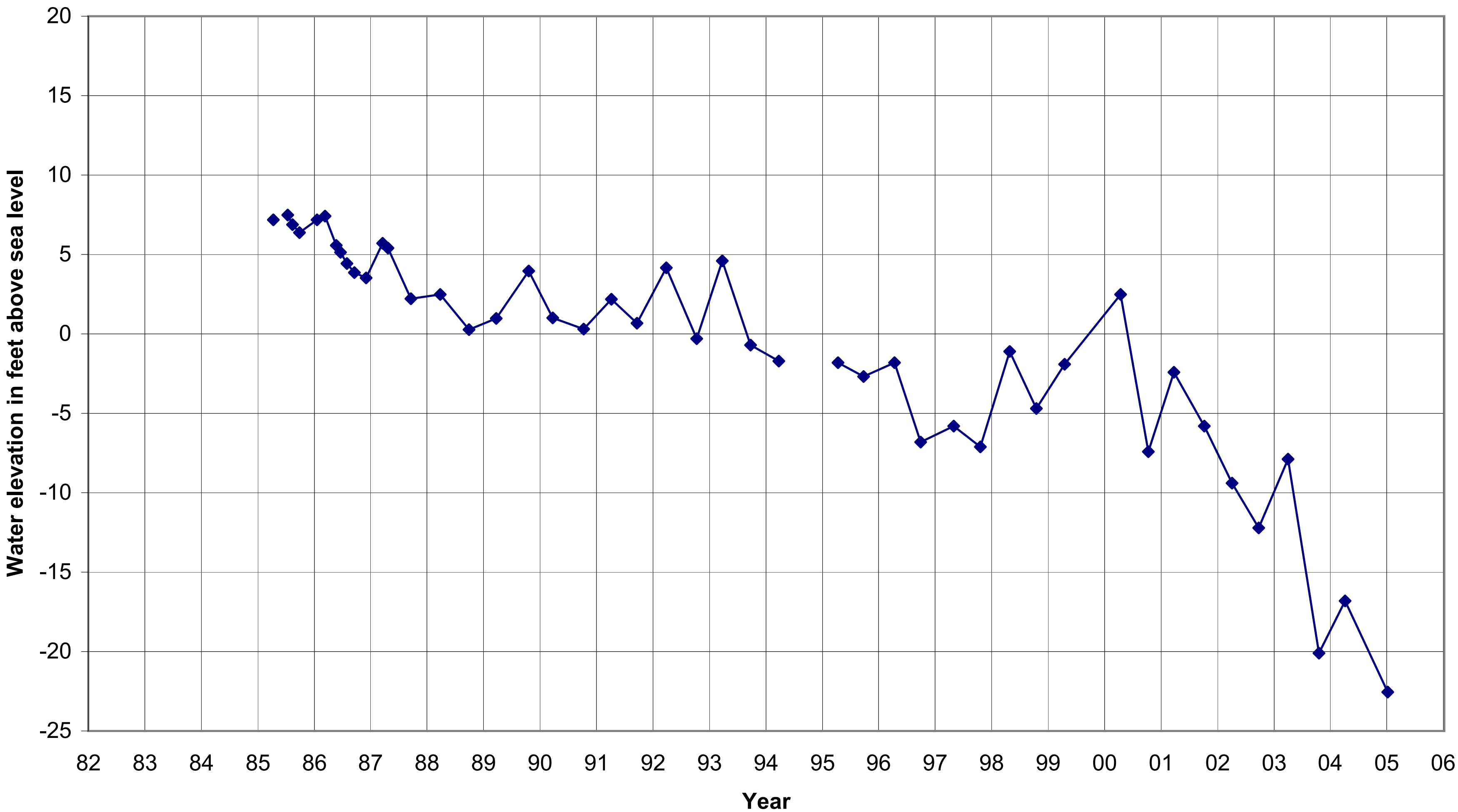
Zone C
West Side
30S/10E-13P01
Water elevation in feet above sea level
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00
Year

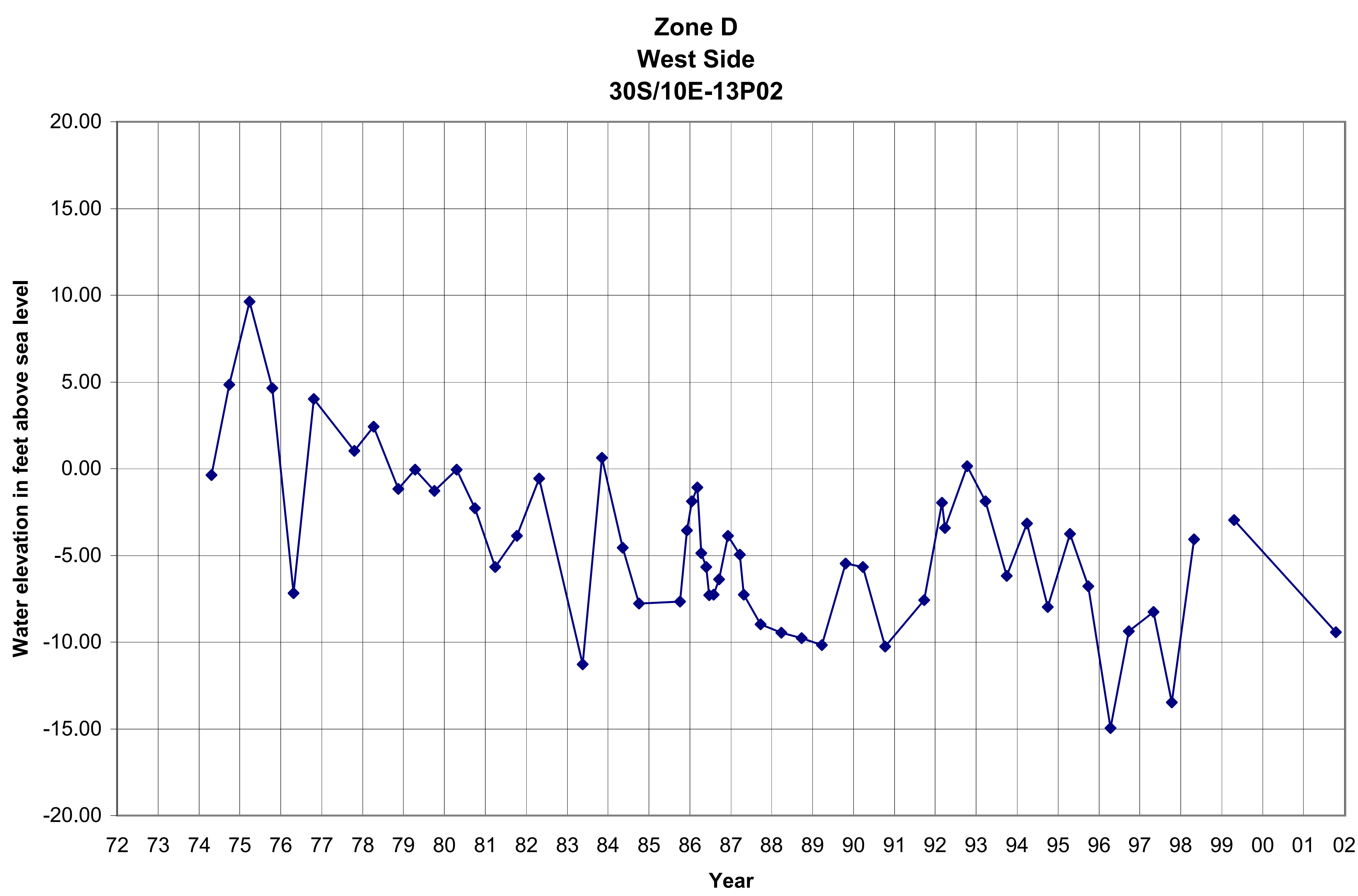

Zone C, D
Sand Spit
30S/10E-14B1, 14B2
Water elevation in feet above sea level
6
5
4
3
2
1
0
-1
-2
-3
-4
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
Year
14B1
14B2

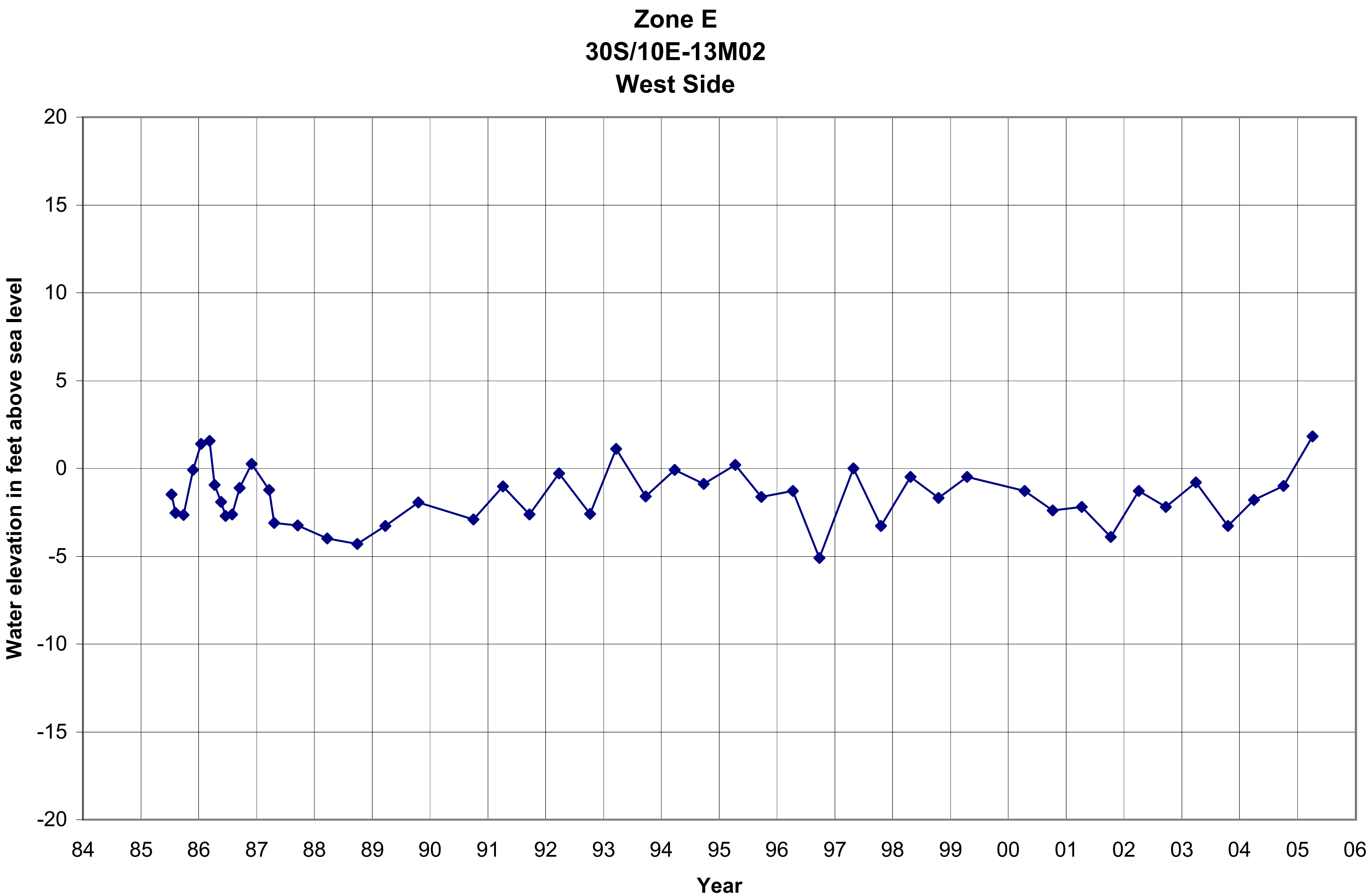


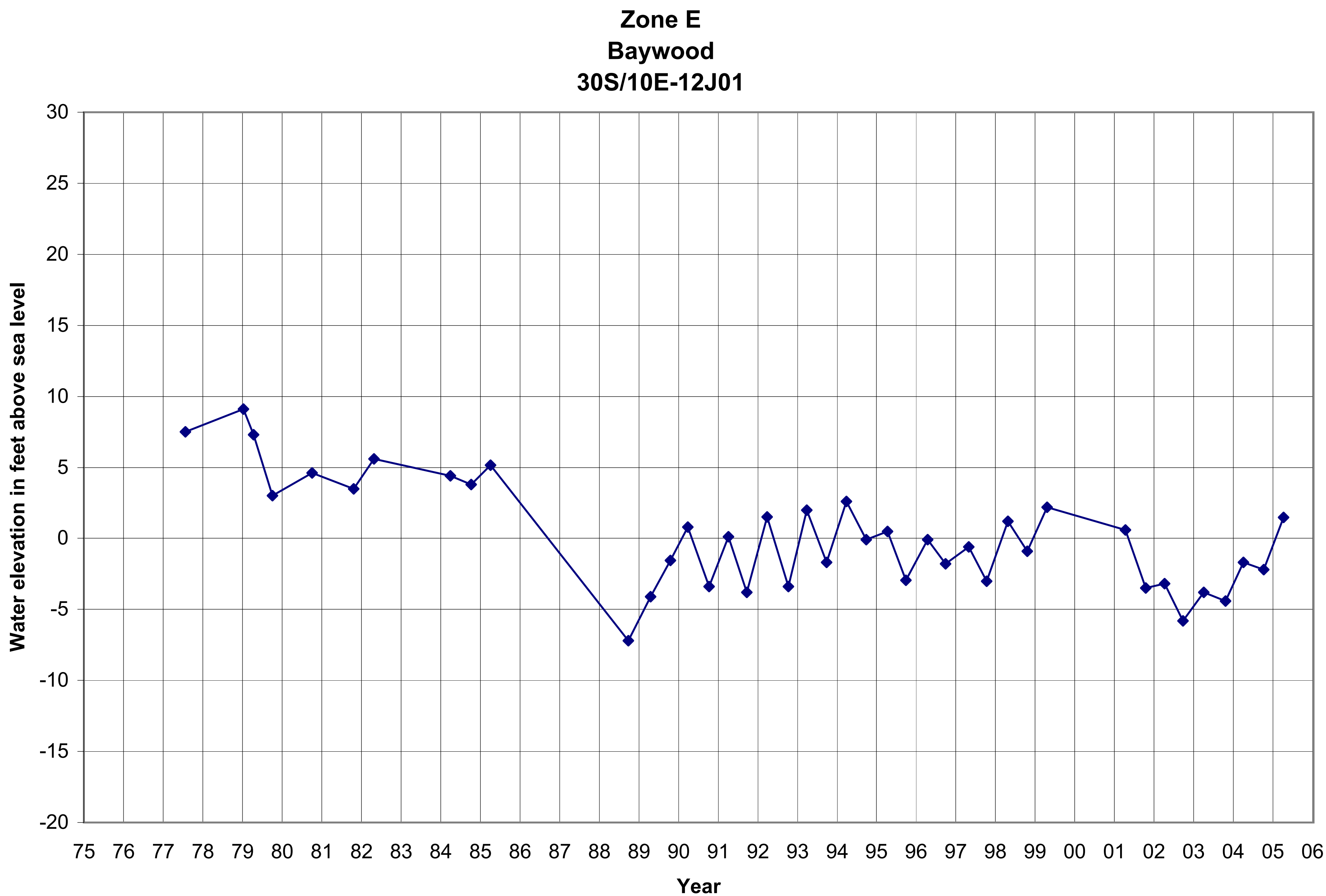
Zone D
Los Osos Creek Valley
30S/11E-21E04
Water elevation in feet above sea level
0
10
20
30
40
50
60
70
80
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
01
02
Year

## Zone D
## Bayview Heights
## 30S/11E-19H02




Zone D
West Side
30S/10E-13P02
Water elevation in feet above sea level
20.00
15.00
10.00
5.00
0.00
-5.00
-10.00
-15.00
-20.00
72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02
Year


Zone E
30S/10E-13M02
West Side
Water elevation in feet above sea level
20
15
10
5
0
-5
-10
-15
-20
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
00
01
02
03
04
05
06
Year



Zone E
Baywood
30S/10E-12J01
Water elevation in feet above sea level
30
25
20
15
10
5
0
-5
-10
-15
-20
75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
Year

# Appendix E

# Water Sampling Procedures

**Sampling Procedures**

Water sampling procedures are presented below. The purpose of the sampling procedures is to ensure that communication is established with the aquifer prior to sample collection.

Non-equipped monitoring wells:

1) Calibrate field monitoring instruments each day prior to sampling.
2) Inspect wellhead condition and note any maintenance required (perform at earliest convenience).
3) Measure depth to static water (record to 0.01 inches) from surveyed reference point.
4) Install temporary pump to at least three feet below the water surface (deeper setting may be needed if water level draw down is too great).
5) Begin well purge, record flow rate.
6) Measure discharge water EC (measured to 10 µmhos/cm), pH (measured to 0.01 units), and temperature (measured to 0.1 degrees C) at regular intervals during well purging. Record time and gallons purged. Note discharge water color, odor, and turbidity (visual).
7) A minimum of three casing volumes of water should be removed during purging, or one borehole volume for small diameter monitoring wells, whichever is greater*. In addition, a set of at least three consecutive field monitoring measurements with stable values should be recorded. For EC, stability within 5 percent of the first value in the set is sufficient (typically within 20-30 µmhos/cm). For pH, stability within 1 percent of the first value is sufficient (typically within 0.07 units). For temperature, stability within 1 percent of the first value is sufficient (typically within 0.2 degrees).
8) Collect sample directly from discharge tube, note sample color, odor, turbidity (visual).
9) Use only laboratory-provided containers with sample preservatives as needed.
10) Place samples on-ice for transport to the laboratory.
11) Remove temporary pump and rinse with clean water.
12) Close well and secure well box lid.

*note: If a well is pumped dry at the minimum pumping rate, the well may be allowed to recover and then sampled by bailer within 24 hours.

Equipped wells:

The sampling port for an equipped well must be upstream of any water filtration or chemical feeds. Sample from the discharge line as close to the wellhead as possible. Sampling procedures for equipped wells will vary, based on whether the well is active or inactive. For active wells (i.e. wells used daily), the need for purging three casing volumes is unnecessary. The well should be turned on for a nominal 5 minutes, and one set of EC, pH, and temperature readings collected prior to sampling. For inactive wells, a field monitoring procedure similar to that described above for unequipped wells would be appropriate. Static water level measurements should also be taken before sampling, if a sounder access port is available. Transport samples on-ice to the laboratory.

# Appendix F

# Water Sampling Results

# Los Osos DWR Grant Project
# Water Sample Legend and Detection Limits

| Category | Description | Practical Quantitation Limit |
|---|---|---|
| Station ID | Well Name or Sample Site | |
| Sample Date | Date Sampled | |
| | | |
| **General Mineral** | | ND = Non-Detect |
| CO3 | Carbonate Alkalinity in mg/L CaCO3 | 5.0 |
| HCO3 | Bicarbonate Alkalinity in mg/L CaCO3 | 5.0 |
| Hardness | Total Hardness in mg/L CaCO3 | 4.0 |
| Cond | Specific Conductance in $\mu$mhos/cm | 1.0 |
| pH | pH in pH units | |
| TDS | Total Dissolved Solids in mg/L | 5.0* |
| Cl | Chloride concentration in mg/L | 5.0* |
| NO3 | Nitrate concentration in mg/L | 2.0 |
| SO4 | Sulfate concentration in mg/L | 0.5 |
| Ca | Calcium concentration in mg/L | 0.5* |
| Mg | Magnesium concentration in mg/L | 0.5* |
| K | Potassium concentration in mg/L | 0.5* |
| Na | Sodium concentration in mg/L | 0.5* |
| SiO2 | Silica concentration in mg/L | 0.5* |
| | | |
| **Trace Constituents** | | |
| Br | Bromide concentration in mg/L | 0.05* |
| B | Boron concentration in mg/L | 0.05* |
| Sr | Strontium concentration in mg/L | 0.01* |
| I | Iodide concentration in mg/L | 0.005* |
| | | |
| **Isotopes** | | |
| $\delta$18O | Ratio of oxygen 18 content in the sample to oxygen 18 content in Standard Mean Ocean Water (SMOW) in parts per thousand | |
| $\delta$D | Ratio of deuterium content in the sample to deuterium content in SMOW in parts per thousand | |
| $\delta$13C | Ratio of carbon 13 content in the sample to carbon 13 content in Vienna-PeeDee Belemnite (VPDB) | |
| 14C Age | Uncalibrated carbon 14 age in years before present (ybp) | |
| Fraction Modern 14C | Deviation between carbon 14 ratio of the sample and modern carbon | |

* Practical Quantitation Limit may be higher for some samples.

# Water Sample Results - General Minerals
# DWR Grant Project - Los Osos CSD

| Station ID | Sample Date | CO3 | HCO3 | Hardness | Cond | pH | TDS | Cl | NO3 | SO4 | Ca | Mg | K | Na | SiO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 30S/10E-11A1 | 3/14/2005 | ND | 140 | 5400 | 52000 | 7.4 | 28000 | 18000 | ND | 2800 | 380 | 1100 | 340 | 9000 | 17 |
| 30S/10E-11A2 | 3/14/2005 | ND | 180 | 4600 | 16000 | 7.3 | 8900 | 5400 | ND | 430 | 770 | 640 | 20 | 1300 | 41 |
| 30S/10E-12J1 | 2/14/2005 | ND | 350 | 370 | 1300 | 8.1 | 840 | 77 | ND | 190 | 51 | 58 | 6.1 | 110 | 42 |
| 30S/10E-13J1 | 12/20/2004 | ND | 72 | 230 | 720 | 7.1 | 410 | 150 | 7 | 14 | 38 | 33 | 1.4 | 29 | 30 |
| 30S/10E-13L4 | 12/20/2004 | ND | 82 | 340 | 1000 | 7 | 590 | 230 | 9.7 | 27 | 56 | 47 | 1.9 | 48 | 32 |
| 30S/10E-13L5 | 11/18/2004 | ND | 42 | 1000 | 3000 | 6.1 | 1600 | 780 | 180 | 41 | 140 | 160 | 1.5 | 140 | 78 |
| 30S/10E-13L7 | 1/10/2005 | ND | 64 | 110 | 410 | 7.2 | 270 | 44 | 55 | 14 | 19 | 15 | 1.5 | 36 | 34 |
| 30S/10E-13M1 | 1/19/2005 | ND | 140 | 6100 | 60000 | 6.8 | 35000 | 17000 | ND | 2700 | 490 | 1200 | 180 | 11000 | 30 |
| 30S/10E-13M2 | 11/22/2004 | ND | 51 | 810 | 2900 | 7.3 | 1500 | 810 | 2.4 | 140 | 130 | 120 | 4.7 | 210 | 32 |
| 30S/10E-13Ma | 11/22/2004 | ND | 62 | 120 | 470 | 6.9 | 250 | 62 | 60 | 12 | 21 | 16 | 1.9 | 43 | 32 |
| 30S/10E-13N | 11/23/2004 | ND | 42 | 80 | 390 | 6.9 | 200 | 67 | 26 | 9.2 | 13 | 12 | 1.7 | 38 | 34 |
| 30S/10E-14B2 | 3/15/2005 | ND | 100 | 3600 | 30000 | 8 | 17000 | 8500 | ND | 960 | 1200 | 130 | 34 | 4300 | 3.1 |
| 30S/10E-24C1 | 12/20/2004 | ND | 64 | 130 | 610 | 7 | 310 | 110 | 20 | 19 | 22 | 19 | 1.6 | 50 | 31 |
| 30S/10E-2A1 | 3/15/2005 | ND | 58 | 1100 | 8700 | 7.8 | 5400 | 2800 | ND | 320 | 430 | 13 | 47 | 1500 | 16 |
| 30S/11E-17E7 | 1/14/2005 | 60 | 150 | 180 | 690 | 8.8 | 440 | 75 | ND | 41 | 33 | 25 | 13 | 78 | 30 |
| 30S/11E-17E8 | 1/14/2005 | ND | 150 | 150 | 440 | 7.5 | 290 | 34 | 9.7 | 11 | 24 | 22 | 1.4 | 28 | 31 |
| 30S/11E-17P4 | 1/12/2005 | ND | 50 | 120 | 480 | 6.6 | 300 | 88 | 33 | 28 | 22 | 16 | 1.8 | 42 | 34 |
| 30S/11E-18K3 | 12/20/2004 | ND | 52 | 73 | 290 | 6.8 | 180 | 31 | 28 | 5.9 | 13 | 9.8 | ND | 25 | 28 |
| 30S/11E-18K7 | 1/19/2005 | ND | 58 | 89 | 360 | 6.9 | 210 | 37 | 35 | 15 | 16 | 12 | 1.4 | 30 | 30 |
| 30S/11E-18K8 | 1/19/2005 | ND | 260 | 290 | 650 | 7.5 | 370 | 33 | ND | 38 | 62 | 33 | 2.5 | 28 | 52 |
| 30S/11E-18L2 | 11/18/2004 | ND | 220 | 330 | 880 | 7.3 | 420 | 120 | ND | 31 | 54 | 48 | 2.2 | 40 | 31 |
| 30S/11E-18L6 | 1/18/2005 | ND | 300 | 380 | 860 | 7.4 | 560 | 63 | ND | 77 | 72 | 48 | 2.4 | 36 | 42 |
| 30S/11E-18L7 | 1/13/2005 | ND | 60 | 50 | 240 | 7.1 | 180 | 26 | 20 | 9.9 | 8.7 | 6.8 | 1.1 | 23 | 29 |
| 30S/11E-18M1 | 1/12/2005 | ND | 96 | 160 | 570 | 7 | 360 | 76 | 46 | 25 | 27 | 23 | 1.8 | 44 | 32 |
| 30S/11E-19H2 | 1/14/2005 | ND | 190 | 190 | 510 | 7.3 | 330 | 36 | ND | 21 | 33 | 26 | 1.7 | 29 | 43 |
| 30S/11E-20A2 | 1/6/2005 | ND | 200 | 260 | 660 | 7.2 | 360 | 66 | ND | 27 | 40 | 40 | 1 | 39 | 35 |
| 30S/11E-20Aa | 2/1/2005 | ND | 240 | 300 | 730 | 7.2 | 380 | 55 | 2.9 | 30 | 45 | 45 | 1.6 | 34 | 43 |
| 30S/11E-20B7 | 1/6/2005 | ND | 98 | 130 | 380 | 7 | 210 | 43 | 8.8 | 13 | 20 | 19 | 1 | 32 | 35 |
| 30S/11E-20La | 1/12/2005 | ND | 300 | 330 | 800 | 7.2 | 510 | 40 | ND | 66 | 63 | 43 | 1.2 | 30 | 25 |
| 30S/11E-21D13 | 1/6/2005 | ND | 370 | 720 | 1400 | 7.3 | 880 | 98 | 140 | 150 | 110 | 110 | ND | 53 | 33 |
| 30S/11E-21P | 2/14/2005 | ND | 340 | 330 | 930 | 7.8 | 540 | 57 | ND | 56 | 65 | 40 | 5.1 | 61 | 41 |
| 30S/11E-7N1 | 1/19/2005 | ND | 66 | 71 | 250 | 7.4 | 170 | 28 | 10 | 6.1 | 13 | 9.3 | 1.1 | 21 | 31 |
| 30S/11E-7Q1 | 1/12/2005 | ND | 91 | 160 | 710 | 6.7 | 460 | 88 | 91 | 47 | 30 | 21 | 5.4 | 63 | 26 |
| 30S/11E-7Q3 | 11/18/2004 | ND | 250 | 270 | 790 | 7.5 | 410 | 73 | ND | 39 | 44 | 40 | 2.3 | 48 | 35 |
| 30S/11E-8M | 2/14/2005 | ND | 86 | 180 | 630 | 7 | 290 | 59 | 77 | 33 | 27 | 26 | 1.7 | 41 | 33 |
| 30S10E-14B1 | 3/15/2005 | ND | 160 | 5200 | 50000 | 7.4 | 27000 | 14000 | ND | 2200 | 440 | 990 | 290 | 8000 | 24 |
| Base Flow | 12/24/2004 | ND | 340 | 420 | 930 | 7.8 | 540 | 62 | ND | 82 | 71 | 58 | 1.4 | 42 | 23 |
| East Fork | 12/24/2004 | ND | 370 | 390 | 860 | 7.9 | 490 | 52 | ND | 58 | 59 | 58 | 1.5 | 36 | 21 |
| West Fork | 12/24/2004 | ND | 300 | 520 | 1300 | 7.9 | 830 | 110 | ND | 230 | 130 | 46 | 2.8 | 73 | 29 |

Water Sample Results - Traces Elements and Isotopes
DWR Grant Project - Los Osos CSD

| StationID | Sample Date | Br | B | Sr | I | δ18O | δD | δ13C | 14C Age | Fraction Modern 14C |
|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/l | mg/l | mg/l | mg/l | % mil | % mil | % VPDB | ybp | % |
| 30S/10E-11A1 | 3/14/2005 | 52 | 3.9 | 6.9 | 0.06 | -1.4 | -10 | | | |
| 30S/10E-11A2 | 3/14/2005 | 16 | ND | 4.1 | 0.04 | -4.5 | -28 | | | |
| 30S/10E-12J1 | 2/14/2005 | 0.21 | 0.36 | 0.41 | 0.042 | -6.7 | -38 | | | |
| 30S/10E-13J1 | 12/20/2004 | 1.1 | ND | 0.21 | 0.029 | -5.8 | -33 | -16.08 | 2972+/-39 | 0.6946+/-0.0034 |
| 30S/10E-13L4 | 12/20/2004 | 1.6 | ND | 0.28 | 0.023 | -6.0 | -35 | -15.02 | 2183+/-43 | 0.7620+/-0.0041 |
| 30S/10E-13L5 | 11/18/2004 | 0.68 | ND | 0.86 | 0.013 | -5.8 | -32 | | | |
| 30S/10E-13L7 | 1/10/2005 | 0.2 | ND | 0.12 | 0.014 | -6.5 | -35 | | | |
| 30S/10E-13M1 | 1/19/2005 | 53 | 3.2 | 6.9 | 0.054 | -0.5 | -4 | | | |
| 30S/10E-13M2 | 11/22/2004 | 4.4 | ND | 0.65 | 0.012 | -6.0 | -36 | | | |
| 30S/10E-13Ma | 11/22/2004 | ND | ND | 0.13 | 0.012 | -6.0 | -34 | | | |
| 30S/10E-13N | 11/23/2004 | 0.3 | ND | 0.08 | 0.013 | -6.2 | -37 | -15.32 | 1151+/-45 | 0.8665+/-0.0049 |
| 30S/10E-14B2 | 3/15/2005 | 24 | ND | 5.2 | ND | -3.2 | -21 | | | |
| 30S/10E-24C1 | 12/20/2004 | 0.7 | ND | 0.13 | 0.012 | -5.9 | -34 | -15.28 | 2595+/-41 | 0.7239+/-0.0037 |
| 30S/10E-2A1 | 3/15/2005 | 7.9 | 0.75 | 3.9 | 0.16 | -5.1 | -34 | | | |
| 30S/11E-17E7 | 1/14/2005 | 1 | 0.31 | 0.46 | 0.037 | -5.4 | -33 | -17.78 | 7166+/-49 | 0.4098+/-0.0025 |
| 30S/11E-17E8 | 1/14/2005 | 0.8 | ND | 0.15 | 0.008 | -5.4 | -35 | -18.27 | 3933+/-39 | 0.6129+/-0.0030 |
| 30S/11E-17P4 | 1/12/2005 | 0.4 | ND | 0.12 | 0.014 | -6.5 | -35 | | | |
| 30S/11E-18K3 | 12/20/2004 | 0.2 | ND | 0.07 | 0.022 | -6.0 | -35 | | | |
| 30S/11E-18K7 | 1/19/2005 | 0.6 | 0.07 | 0.08 | 0.02 | -5.4 | -37 | | | |
| 30S/11E-18K8 | 1/19/2005 | 1.6 | 0.06 | 0.24 | ND | -5.2 | -33 | | | |
| 30S/11E-18L2 | 11/18/2004 | 1.8 | ND | 0.3 | 0.007 | -5.6 | -34 | -13.53 | 3340+/-30 | 0.6598+/-0.0025 |
| 30S/11E-18L6 | 1/18/2005 | 2.2 | 0.08 | 0.31 | 0.01 | -5.3 | -34 | | | |
| 30S/11E-18L7 | 1/13/2005 | 0.2 | ND | 0.06 | 0.011 | -5.4 | -34 | -18.17 | <50 | 1.0148+/-0.0043 |
| 30S/11E-18M1 | 1/12/2005 | 0.6 | 0.08 | 0.15 | 0.011 | -6.0 | -34 | | | |
| 30S/11E-19H2 | 1/14/2005 | 1.2 | 0.08 | 0.18 | 0.011 | -5.4 | -33 | -15.14 | 3651+/-39 | 0.6347+/-0.0031 |
| 30S/11E-20A2 | 1/6/2005 | 1.5 | 0.08 | 0.17 | 0.017 | -6.0 | -33 | | | |
| 30S/11E-20Aa | 2/1/2005 | ND | 0.08 | 0.2 | 0.01 | -5.5 | -32 | | | |
| 30S/11E-20B7 | 1/6/2005 | 0.8 | ND | 0.1 | 0.012 | -5.9 | -33 | | | |
| 30S/11E-20La | 1/12/2005 | 1.6 | 0.1 | 0.32 | 0.012 | -6.0 | -31 | | | |
| 30S/11E-21D13 | 1/6/2005 | 2.3 | 0.12 | 0.57 | 0.018 | -5.5 | -30 | | | |
| 30S/11E-21P | 2/14/2005 | 0.1 | 0.09 | 0.2 | 0.012 | -5.7 | -32 | | | |
| 30S/11E-7N1 | 1/19/2005 | 0.4 | ND | 0.07 | ND | -5.5 | -38 | | | |
| 30S/11E-7Q1 | 1/12/2005 | 0.7 | 0.17 | 0.17 | 0.013 | -6.2 | -33 | | | |
| 30S/11E-7Q3 | 11/18/2004 | 1.6 | 0.2 | 0.26 | 0.015 | -5.9 | -35 | -14.47 | 4796+/-50 | 0.5504+/-0.0034 |
| 30S/11E-8M | 2/14/2005 | 0.11 | 0.11 | 0.09 | 0.012 | -6.5 | -36 | | | 0.6598+/-0.0025 |
| 30S10E-14B1 | 3/15/2005 | 43 | 2.6 | 6.1 | 0.06 | -2.0 | -9 | | | |
| Base Flow | 12/24/2004 | 2.3 | 0.12 | 0.36 | 0.017 | -4.9 | -33 | | | |
| East Fork | 12/24/2004 | 1.8 | 0.13 | 0.34 | 0.023 | -5.7 | -33 | | | |
| West Fork | 12/24/2004 | 2 | 0.14 | 0.46 | 0.007 | -6.1 | -35 | | | |

# Appendix G

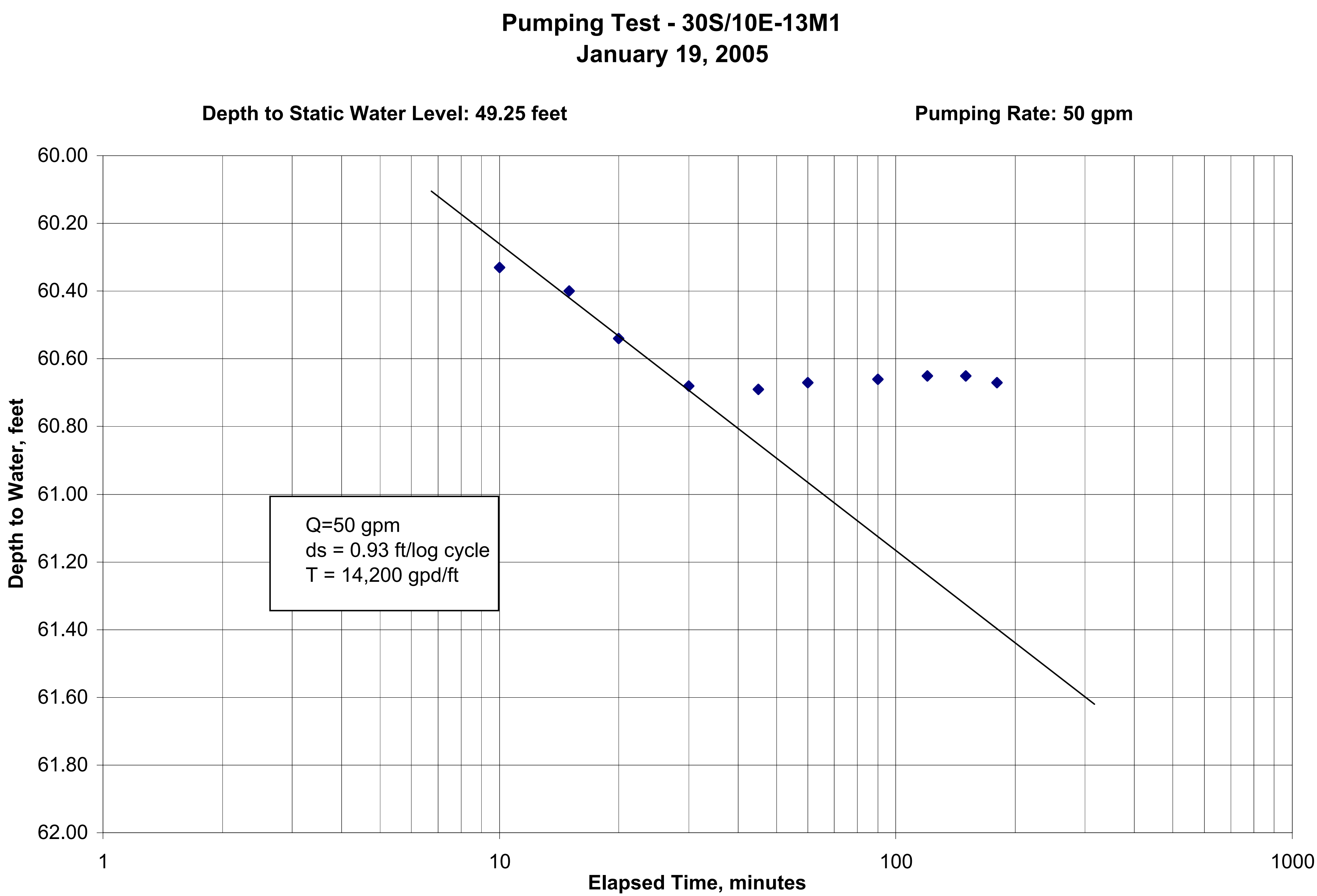
# Pumping Test Data

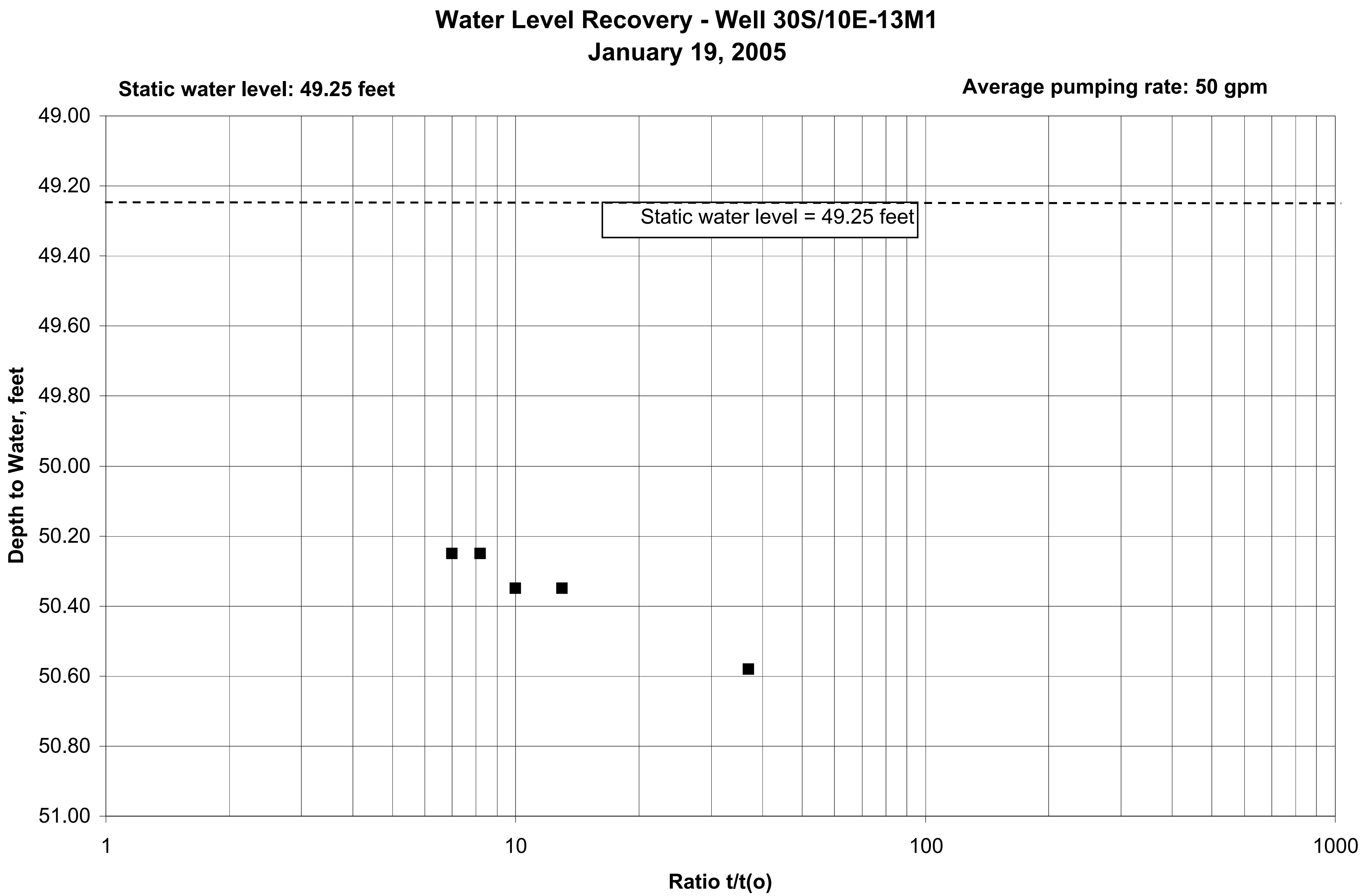
**Pumping Test, 30S/10E-13M1 - January 19, 2005**

| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Meter | Recorded Pumping Rate |
|---|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | cubic feet | gallons per minute |
| 1/19/2005 | 12:50 | 0 | 0 | 49.25 | 0 | | Start |
| | 12:52 | 0:02 | 2 | 67.00 | 17.75 | | 75 |
| | 12:55 | 0:05 | 5 | 60.83 | 11.58 | | 50 |
| | 13:00 | 0:10 | 10 | 60.33 | 11.08 | | |
| | 13:05 | 0:15 | 15 | 60.4 | 11.15 | | |
| | 13:10 | 0:20 | 20 | 60.54 | 11.29 | | |
| | 13:20 | 0:30 | 30 | 60.68 | 11.43 | | |
| | 13:35 | 0:45 | 45 | 60.69 | 11.44 | | |
| | 13:50 | 1:00 | 60 | 60.67 | 11.42 | | 50 |
| | 14:20 | 1:30 | 90 | 60.66 | 11.41 | | |
| | 14:50 | 2:00 | 120 | 60.65 | 11.40 | | |
| | 15:20 | 2:30 | 150 | 60.65 | 11.40 | | |
| | 15:50 | 3:00 | 180 | 60.67 | 11.42 | | 50 |
| | STOP | | | | | | |

