HYDROGEOLOGIC ASSESSMENT OF THE MOUND BASIN

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THIS REPORT IS PRELIMINARY AND IS SUBJECT TO MODIFICATION BASED UPON FUTURE ANALYSIS AND EVALUATION

PREPARED BY:

GROUNDWATER DEPARTMENT

UNITED WATER CONSERVATION DISTRICT

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HYDROGEOLOGIC ASSESSMENT OF THE MOUND BASIN

UWCD OPEN-FILE REPORT 2012-001

EXECUTIVE SUMMARY / ABSTRACT

This open file report addresses the hydrogeologic and geologic conditions of the Mound Basin in Ventura County, California. The United Water Conservation District (United Water) manages the surface water and groundwater resources for either all or part of eight groundwater basins. United Water manages the most significant portion of the Mound Basin. Much of the Mound Basin lies within the boundaries of the City of Ventura. The downtown, midtown, and west side areas of the city fall within the boundaries of the Casitas Municipal Water District. Areas south and east of midtown Ventura fall within the United Water Conservation District.

The Mound Basin has a limited amount of data for characterization of the conditions within the basin. However, the purpose of this report is to assess and outline the hydrogeologic conditions of the Mound Basin with the data that are available. This includes the geology, hydrogeology and groundwater dynamics within the basin as they relate to water supply issues. This was completed by compiling United Water's direct technical data and information from previous works related to the Mound Basin. This information can potentially be used for establishing a basis for further development and management of the groundwater resources of the basin. The scope of work included:

- Assessing the geology and hydrogeology which characterizes the Mound Basin;
- Assessing recharge characteristics and mechanisms for the basin;
- Assessing water level hydrograph records for key wells;
- Assessing water quality data for the basin;
- Assessing changes in well status throughout the basin; and
- Assessing groundwater extractions from the basin for recent years.

The Mound Basin is essentially characterized by a low lying alluvial plain mainly occupied by the City of San Buenaventura. Much of the remainder of the basin is occupied by agricultural lands. The present day boundaries of the basin include: the Ventura fault and foothills to the north, the Country Club fault to the east, the Montalvo anticline to the south and the Pacific Ocean to the west. The Santa Paula Basin borders the Mound Basin on the east side and the Oxnard Plain Basin and Forebay Basin are adjacent to the Mound Basin on the south side.

The Mound Basin lies within the greater regional Ventura Basin which is part of the Transverse Ranges geologic province. In the Ventura Basin the total stratigraphic thickness of upper Cretaceous, Tertiary, and Quaternary strata exceeds 55,000 feet

The Mound Basin is characterized by a significant east-west trending fold axis (Ventura syncline) and a significant amount of faulting. This study conducted a thorough review of geologic articles and reports, which covered 87 years of information, to generate the Mound Basin conceptual geologic model. The Mound Basin water-bearing sediments are generally Pleistocene (San Pedro formation) and Holocene (alluvium) deposits. These deposits are limited to approximately the upper 3,000 feet. The faulting is primarily reverse faulting, with some strike-slip movement, on the north (Ventura and Foothill faults), south (Oak Ridge, McGrath faults, Mound NW 3, and Mound NW 2 faults), and east (Country Club fault) sides of the basin. The Ventura and Oak Ridge faults contribute to the structural boundaries on the north and south side of the basin. The Montalvo anticline located south of the Oak Ridge fault is the present day southern boundary of the basin. However, some researchers suggest that the Oak Ridge fault may be a more appropriate southern structural boundary of the basin, as it forms the southern structural fault and uplift on the south side of the basin.

Aquifer materials and sediments within the adjacent Oxnard Plain and Forebay Basins extend into the Mound Basin. However, the sediments change in character. Some of the shallow alluvium is dominated by clays in the Mound Basin. In addition, the Fox Canyon aquifer zone becomes much more lenticular in nature on the northern side of the Mound Basin. Water level records suggest groundwater likely flows from the Oxnard Plain Basin, Forebay Basin, and Santa Paula Basin into the Mound Basin. Although there are some appreciable offsets on the faults bounding the Mound Basin, the low-permeability Santa Barbara formation does not extend to sufficiently shallow depths to impede groundwater flow. In most cases, there is a significant thickness of the San Pedro formation (aquifer materials) existing above the faults, or on both sides of the faults. The nature of the faults themselves as an impedance to flow is not known. However, groundwater flow and basin recharge across these zones is most probable.