**Recovery 30S/10E-13M1**

| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Ratio |
|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | t/t(o) |
| Recovery | | | | | | |
| 1/19/2005 | 15:50 | 3:00 | 0 | 60.67 | 11.40 | |
| | 15:55 | 3:05 | 5 | 50.58 | 1.30 | 37 |
| | 16:05 | 3:15 | 15 | 50.35 | 1.10 | 13 |
| | 16:10 | 3:20 | 20 | 50.35 | 1.10 | 10 |
| | 16:15 | 3:25 | 25 | 50.25 | 1.00 | 8.2 |
| | 16:20 | 3:30 | 30 | 50.25 | 1.00 | 7 |
| | STOP | | | | | |


Pumping Test - 30S/10E-13M1
January 19, 2005
Depth to Static Water Level: 49.25 feet
Pumping Rate: 50 gpm
Depth to Water, feet
60.00
60.20
60.40
60.60
60.80
61.00
61.20
61.40
61.60
61.80
62.00
Q=50 gpm
ds = 0.93 ft/log cycle
T = 14,200 gpd/ft
1
10
100
1000
Elapsed Time, minutes


Water Level Recovery - Well 30S/10E-13M1
January 19, 2005
Static water level: 49.25 feet
Average pumping rate: 50 gpm
Static water level = 49.25 feet
Depth to Water, feet
49.00
49.20
49.40
49.60
49.80
50.00
50.20
50.40
50.60
50.80
51.00
1
10
100
1000
Ratio t/t(o)

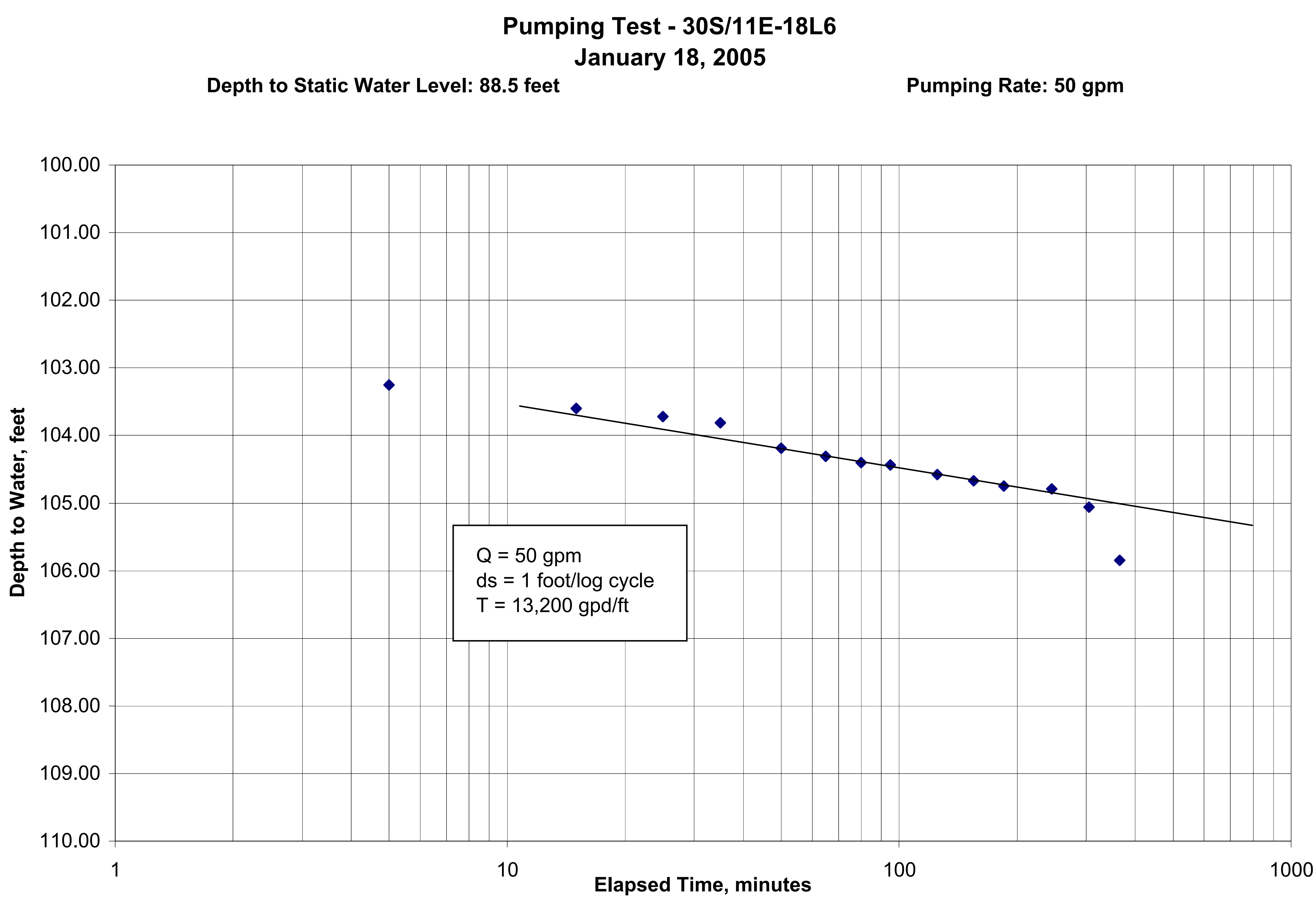
**Pumping Test, 30S/11E-18L6 - January 18 2005**

| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Meter | Recorded Pumping Rate |
|---|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | cubic feet | gallons per minute |
| 1/18/2005 | 8:40 | 0 | 0 | 88.50 | 0 | 0.0 | Start |
| | 8:45 | 0:05 | 5 | 103.25 | 14.75 | | 50.1 |
| | 8:55 | 0:15 | 15 | 103.60 | 15.10 | | 49.3 |
| | 9:05 | 0:25 | 25 | 103.72 | 15.22 | | 50 |
| | 9:15 | 0:35 | 35 | 103.81 | 15.31 | | 50 |
| | 9:30 | 0:50 | 50 | 104.19 | 15.69 | | 49.5 |
| | 9:45 | 1:05 | 65 | 104.31 | 15.81 | | 49.5 |
| | 10:00 | 1:20 | 80 | 104.40 | 15.90 | | 49.4 |
| | 10:15 | 1:35 | 95 | 104.44 | 15.94 | | 49.2 |
| | 10:45 | 2:05 | 125 | 104.58 | 16.08 | | 49.2 |
| | 11:15 | 2:35 | 155 | 104.67 | 16.17 | | 49.2 |
| | 11:45 | 3:05 | 185 | 104.75 | 16.25 | | 49.1 |
| | 12:45 | 4:05 | 245 | 104.79 | 16.29 | | 48.9 |
| | 13:45 | 5:05 | 305 | 105.06 | 16.56 | | 49.9 |
| | 14:45 | 6:05 | 365 | 105.85 | 17.35 | | 49.9 |
| | 15:55 | 7:15 | 435 | 106.67 | 18.17 | | 49.9 |
| | STOP | | | | | 2883.0 | |
| | | | | | | Average Rate= 50 gpm | |

**Recovery 30S/11E-18L6**

| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Ratio |
|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | t/t(o) |
| Recovery | | | | | | |
| 1/14/2005 | 15:55 | 7:15 | 0 | 106.67 | 18.17 | |
| | 15:57 | 7:17 | 2 | 93.40 | 4.9 | 218.5 |
| | 15:59 | 0:03 | 4 | 92.75 | 4.25 | 109.8 |
| | 16:01 | 7:21 | 6 | 92.42 | 3.92 | 73.5 |
| | 16:03 | 7:23 | 8 | 92.15 | 3.65 | 55.4 |
| | 16:05 | 7:25 | 10 | 91.96 | 3.46 | 44.5 |
| | 16:10 | 7:30 | 15 | 91.73 | 3.23 | 30 |
| | 16:15 | 7:35 | 20 | 91.60 | 3.1 | 22.8 |
| | 16:20 | 7:40 | 25 | 91.42 | 2.92 | 18.4 |
| | 16:25 | 7:45 | 30 | 91.23 | 2.73 | 15.5 |
| | 16:30 | 7:50 | 35 | 91.13 | 2.63 | 13.4 |
| | 16:35 | 7:55 | 40 | 91.04 | 2.54 | 11.9 |
| | 16:45 | 8:05 | 50 | 90.90 | 2.4 | 9.7 |
| | 16:55 | 8:15 | 60 | 90.77 | 2.27 | 8.3 |
| | STOP | | | | | |

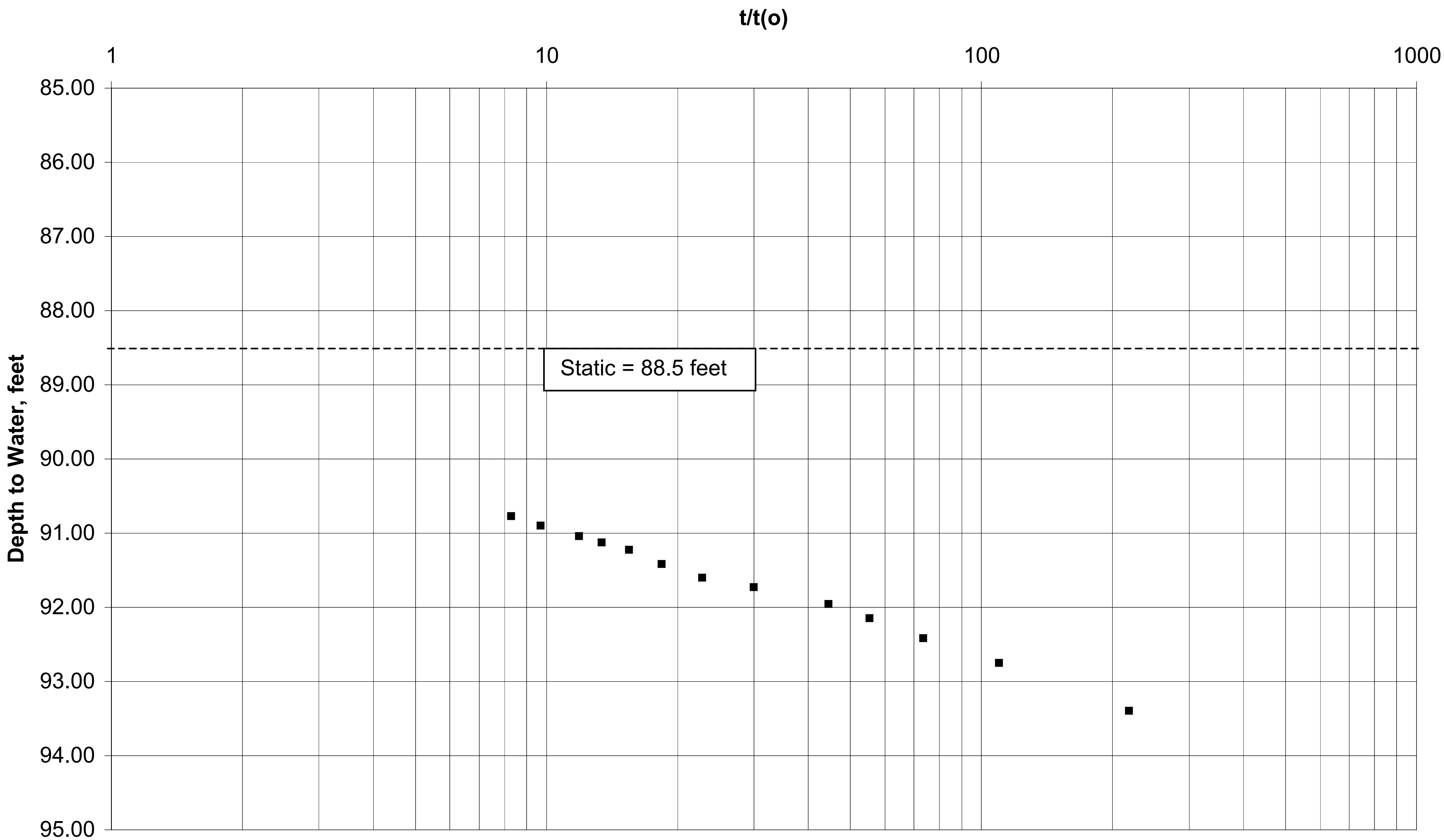
NOTE: Drawdown curve (rather than recovery) used for transmissivity calculation for two reasons,
(1) possible well interference at end of pumping test and through recovery test from another well
(2) the K value derived from the drawdown portion of the test best matches other values in the area



Pumping Test - 30S/11E-18L6
January 18, 2005
Depth to Static Water Level: 88.5 feet
Pumping Rate: 50 gpm
Depth to Water, feet
100.00
101.00
102.00
103.00
104.00
105.00
106.00
107.00
108.00
109.00
110.00
1
10
100
1000
Elapsed Time, minutes
Q = 50 gpm
ds = 1 foot/log cycle
T = 13,200 gpd/ft

## Recovery Test - 30S/11E-18L6
## January 18, 2005

**Depth to Static Water Level: 88.5 feet** **Pumping Rate: 50 gpm**

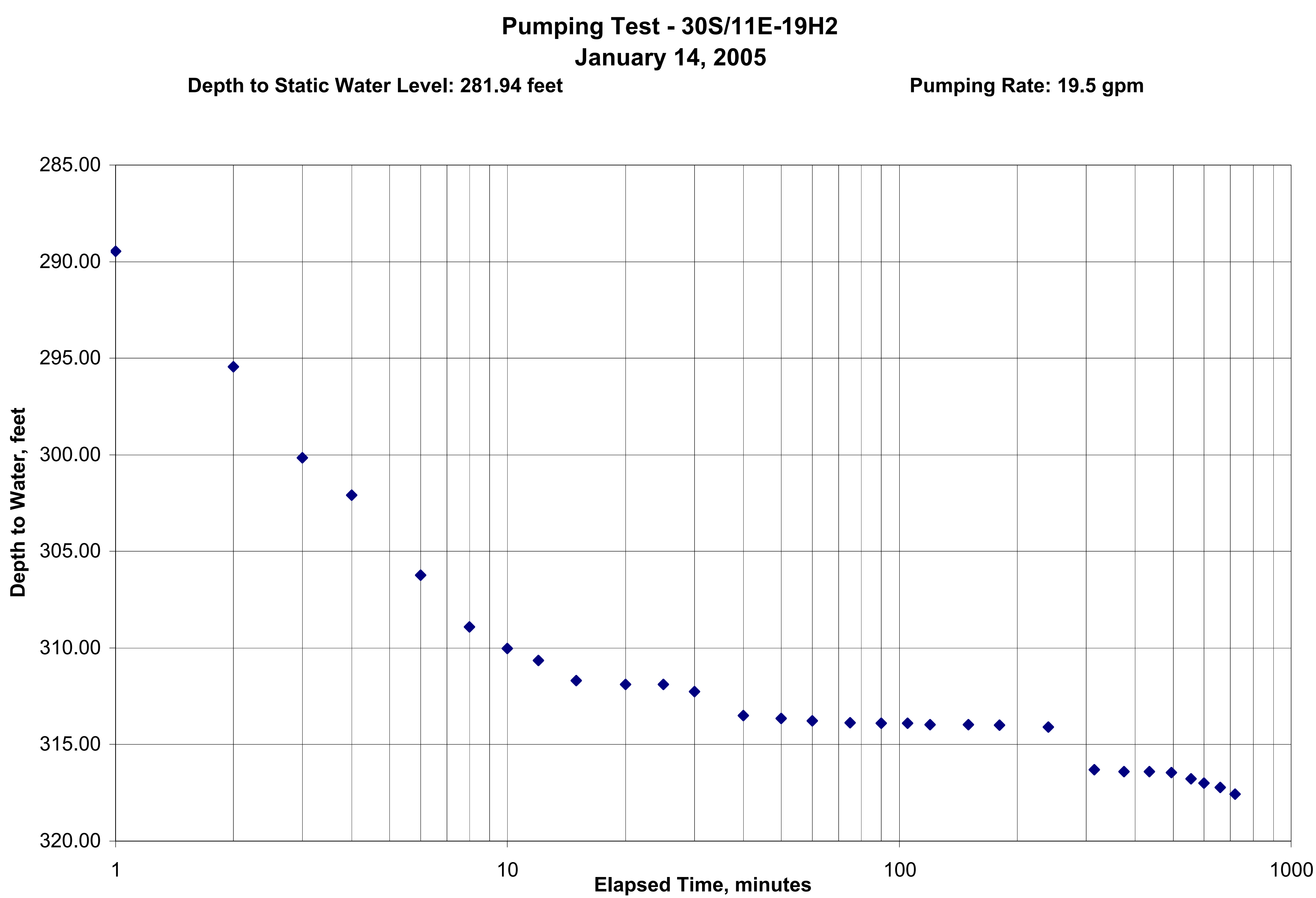


**Pumping Test, 30S/11E-19H2 - January 14 2005**

| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Meter | Recorded Pumping Rate |
|---|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | cubic feet | gallons per minute |
| 1/14/2005 | 7:40 | 0 | 0 | 281.94 | 0 | 0.0 | Start |
| | 7:41 | 0:01 | 1 | 289.46 | 7.52 | | 18.7 |
| | 7:42 | 0:02 | 2 | 295.44 | 13.50 | | |
| | 7:43 | 0:03 | 3 | 300.15 | 18.21 | | |
| | 7:44 | 0:04 | 4 | 302.08 | 20.14 | | 19.5 |
| | 7:46 | 0:06 | 6 | 306.23 | 24.29 | | |
| | 7:48 | 0:08 | 8 | 308.92 | 26.98 | | |
| | 7:50 | 0:10 | 10 | 310.04 | 28.10 | | |
| | 7:52 | 0:12 | 12 | 310.65 | 28.71 | | 19 |
| | 7:55 | 0:15 | 15 | 311.69 | 29.75 | | 19 |
| | 8:00 | 0:20 | 20 | 311.88 | 29.94 | | 19 |
| | 8:05 | 0:25 | 25 | 311.88 | 29.94 | | 19.8 |
| | 8:10 | 0:30 | 30 | 312.27 | 30.33 | | 19.8 |
| | 8:20 | 0:40 | 40 | 313.50 | 31.56 | | 19.8 |
| | 8:30 | 0:50 | 50 | 313.65 | 31.71 | | 19.7 |
| | 8:40 | 1:00 | 60 | 313.77 | 31.83 | | 19.6 |
| | 8:55 | 1:15 | 75 | 313.88 | 31.94 | | 19.6 |
| | 9:10 | 1:30 | 90 | 313.90 | 31.96 | | 19.5 |
| | 9:25 | 1:45 | 105 | 313.90 | 31.96 | | 19.4 |
| | 9:40 | 2:00 | 120 | 313.96 | 32.02 | | 19.4 |
| | 10:10 | 2:30 | 150 | 313.98 | 32.04 | | 19.3 |
| | 10:40 | 3:00 | 180 | 314.00 | 32.06 | | 19.1 |
| | 11:40 | 4:00 | 240 | 314.10 | 32.16 | | 19.8 |
| | 12:55 | 5:15 | 315 | 316.30 | 34.36 | | 19.8 |
| | 13:55 | 6:15 | 375 | 316.40 | 34.46 | | 19.8 |
| | 14:55 | 7:15 | 435 | 316.40 | 34.46 | | 19.7 |
| | 15:55 | 8:15 | 495 | 316.46 | 34.52 | | 19.7 |
| | 16:55 | 9:15 | 555 | 316.77 | 34.83 | | 19.7 |
| | 17:40 | 10:00 | 600 | 317.00 | 35.06 | | 19.7 |
| | 18:40 | 11:00 | 660 | 317.23 | 35.29 | | |
| | 19:40 | 12:00 | 720 | 317.56 | 35.62 | | 19.7 |
| | STOP | | | | | 1889.9 | |
| | | | | | | Average Rate= 19.45 gpm | |

**Recovery 30S/11E-19H2**

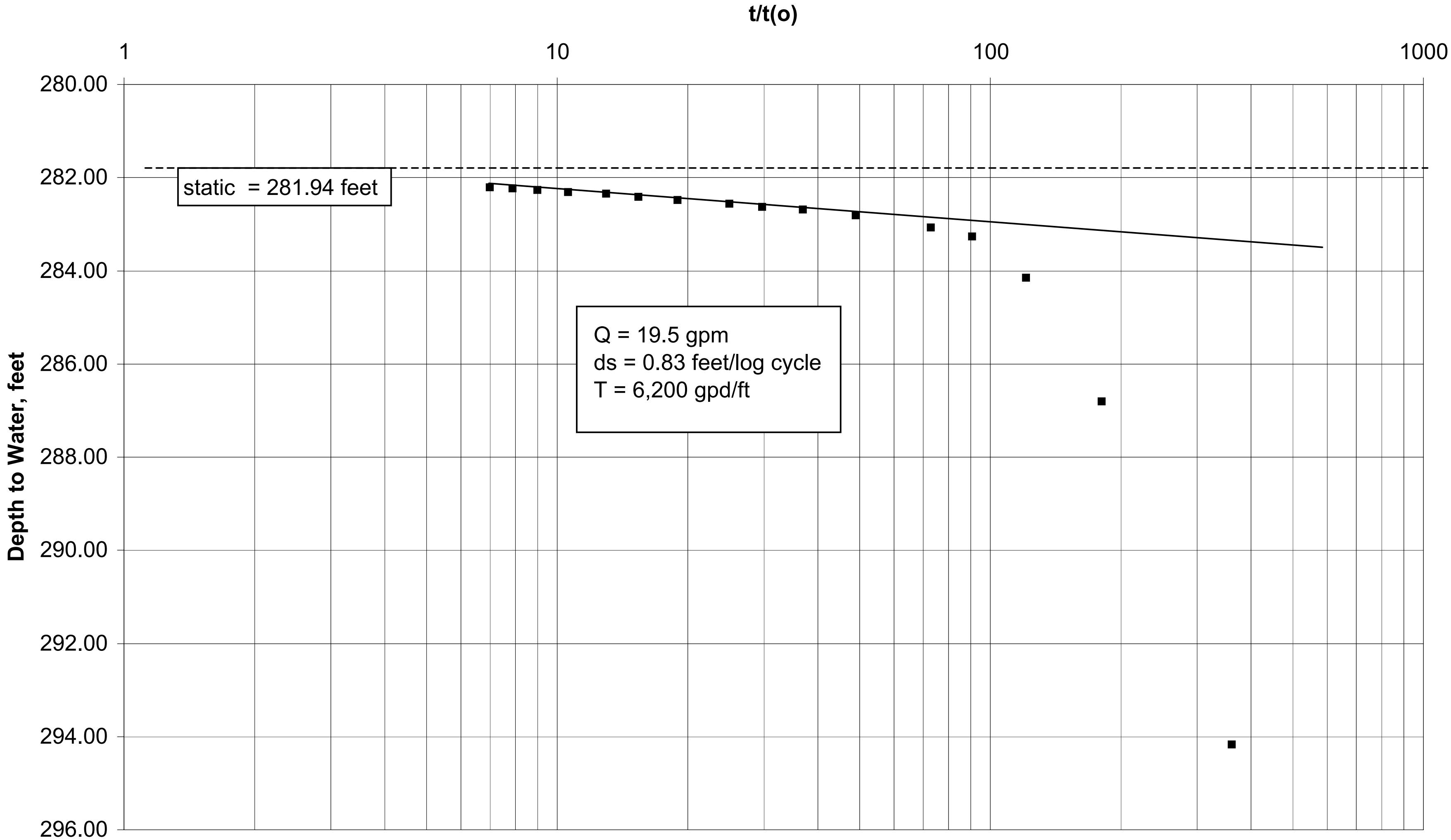
| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Ratio |
|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | t/t(o) |
| Recovery | | | | | | |
| 1/14/2005 | 19:40 | 12:00 | 0 | 317.56 | 35.62 | |
| | 19:42 | 12:02 | 2 | 294.17 | 12.23 | 361 |
| | 19:44 | 0:03 | 4 | 286.81 | 4.87 | 181 |
| | 19:46 | 12:06 | 6 | 284.15 | 2.21 | 121 |
| | 19:48 | 12:08 | 8 | 283.27 | 1.33 | 91 |
| | 19:50 | 12:10 | 10 | 283.08 | 1.14 | 73 |
| | 19:55 | 12:15 | 15 | 282.81 | 0.87 | 49 |
| | 20:00 | 12:20 | 20 | 282.69 | 0.75 | 37 |
| | 20:05 | 12:25 | 25 | 282.63 | 0.69 | 29.8 |
| | 20:10 | 12:30 | 30 | 282.56 | 0.62 | 25 |
| | 20:20 | 12:40 | 40 | 282.48 | 0.54 | 19 |
| | 20:30 | 12:50 | 50 | 282.42 | 0.48 | 15.4 |
| | 20:40 | 13:00 | 60 | 282.35 | 0.41 | 13 |
| | 20:55 | 13:15 | 75 | 282.31 | 0.37 | 10.6 |
| | 21:10 | 13:30 | 90 | 282.27 | 0.33 | 9 |
| | 21:25 | 13:45 | 105 | 282.23 | 0.29 | 7.9 |
| | 21:40 | 14:00 | 120 | 282.21 | 0.27 | 7 |
| | STOP | | | | | |



Pumping Test - 30S/11E-19H2
January 14, 2005
Depth to Static Water Level: 281.94 feet
Pumping Rate: 19.5 gpm
Depth to Water, feet
285.00
290.00
295.00
300.00
305.00
310.00
315.00
320.00
1
10
100
1000
Elapsed Time, minutes

## Recovery Test - 30S/11E-19H2
## January 14, 2005

**Depth to Static Water Level: 281.94 feet** **Pumping Rate: 19.5 gpm**



**Pumping Test, 30S/11E-20Aa - February 1, 2005**

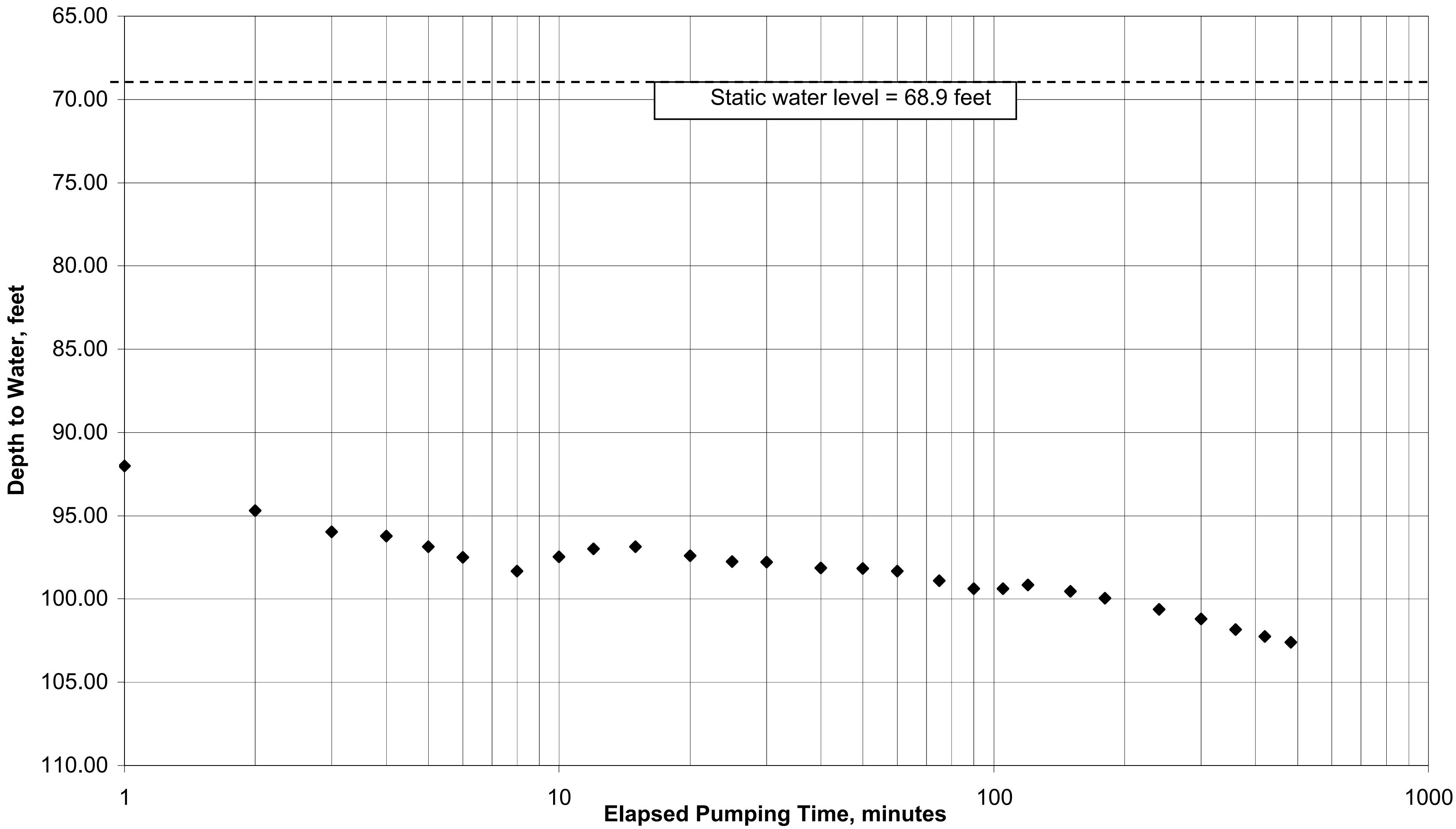
| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Meter | Recorded Pumping Rate |
|---|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | cubic feet | gallons per minute |
| 2/1/2005 | 8:57 | 0 | 0 | 68.88 | 0 | 0.0 | Start |
| | 8:58 | 0:01 | 1 | 92.00 | 23.12 | | |
| | 8:59 | 0:02 | 2 | 94.69 | 25.81 | | 27-30 |
| | 9:00 | 0:03 | 3 | 95.96 | 27.08 | | |
| | 9:01 | 0:04 | 4 | 96.21 | 27.33 | | |
| | 9:02 | 0:05 | 5 | 96.85 | 27.97 | | |
| | 9:03 | 0:06 | 6 | 97.50 | 28.62 | | |
| | 9:05 | 0:08 | 8 | 98.33 | 29.45 | | |
| | 9:07 | 0:10 | 10 | 97.46 | 28.58 | | 26.5 (adjusting to 29) |
| | 9:09 | 0:12 | 12 | 97.00 | 28.12 | | (adjusting) |
| | 9:12 | 0:15 | 15 | 96.88 | 28.00 | | (adjusting) |
| | 9:17 | 0:20 | 20 | 97.40 | 28.52 | | |
| | 9:22 | 0:25 | 25 | 97.75 | 28.87 | | 28.6 |
| | 9:27 | 0:30 | 30 | 97.77 | 28.89 | | 28.5 |
| | 9:37 | 0:40 | 40 | 98.13 | 29.25 | | 28.8 |
| | 9:47 | 0:50 | 50 | 98.17 | 29.29 | | 29.3 |
| | 9:57 | 1:00 | 60 | 98.33 | 29.45 | | 30.1 |
| | 10:12 | 1:15 | 75 | 98.90 | 30.02 | | 30 |
| | 10:27 | 1:30 | 90 | 99.38 | 30.50 | | 30.2 |
| | 10:42 | 1:45 | 105 | 99.38 | 30.50 | | 30.1 |
| | 10:57 | 2:00 | 120 | 99.17 | 30.29 | | 30.1 |
| | 11:27 | 2:30 | 150 | 99.54 | 30.66 | | 30.4 |
| | 11:57 | 3:00 | 180 | 99.96 | 31.08 | | 30.2 |
| | 12:57 | 4:00 | 240 | 100.63 | 31.75 | | 30.5 |
| | 13:57 | 5:00 | 300 | 101.19 | 32.31 | | 30.5 |
| | 14:57 | 6:00 | 360 | 101.83 | 32.95 | | 30.1 |
| | 15:57 | 7:00 | 420 | 102.25 | 33.37 | | 30.2 |
| | 17:00 | 8:03 | 483 | 102.60 | 33.72 | | 30.2 |
| | STOP | | | | | 1939.6 | |
| | | | | | | Average Rate= 30 gpm | |

**Recovery 30S/11E-20Aa**

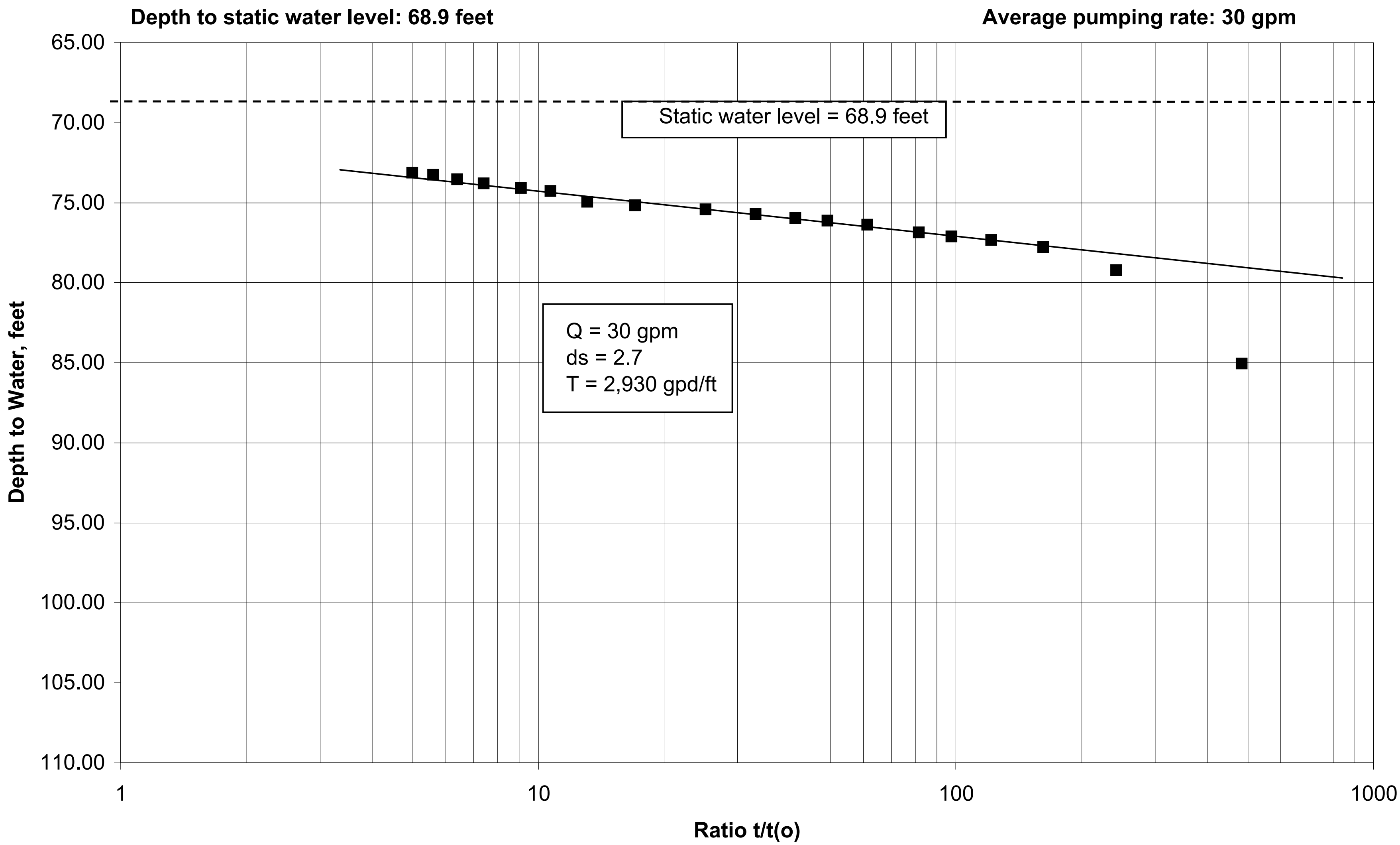
| Day | Time | Elapsed Time | | Depth to Water | Drawdown | Ratio |
|---|---|---|---|---|---|---|
| Mo./Day/Yr | hr:min | hours:minutes | minutes | feet | feet | t/t(o) |
| Recovery | | | | | | |
| 2/1/2005 | 17:00 | 8:03 | 0 | 102.60 | 33.70 | |
| | 17:01 | 8:04 | 1 | 85.06 | 16.20 | 484 |
| | 17:02 | 0:03 | 2 | 79.21 | 10.30 | 242.5 |
| | 17:03 | 8:06 | 3 | 77.79 | 8.90 | 162 |
| | 17:04 | 8:07 | 4 | 77.35 | 8.50 | 121.8 |
| | 17:05 | 8:08 | 5 | 77.10 | 8.20 | 97.6 |
| | 17:06 | 8:09 | 6 | 76.88 | 8.00 | 81.5 |
| | 17:08 | 8:11 | 8 | 76.38 | 7.50 | 61.4 |
| | 17:10 | 8:13 | 10 | 76.13 | 7.20 | 49.3 |
| | 17:12 | 8:15 | 12 | 75.96 | 7.10 | 41.3 |
| | 17:15 | 8:18 | 15 | 75.73 | 6.80 | 33.2 |
| | 17:20 | 8:23 | 20 | 75.42 | 6.50 | 25.2 |
| | 17:30 | 8:33 | 30 | 75.17 | 6.30 | 17.1 |
| | 17:40 | 8:43 | 40 | 74.94 | 6.10 | 13.1 |
| | 17:50 | 8:53 | 50 | 74.29 | 5.40 | 10.7 |
| | 18:00 | 9:03 | 60 | 74.08 | 5.20 | 9.1 |
| | 18:15 | 9:18 | 75 | 73.79 | 4.90 | 7.4 |
| | 18:30 | 9:33 | 90 | 73.54 | 4.70 | 6.4 |
| | 18:45 | 9:48 | 105 | 73.27 | 4.40 | 5.6 |
| | 19:00 | 10:03 | 120 | 73.13 | 4.20 | 5 |
| | STOP | | | | | |

## Pumping Water Levels - Well 30S/11E-20Aa
## February 1, 2005

**Depth to Static Water Level: 68.9 feet** **Pumping Rate: 30 gpm**

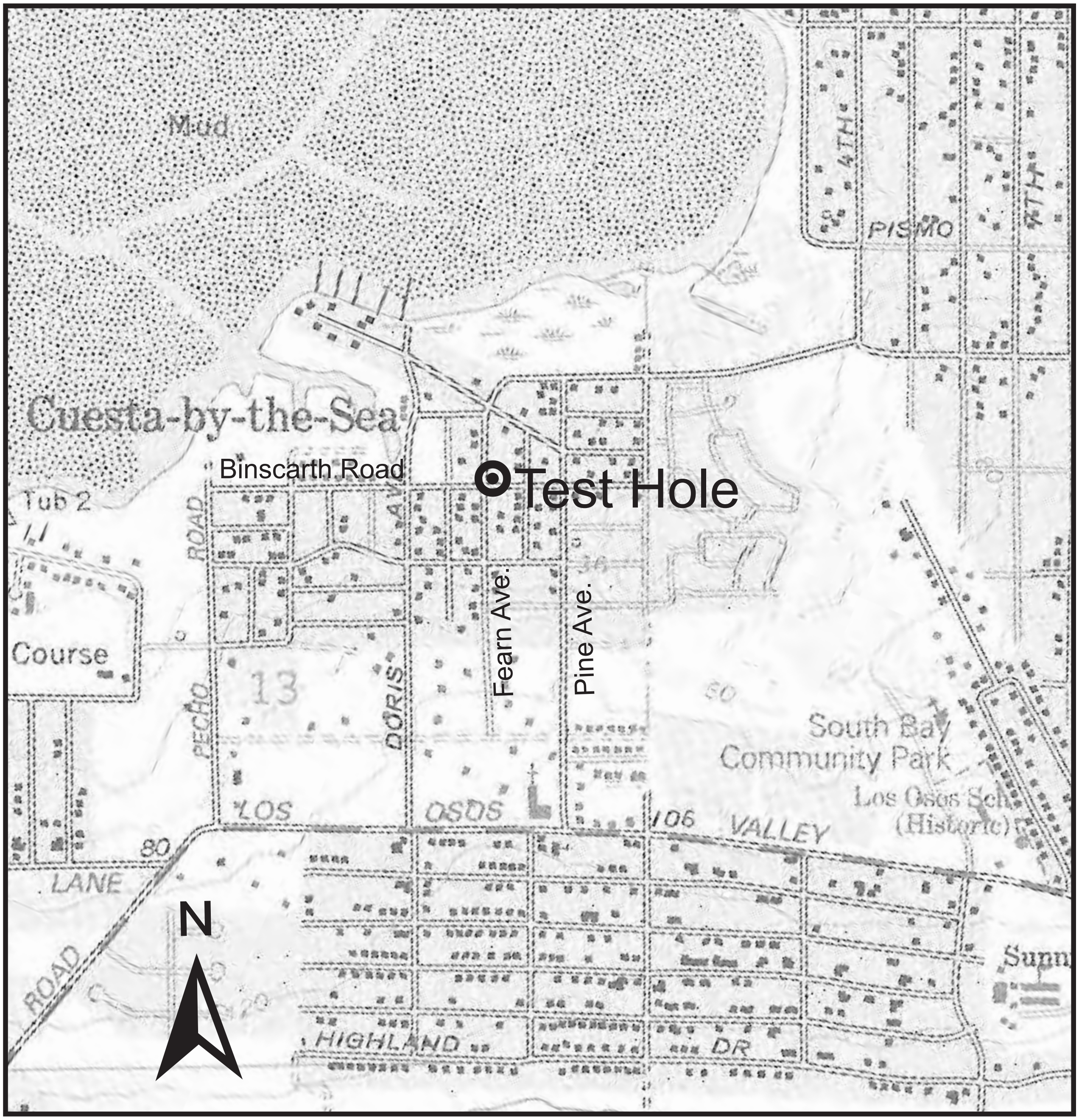


## Water Level Recovery - Well 30S/11E-20Aa
## February 1, 2005



# Appendix H

# Test Hole Documentation




Base Map: USGS Topographic Map
Morro Bay South, 1994

Scale: 1" = 1000'

Figure H1
Test Hole Location

DWR Grant Project
Los Osos CSD

Cleath & Associates

**Los Osos Community Services District**
**Test Hole on Binscarth Road at Fearn Avenue**

Date: March 1, 2005
Location: Binscarth Road, Los Osos
Elevation: Approx. 18 feet above sea level
Geologist: S. Harris, Cleath & Assoc.
Drilling Company: F&T
Drilling Method: mud rotary
Pilot hole diameter: 9-7/8 inches
Total depth: 660 feet

**Lithologic Log**
Depth to top and bottom in feet

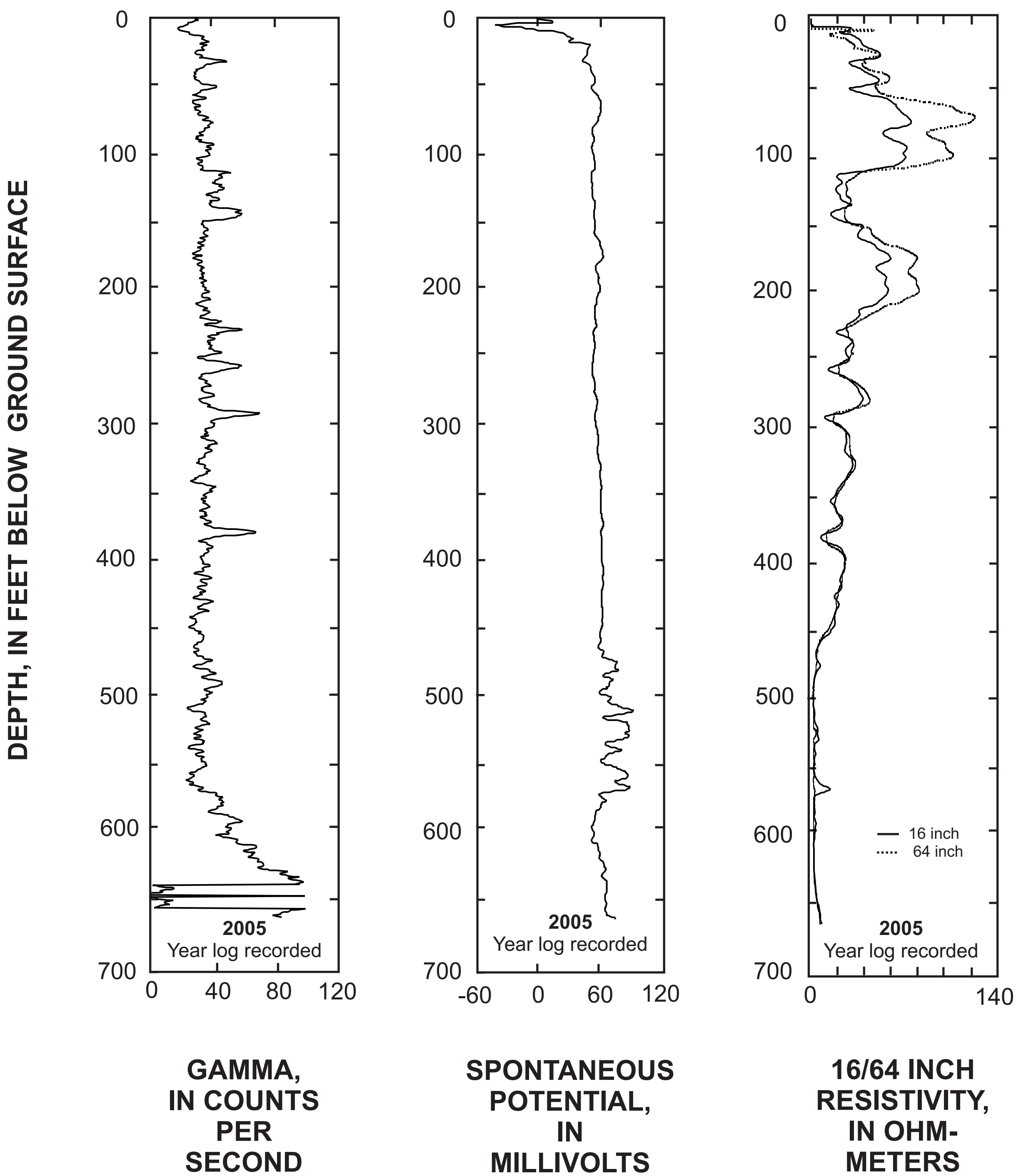
| Top | Bottom | Thickness | Description |
|---|---|---|---|
| 0 | 3 | 3 | **Sand,** dark yellowish brown (10YR 3/4), trace silt, fine to medium grained. |
| 3 | 30 | 27 | **Sand**, yellowish brown (10YR 5/4), fine to medium grained. |
| 33 | 38 | 5 | **Clayey Sand**, olive (5Y 5/3) to yellowish brown (10YR 5/6), fine to medium grained sand, interbedded light greenish gray (5GY 7/1) clay lenses at 33 feet depth. |
| 38 | 48 | 10 | **Sand**, yellowish brown (10YR 5/4), fine to medium grained. |
| 48 | 56 | 12 | **Clayey Sand**, olive (5Y 5/3) to yellowish brown (10YR 5/6), fine to medium grained sand, interbedded light greenish gray (5GY 7/1) clay lenses at 52 feet depth. |
| 56 | 114 | 58 | **Sand**, yellowish brown (10YR 5/4), fine to medium grained. |
| 114 | 152 | 38 | **Clayey Sand**, light yellowish brown (2.5Y 6/4), with interbedded clay lenses and some yellowish brown (10YR 5/6) fine gravel and coarse sand stringers. |
| 152 | 214 | 62 | **Sand and Gravel**, yellowish brown (10YR 5/4) to olive brown (2.5Y 4/4), fine to coarse sand, gravel clasts up to ½ inch, subangular to rounded, mostly siliceous shale and chert, also siltsones, sandstones, and metavolcanics. |
| 214 | 228 | 14 | **Clayey Sand**, light yellowish brown (2.5Y 6/4), fine to medium sand. |
| 228 | 234 | 6 | **Sandy Clay**, light olive brown (2.5Y 5/4), fine to coarse grained sand. |

Binscarth at Fearn (Continued)

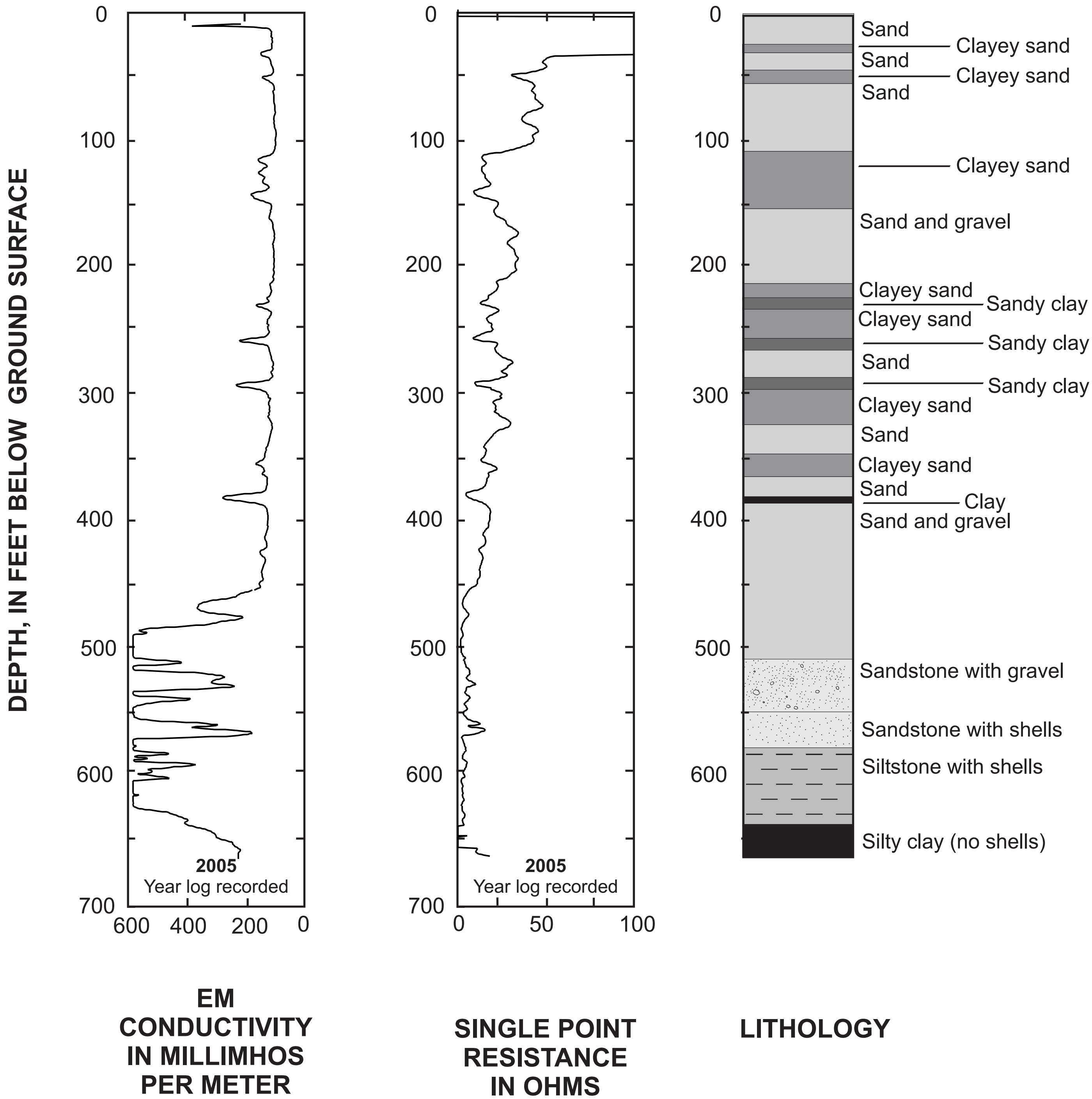
| Top | Bottom | Thickness | Description |
|---|---|---|---|
| 234 | 254 | 20 | **Clayey Sand**, yellowish brown (10YR 5/6), fine to medium grained sand, with occasional dark yellowish brown (10YR 4/4) coarse sand and fine gravel stringers with shells. |
| 254 | 262 | 8 | **Sandy Clay**, light olive brown (2.5Y 5/3), fine to medium grained sand with red (2.5YR 5/8) clay. |
| 262 | 288 | 26 | **Sand**, yellowish brown (10YR 5/3); fine to medium. |
| 288 | 298 | 10 | **Sandy Clay**, very dark gray (2.5Y 3/1) streaked with yellowish brown (10YR 5/8), fine to medium sand. |
| 298 | 320 | 22 | **Clayey Sand**, light yellowish brown (2.5Y 6/4), fine to medium sand, with occasional very dark gray (2.5Y 3/1) sandy clay lenses. |
| 320 | 346 | 26 | **Sand**, light olive brown (2.5Y 5/4), fine to medium grained. |
| 346 | 364 | 18 | **Clayey Sand**, light yellowish brown (2.5Y 6/4), fine to medium sand with very dark gray (2.5Y 3/1) clay stringers. |
| 364 | 378 | 14 | **Sand**, trace gravel, light olive brown (2.5Y 5/4), fine to coarse sand, with very dark gray (2.5Y 3/1) clay stringers grading to fine gravel at base. |
| 378 | 386 | 8 | **Clay**, black (2.5Y 2.5/1), with light olive brown (2.5Y 5/4) fine to medium sand. |
| 386 | 510 | 124 | **Sand and Gravel**, yellowish brown (10YR 5/4), occasional gray (10YR 6/1) and light yellowish brown (2.5Y 6/4) sandy clay lenses, fine to coarse sand, gravel clasts up to ½ inch, subangular to rounded with reddish brown and olive green siliceous shales and chert, also fine sandstones, siltstones and metavolcanics. |
| 510 | 550 | 40 | **Sandstone with Gravel**, grayish brown (10YR 5/2) with some interbedded yellowish brown (10YR 5/8) clay lenses, fine to coarse sand, angular to subrounded fine gravel, mostly dark gray siltstone clasts with up to 20% white siltstone clasts, cemented. |
| 550 | 580 | 30 | **Sandstone**, greenish gray (10Y 5/1), fine to coarse sandstone with abundant shells. |
| 580 | 640 | 60 | **Siltstone**, dark greenish gray (10Y 4/1), with abundant shells. |
| 640 | 660 | 20 | **Silty Clay**, dark olive gray (5Y 3/2), no shells. |

Total depth 660 feet

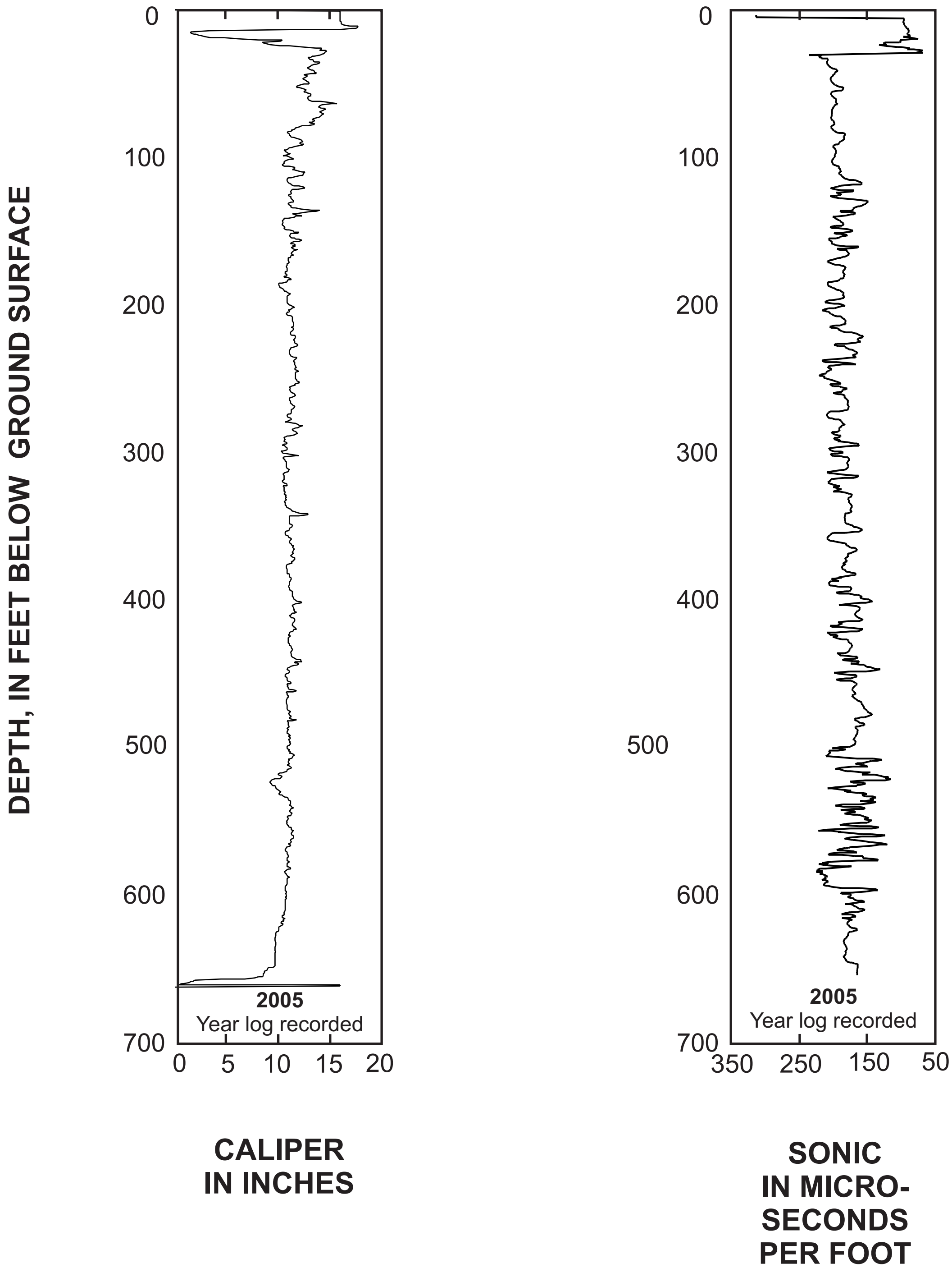
# Binscarth Road Test Hole
# 30S/10E-13H



# Binscarth Road Test Hole
# 30S/10E-13H



# Binscarth Road Test Hole
# 30S/10E-13H



Water Quality Calculations
Test Hole at Fearn and Binscarth
30S/10E-13H
Based on 64-inch normal resistivity log

Borehole fluid resistivity = 4.5 ohm/m

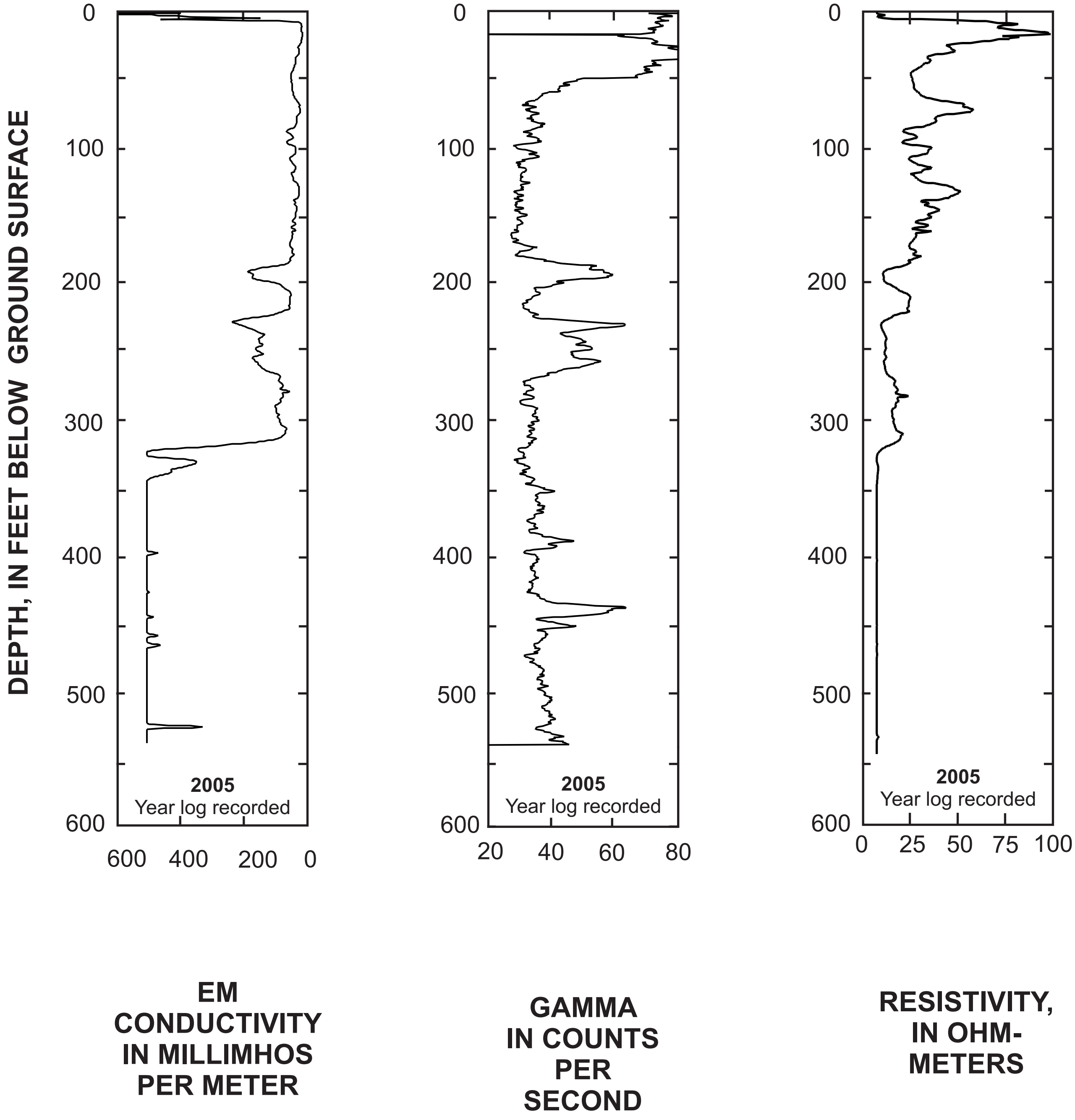
| depth ft | Aquifer Zone | SP deflection mV (ref only) | R64 ohm-m | Format. factor @ 40% porosity | Rw ohm-m | Test Hole Calculated TDS (NaCl) ppm | estimated chloride mg/l | Comparison with Section 13 wells TDS mg/l | Cl mg/l | well ID |
|---|---|---|---|---|---|---|---|---|---|---|
| 75 | C | +10 | 113 | 4.446 | 25 | 210 | 50 | 290 | 63 | well 13A2 |
| 175 | C | +9 | 81 | 4.446 | 18 | 290 | 60 | 320 | 67 | well 13F1 |
| 282 | D | +3.5 | 45 | 4.446 | 10.1 | 520 | 190 | 420 | 150 | well 13J1 |
| 325 | D | +3 | 35 | 4.446 | 7.9 | 670 | 260 | 590 | 230 | well 13L4 |
| 400 | E | 0 | 27 | 4.446 | 6.1 | 870 | 340 | | | |
| 450 | E | -5 | 12 | 4.446 | 2.7 | 1960 | 840 | | | |
| 480 | E | unstable | 4 | 4.446 | 0.9 | 5890 | 2650 | | | |
| 500 | E | unstable | 2.5 | 4.446 | 0.6 | 8830 | 4290 | 35000 | 17000 | well 13M1 |

NOTE: Sponteneous potential deflection from clay baseline shown for comparison only. Confirms significant changes in water quality between aquifer Zone C and D, between D and E, and below 480 feet.

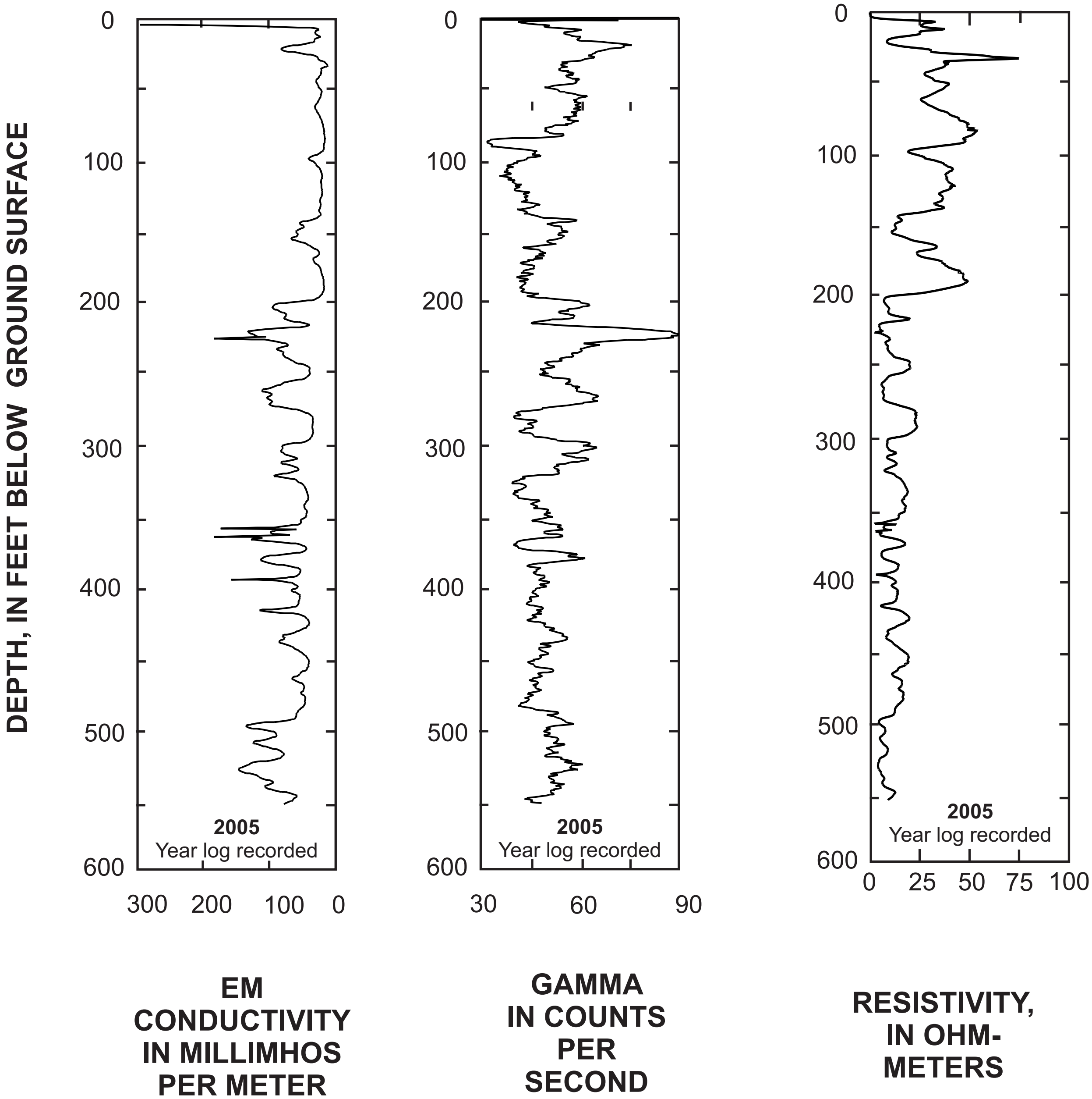
# Appendix I

## Geophysical Logging at 30S/10E-13M1 and 30S/11E-18L6

# Well 30S/10E-13M1

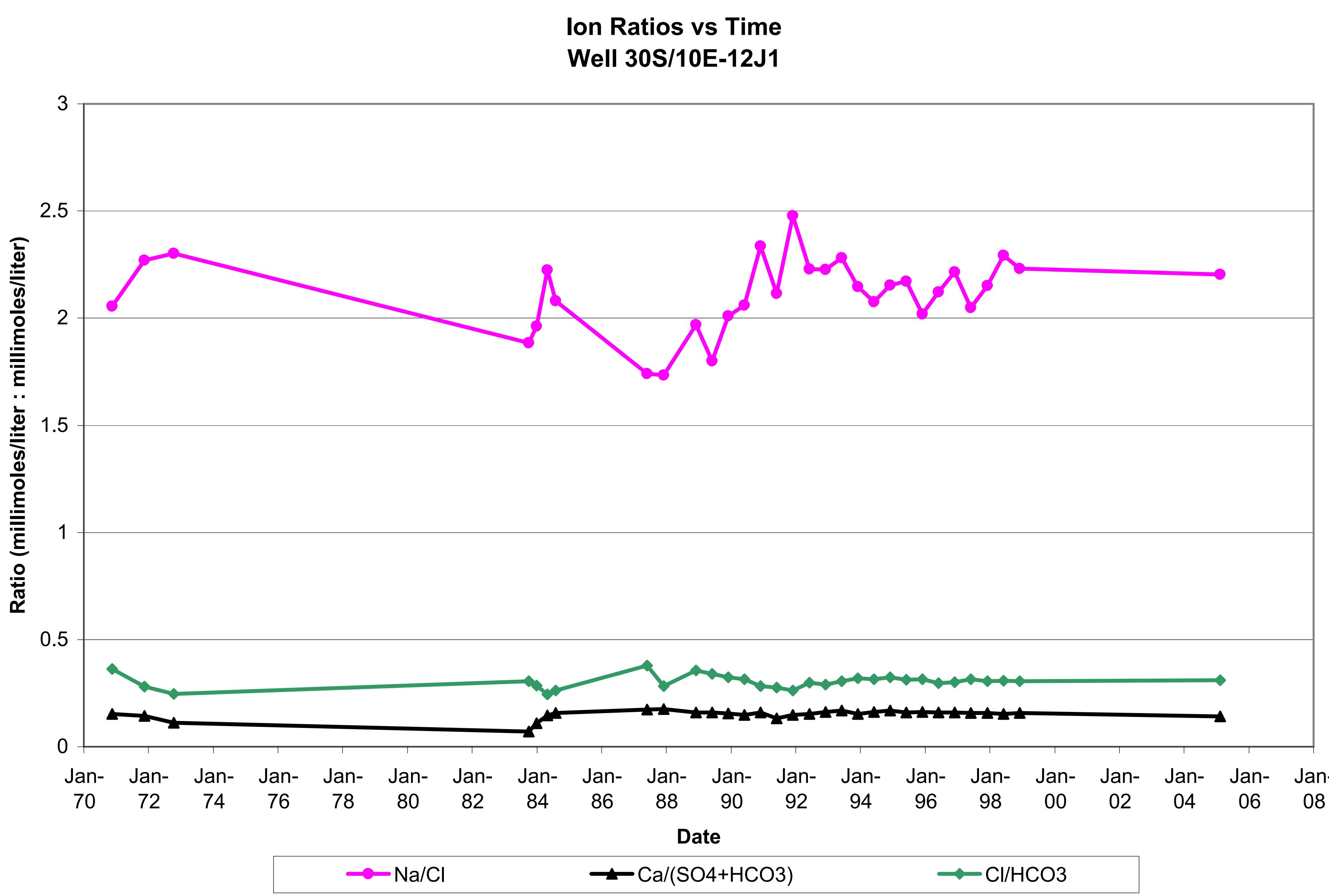


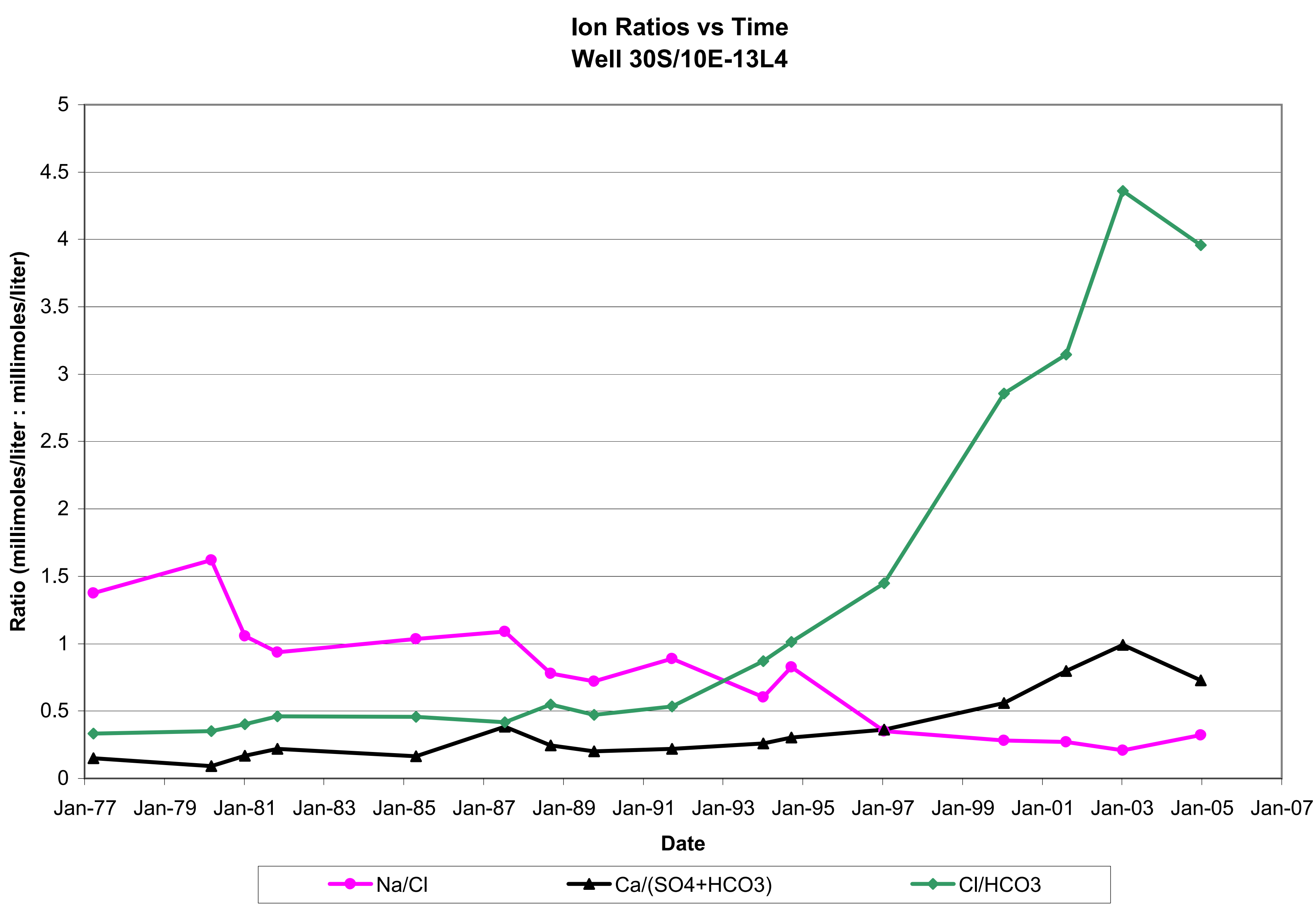
# Well 30S/11E-18L6

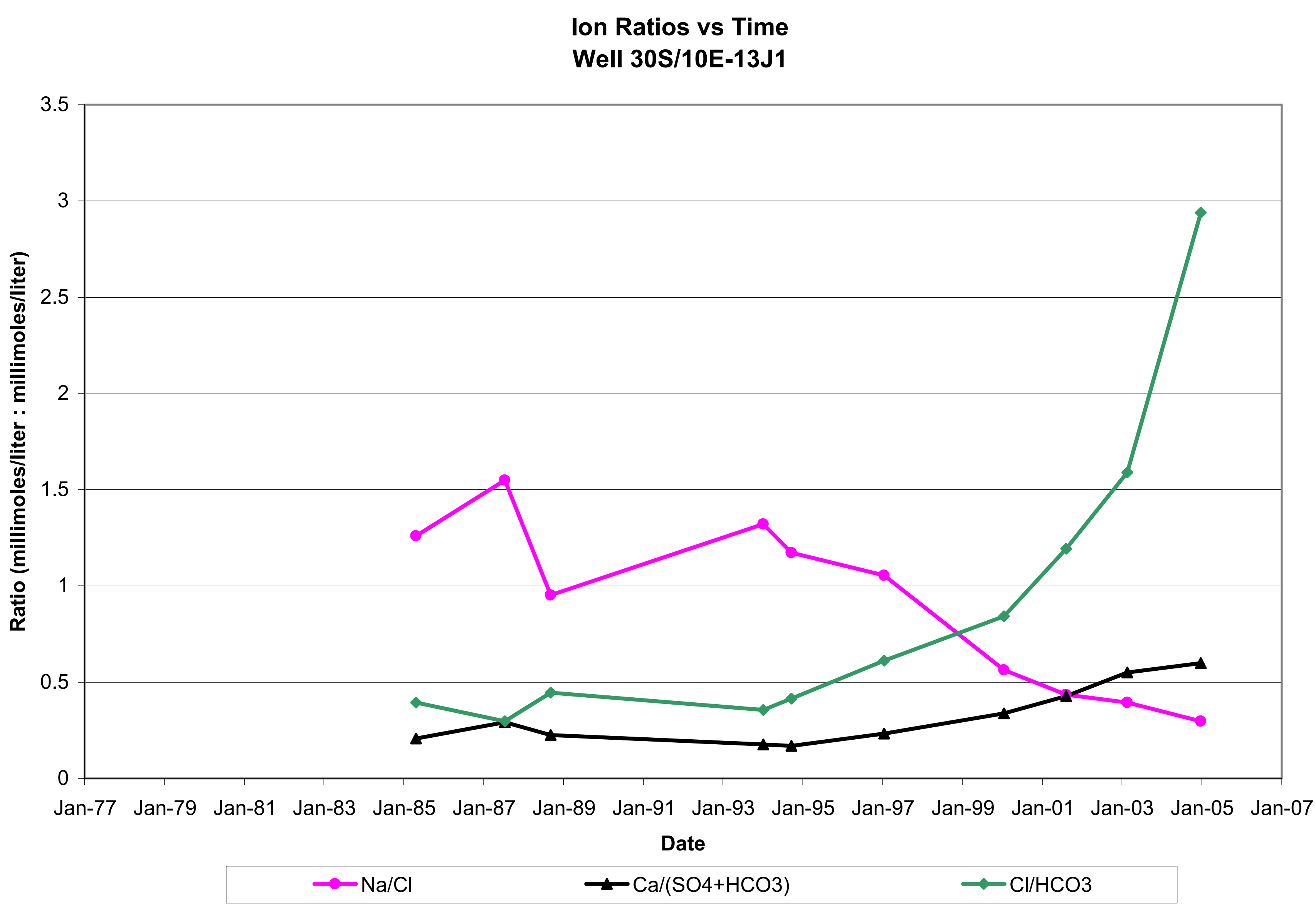


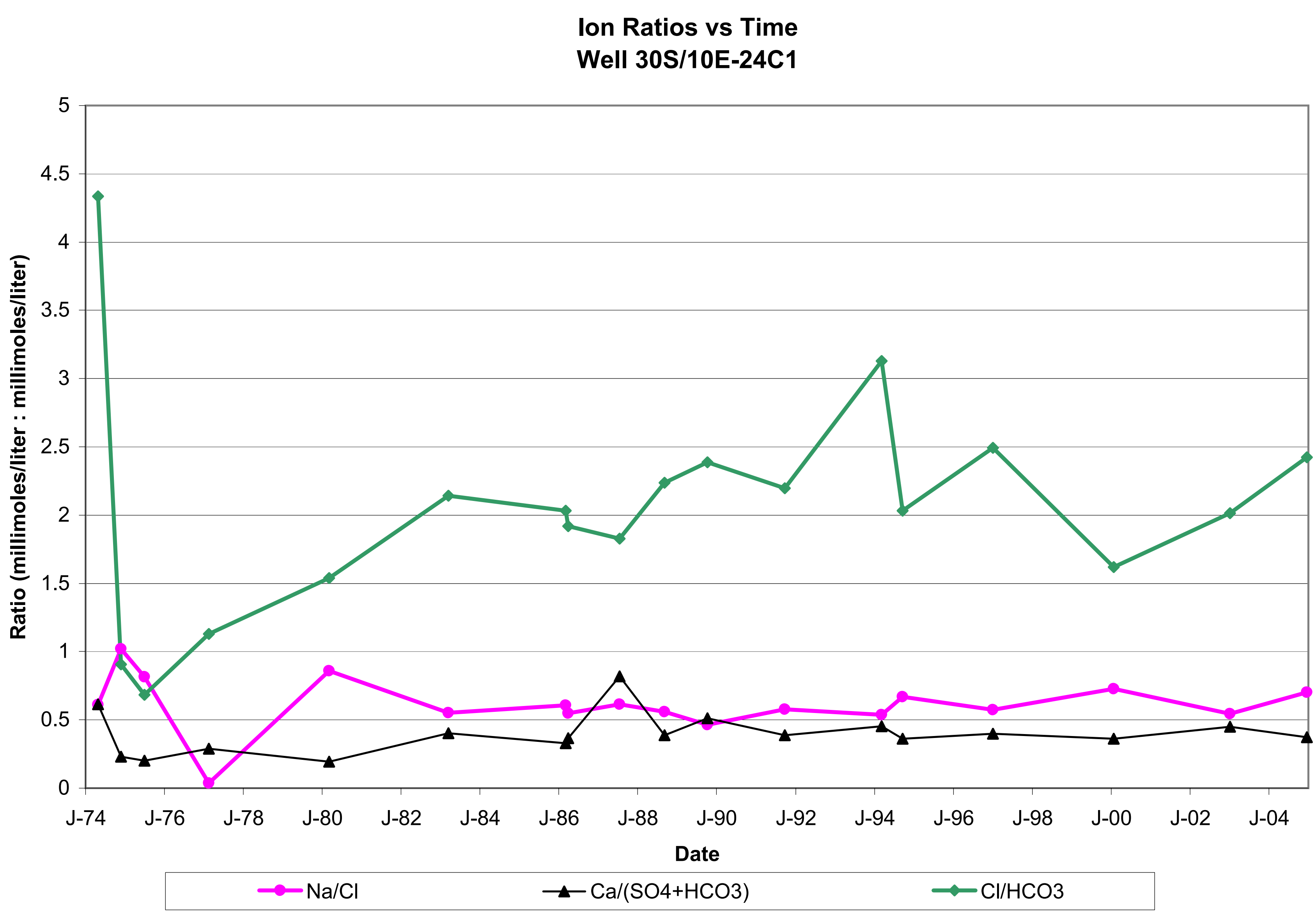
# Appendix J

# Ion Ratios vs Time at Selected Lower Aquifer Wells

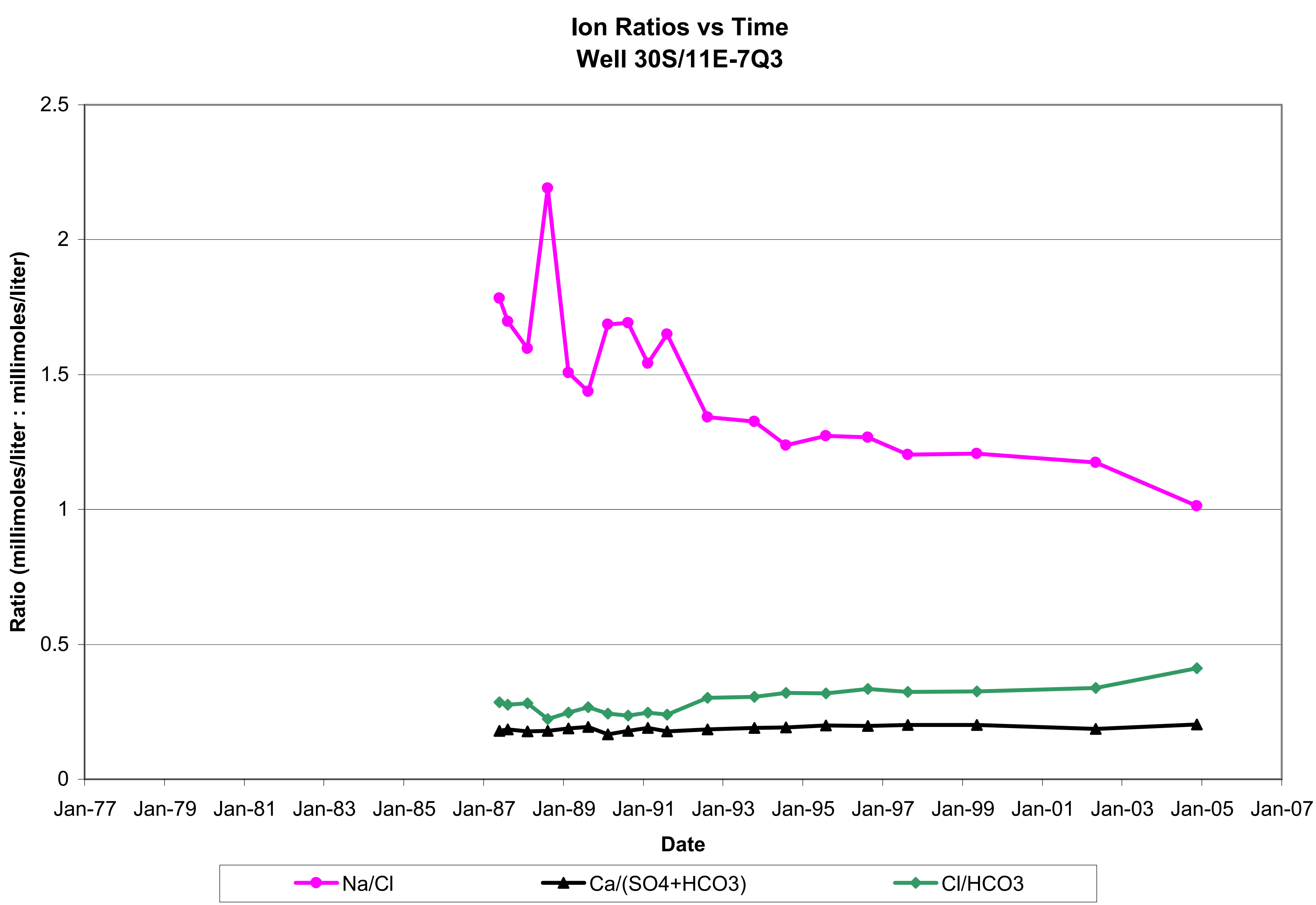

Ion Ratios vs Time
Well 30S/10E-12J1
Ratio (millimoles/liter : millimoles/liter)
0
0.5
1
1.5
2
2.5
3
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3


Ion Ratios vs Time
Well 30S/10E-13L4
Ratio (millimoles/liter : millimoles/liter)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3

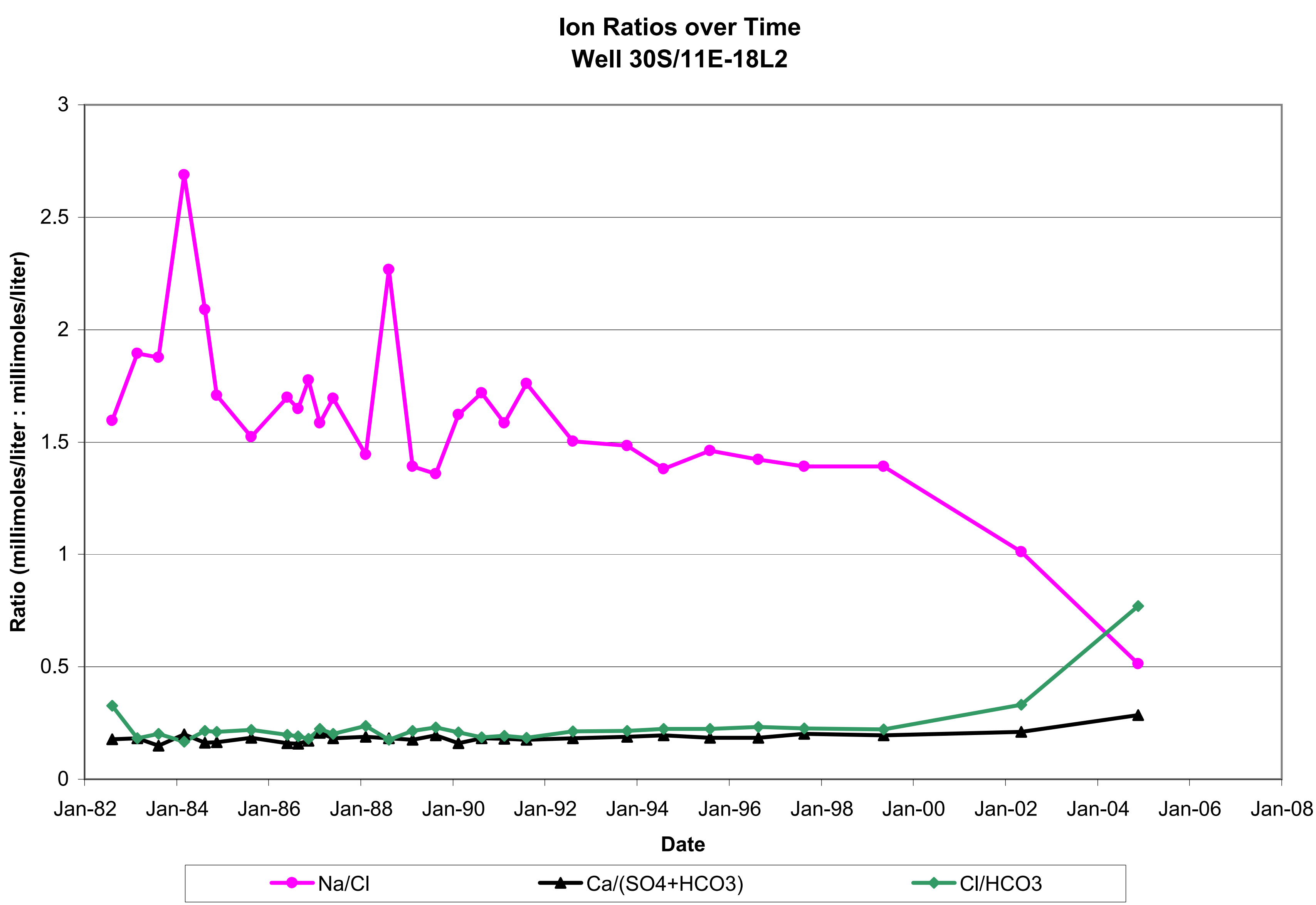

Ion Ratios vs Time
Well 30S/10E-13J1
Ratio (millimoles/liter : millimoles/liter)
3.5
3
2.5
2
1.5
1
0.5
0
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3



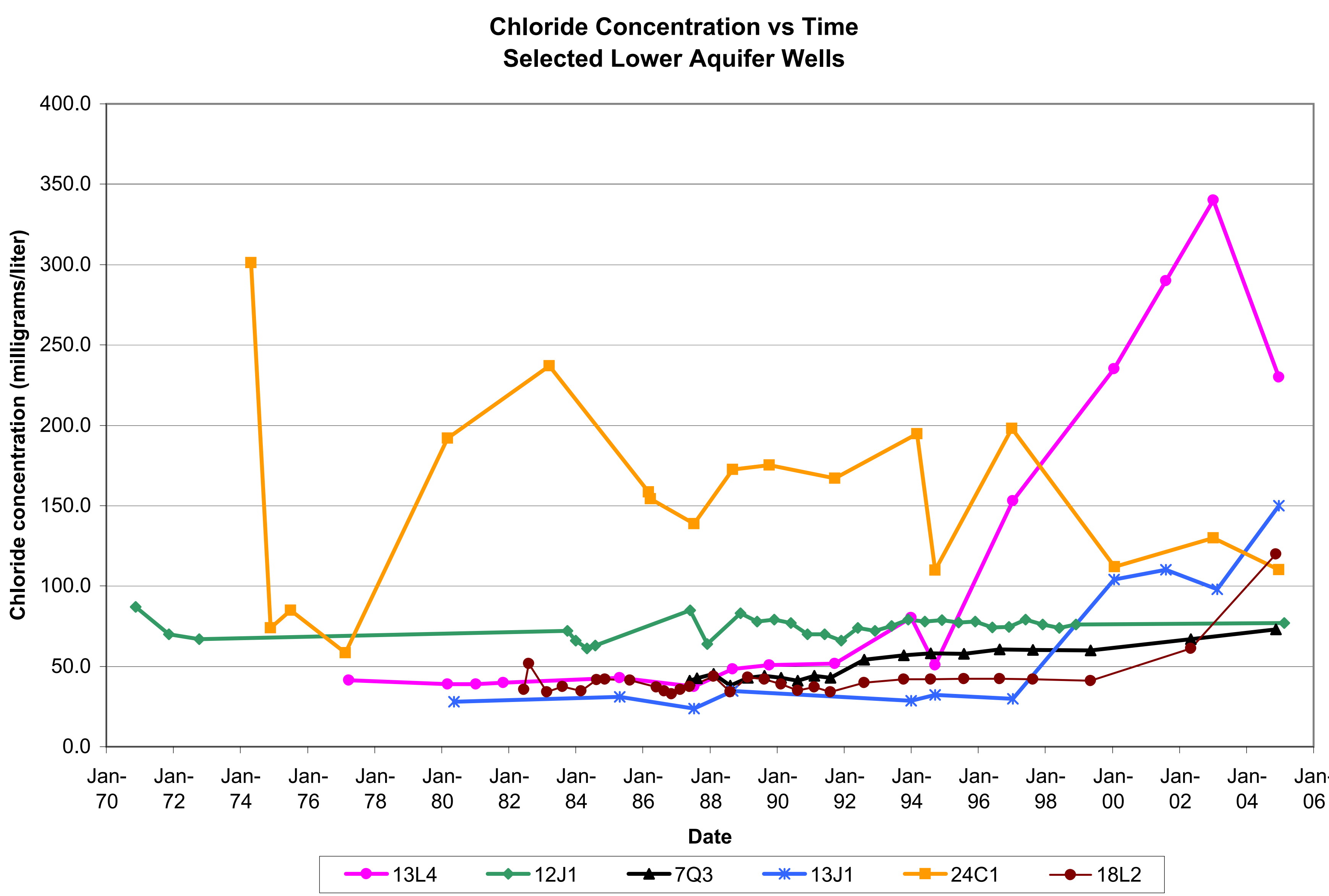
Ion Ratios vs Time
Well 30S/10E-24C1
Ratio (millimoles/liter : millimoles/liter)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
J-74
J-76
J-78
J-80
J-82
J-84
J-86
J-88
J-90
J-92
J-94
J-96
J-98
J-00
J-02
J-04
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3



Ion Ratios vs Time
Well 30S/11E-7Q3
Ratio (millimoles/liter : millimoles/liter)
2.5
2
1.5
1
0.5
0
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3



Ion Ratios over Time
Well 30S/11E-18L2
Ratio (millimoles/liter : millimoles/liter)
3
2.5
2
1.5
1
0.5
0
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Jan-08
Date
Na/Cl
Ca/(SO4+HCO3)
Cl/HCO3


Chloride Concentration vs Time
Selected Lower Aquifer Wells
Chloride concentration (milligrams/liter)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96
Jan-98
Jan-00
Jan-02
Jan-04
Jan-06
Date
13L4
12J1
7Q3
13J1
24C1
18L2

## Appendix K

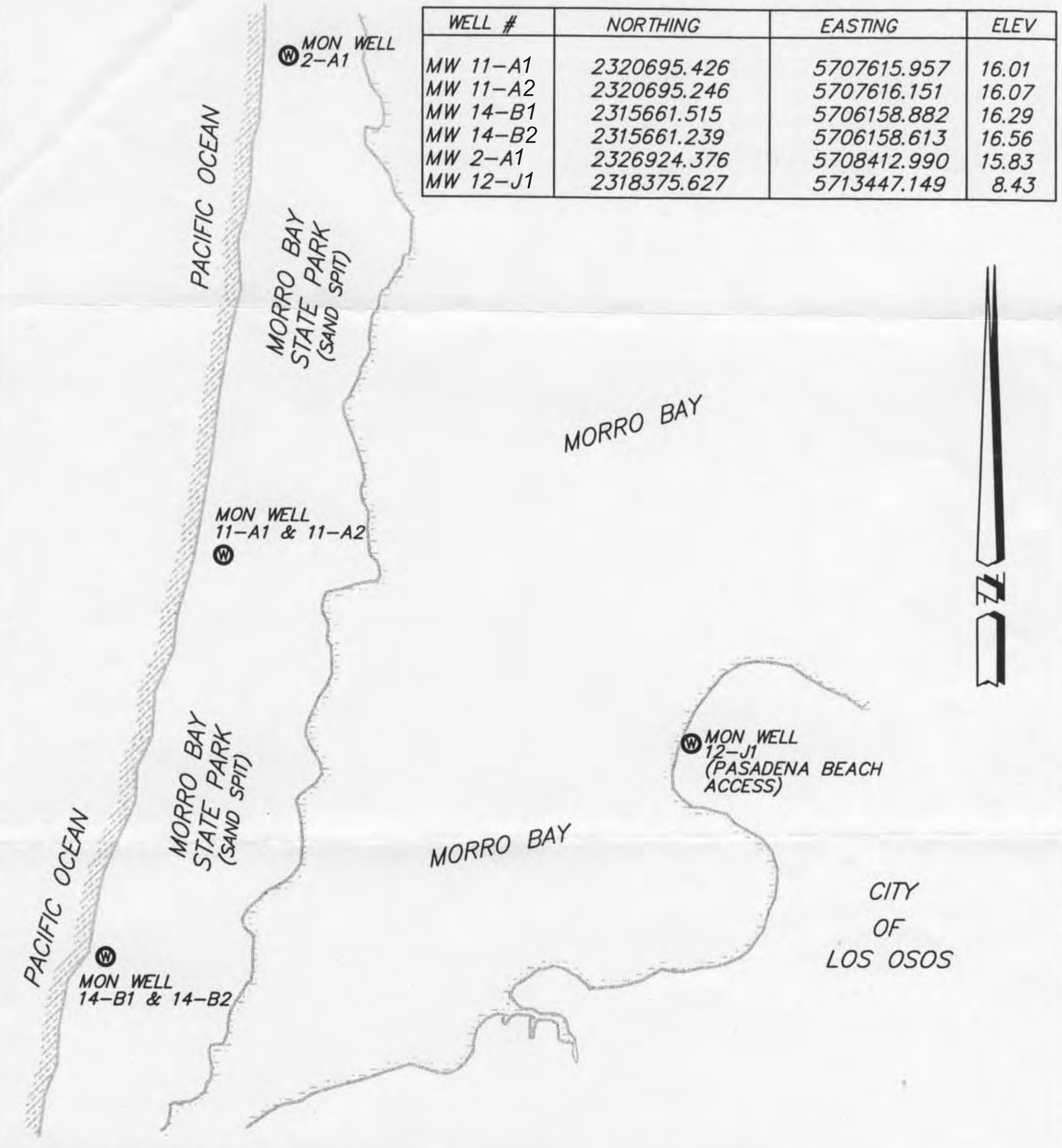
## Summary of Sand Spit Monitoring Well Water Quality

**SUMMARY OF SAND SPIT MONITORING WELL WATER QUALITY**

| StationID | Location | Sample_Date | Geology | TDS mg/l | Cond µmhos/cm | HCO3 mg/l | Cl mg/l | K mg/l | Na mg/l | SO4 mg/l | Ca mg/l | Mg mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Seawater | sandspit | 6/29/1977 | Surface | 36300 | 72800 | 145 | 18565 | 383 | 10630 | 2603 | 451 | 1301 |
| 30S/10E-11A1 | Site #1 west tube | 6/29/1977 | Zone C | 30800 | 38700 | 145 | 15200 | 328 | 8450 | 2130 | 446 | 1030 |
| 30S/10E-11A1 | Site #1 west tube | 3/5/1986 | Zone C | 29700 | 41400 | 148 | 16000 | 310 | 8300 | 2300 | 150 | 940 |
| 30S/10E-11A1 | Site #1 west tube | 4/16/1991 | Zone C | 30576 | | | 15397 | | | | | |
| 30S/10E-11A1 | Site #1 west tube | 10/30/2002 | Zone C | 28000 | 47000 | | | | | | | |
| 30S/10E-11A1 | Site #1 west tube | 3/14/2005 | Zone C | 28000 | 52000 | 140 | 18000 | 340 | 9000 | 2800 | 380 | 1100 |
| 30S/10E-11A2 | Site #1 east tube | 6/29/1977 | Zone D | 5600 | 8680 | 79 | 2670 | 15 | 910 | 320 | 403 | 309 |
| 30S/10E-11A2 | Site #1 east tube | 3/5/1986 | Zone D | 6100 | 10400 | 207 | 3700 | 15 | 1000 | 420 | 500 | 450 |
| 30S/10E-11A2 | Site #1 east tube | 4/16/1991 | Zone D | 8810 | | | 4007 | | | | | |
| 30S/10E-11A2 | Site #1 east tube | 10/30/2002 | Zone D | 6300 | 9200 | | | | | | | |
| 30S/10E-11A2 | Site #1 east tube | 3/14/2005 | Zone D | 8900 | 16000 | 180 | 5400 | 20 | 1300 | 430 | 770 | 640 |
| 30S/10E-14B1 | Site #3 north tube | 6/22/1977 | Zone C | 24000 | 31400 | 154 | 11700 | 220 | 6350 | 1780 | 512 | 815 |
| 30S/10E-14B1 | Site #3 north tube | 3/5/1986 | Zone C | 24600 | | | 14000 | | | | | |
| 30S/10E-14B1 | Site #3 north tube | 4/16/1991 | Zone C | 25006 | | | 13461 | | | | | |
| 30S/10E-14B1 | Site #3 north tube | 10/17/2002 | Zone C | 27000 | 47000 | | | | | | | |
| 30S/10E-14B1 | Site #3 north tube | 3/15/2005 | Zone C | 27000 | 50000 | 160 | 14000 | 290 | 8000 | 2200 | 440 | 990 |
| 30S/10E-14B2 | Site #3 south tube | 6/22/1977 | Zone D | 16600 | 23200 | 23 | 8100 | 42 | 3900 | 1290 | 1130 | 412 |
| 30S/10E-14B2 | Site #3 south tube | 3/15/2005 | Zone D | 17000 | 30000 | 18 | 8500 | 34 | 4300 | 960 | 1200 | 130 |
| 30S/10E-2A1 | Site #2 east tube | 7/8/1977 | Zone E | 2420 | 4537 | 46.8 | 1379 | | 694 | 53 | 128 | 11 |
| 30S/10E-2A1 | Site #2 east tube | 4/16/1991 | Zone E | 5692 | | | 2791 | | | | | |
| 30S/10E-2A1 | Site #2 east tube | 3/15/2005 | Zone E | 5400 | 8700 | 58 | 2800 | 47 | 1500 | 320 | 430 | 13 |

# LOS OSOS WELL SITES

| WELL # | NORTHING | EASTING | ELEV |
|---|---|---|---|
| MW 11–A1 | 2320695.426 | 5707615.957 | 16.01 |
| MW 11–A2 | 2320695.246 | 5707616.151 | 16.07 |
| MW 14–B1 | 2315661.515 | 5706158.882 | 16.29 |
| MW 14–B2 | 2315661.239 | 5706158.613 | 16.56 |
| MW 2–A1 | 2326924.376 | 5708412.990 | 15.83 |
| MW 12–J1 | 2318375.627 | 5713447.149 | 8.43 |




E:\2005\2005020–San–Spit–Well–Sites\Survey\Drawings\Los Osos Well Sites SP.dwg, Layout1, Mar 28, 2005 11:53am, dischiosser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Vic Montgomery, Architect CA 11090 • Jerry Michael, RCE 36895, LS 6376 • Jeff Ferber, Landscape Architect 2844


PLAT

OF LOS OSOS WELL SITES ALONG SAND SPIT AND AT PASADENA BEACH ACCESS

DATE: 3–28–05 SCALE: NTS

# Appendix L

## Water Quality Figures - Creek Valley Group

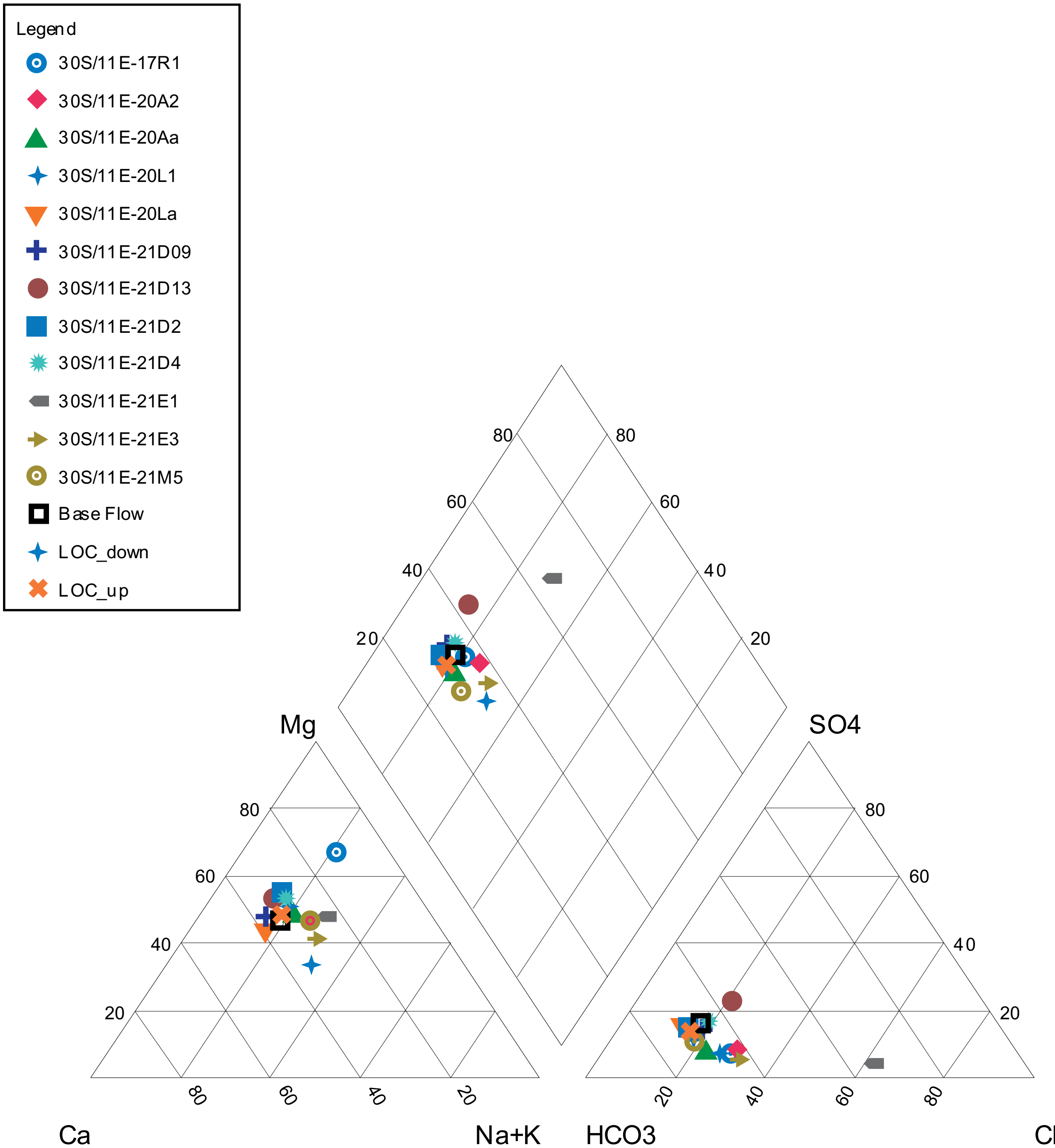



Figure L1
Piper Diagram
Creek Valley Group

DWR Grant Project
Los Osos CDS

Cleath & Associates

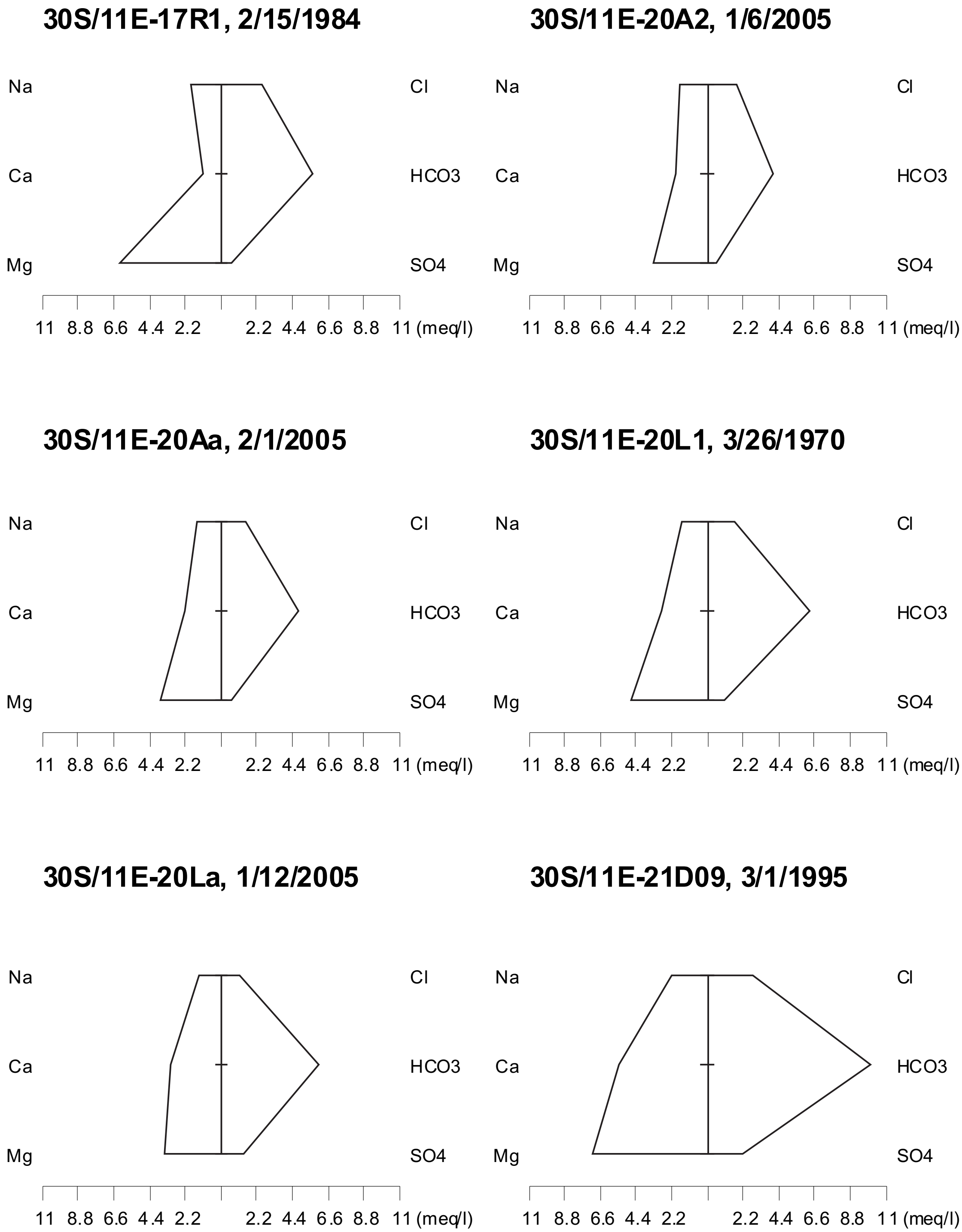
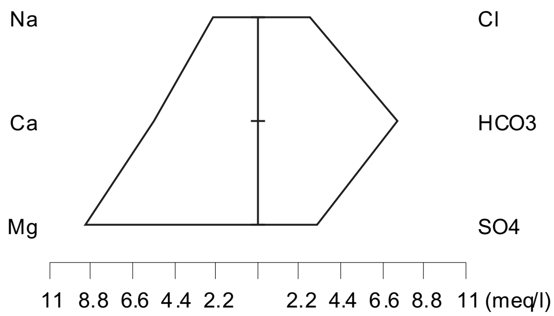



Figure L2
Stiff Diagrams
Creek Valley Group

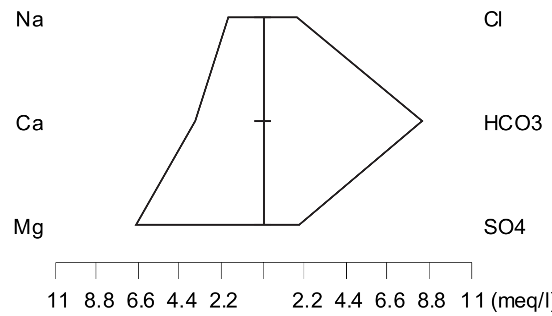
DWR Grant Project
Los Osos CDS

Cleath & Associates

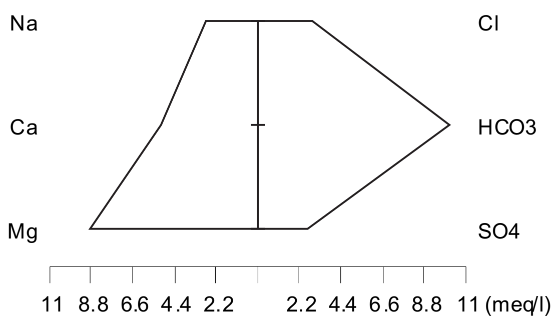
**30S/11E-21D13, 1/6/2005**



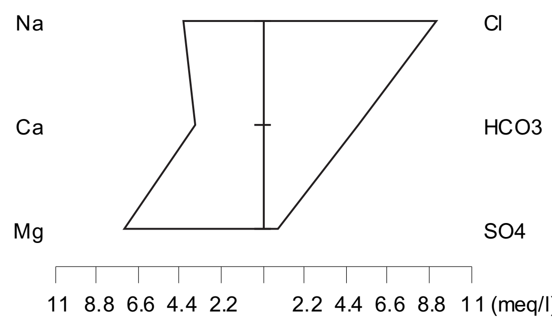

**30S/11E-21D2, 6/15/1989**



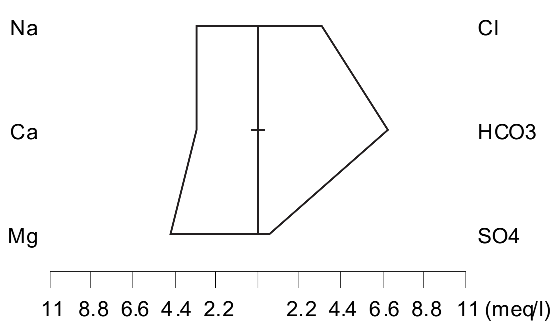

**30S/11E-21D4, 6/6/1973**




**30S/11E-21E1, 3/27/1970**




**30S/11E-21E3, 3/3/1982**




**30S/11E-21M5, 3/3/1982**

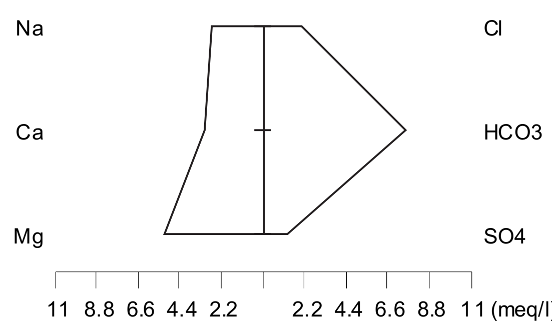
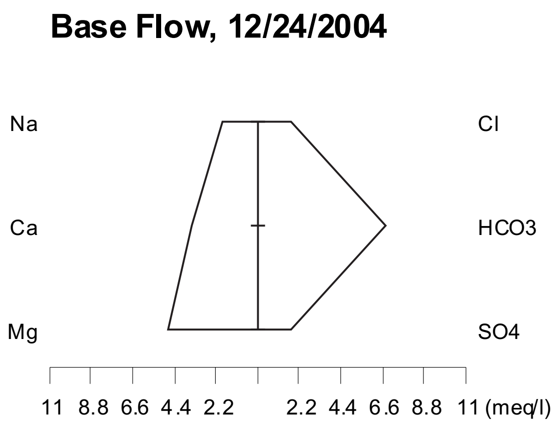
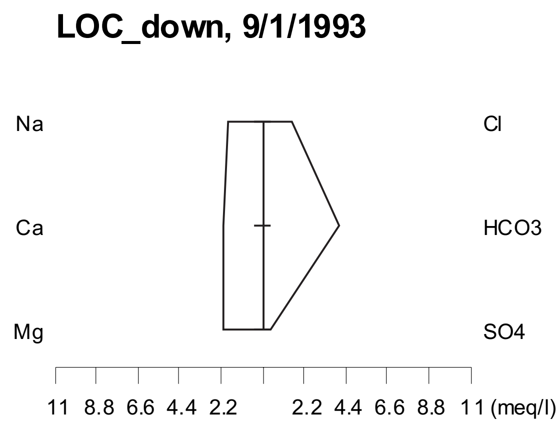



Figure L3
Stiff Diagrams
Creek Valley Group

DWR Grant Project
Los Osos CDS

Cleath & Associates



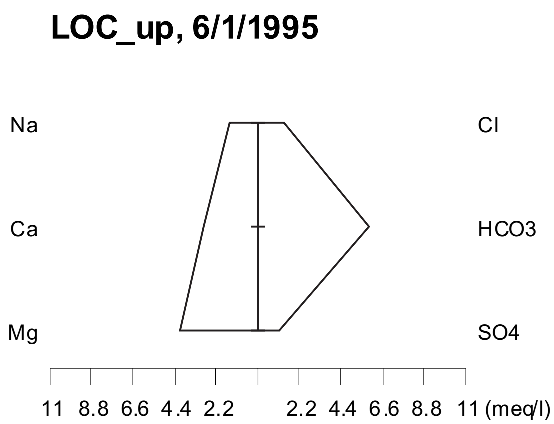
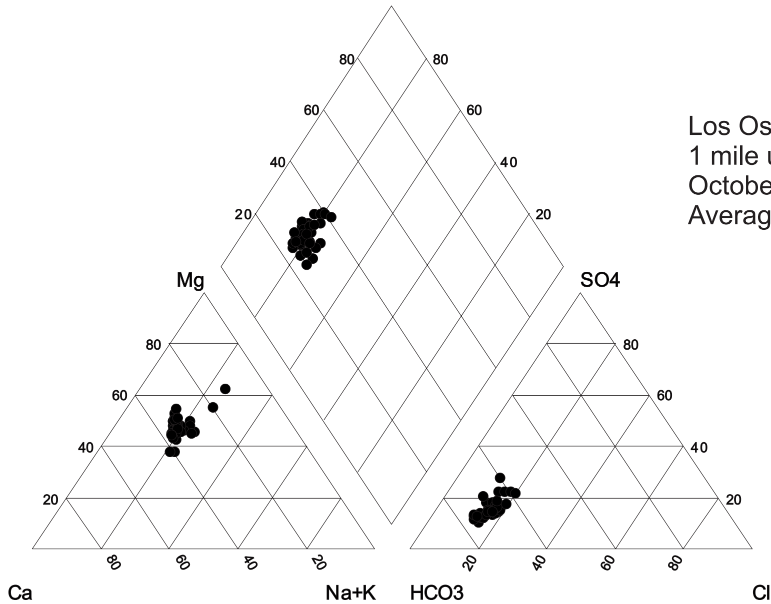



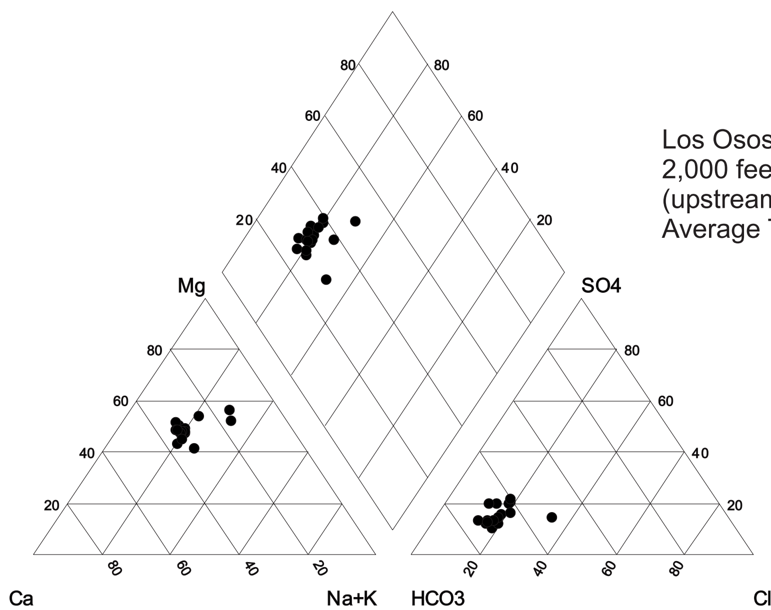

Figure L4
Stiff Diagrams
Creek Valley Group

DWR Grant Project
Los Osos CDS

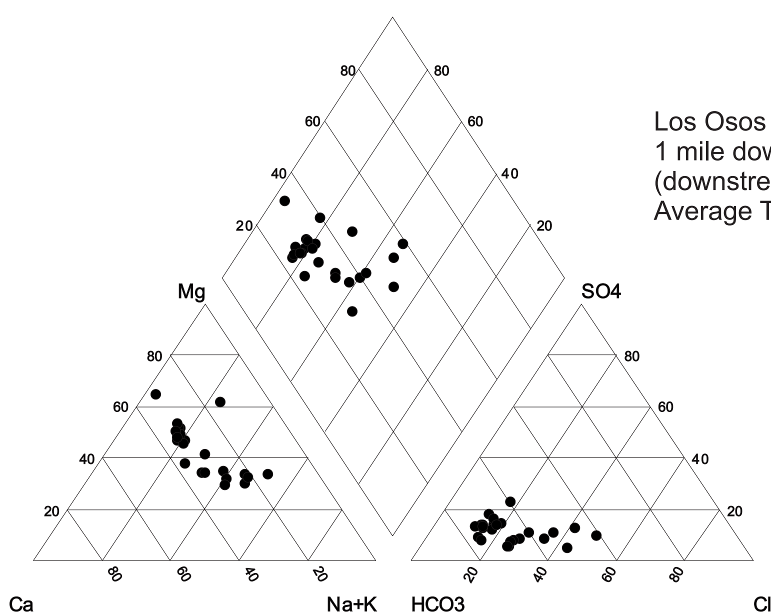
Cleath & Associates




Los Osos Creek
1 mile upstream of LOVR
October 1983 - December 1998
Average TDS = 540 mg/l




Los Osos Creek
2,000 feet downstream of LOVR
(upstream of Eto Lake)
Average TDS = 505 mg/l




Los Osos Creek
1 mile downstream of LOVR
(downstream of Eto Lake)
Average TDS = 400 mg/l

Figure L5
Piper Diagrams
Los Osos Creek Water

DWR Grant Project
Los Osos CSD

Cleath & Associates

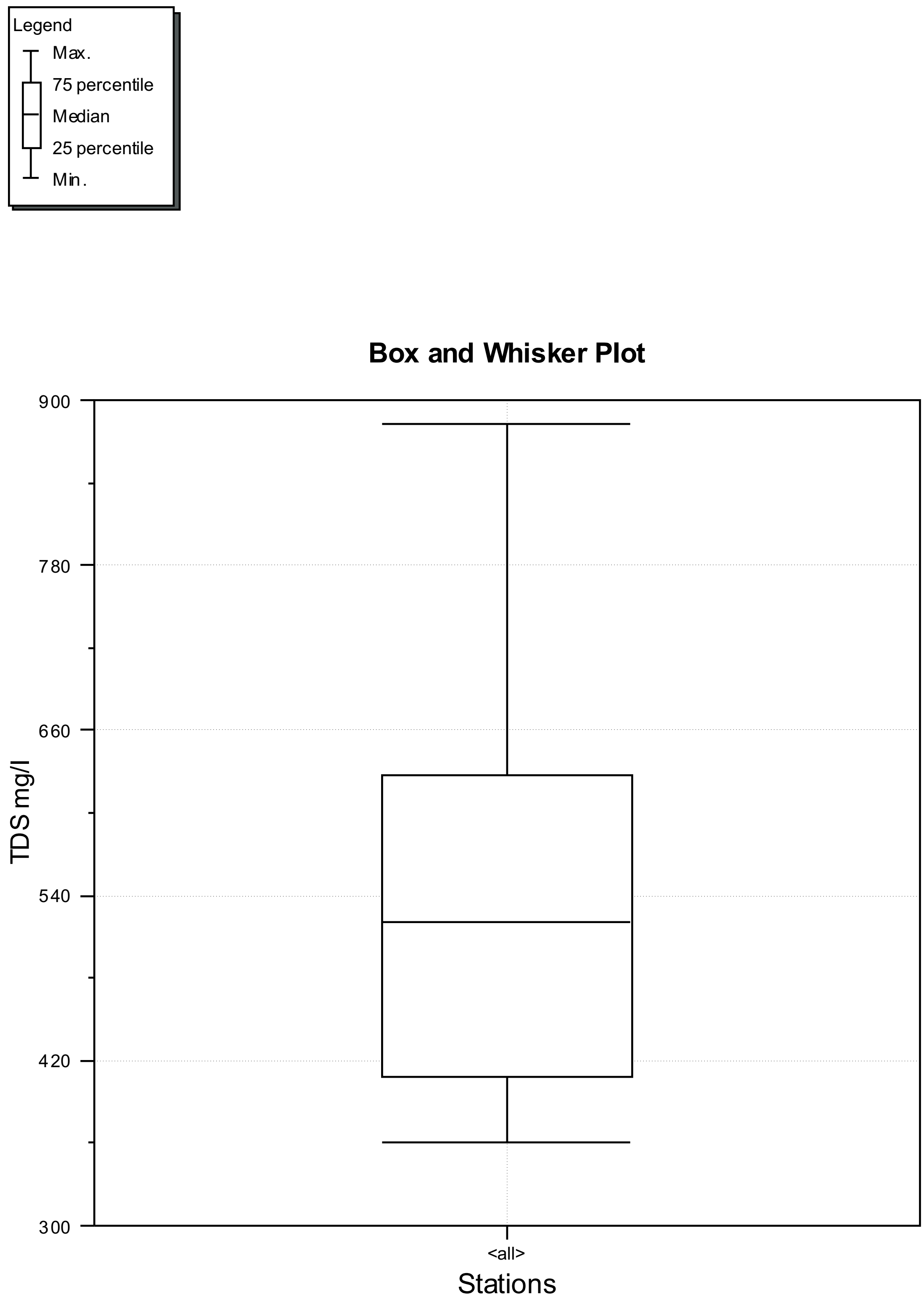



Figure L6
Total Dissolved Solids
Creek Valley Group

DWR Grant Project
Los Osos CSD

Cleath & Associates

# Appendix M

## Water Quality Figures - Upper Aquifer Group

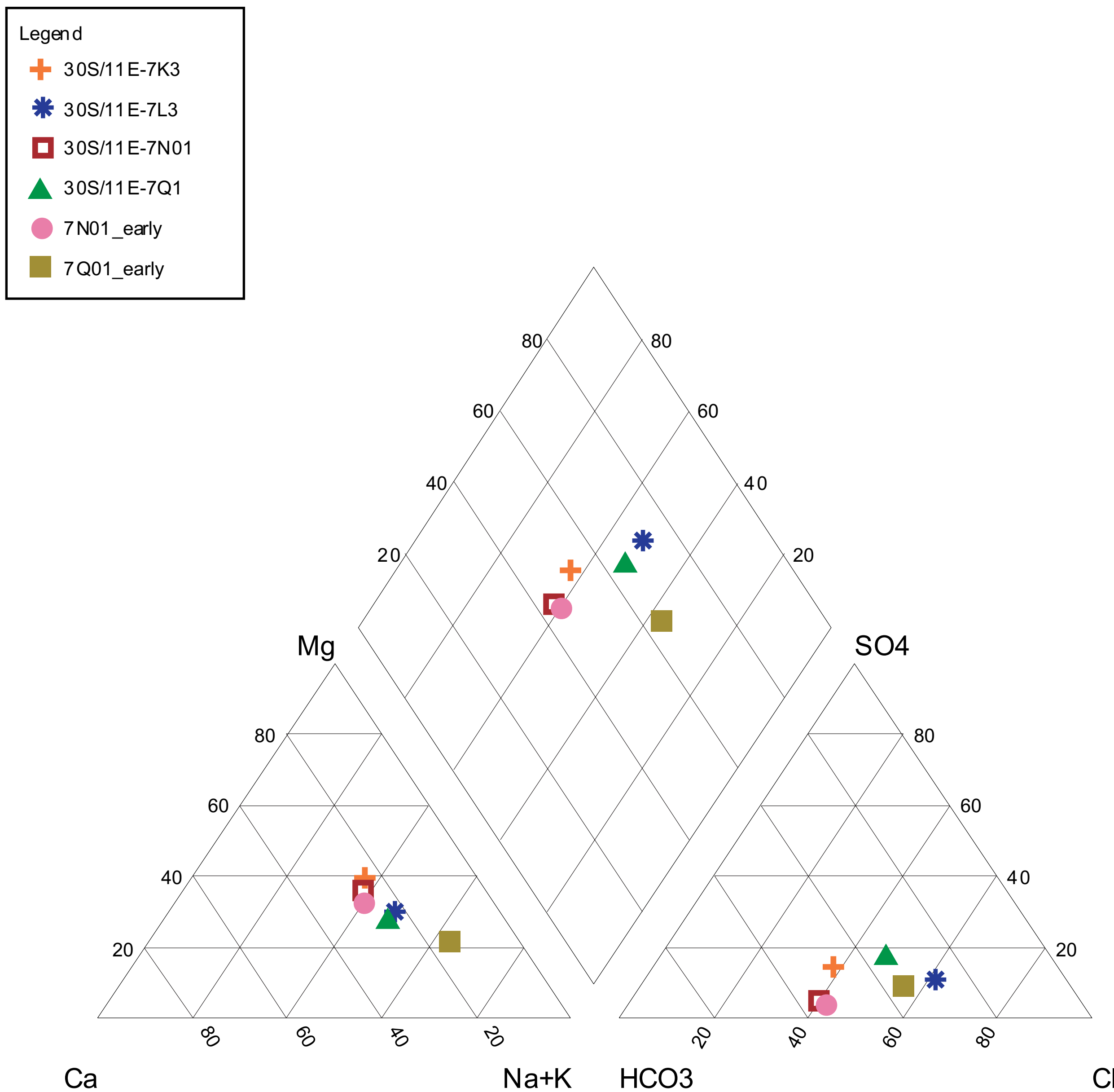



Figure M1
Piper Diagram
Upper Aquifer Group - Section 7

DWR Grant Project
Los Osos CDS

Cleath & Associates

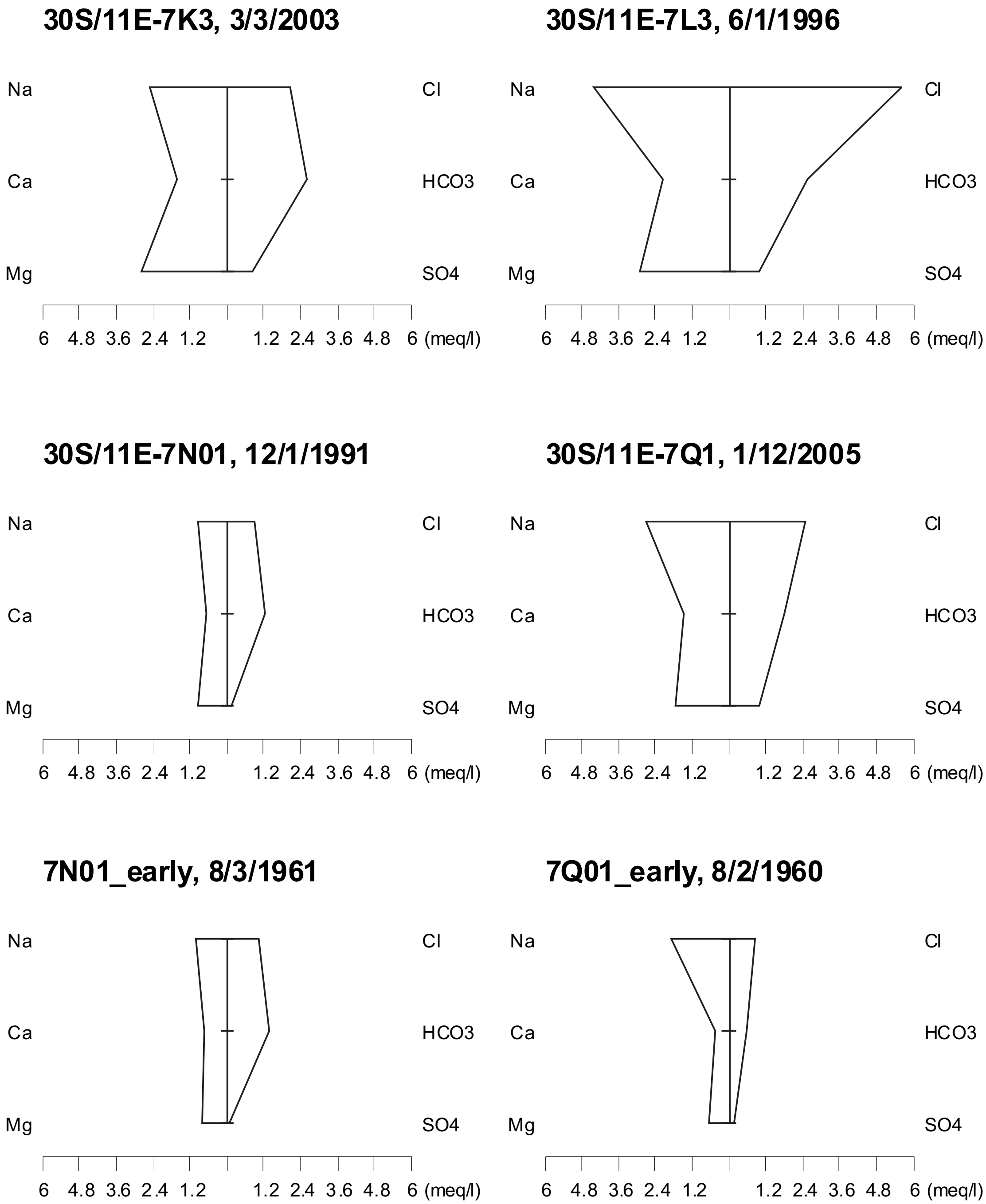



Figure M2
Stiff Diagrams
Upper Aquifer Group - Section 7

DWR Grant Project
Los Osos CDS

Cleath & Associates

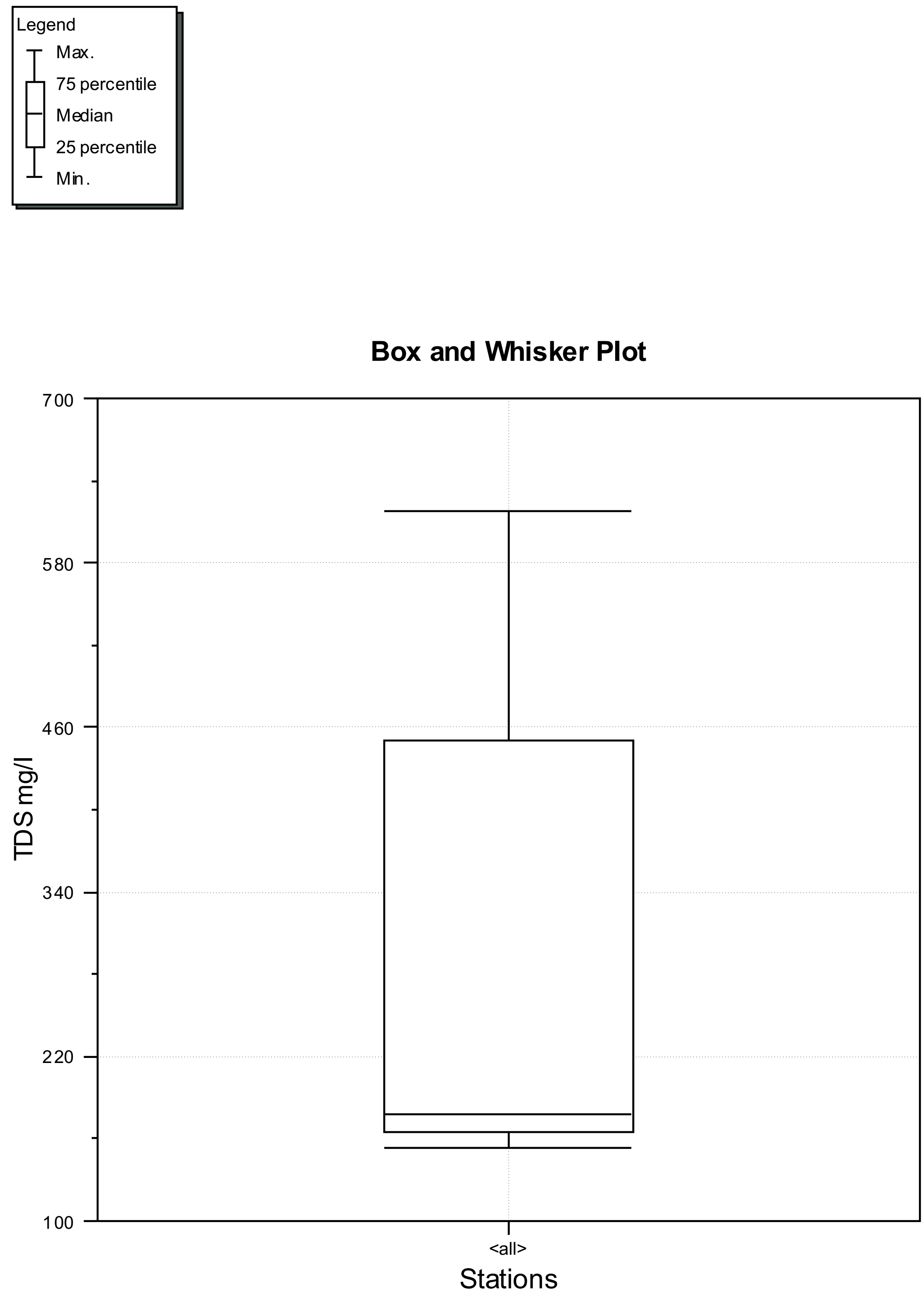



Figure M3
Total Dissolved Solids
Upper Aquifer Group - Section 7

DWR Grant Project
Los Osos CDS

Cleath & Associates

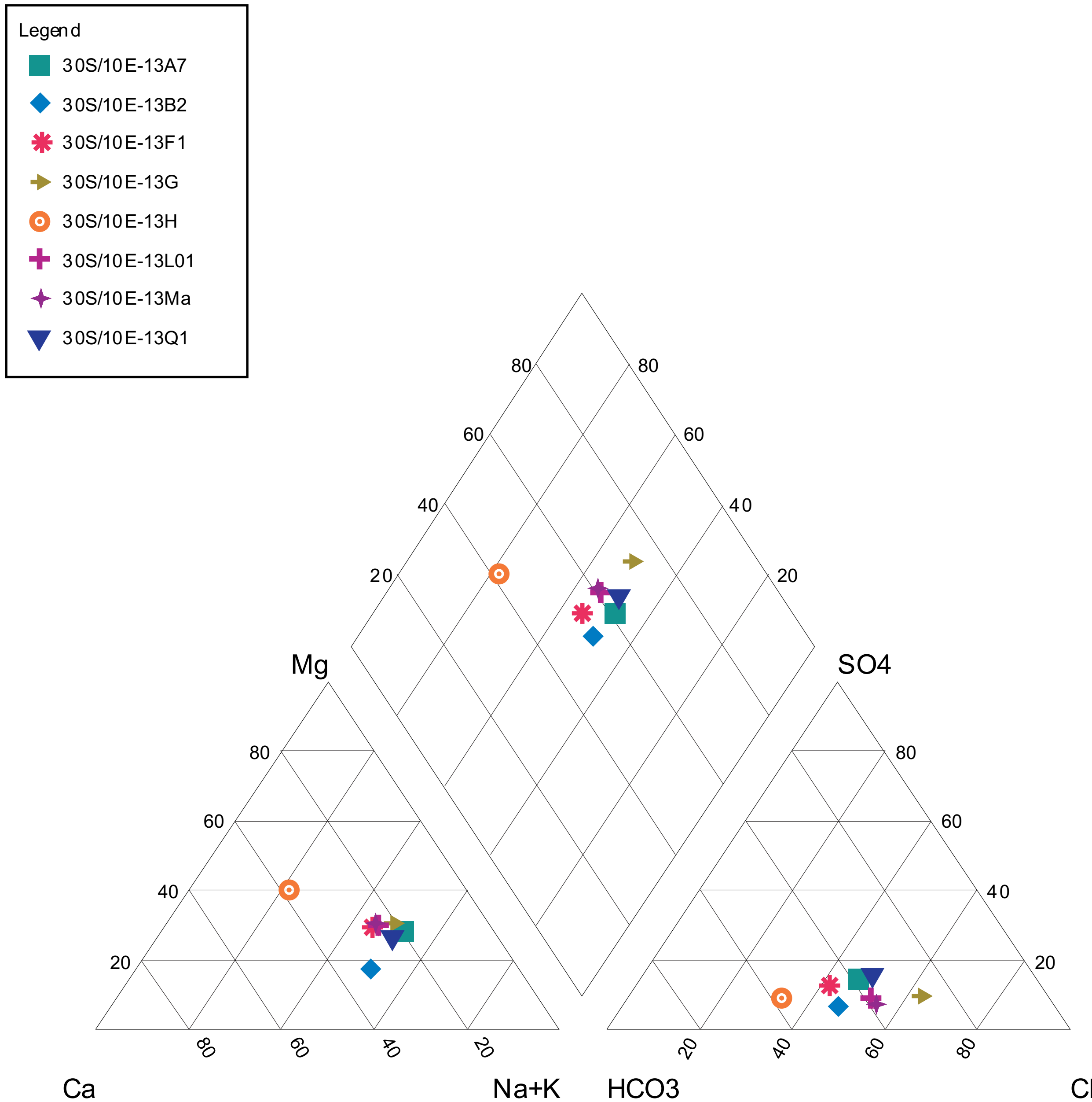



Figure M4
Piper Diagram
Upper Aquifer Group - Section 13

DWR Grant Project
Los Osos CDS

Cleath & Associates

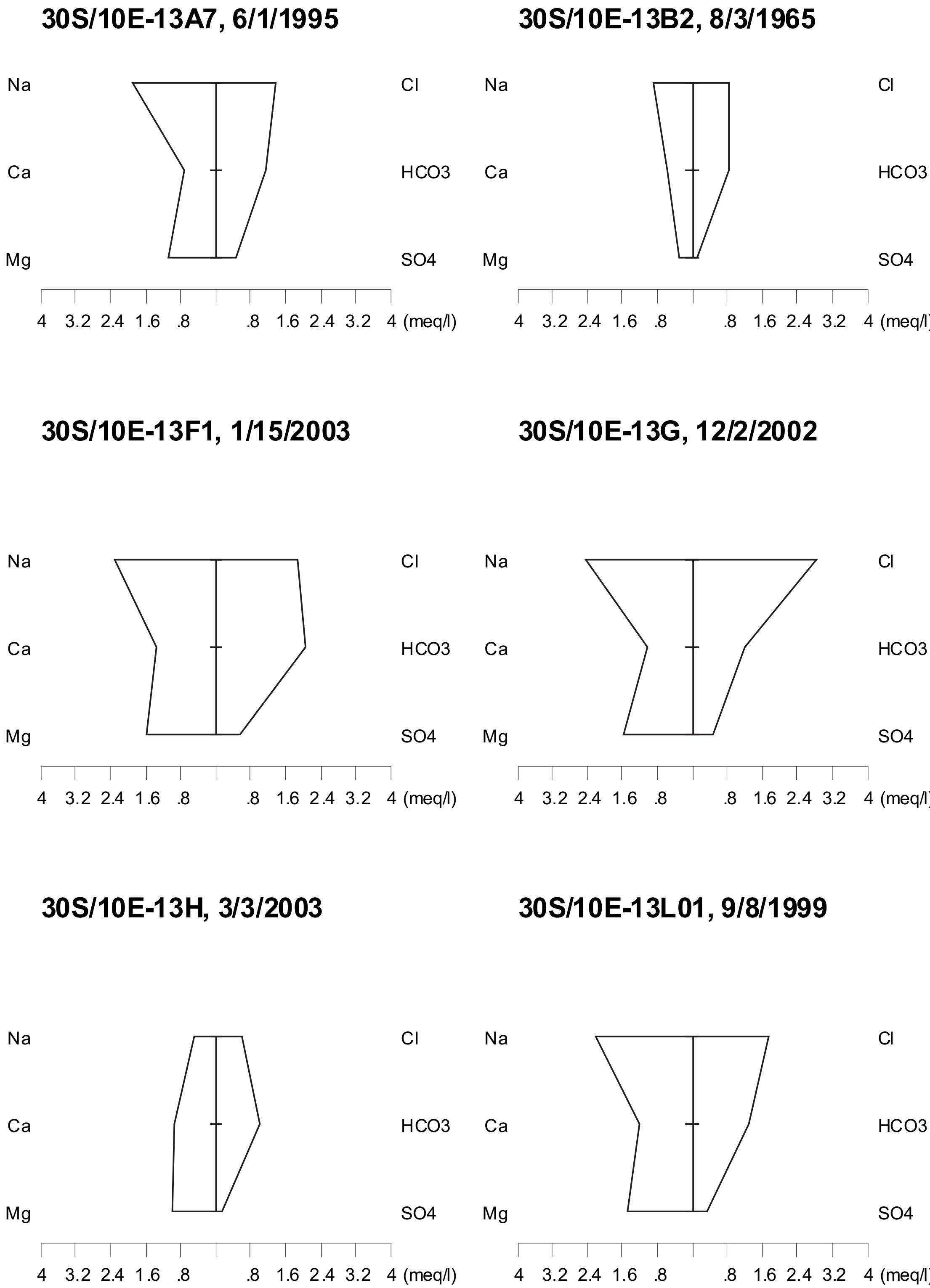
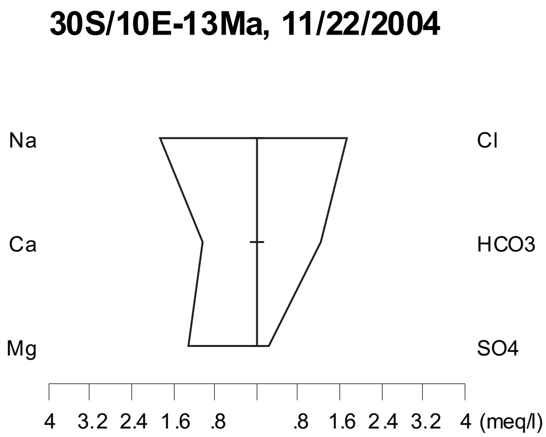



Figure M5
Stiff Diagrams
Upper Aquifer Group - Section 13

DWR Grant Project
Los Osos CDS

Cleath & Associates



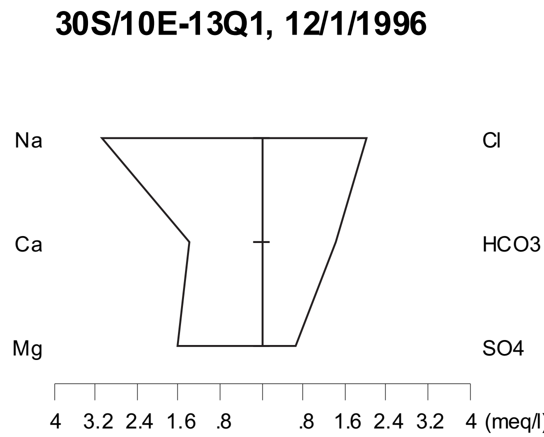




Figure M6
Stiff Diagrams
Upper Aquifer Group - Section 13

DWR Grant Project
Los Osos CDS

Cleath & Associates

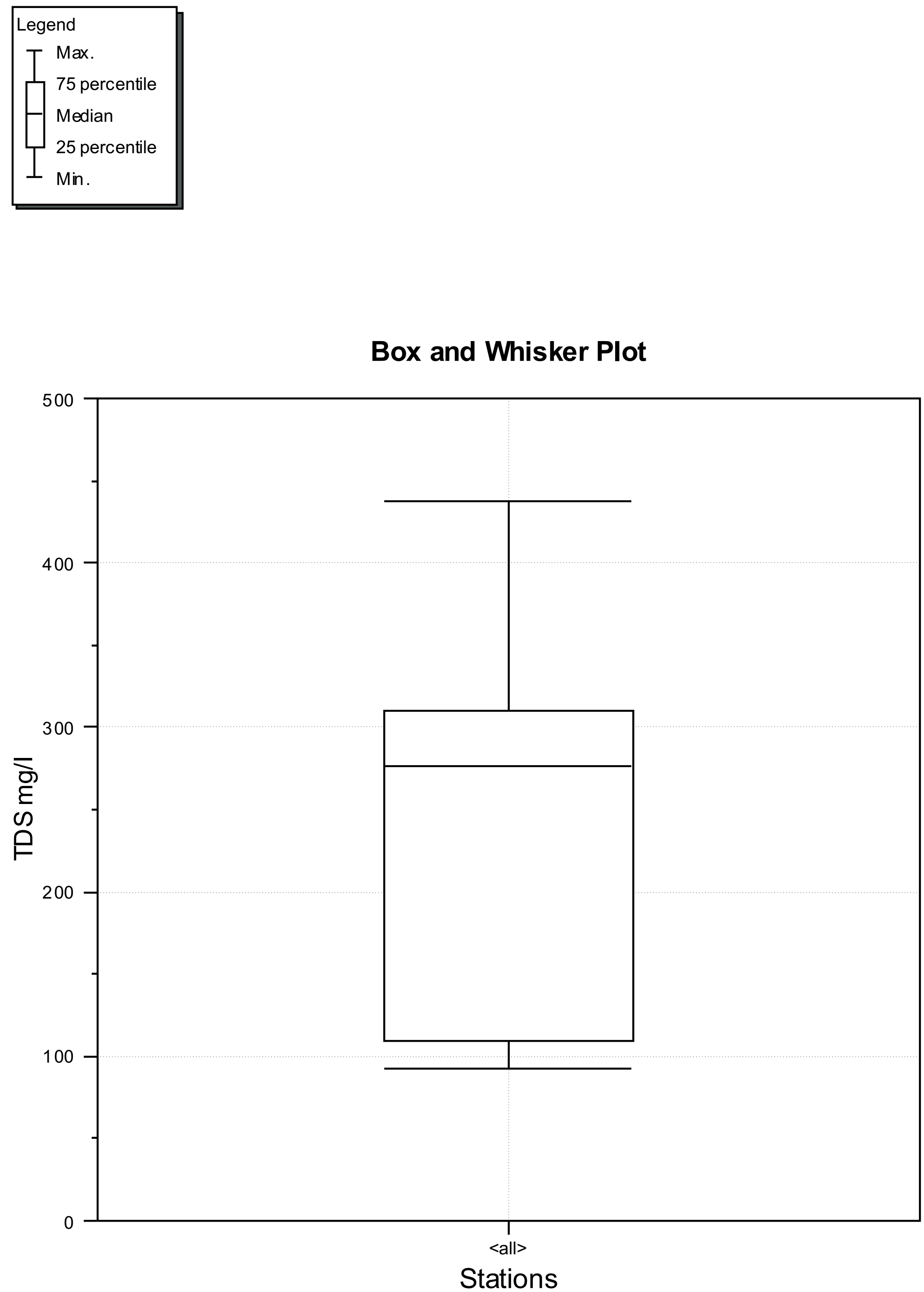



Figure M7
Total Dissolved Solids
Upper Aquifer Group - Section 13

DWR Grant Project
Los Osos CDS

Cleath & Associates

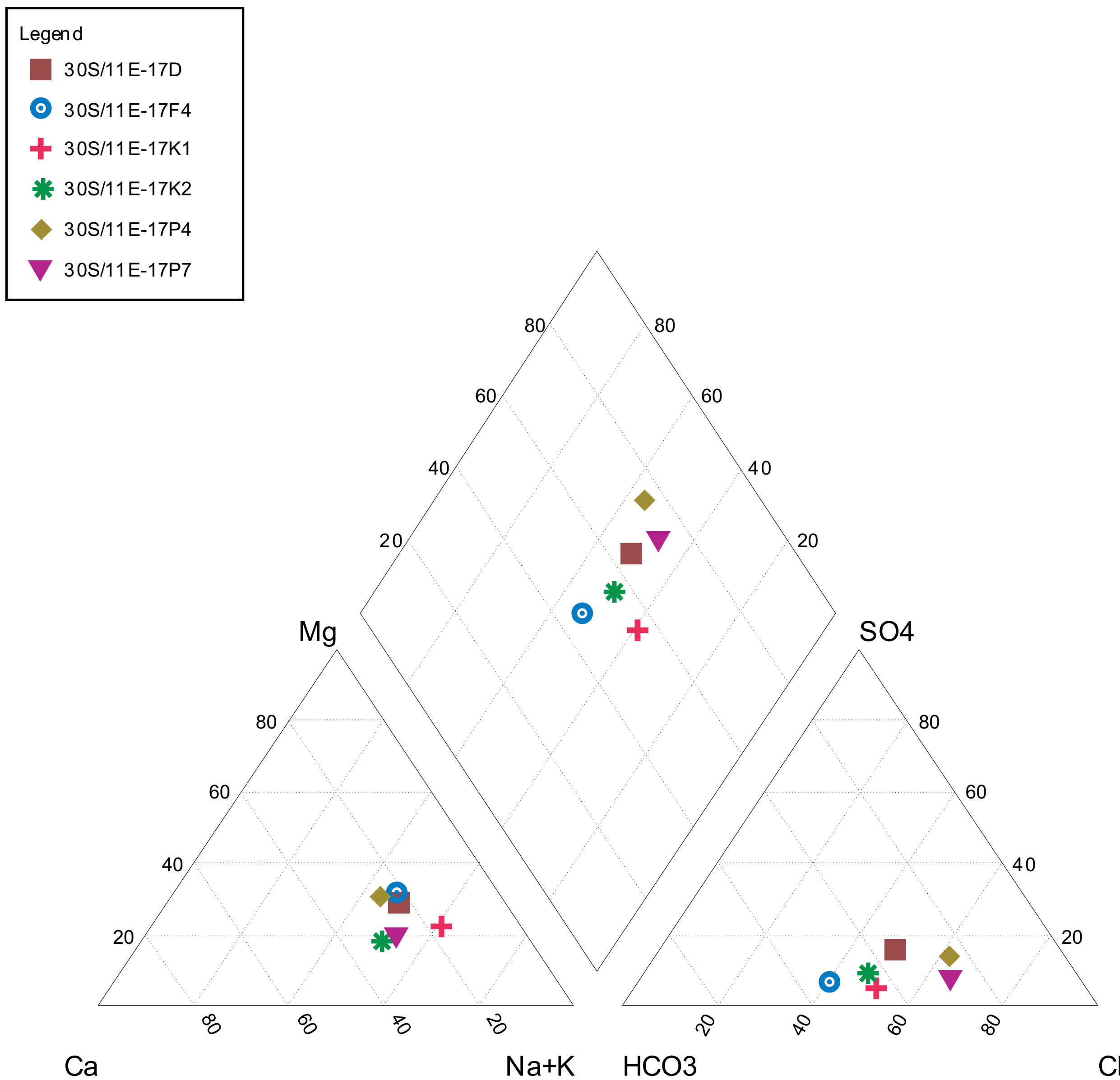



Figure M8
Piper Diagram
Upper Aquifer Group - Section 17

DWR Grant Project
Los Osos CDS

Cleath & Associates

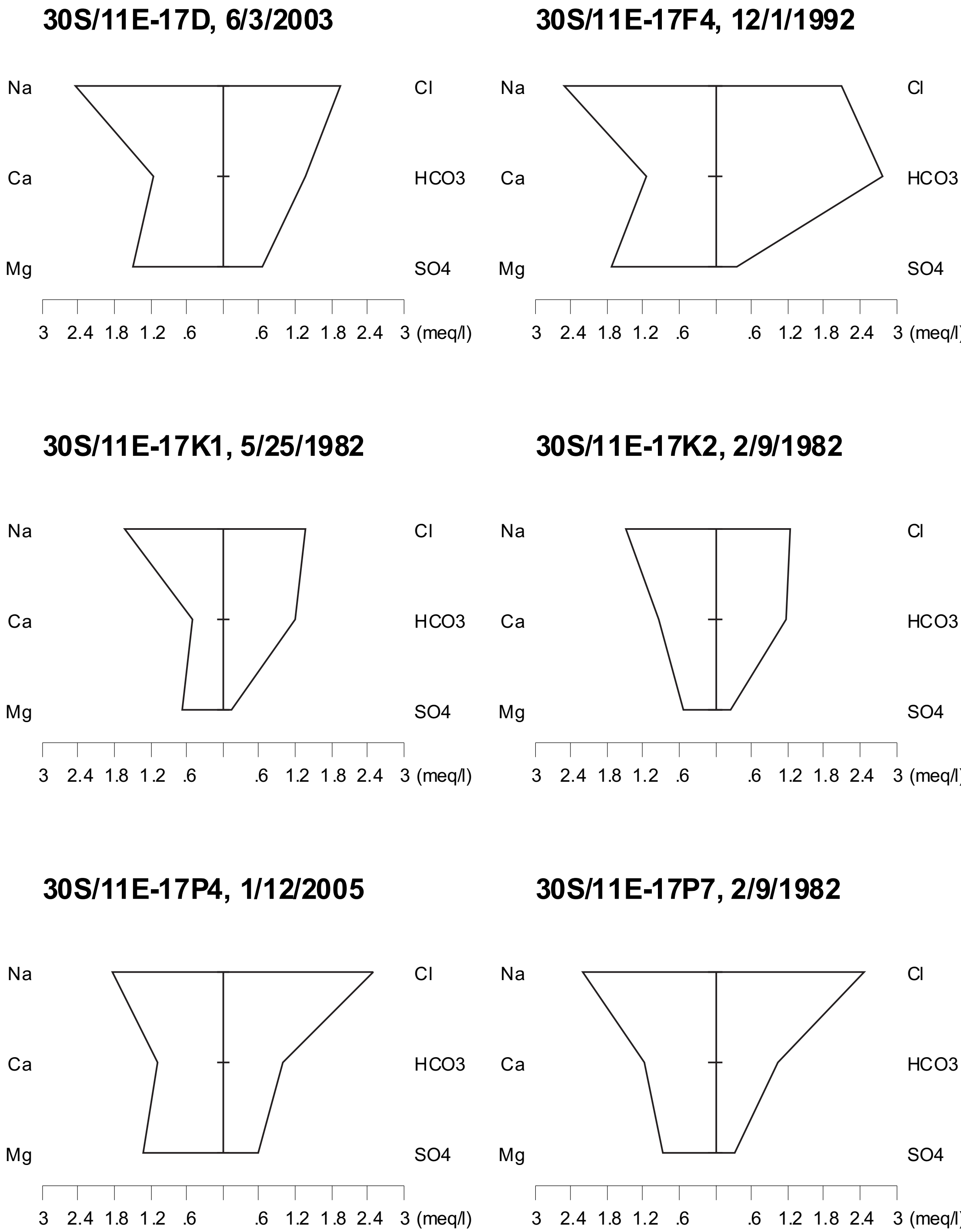



Figure M9
Stiff Diagrams
Upper Aquifer Group - Section 17

DWR Grant Project
Los Osos CDS

Cleath & Associates

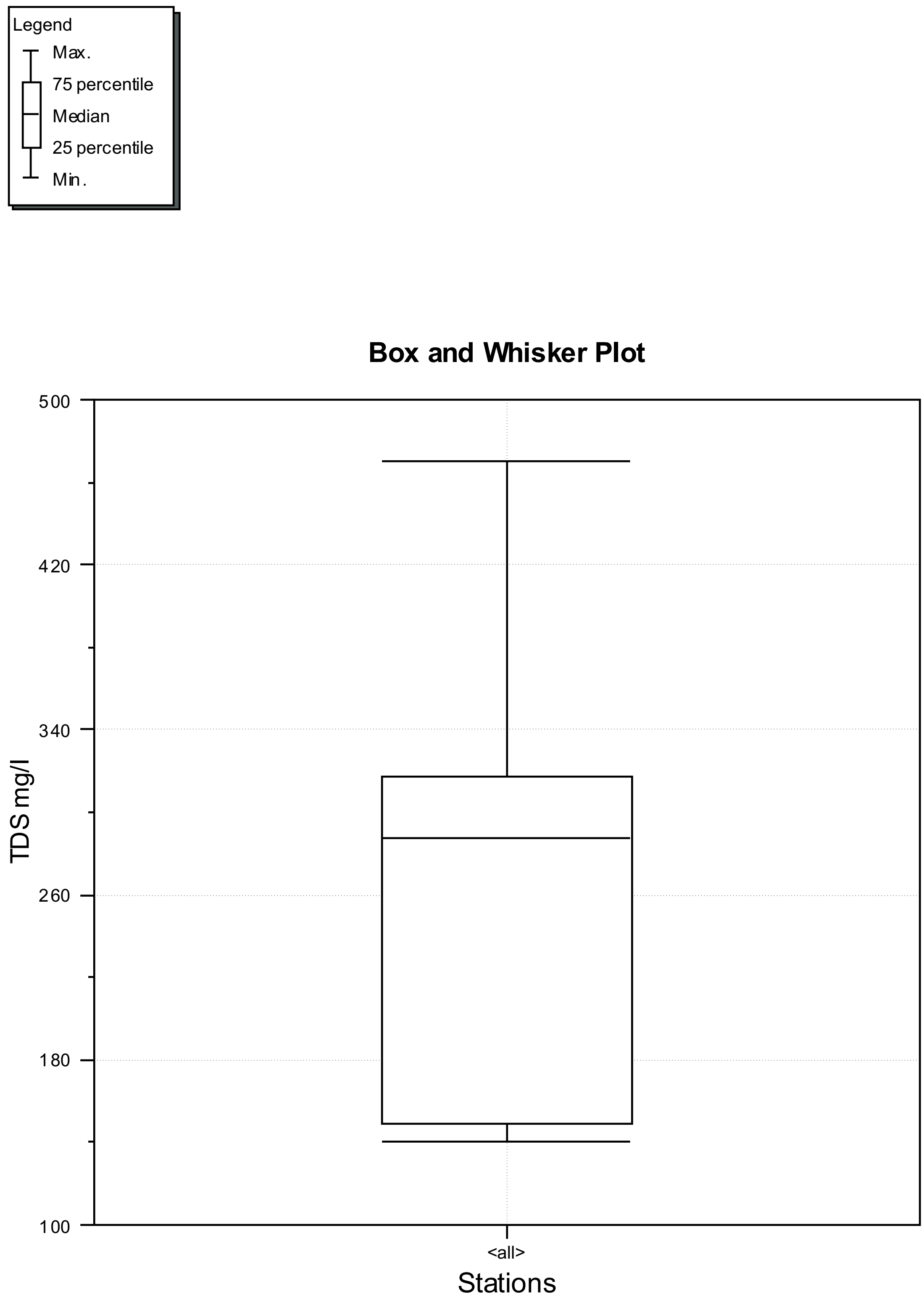



Figure M10
Total Dissolved Solids
Upper Aquifer Group - Section 17

DWR Grant Project
Los Osos CDS

Cleath & Associates

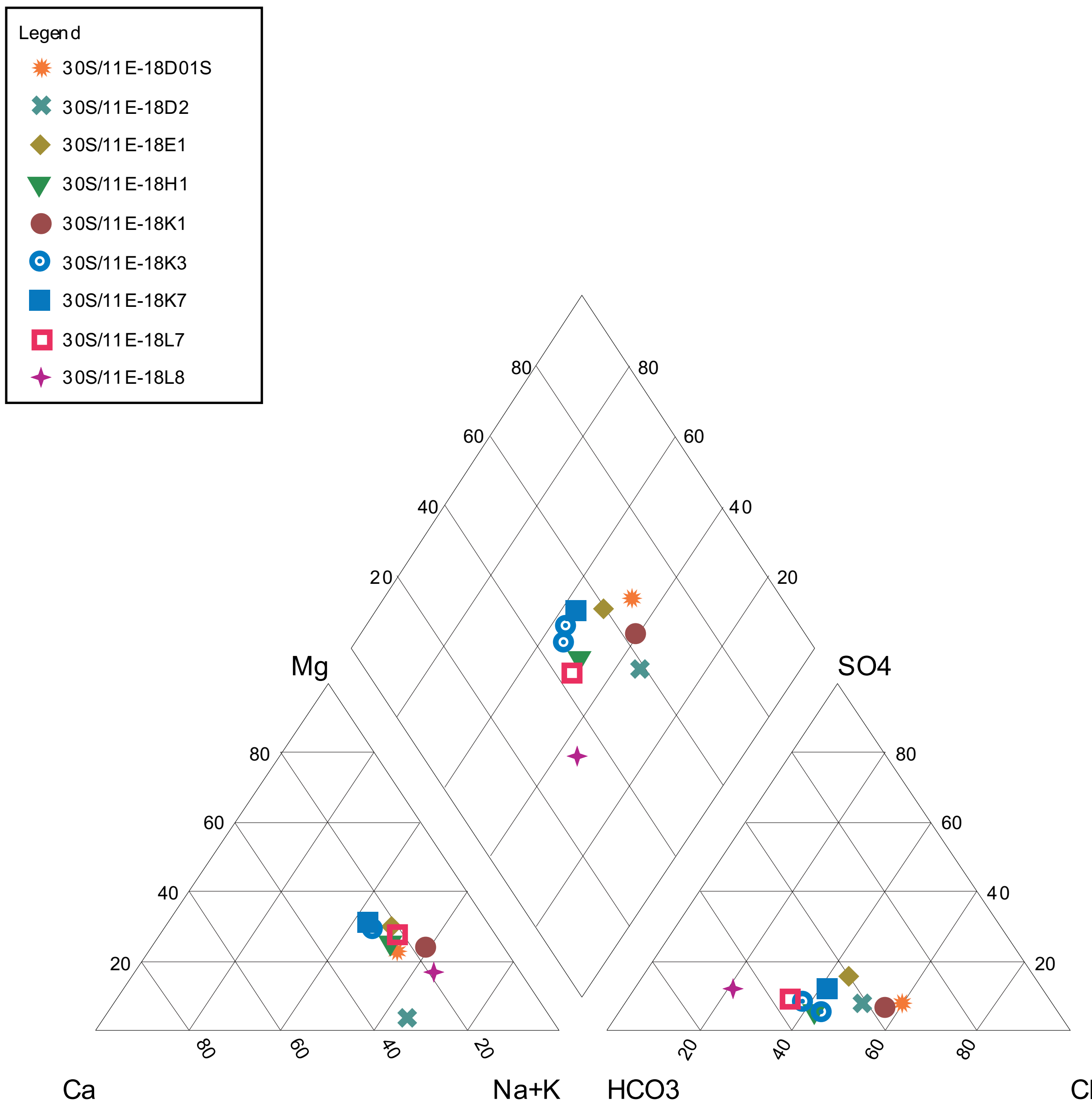



Figure M11
Piper Diagram
Upper Aquifer Group - Section 18

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Los Osos CDS

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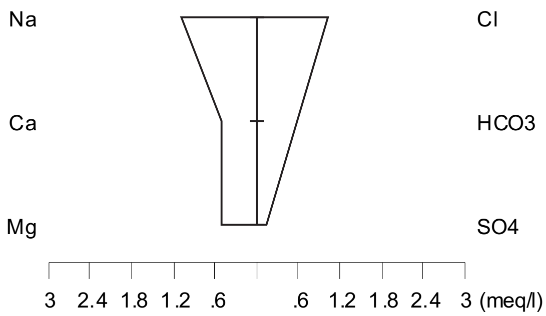
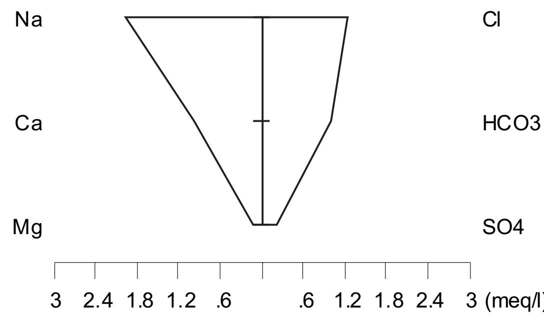
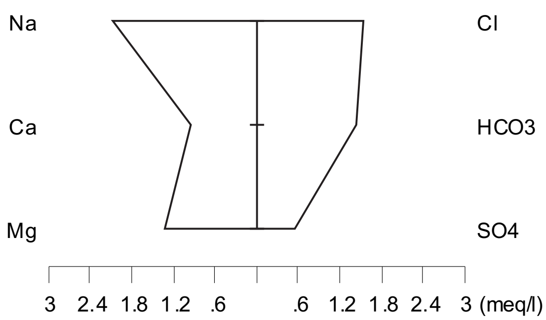
**30S/11E-18D01S, 3/26/1970**



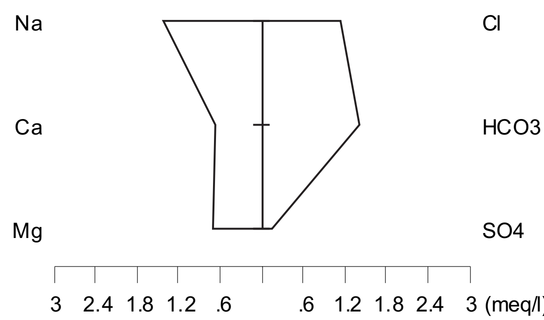

**30S/11E-18D2, 2/9/1982**



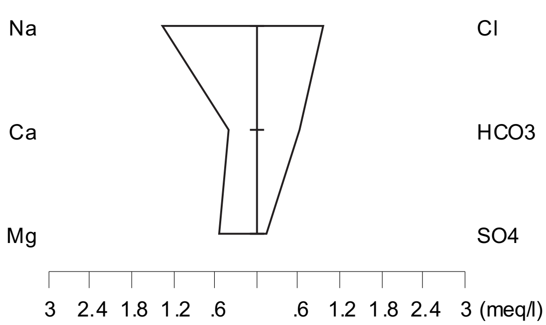

**30S/11E-18E1, 6/3/2003**




**30S/11E-18H1, 8/9/1983**




**30S/11E-18K1, 8/14/1984**




**30S/11E-18K3, 9/23/1991**

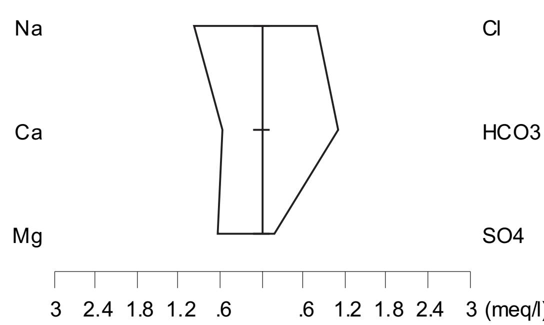



Figure M12
Stiff Diagrams
Upper Aquifer Group - Section 18

DWR Grant Project
Los Osos CDS

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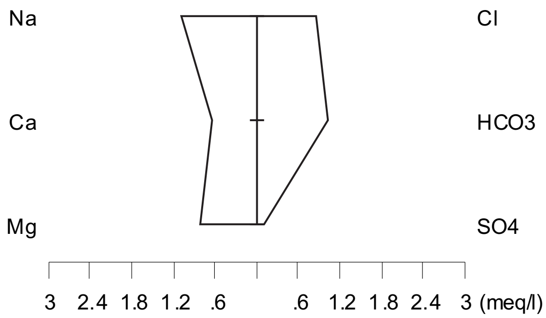
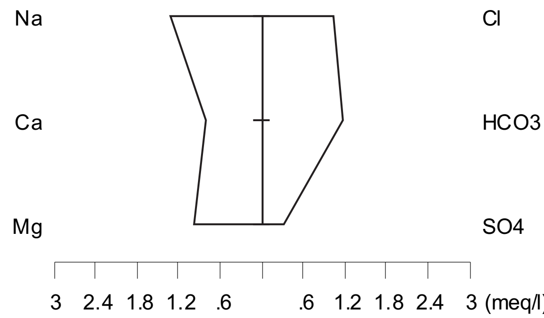
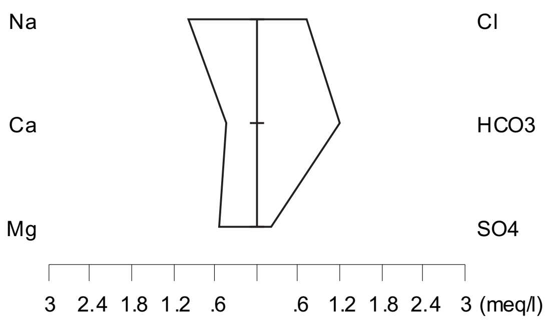
**30S/11E-18K3, 12/20/2004**




**30S/11E-18K7, 1/19/2005**




**30S/11E-18L7, 1/13/2005**




**30S/11E-18L8, 8/7/1985**

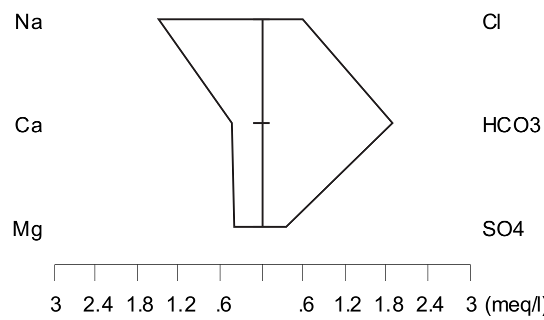



Figure M13
Stiff Diagrams
Upper Aquifer Group - Section 18

DWR Grant Project
Los Osos CDS

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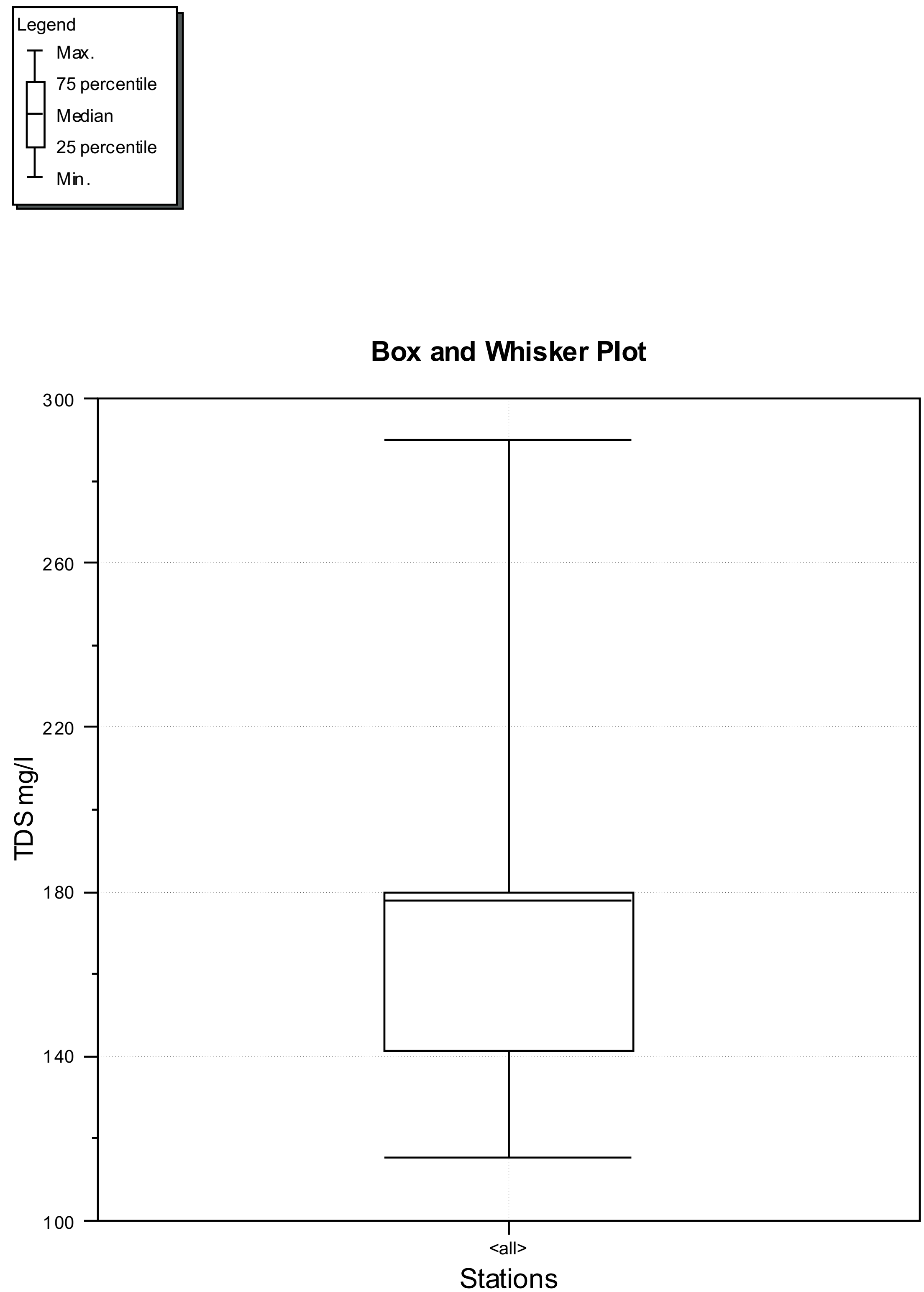


Figure M14
Total Dissolved Solids
Upper Aquifer Group - Section 18

DWR Grant Project
Los Osos CDS

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# Appendix N

## Water Quality Figures - Sea Water

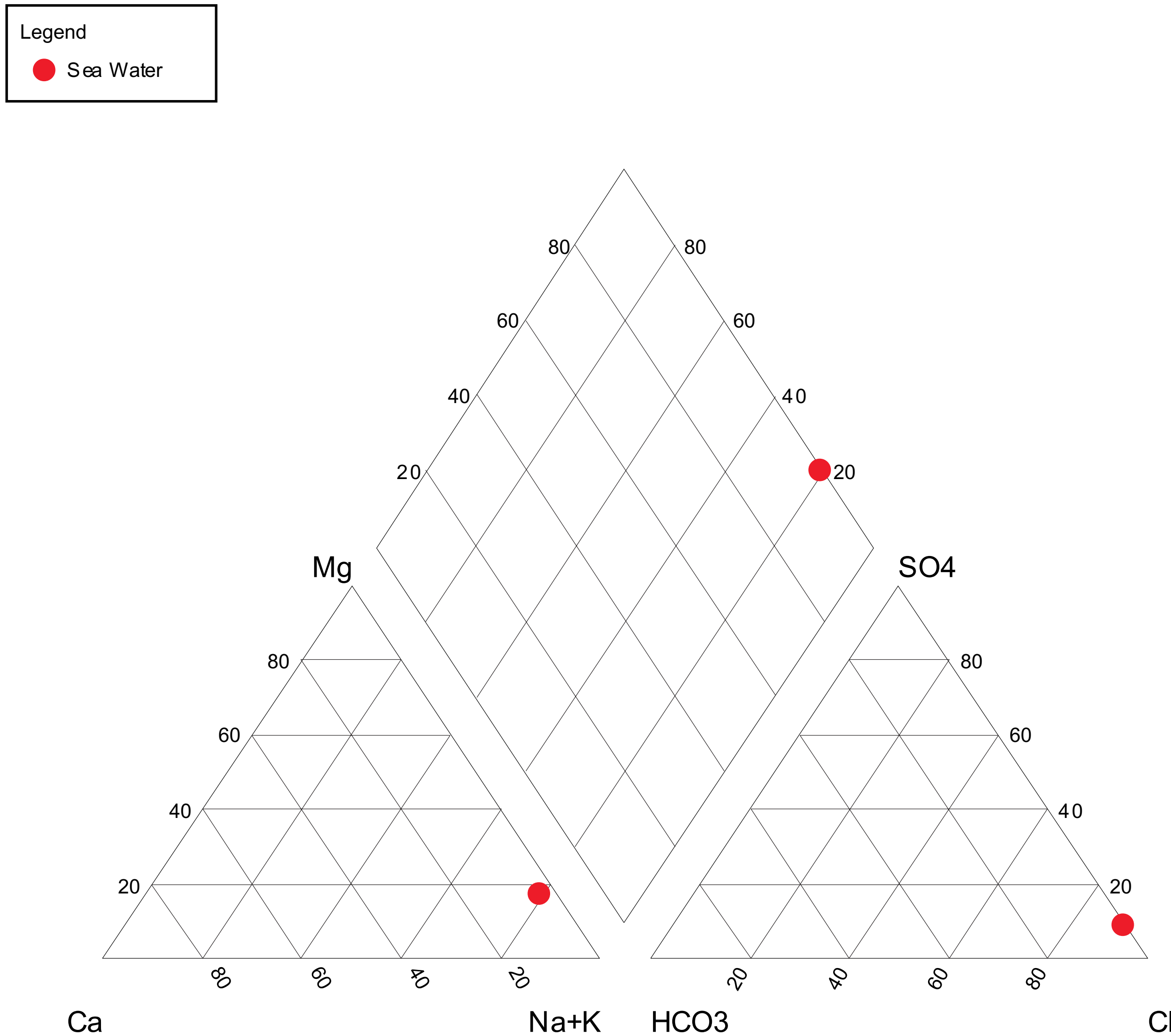


Figure N1
Piper Diagram
Sea Water

DWR Grant Project
Los Osos CDS

Cleath & Associates

**Sea Water, 6/29/1977**

# TDS = 36,300 mg/l

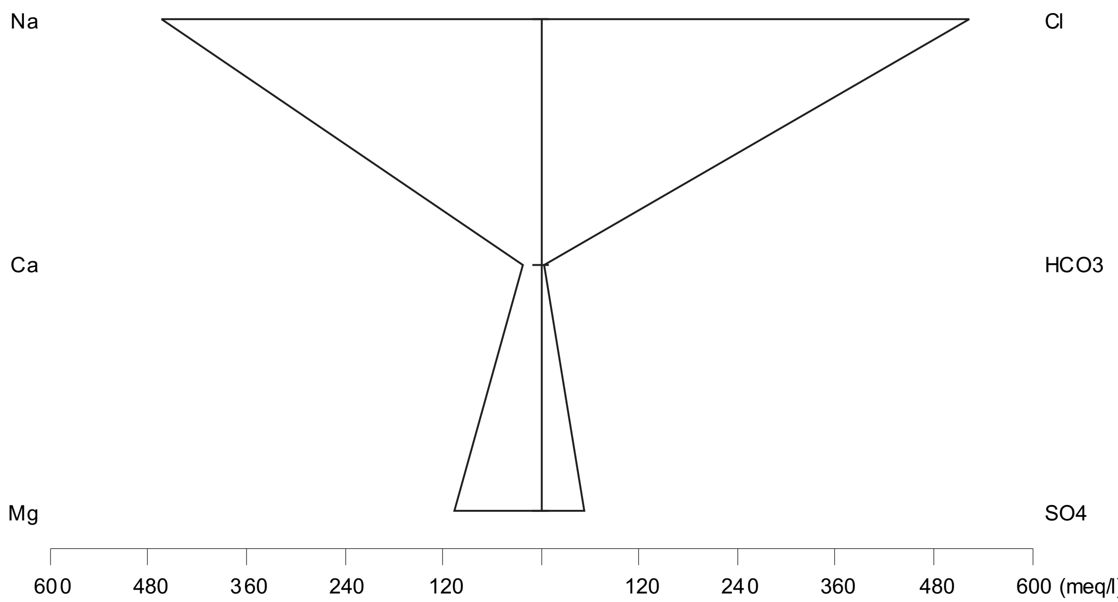


Figure N2
Stiff Diagram
Sea Water

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# Appendix O

# Water Quality Figures - Bedrock Group

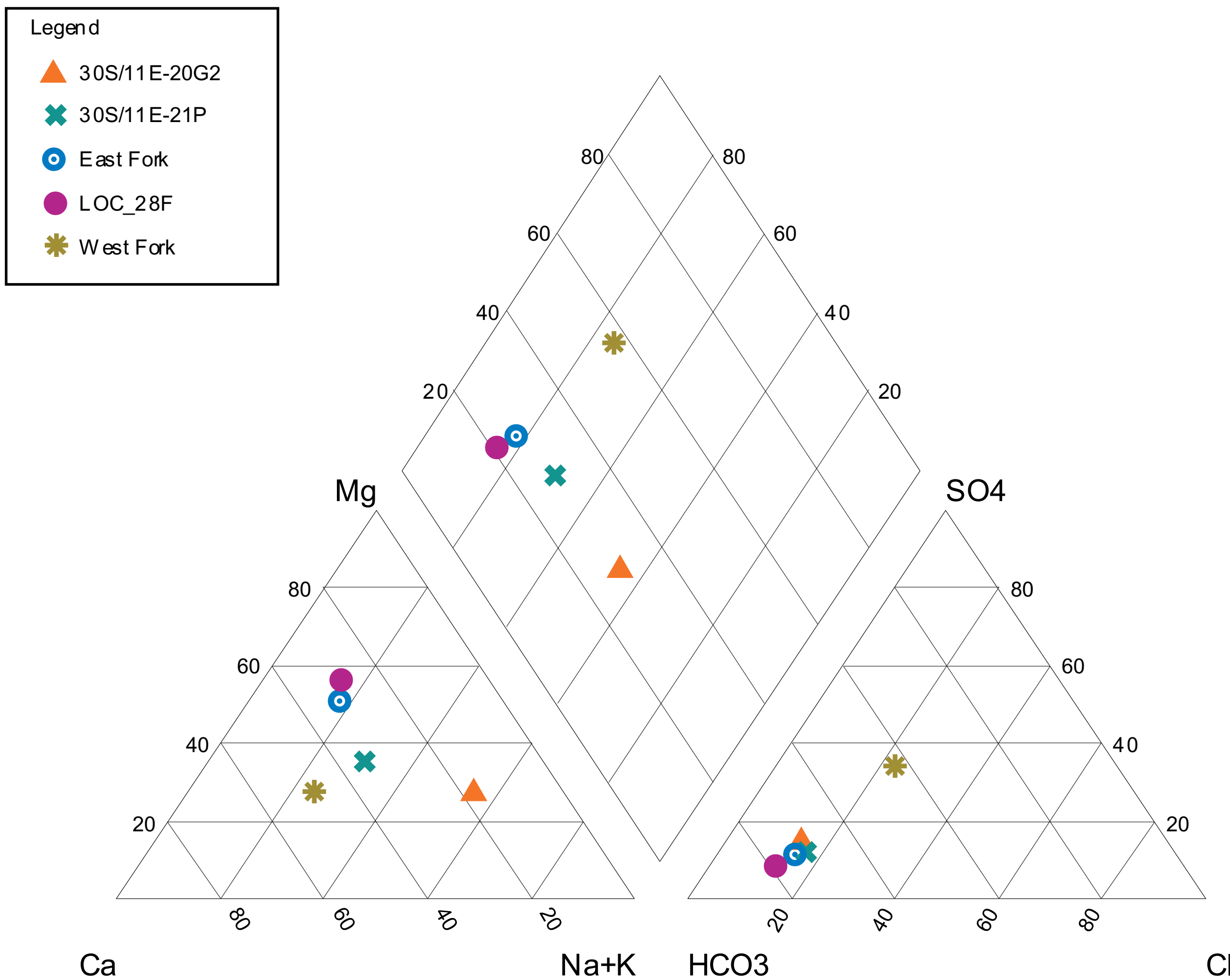


Figure O1
Piper Diagram
Bedrock Group

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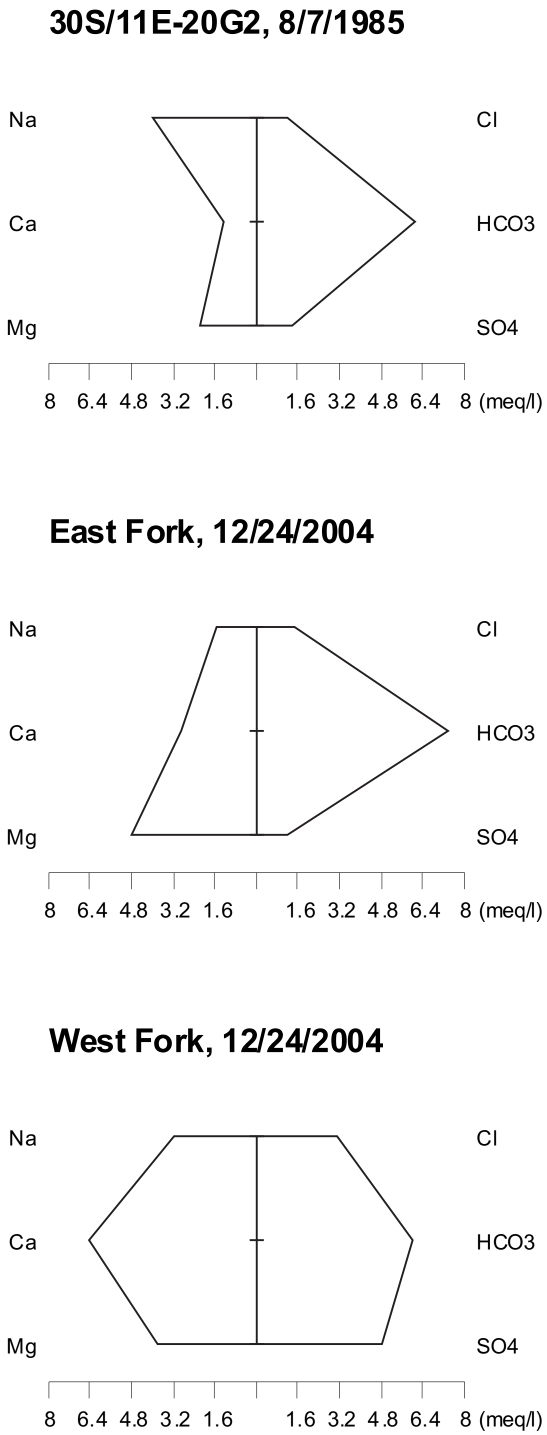


Figure O2
Stiff Diagrams
Bedrock Group

DWR Grant Project
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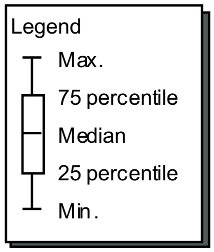


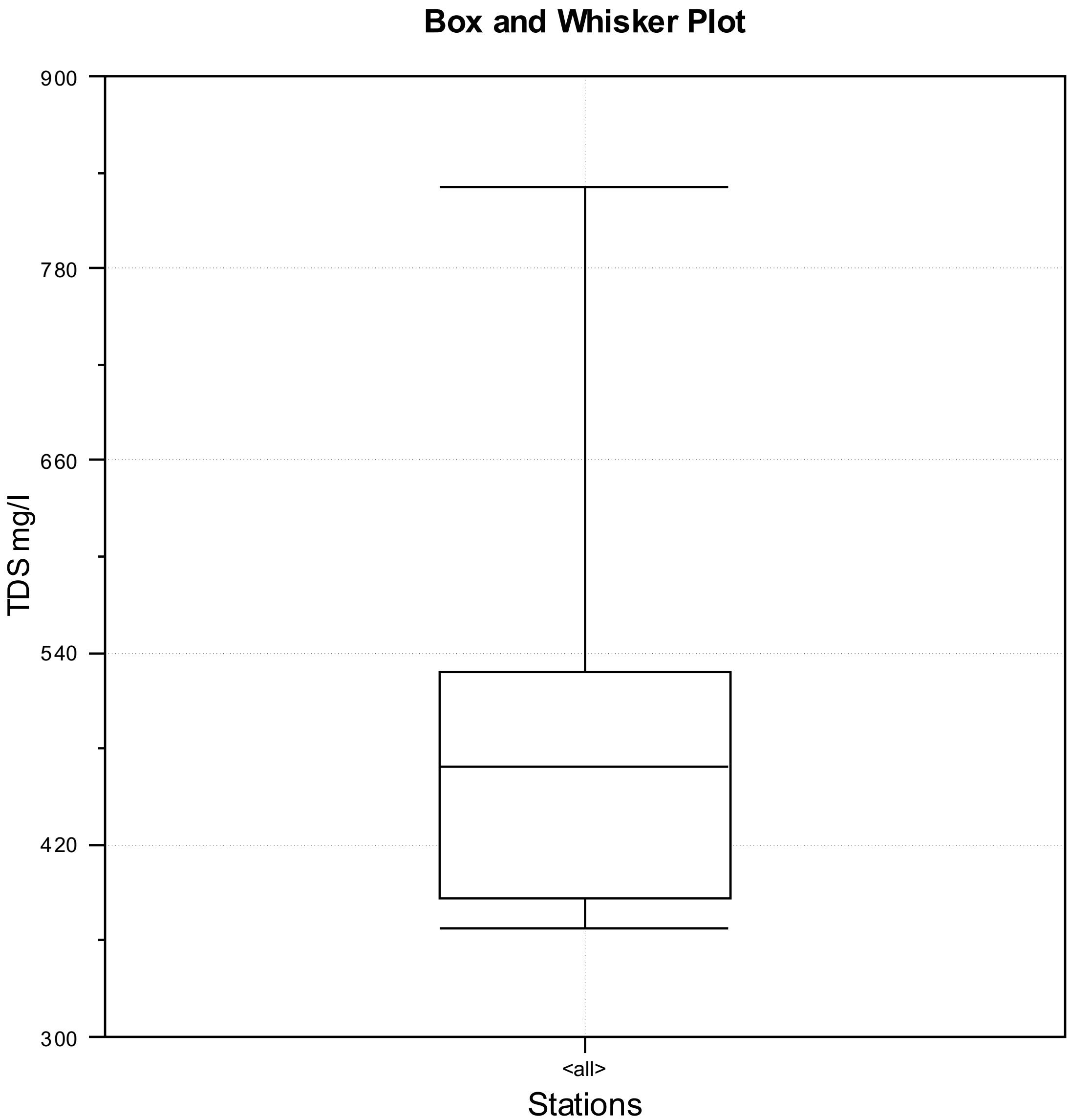


Figure O3
Total Dissolved Solids
Bedrock Group

DWR Grant Project
Los Osos CDS

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# Appendix P

## Water Quality Figures - Lower Aquifer Group

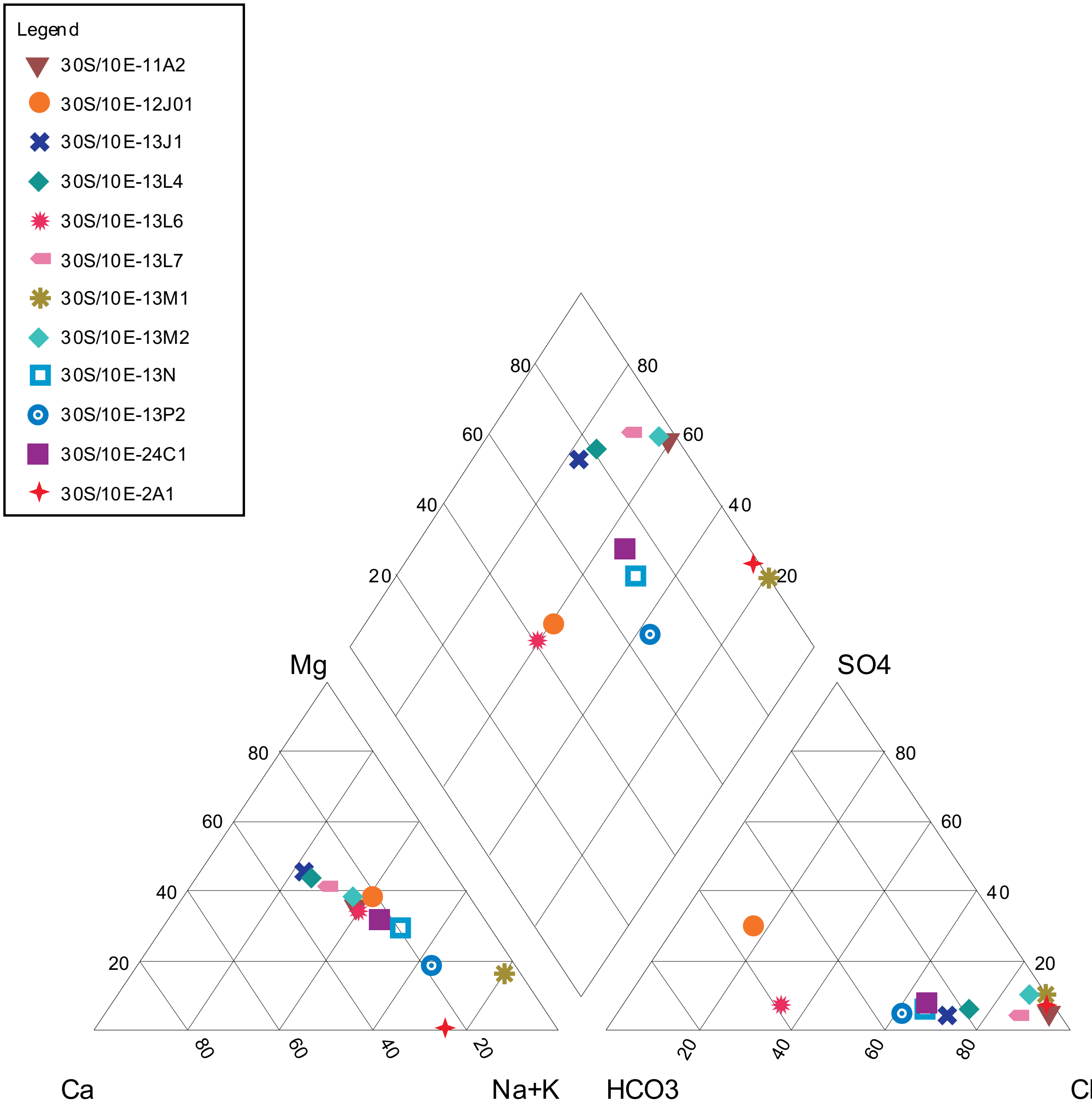


Figure P1
Piper Diagram
Lower Aquifer Group - Range 10 East

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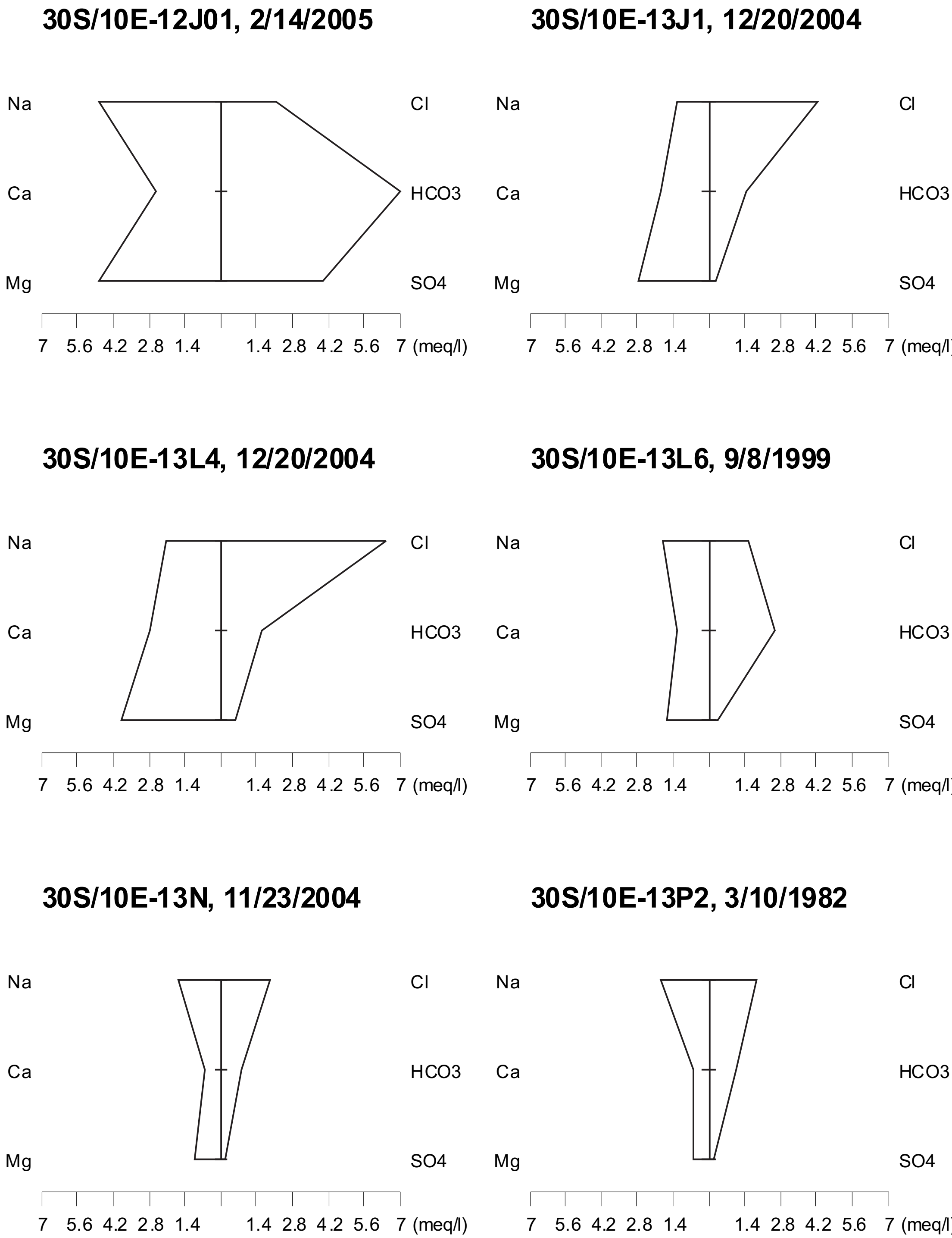


Figure P2
Stiff Diagrams
Lower Aquifer - Range 10 East

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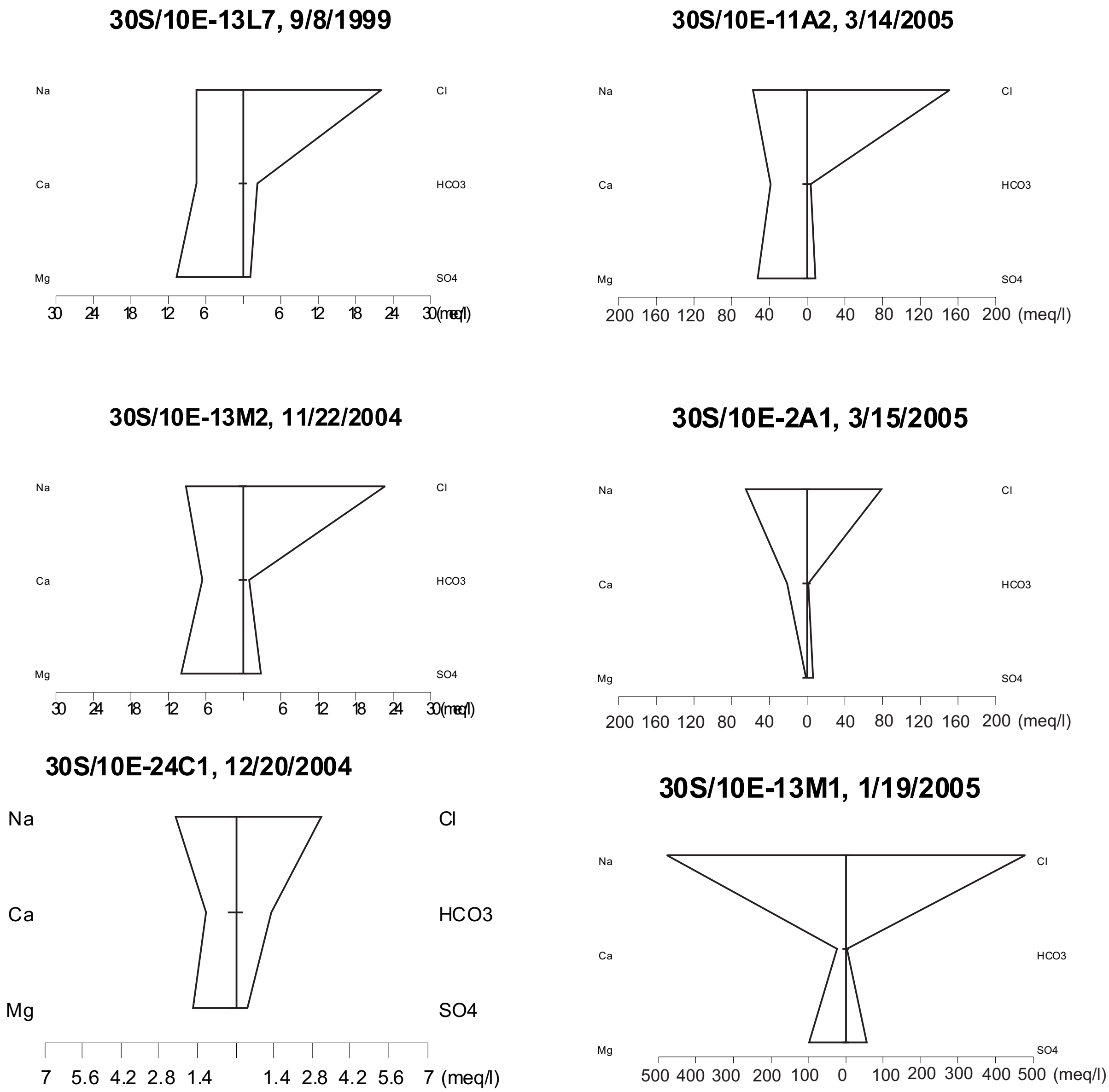


Note: This page contains scale changes between samples

Figure P3
Stiff Diagrams
Lower Aquifer - Range 10 East

DWR Grant Project
Los Osos CDS

Cleath & Associates

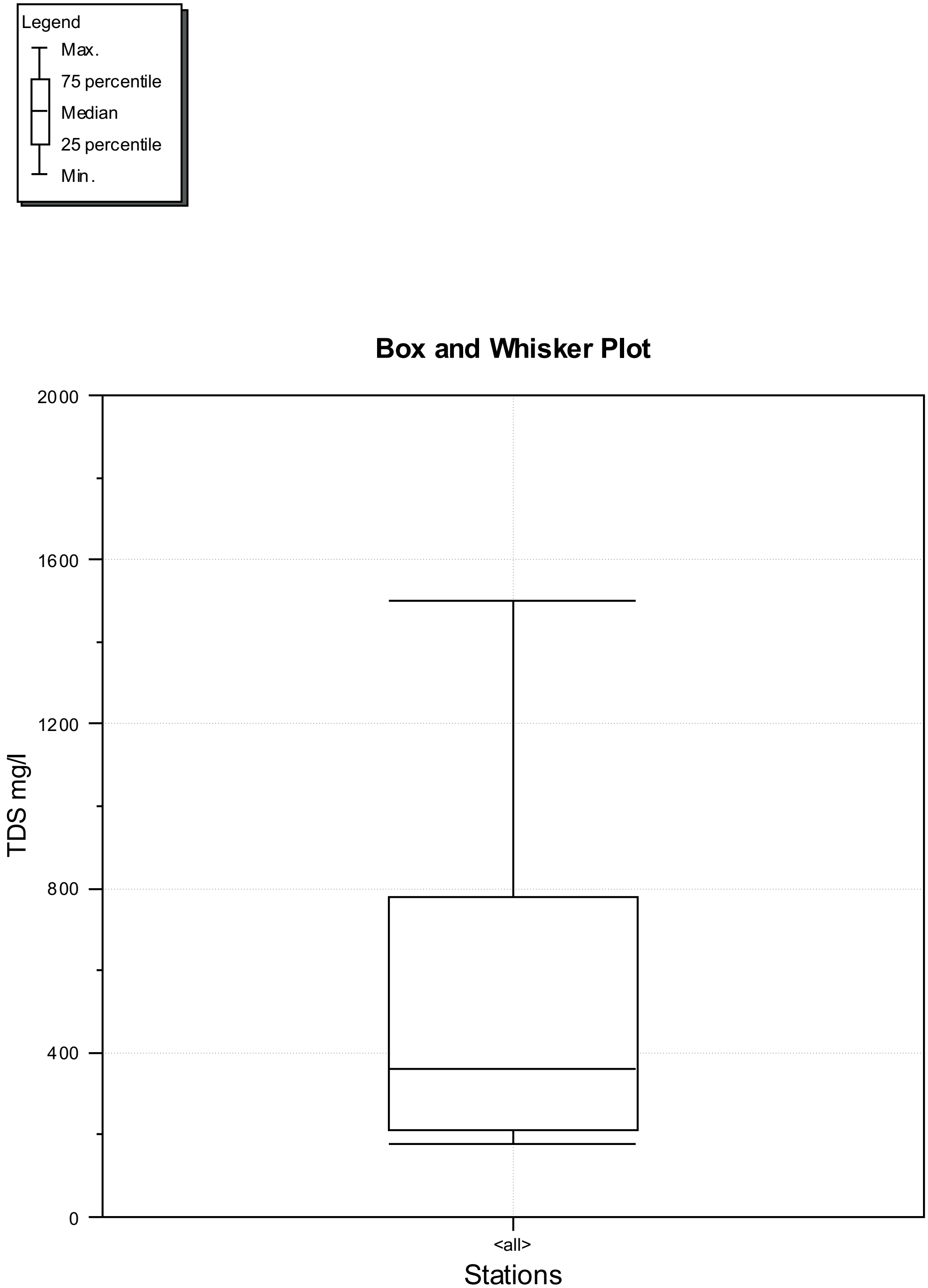


Figure P4
Total Dissolved Solids
Lower Aquifer - Range 10 East
(excluding sandspit and 13M1)

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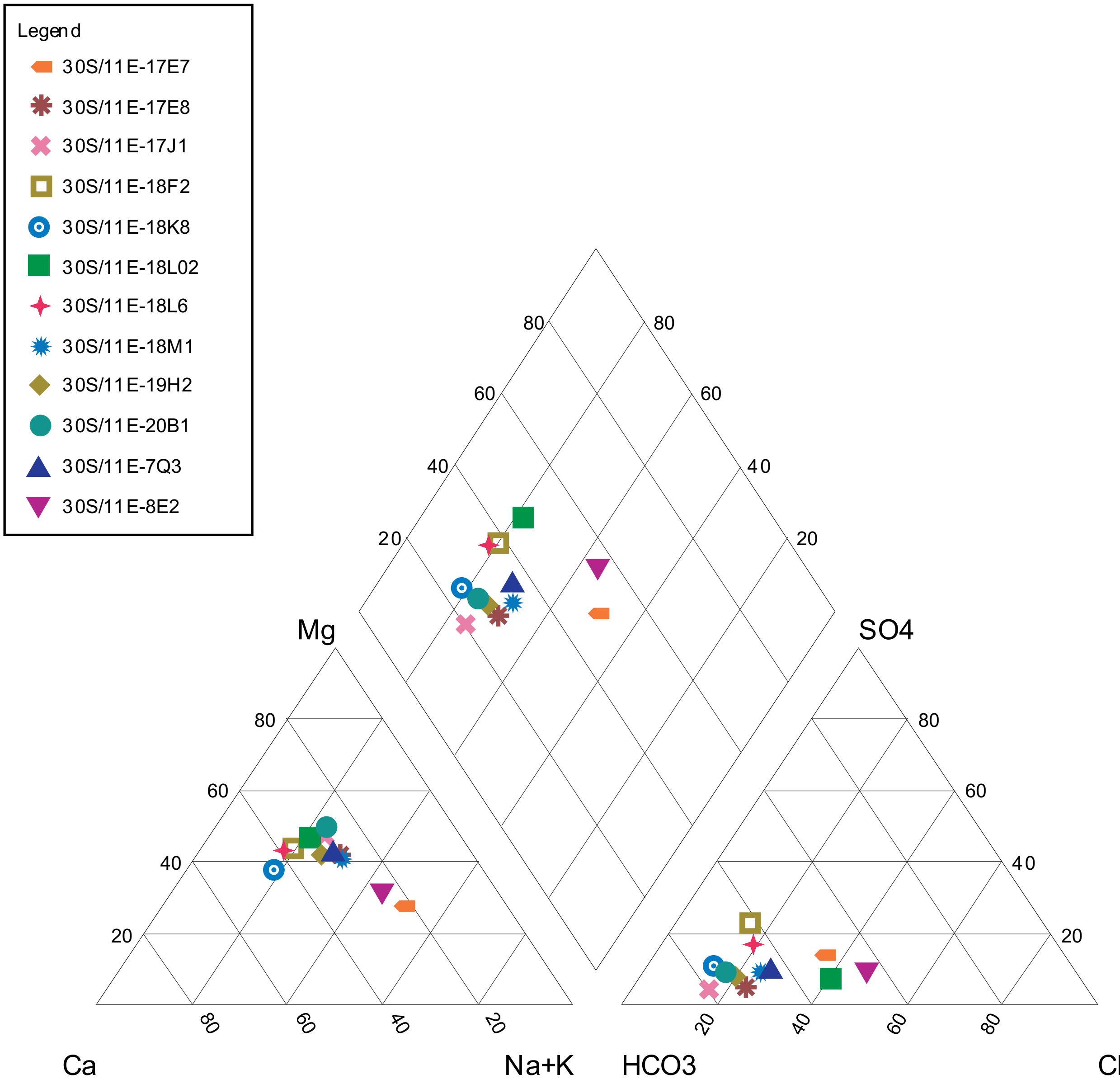


Figure P5
Piper Diagram
Lower Aquifer Group - Range 11 East

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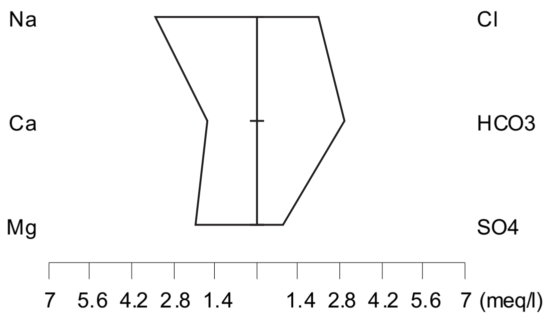
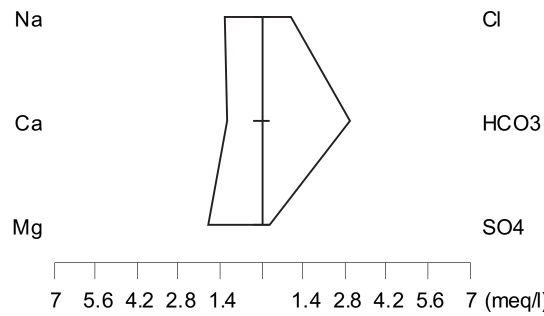
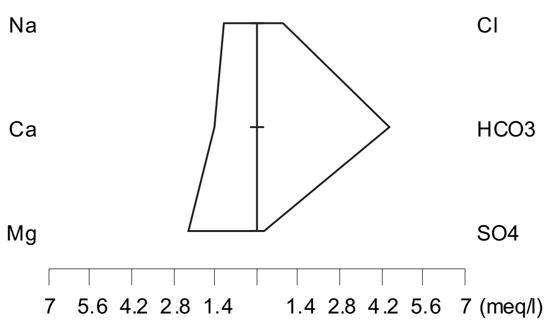
**30S/11E-17E7, 1/14/2005**



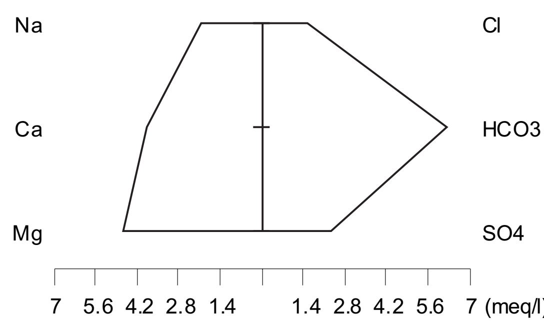

**30S/11E-17E8, 1/14/2005**



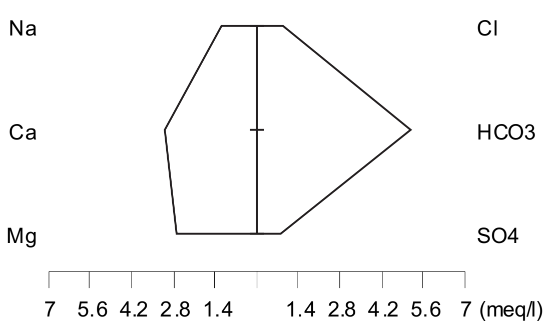

**30S/11E-17J1, 8/6/1985**




**30S/11E-18F2, 5/27/1986**




**30S/11E-18K8, 1/19/2005**




**30S/11E-18L02, 11/18/2004**

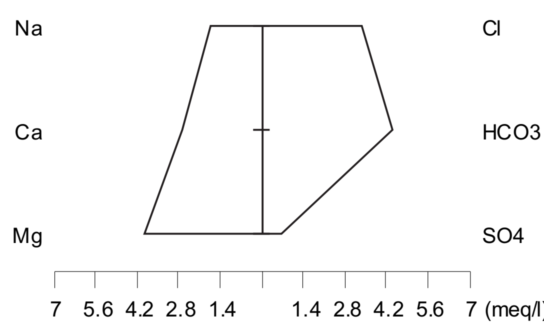



Figure P6
Stiff Diagrams
Lower Aquifer - Range 11 East

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Los Osos CDS

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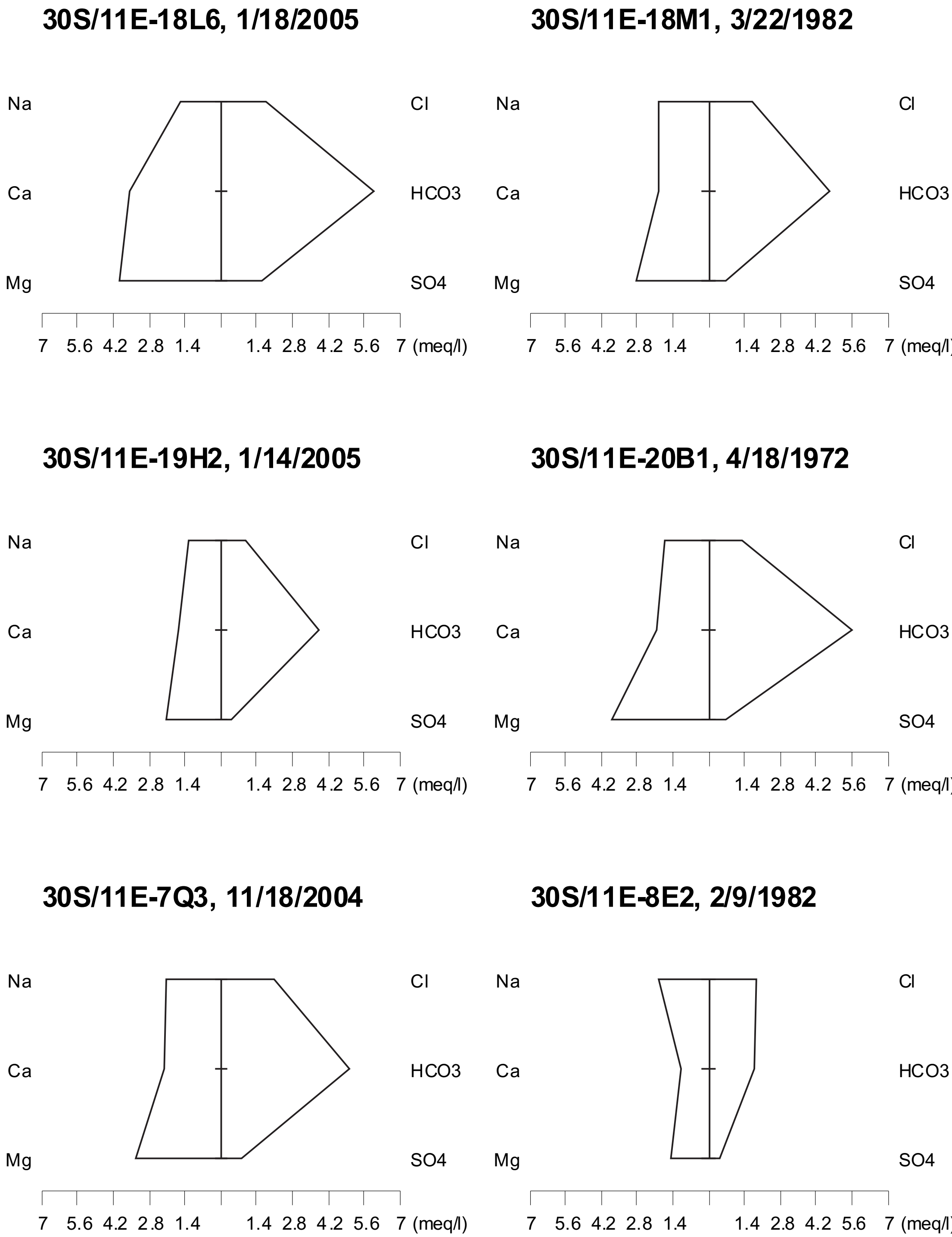



Figure P7
Stiff Diagrams
Lower Aquifer - Range 11 East

DWR Grant Project
Los Osos CDS

Cleath & Associates

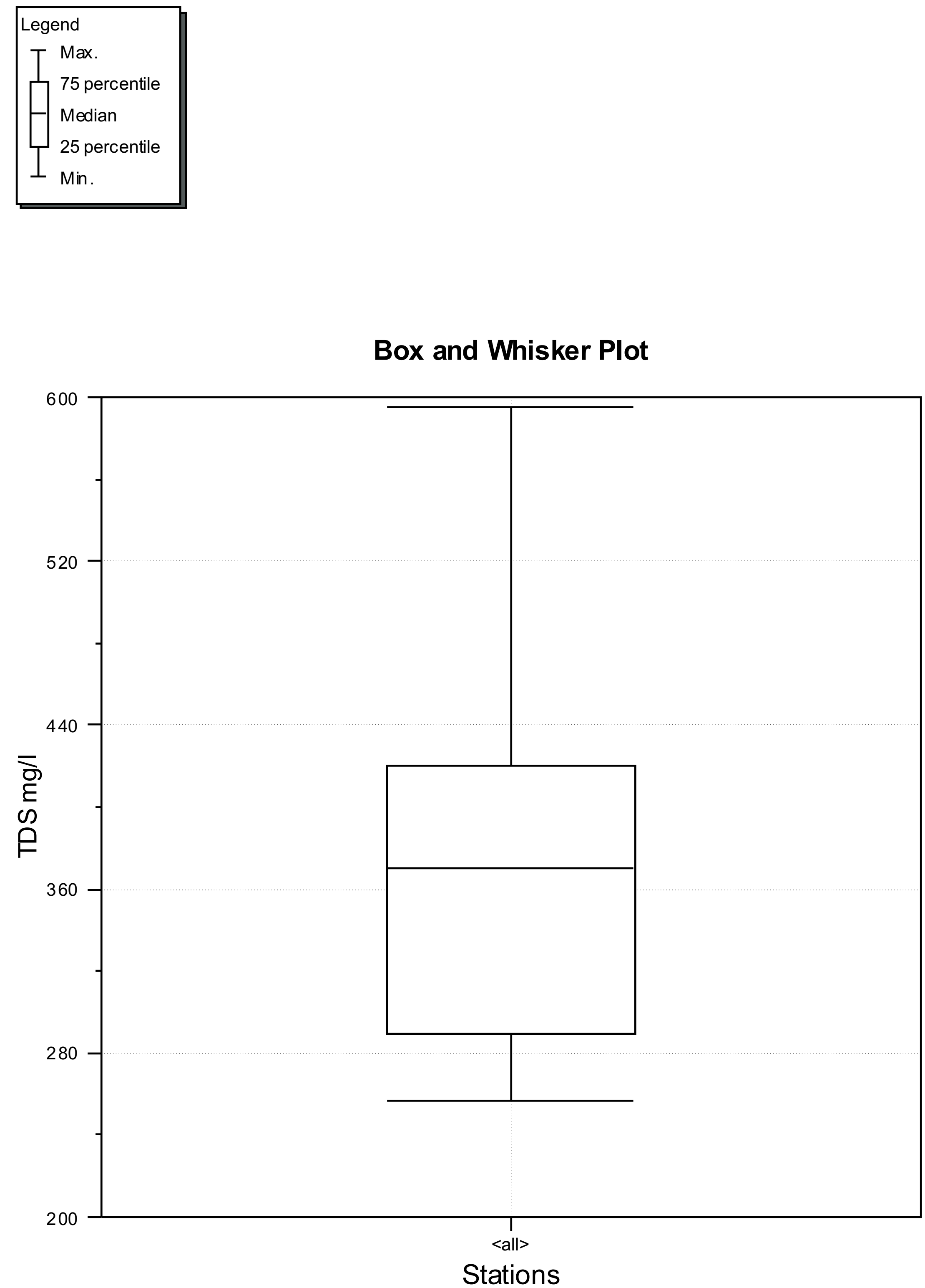



Figure P8
Total Dissolved Solids
Lower Aquifer - Range 11 East

DWR Grant Project
Los Osos CDS

Cleath & Associates

# Appendix Q

## Chemographs - Lower Aquifer Group

**Figure Q1**
**Chemograph**
**Well 30S/10E-12J1**

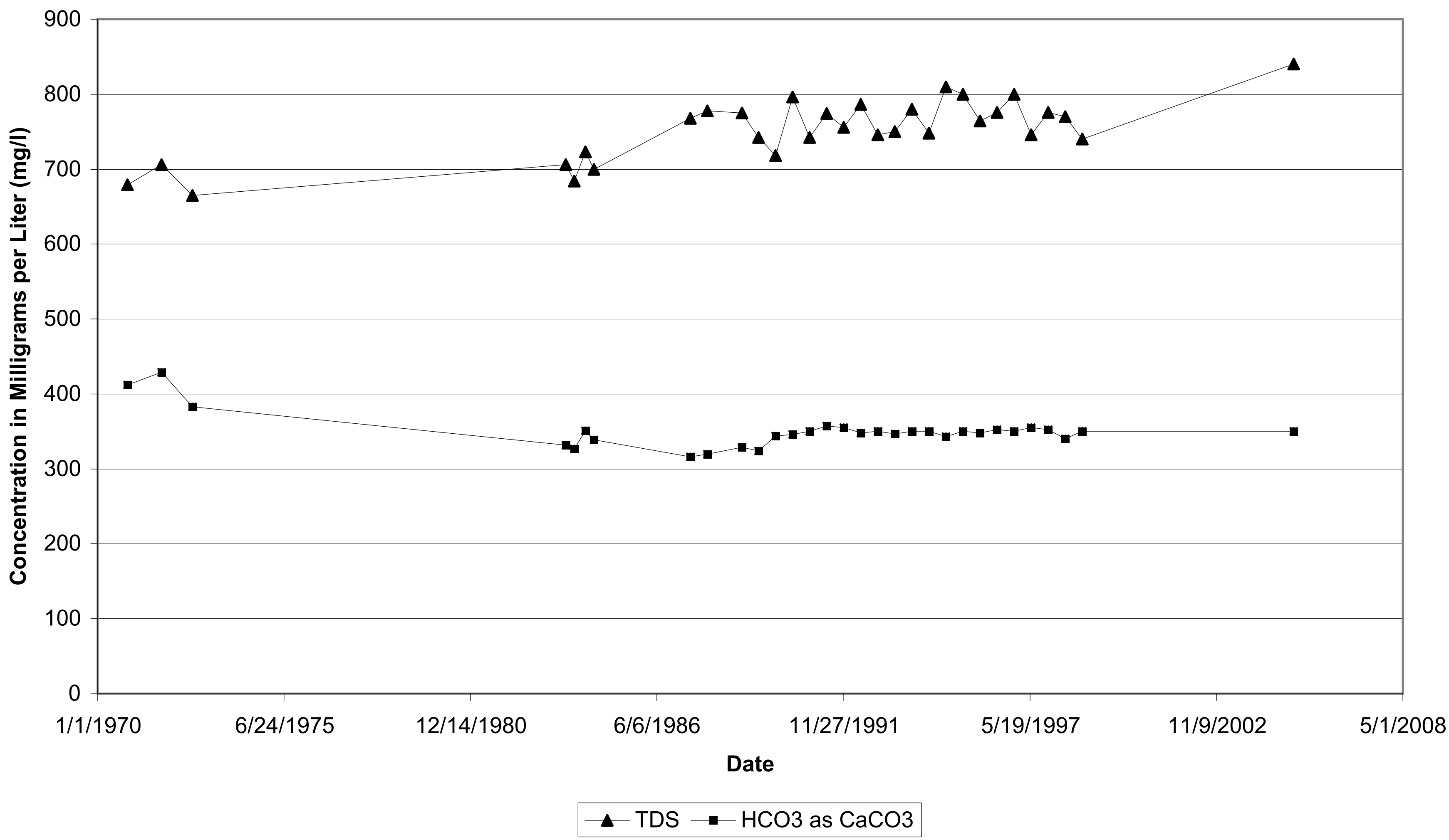


**Figure Q2**
**Chemograph**
**Well 30S/10E-12J1**

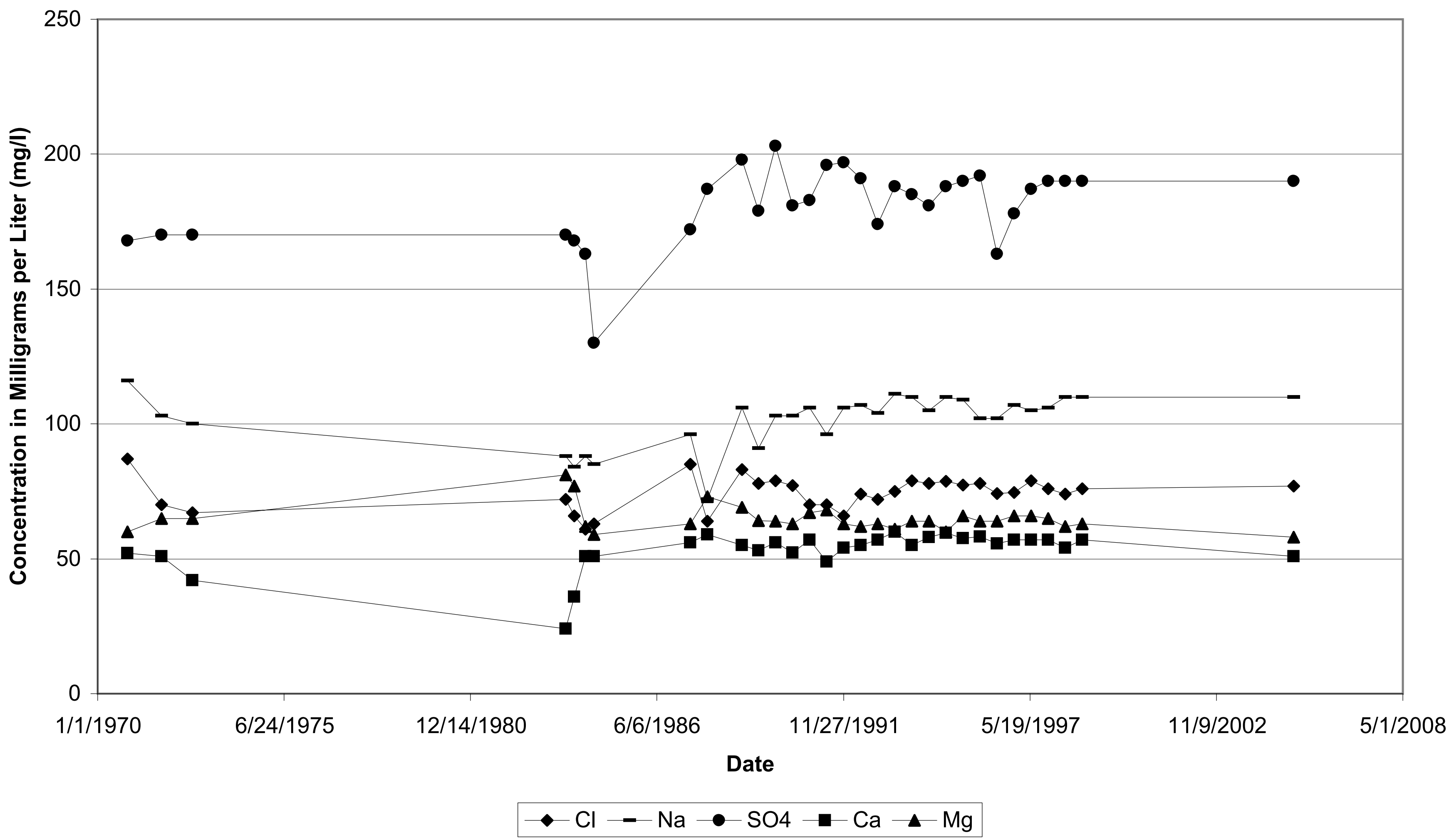


**Figure Q3**
**Chemograph**
**Well 30S/11E-7Q3**

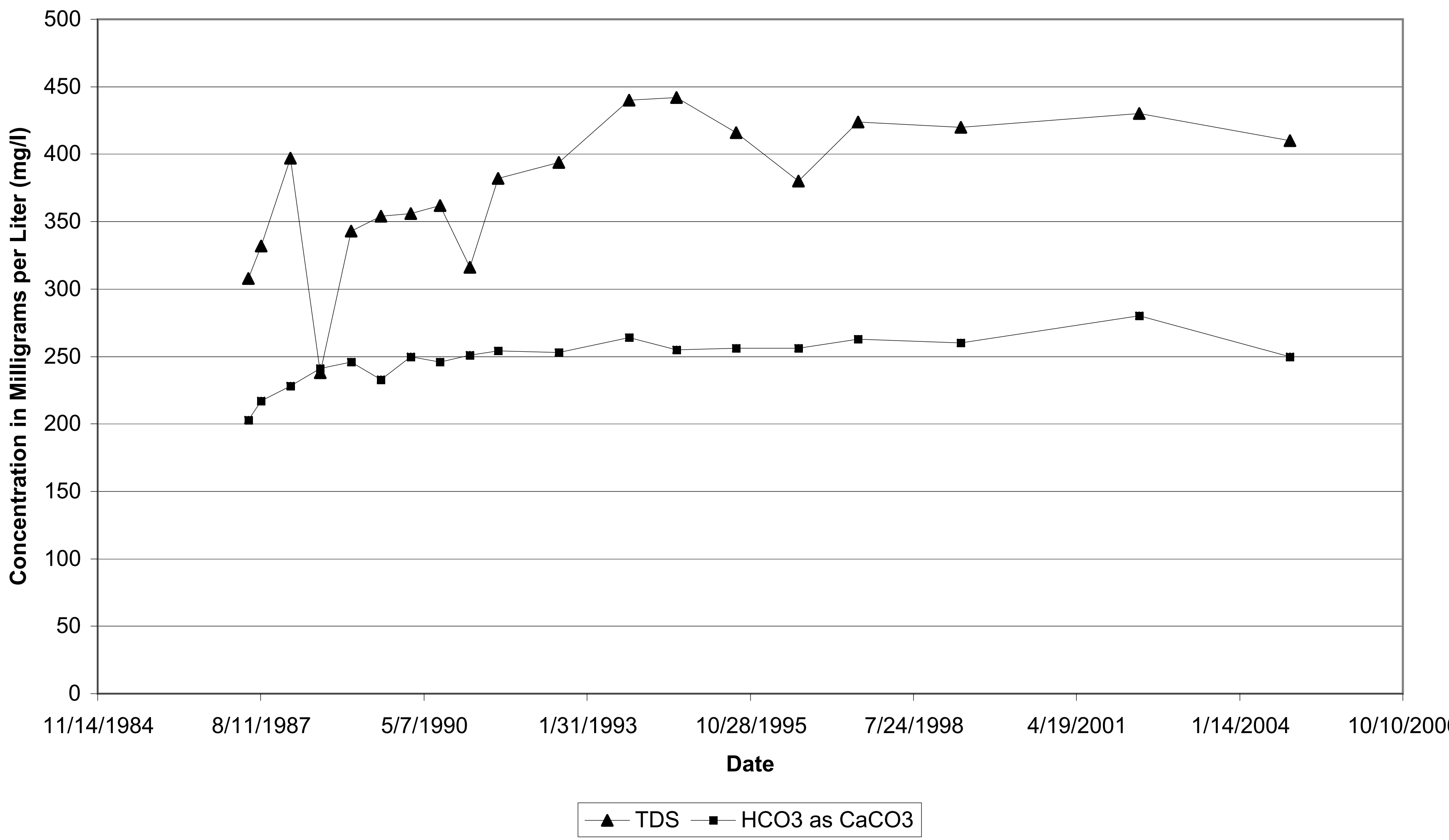
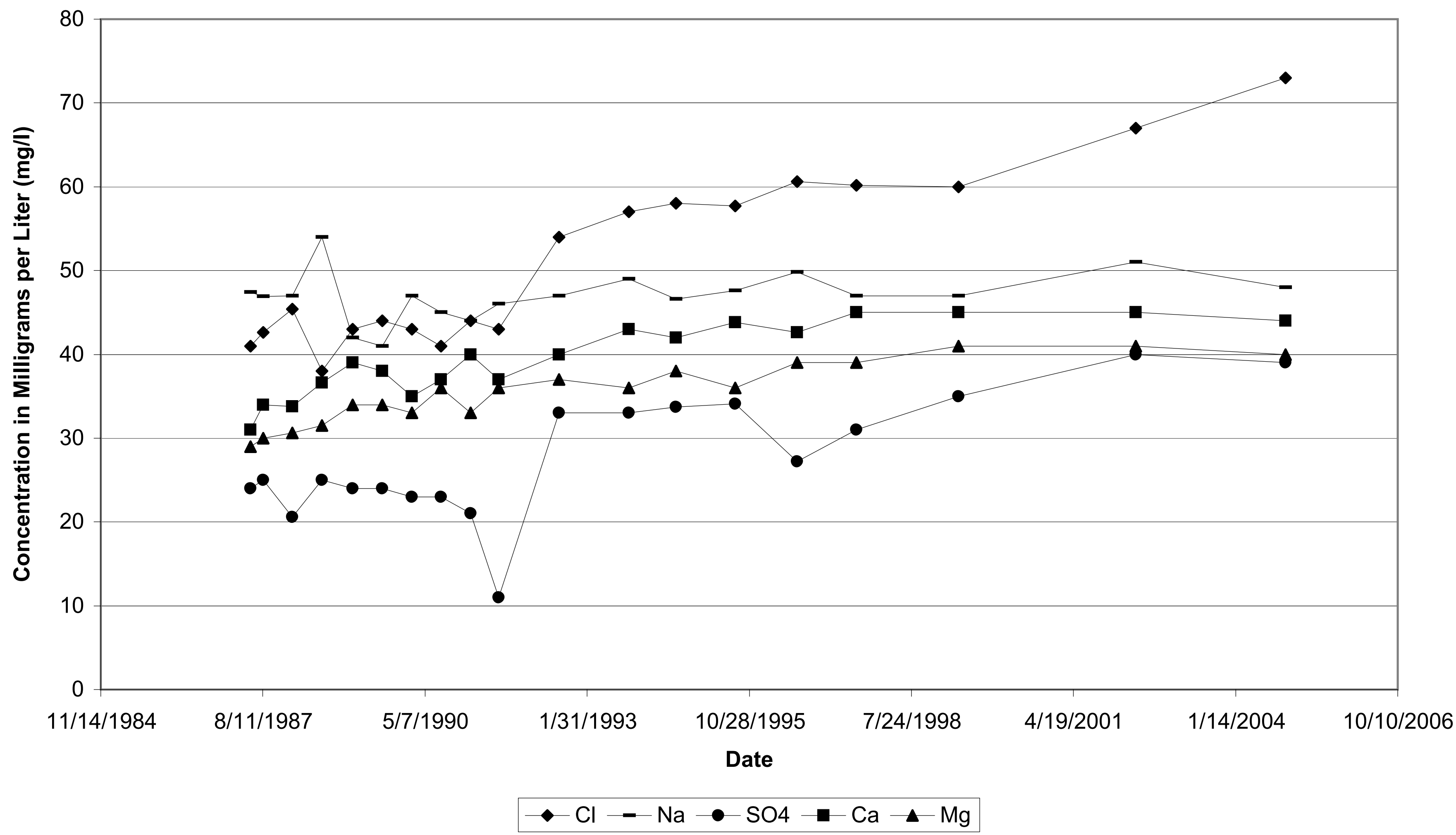


**Figure Q4**
**Chemograph**
**Well 30S/11E-7Q3**



## Figure Q5
## Chemograph
## Well 30S/11E-18F2

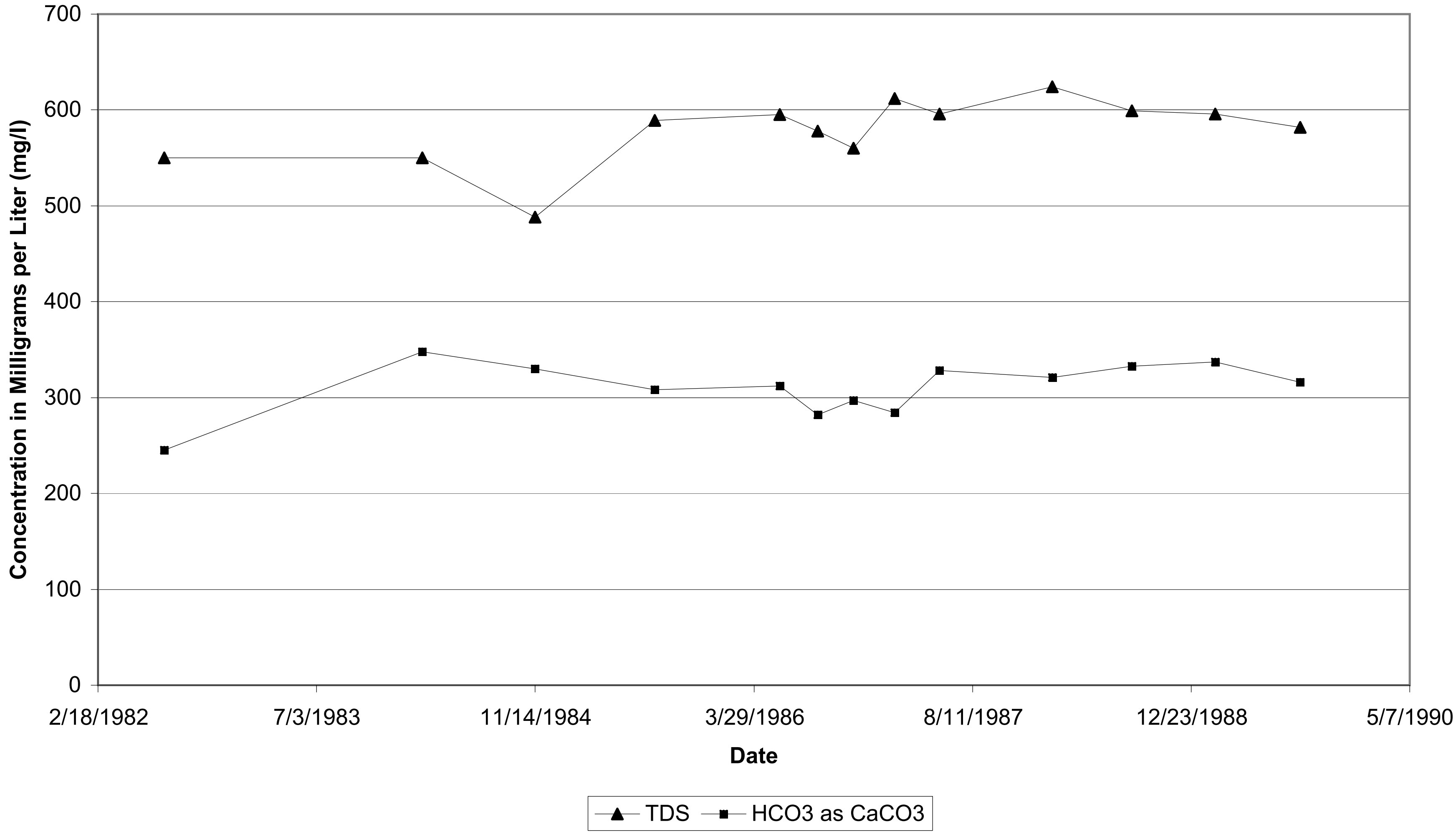


**Figure Q6**
**Chemograph**
**Well 30S/11E-18F2**

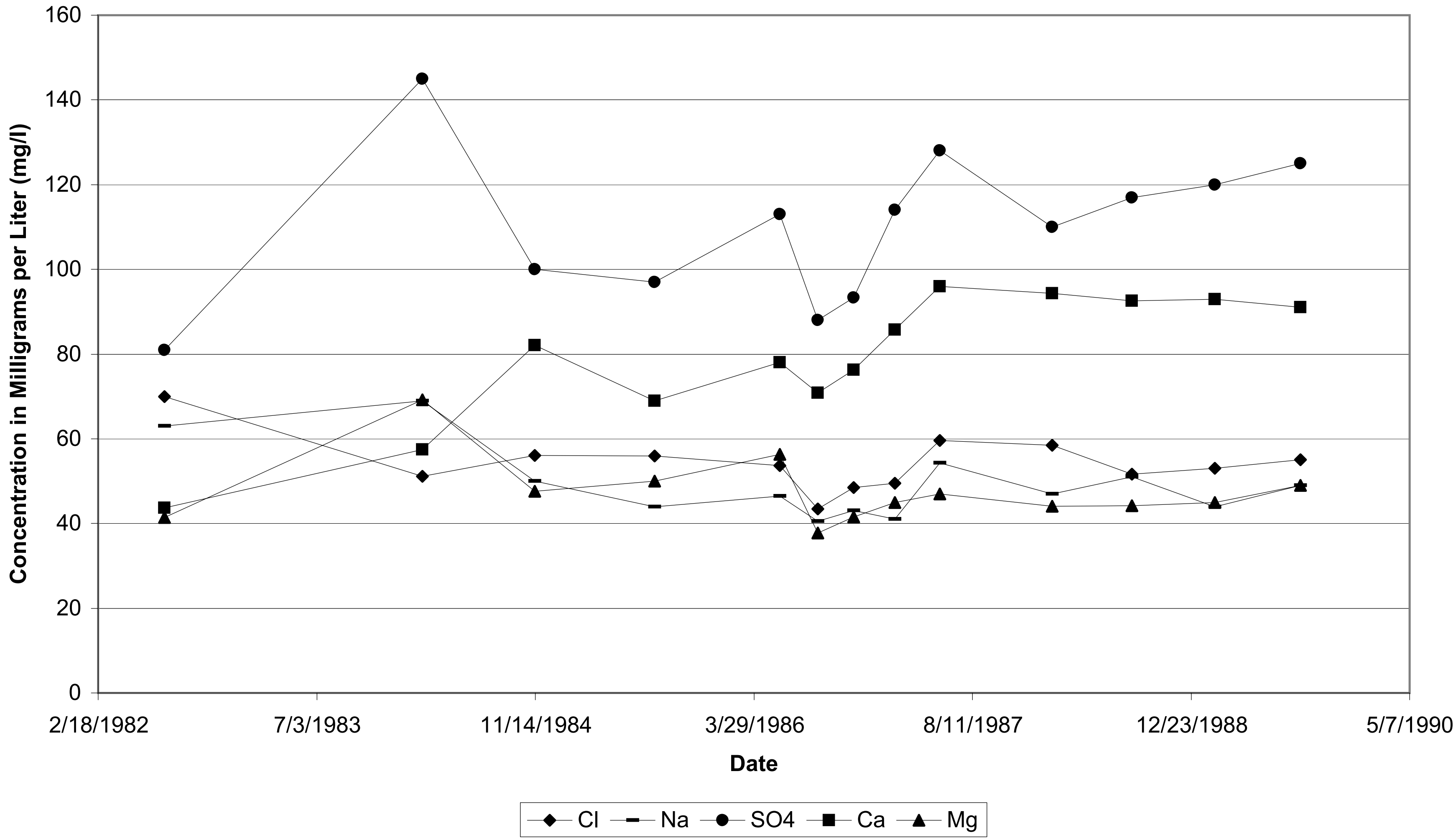


**Figure Q7**
**Nitrate Chemograph**
**Well 30S/11E-18L2**

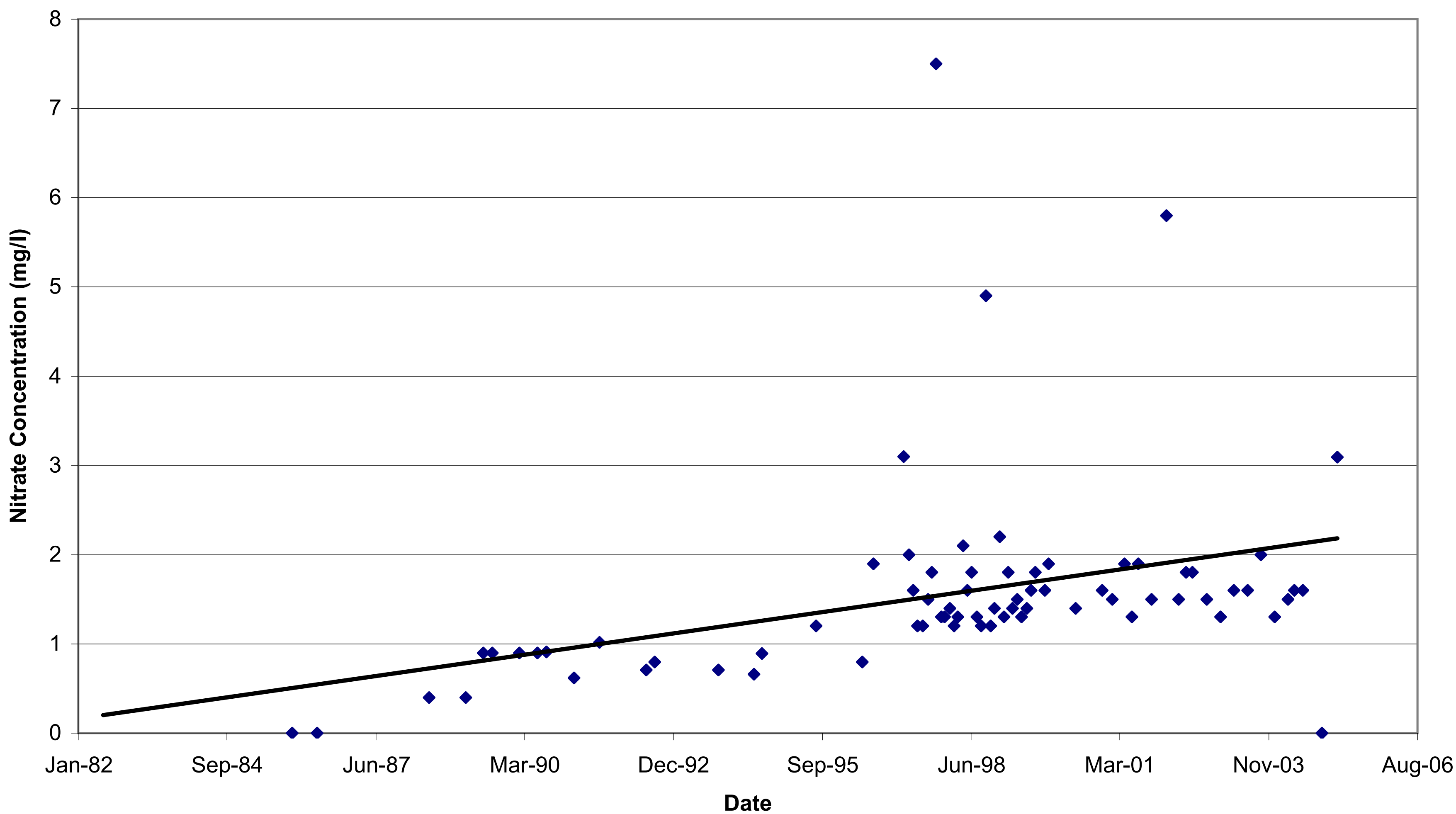
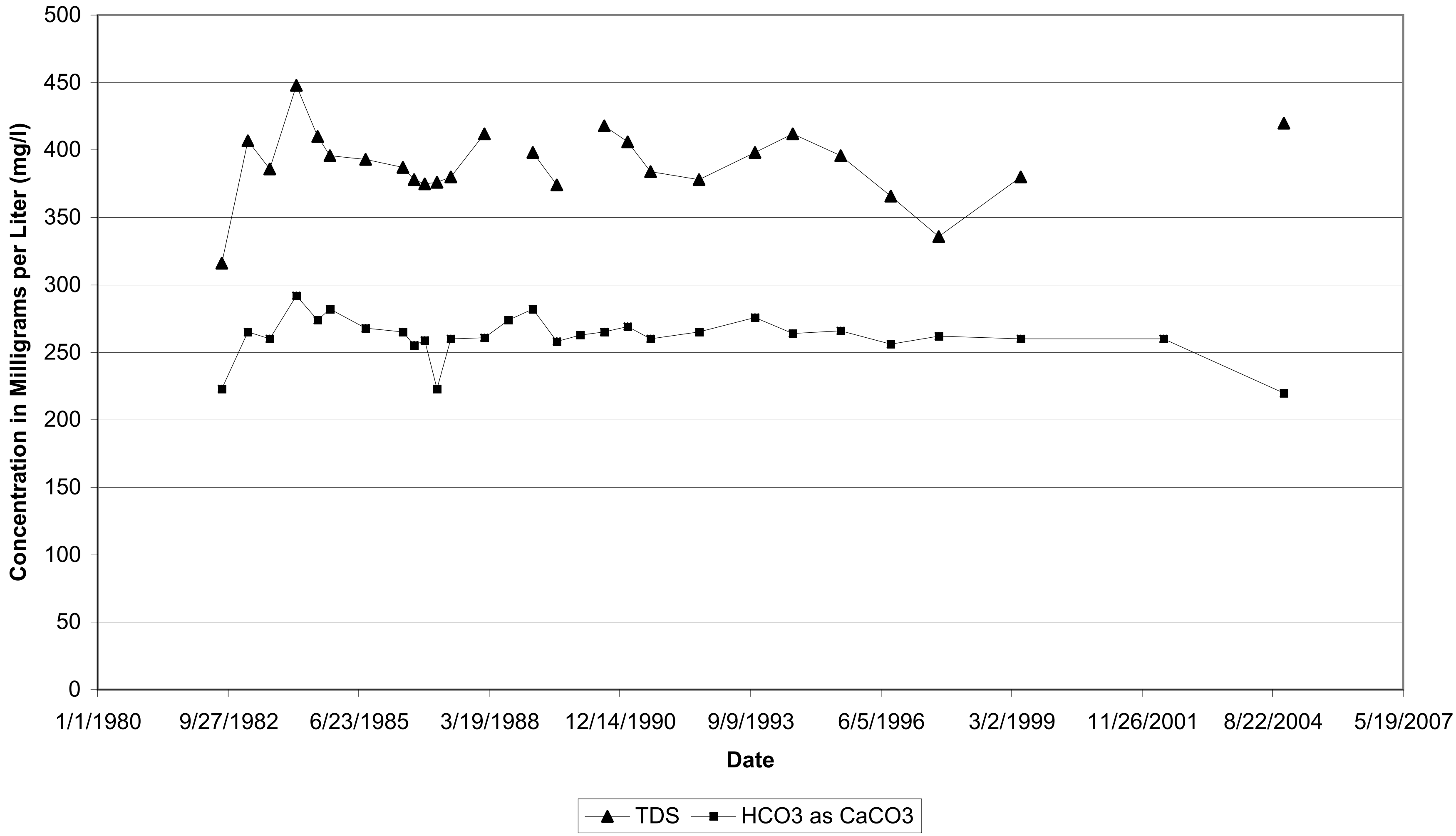
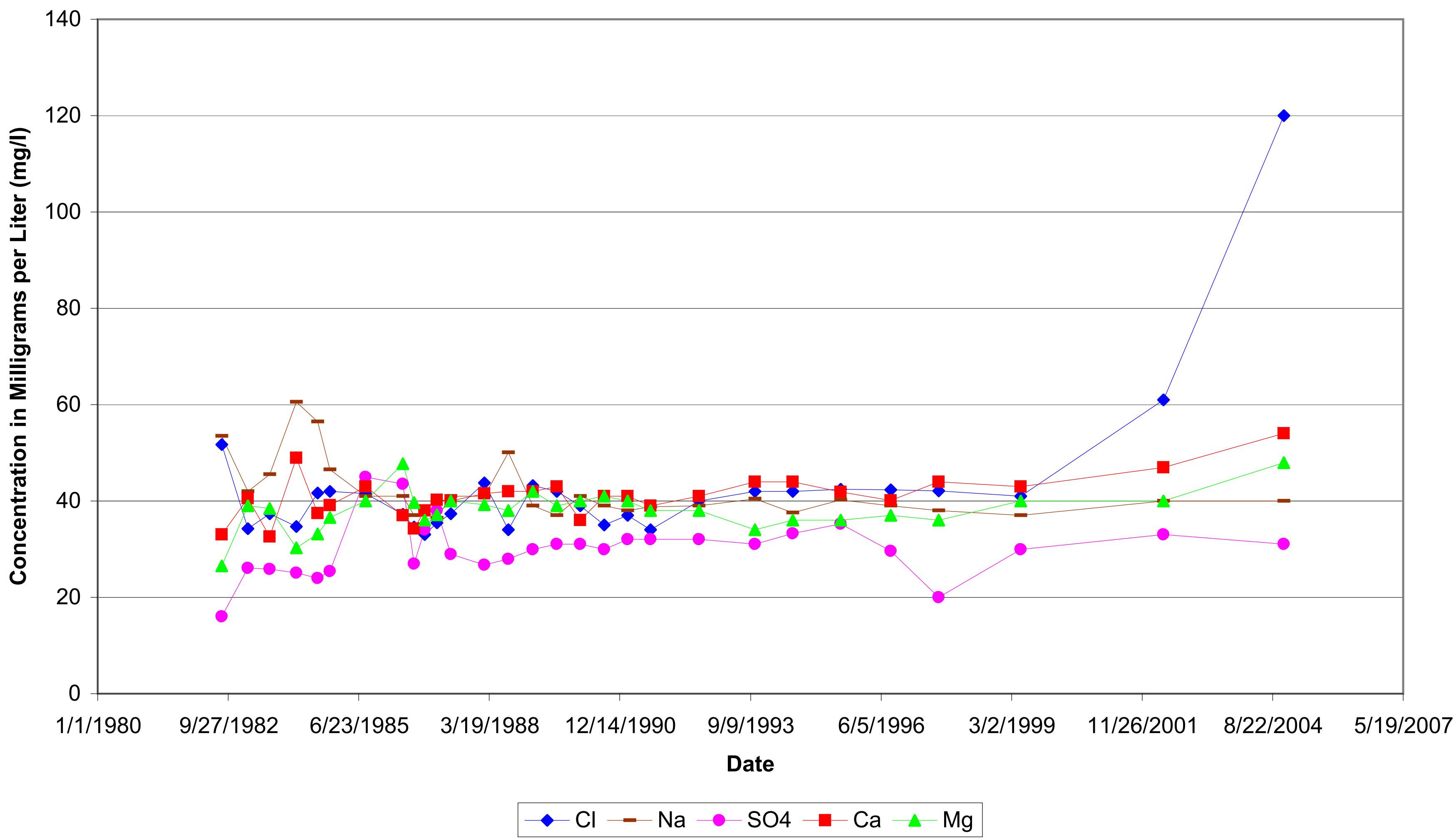


**Figure Q8**
**Chemograph**
**Well 30S/11E-18L2**



## Figure Q9
## Chemograph
## Well 30S/11E-18L2



# Appendix R

## Subsurface Flow Calculations - Lower Aquifer

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**Ocean Boundary Inflow Calculations**

**ZONE D**

| Sandspit location | head (ft) | percent sea water | average Zone D elev (ft) | equivalent fresh water head (ft) | inland head (dh) (ft) | inland percent sea water | inland aquifer elev (ft) | inland equivalent fresh water head (ft) | inland length (dl) (ft) | gradient perpendicular to section D-D' (dh/dl) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2A1 | 8 | 15% | -100 | 8.4 | 10 | >1% | ---- | 10 | 3500 | -0.00046 (outflow) |
| midpoint 1 | 5 | 20% | -200 | 6 | 8 | >1% | ---- | 8 | 4000 | 0 |
| 11A2 | 3 | 25% | -260 | 4.6 | 2 | >1% | ---- | 2 | 4000 | 0.00065 |
| midpoint 2 | 2 | 36% | -270 | 4.4 | -1 | 14% | -240 | -0.2 | 4500 | 0.00102 |
| 14B2 | 1.5 | 46% | -310 | 5.1 | -1 | 14% | -250 | -0.1 | 2500 | 0.00208 |
| Fault | 0.7 | 46% | -260 | 3.7 | -2 | 14% | -180 | -1.4 | 3000 | 0.0017 |

| Section D-D' segment from | to | Gradient (dh/dl) | Thickness (ft) | Length (ft) | Area (ft2) | K (ft/day) | Q (ft3/day) | Q (afy) |
|---|---|---|---|---|---|---|---|---|
| Midpoint 1 | Midpoint 2 | 0.000557 | 80 | 5000 | 400000 | 10 | 2200 | 18 |
| Midpoint 2 | Fault | 0.0016 | 110 | 6500 | 715000 | 20 | 22900 | 192 |

**Zone D total inflow** **210 afy**

**ZONE E**

| Sandspit location | head (ft) | percent sea water | average aquifer elev (ft) | equivalent fresh water head (ft) | inland head (dh) (ft) | inland percent sea water | inland aquifer elev (ft) | inland equivalent fresh water head (ft) | inland length (dl) (ft) | gradient perpendicular to section D-D' (dh/dl) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2A1 | 8 | 15% | -250 | 8.9 | 10 | 15% | -150 | 10.6 | 3500 | -0.00049 (outflow) |
| midpoint 1 | 4 | 50% | -320 | 8 | 4 | 15% | -220 | 4.8 | 4000 | 0.0008 |
| 11A2 | 0 | 100% | -380 | 9.5 | 0 | 25% | -280 | 1.8 | 6000 | 0.00128 |
| midpoint 2 | 0 | 100% | -450 | 11.3 | 0 | 50% | -350 | 4.4 | 3000 | 0.0023 |
| 14B2 | 0 | 100% | -520 | 13 | -3 | 90% | -500 | 8.3 | 4500 | 0.00104 |
| Fault | 0 | 100% | -520 | 13 | -7.8 | 90% | -500 | 3.5 | 4500 | 0.00211 |

| Section D-D' segment from | to | Gradient (dh/dl) | Thickness (ft) | Length (ft) | Area (ft2) | K (ft/day) | Q (ft3/day) | Q (afy) |
|---|---|---|---|---|---|---|---|---|
| Midpoint 1 | Midpoint 2 | 0.00146 | 140 | 5000 | 700000 | 5 | 5100 | 43 |
| Midpoint 2 | Fault | 0.001817 | 250 | 6500 | 1625000 | 10 | 29500 | 247 |

**Zone E total inflow** **290 afy**

**Grand Total** **500 afy**

NOTE: The K for Zone E used in south segment is greater then used in Layer 5 of the steady-state model. This is because Layer 5 includes the AT3 clay, which is excluded from the thickness assigned to south segment of Zone E.

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**Creek Valley Subsurface Outflow Calculations**

| Zone D | | | | | | |
|---|---|---|---|---|---|---|
| Segment | Length (ft) | i (dh/dl) (ft/ft) | thick (ft) | K (ft/day) | Q (ft3/day) | Q (afy) |
| Lower Valley | 1600 | 0.004 | 50 | 8 | 2560 | 21 |
| Pumping Trough | 700 | 0.03 | 40 | 8 | 6720 | 56 |
| Central Valley | 2600 | 0.007 | 40 | 8 | 5824 | 49 |
| Upper Valley | 2500 | 0.01 | 80 | 8 | 16000 | 134 |
| | | | | | subttl | 260 |
| Zone E | | | | | | |
| Central Valley | 3500 | 0.007 | 100 | 5 | 12250 | 103 |
| Upper Valley | 2500 | 0.01 | 100 | 5 | 12500 | 105 |
| | | | | | subttl | 208 |
| | | | | | **total** | **468** |

NOTE: The K for Zone E used in analytical sections is greater than that used in Layer 5 of the steady-state model. This is because Layer 5 includes the AT3 clay, which is excluded from the thickness assigned to Zone E.

# Appendix S

# EFH Steady-State Model Documentation

## EQUIVALENT FRESH WATER HEAD (EFH) MODEL

The steady-state model is based on a realistic conceptual model and is an interim step toward completion of a final (transient) basin model. Model layers were selected to represent significant lithologic horizons in the basin, which control the movement of ground water. Documentation of the development of the steady-state model is summarized in Yates and Williams (2003) and Cleath & Associates (2003 and 2004). The model layers are related to basin horizons as summarized below:

- Layer 1: From ground surface to 10 feet below the water table (for solute only).
- Layer 2: Upper aquifer (Zone C) and alluvial aquifer (Creek Valley).
- Layer 3: Regional aquitard (AT2 Clay).
- Layer 4: Lower Aquifer (Zone D).
- Layer 5: Lower Aquifer (Zone E).

The equivalent fresh water head (EFH) version of the steady-state model was developed to provide an estimate of sea water intrusion. General head boundaries at the ocean were set according their equivalent fresh water head for each aquifer layer. The regional aquitard (model Layer 3) was assigned a no flow boundary at the ocean. A fault barrier wall was also re-introduced between Baywood Heights and the Los Osos Creek Valley in Zones D and E. This feature was present in the U.S.G.S. model (Yates and Wiese, 1988) and is supported by geologic and hydrogeologic data.

Figure S1 through S5 show the model plan, the maximum fresh water head assigned to each aquifer, and the hydraulic conductivity distribution for each model layer. Table 1 below summarizes the calibration statistics for the EFH version of the steady-state model, as compared to the transient URS model and prior version of the steady-state model. Table 2 summarizes the each model's mass balance.

**Table 1**
**Residuals Statistics**

| Parameter | URS Model (2002 Update) | Steady-State (2004 Update) | Steady-State (2005 EFH) |
|---|---|---|---|
| Residual Mean | 3.50 feet | 0.03 feet | 0.57 feet |
| Residual Standard Deviation | 12.82 feet | 5.61 feet | 5.34 feet |
| Absolute residual mean | 8.73 feet | 4.42 feet | 4.24 feet |
| Ratio of RSD to range | 10.3% | 8.9% | 8.0% |
| Range in head | 125 feet | 63 feet | 67 feet |
| Residual difference <10 feet | 76% | 92% | 92% |
| Residual difference <20 feet | 93% | 100% | 100% |

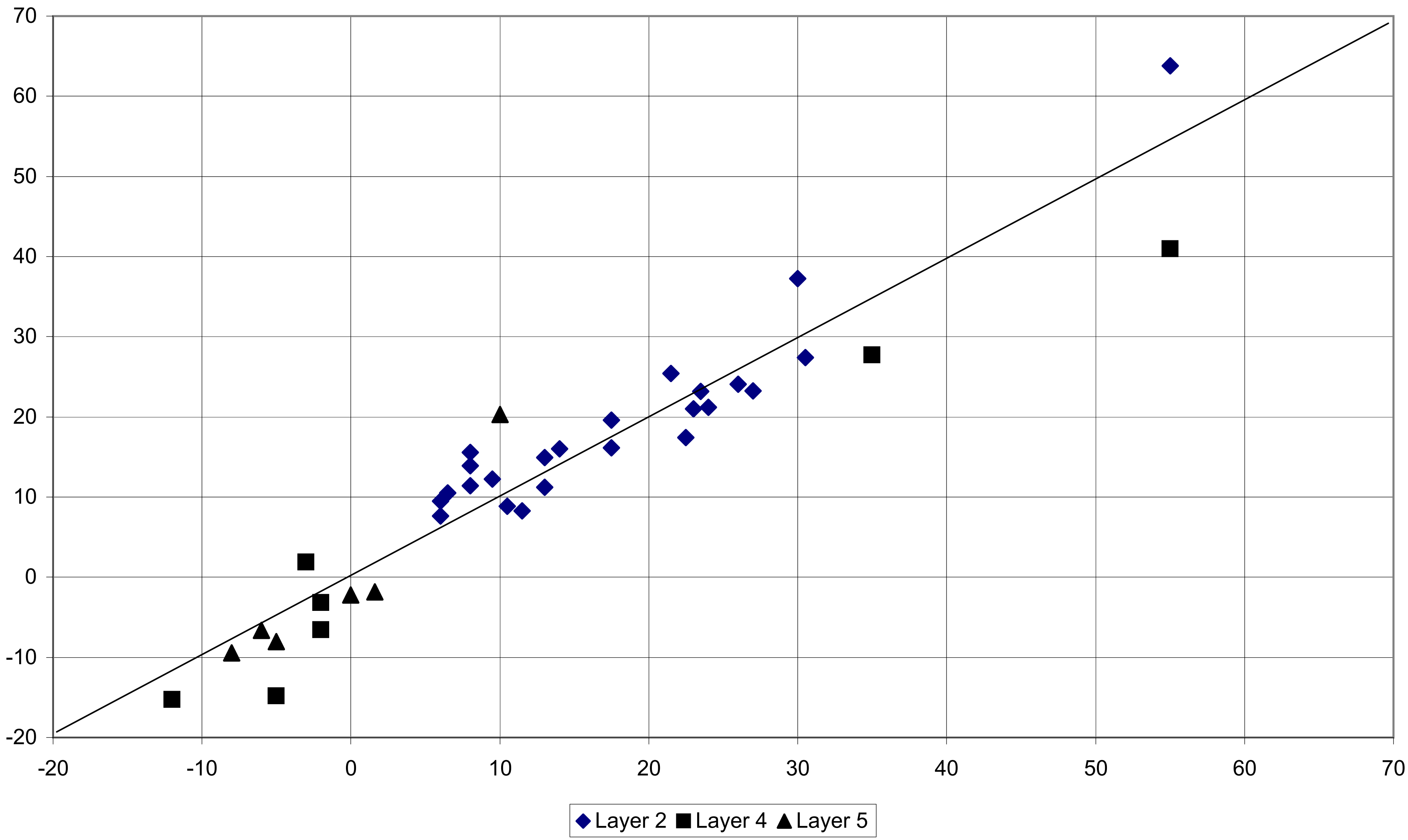
**Table 2**
**MODFLOW Mass Balance Data - Model Summaries**

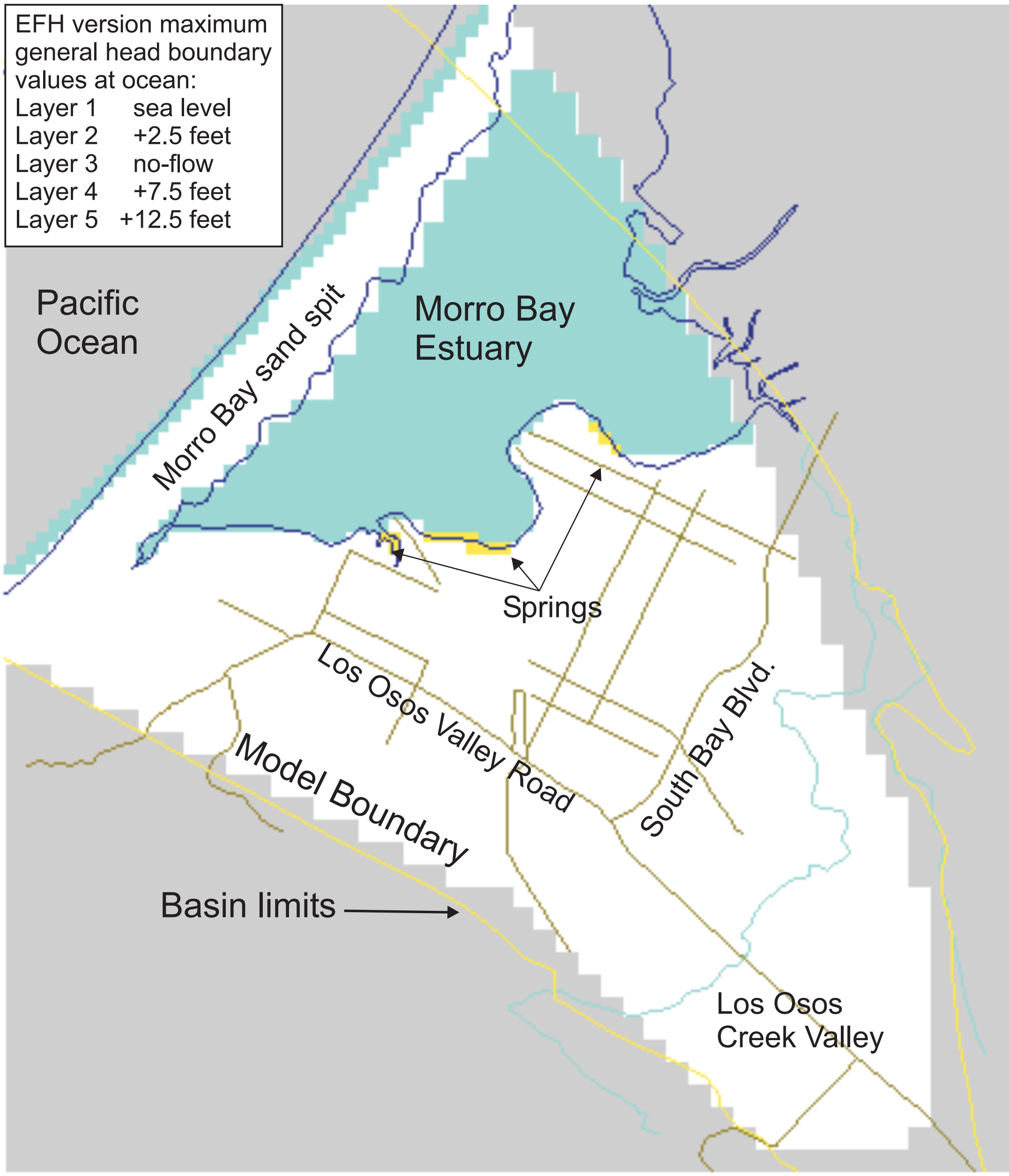
| Parameter | | URS Model 2002 Update (afy) | Steady-State 2004 Update (afy) | Steady-State EFH (afy) |
|---|---|---|---|---|
| Inflow | Subsurface (basin boundary) | 10 | 12 | 141 |
| | Subsurface (ocean and bay) | 138 | 0 | 624 |
| | Los Osos Creek seepage | 126 | 965 | 656 |
| | Septic discharges | 1,836 | 1,267 | 1,267 |
| | Other Inflow | 2,540 | 3,603 | 2,088 |
| | Total Inflow | 4,652 | 5,847 | 4,776 |
| Outflow | Springs | 0 | 190 | 119 |
| | Los Osos Creek base flow | 4 | 103 | 121 |
| | Wells | 2,736 | 3,287 | 3,287 |
| | Subsurface (basin boundary) | 0 | 0 | 0 |
| | Subsurface (ocean and bay) | 550 | 2,267 | 1,249 |
| | Other Outflow | 288 | 0 | 0 |
| | Error | 16 | 0 | 0 |
| | Total Outflow | 4,652 | 5,847 | 4,776 |

Differences in the mass balance between the URS Model and the 2004 steady-state model have been discussed previously (Cleath & Associates, 2004). There are several notable difference between the 2004 steady-state model and the EFH version. Subsurface inflow from the ocean boundary, which is not simulated in prior basin models, is estimated by the EFH model at 624 afy under 1999-2001 basin conditions.

The EFH version also shows a decline in recharge from Los Osos Creek, an increase in bedrock inflow (creek valley), less spring ouflow along the bay, and close to 1,515 afy less "other inflow", which represents recharge from percolation of precipitation and perching layer effects. The significant reduction in "other inflow" is due primarily to turning the recharge package off over the bay. Recharge to bay cells in the original steady-state model had been flowing out (short-circuiting) through the Layer 1 general head boundary without any significant effect on basin dynamics. Another reduction in inflow was due to removing the southwest corner of the model where bedrock is inferred to encroach based on offshore outcrops. Pertinent results of the EFH model are discussed in the main report text.

**EFH Model Calibration**
**Observed versus Computed Water Levels**






EFH Version adapted from
Yates and Williams, 2003 and
Cleath & Associates, 2004

Figure S1
EFH Steady State Model Limits

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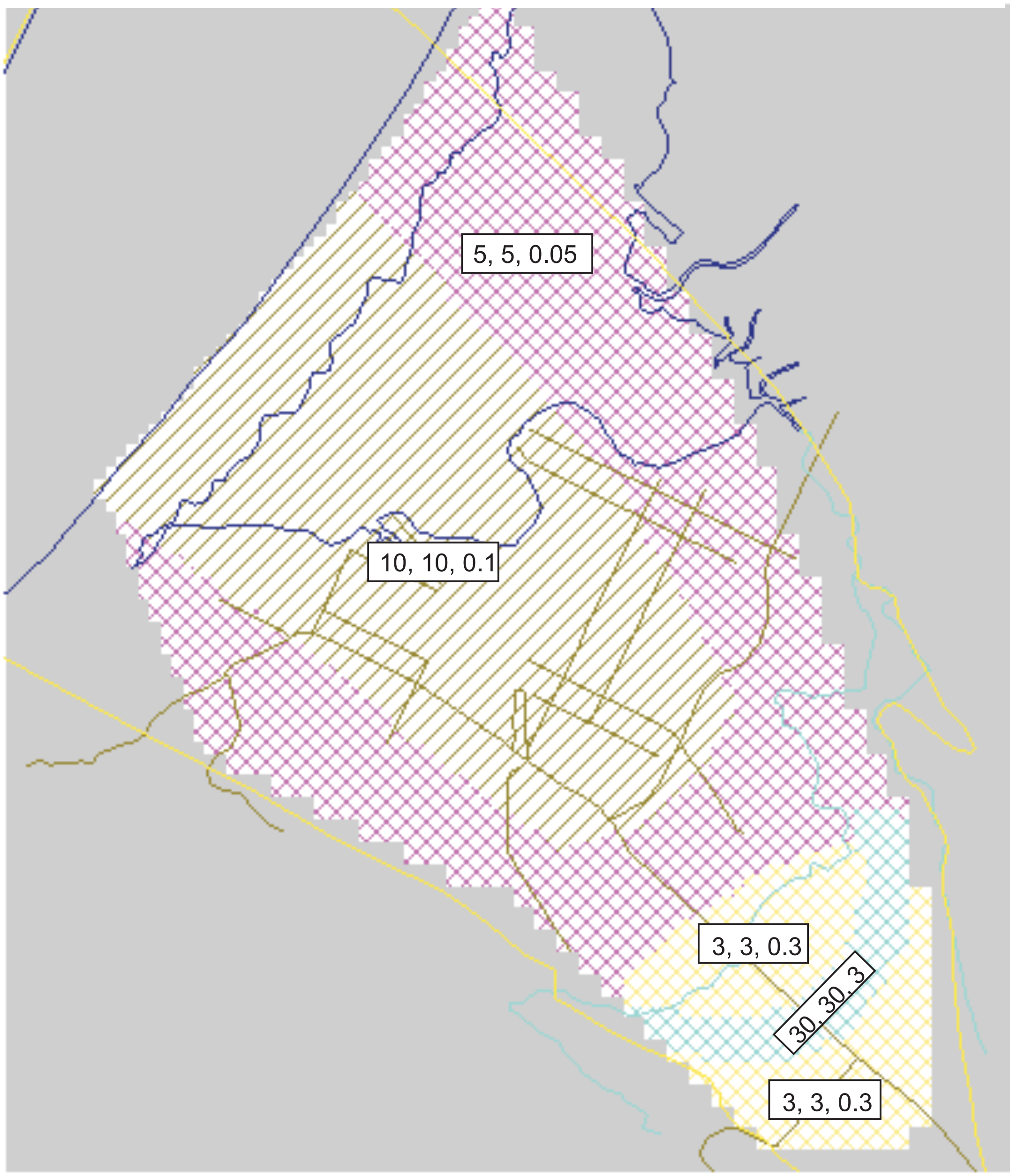


Explanation:

5, 5, 0.05 K (x, y, z) in feet/day

Figure S2
EFH Steady State Model
Hydraulic Conductivity - Layers 1, 2

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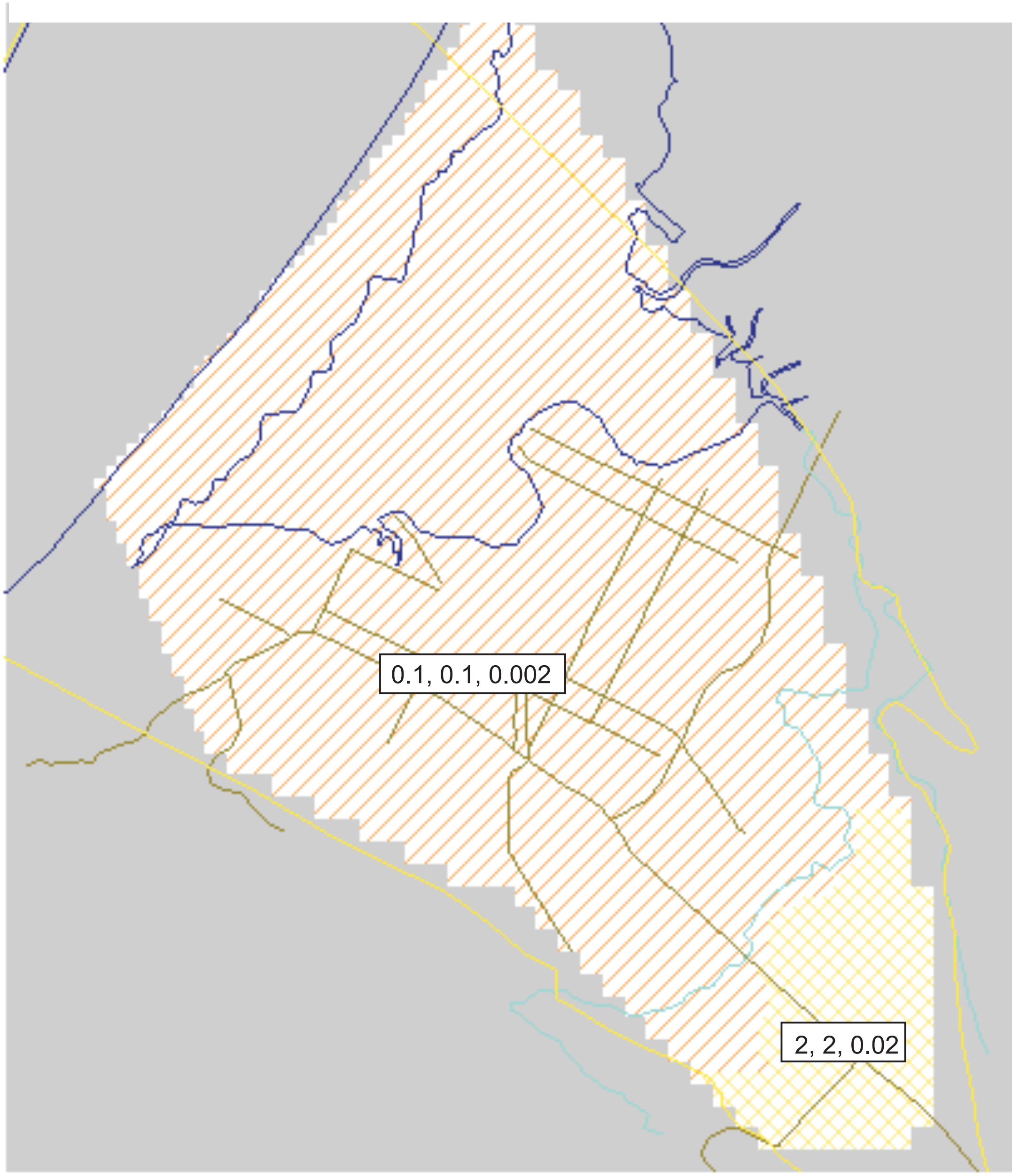


Explanation:

5, 5, 0.05 K (x, y, z) in feet/day

Figure S3
EFH Steady State Model
Hydraulic Conductivity - Layer 3

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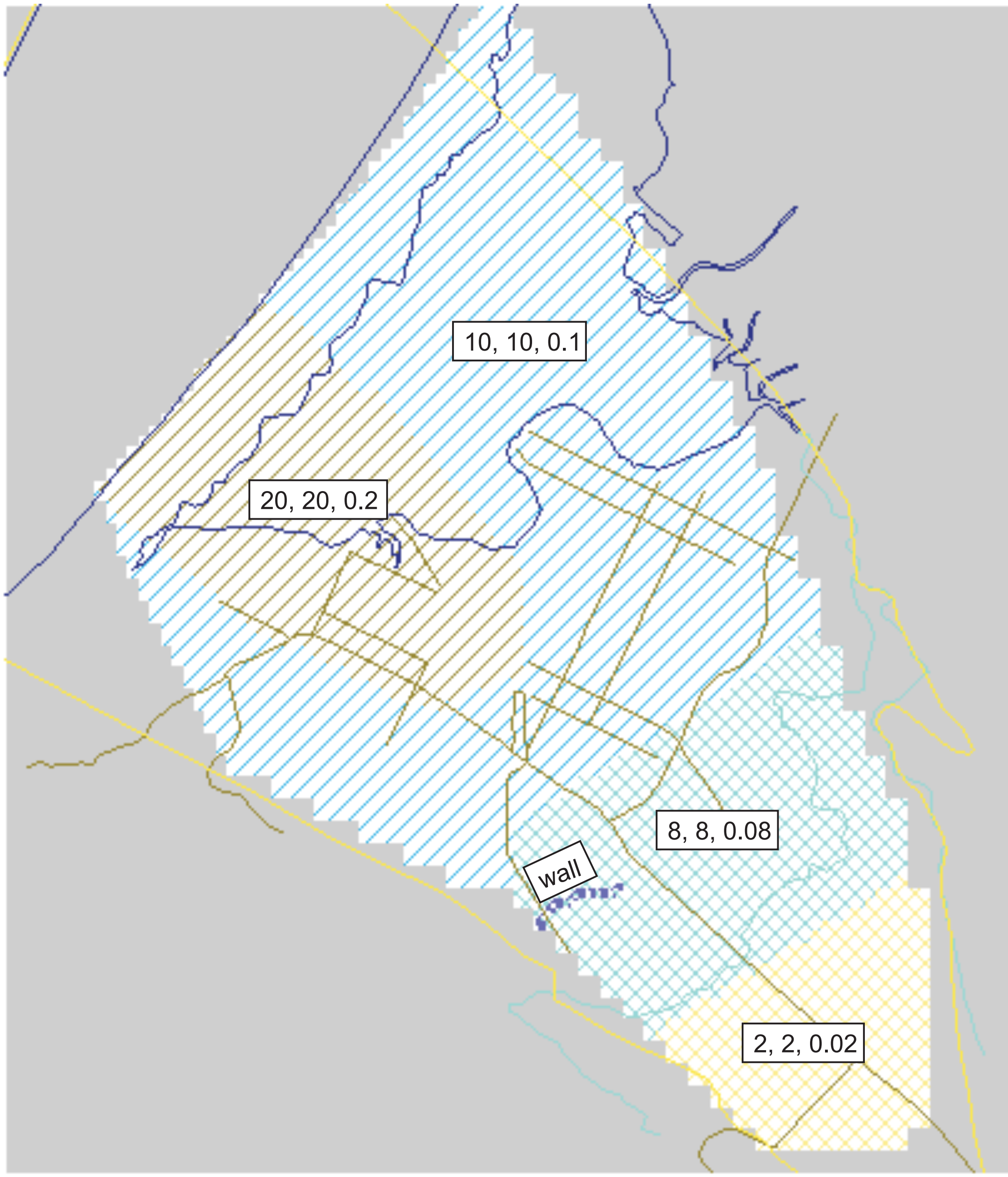


Figure S4
EFH Steady State Model
Hydraulic Conductivity - Layer 4

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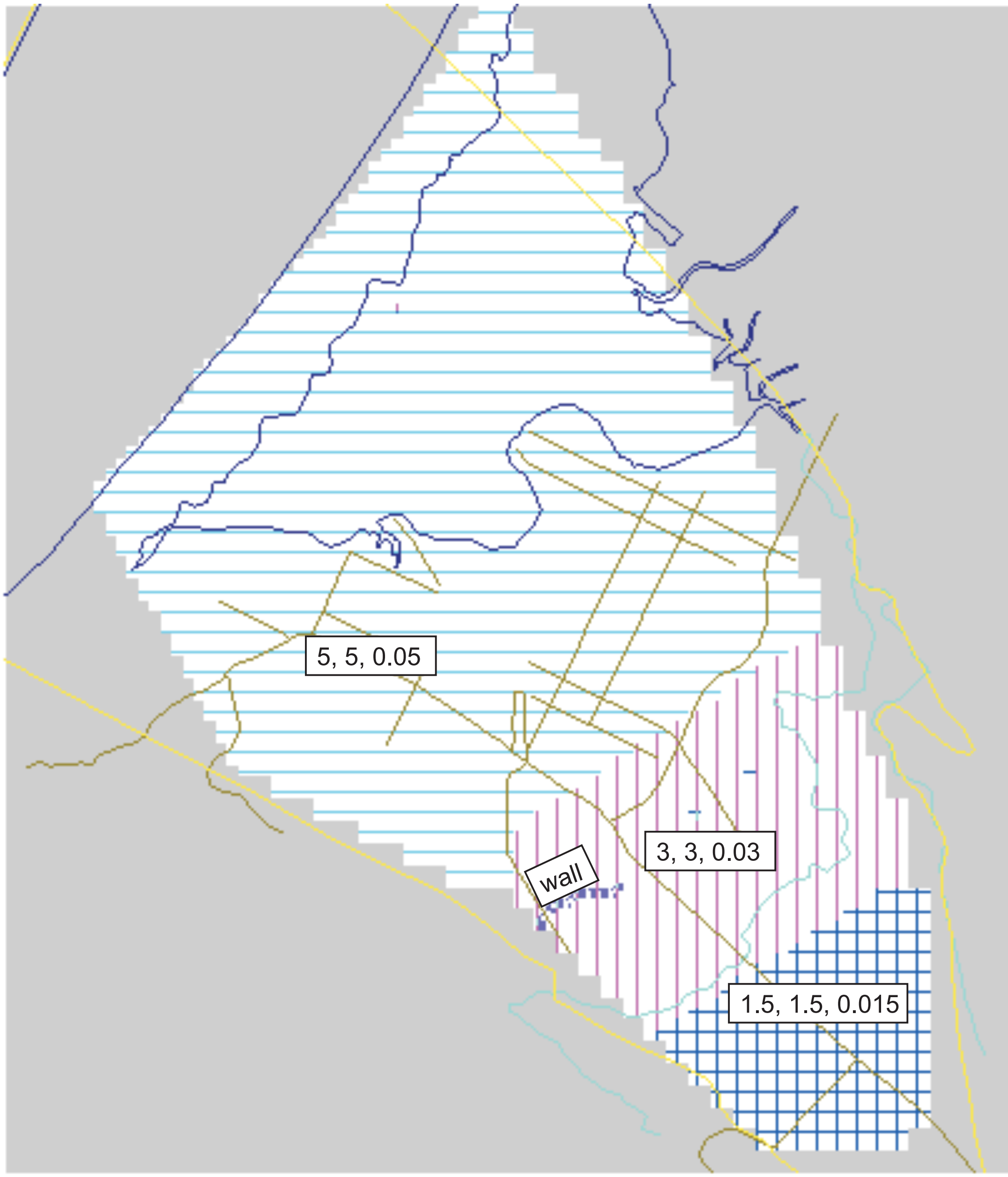
Explanation:

| | |
|---|---|
| 5, 5, 0.05 | K (x, y, z) in feet/day |




Explanation:

| 5, 5, 0.05 | K (x, y, z) in feet/day |

Figure S5
EFH Steady State Model
Hydraulic Conductivity - Layer 5

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