Water levels vary considerably within the Mound Basin as evidenced in the few wells that are located within the basin. Groundwater flows generally from east to west. Gradients within the basin remain fairly flat most of the time (especially during dry periods) and water levels tend to vary somewhat among nearby wells. Water levels in many wells respond in a similar fashion to wet and dry periods, although deeper wells often have lower groundwater elevations. Groundwater production is concentrated in several areas within and around the basin, creating the potential for pumping interference in some water-level measurements.

Agricultural pumping has been the main water user in the Mound Basin (approximately 70 percent). Since the mid-1980s agricultural pumping has averaged nearly 4,200 acre-feet per year with a peak annual production of 5,850 acre-feet recorded in 1990. The City of Ventura’s pumping generally increased through the 1980s, and was variable in the 1990s. Municipal pumping peaked in 2003 and has declined fairly steadily in recent years.

While the quality of the groundwater produced by most wells within the Mound Basin is suitable for municipal and agricultural uses, the basin is not known for the high quality of its groundwater. In addition, the lenticular nature of many San Pedro formation sediments within the basin, and their suggested connate waters that likely remain in this setting, impair water quality in many zones. Although groundwater flow likely occurs through areas where interconnected or continuous aquifer materials exist, the less-continuous nature of some highly permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin. Water quality is variable between wells, and many records indicate somewhat elevated concentrations of TDS, sulfate, hardness and other analytes. Water quality appears to be relatively stable among many of the Mound Basin wells having long-term water quality records. Available records from wells near the coast do not show evidence of saline intrusion.

1 INTRODUCTION AND BACKGROUND

United Water Conservation District (United Water) is a public agency within Ventura County, California that is charged with conserving the water of the Santa Clara Rivers and tributaries. United Water works to manage the surface water and groundwater resources within all or part of eight groundwater basins. These basins include the Piru, Fillmore, Santa Paula, Oxnard Forebay, Oxnard Plain, Pleasant Valley, and parts of the west Las Posas and Mound basins. Figure 1-1 shows the locations of the basins relative to each other.

United Water stores surface water in a surface reservoir (Lake Piru impounded by Santa Felicia Dam), replenishes the groundwater aquifers along the Santa Clara River, diverts natural and reservoir released water, replenishes groundwater through percolation ponds, and delivers both diverted surface water and pumped water to those areas vulnerable to overdraft and saline water intrusion. Since the 1950s, United Water has been studying means to improve groundwater management throughout the District. Projects for improved conservation of water and groundwater management have been executed since the 1950s and these efforts continue to the present day.

During the 1990s and up to the present represents a period of more detailed studies by United Water to improve the understanding of the hydrogeology, basin yields, additional water quality issues, river dynamics, and impacts of the continued high demand for water resources. These studies progressively became more fine-tuned to address more localized issues. One major issue is to actively assess and outline the hydrogeologic conditions of the Mound Basin. This includes understanding the geology, hydrogeology and groundwater dynamics within the basin. The purpose of this study is to establish a basis for planned development and management of the groundwater resources of the Mound Basin.

1.1 OBJECTIVE AND PURPOSE

The objective of this report is to investigate and compile direct technical data and other information from previous works related to the Mound Basin. This information is required to manage the groundwater resources of the basin to maximize its long-term supply, protect the groundwater quality of the basin, and balance long-term average annual water replenishment and extractions. The direct technical data are data that United Water has had direct access or has developed from its own efforts. A review of previous work, spanning eighty-seven years of available literature related to the Mound Basin, was also conducted.

The scope of this report includes the following tasks:

- Assess geology and hydrogeology which characterizes the Mound Basin;
- Assess recharge characteristics and mechanisms for the basin;
- Assess water level hydrograph records for key wells;
- Assess water quality data for the basin;
- Assess changes in well status throughout the basin; and
- Assess groundwater extractions from the basin for recent years.

Since this report is intended to be a tool for the management of the groundwater resources of the Mound Basin it relies heavily on basic hydrogeologic and GIS data from United Water, as well as data obtained from the City of San Buenaventura and the County of Ventura.

1.2 PHYSICAL SETTING

The Mound Basin is located in Ventura County, California, and has been an important source of water supply to both agricultural and municipal users since at least the 1920s. The basin is characterized by a low-lying alluvial plain which gently rises in a northerly direction. It is the westernmost basin within the Santa Clara River Valley drainage. The basin is approximately 7 miles long and 4 miles wide and contains approximately 10,000 acres. The majority of the Mound Basin is occupied by the city/suburban environment of San Buenaventura (Ventura), California. The remainder of the basin is occupied by agricultural lands.

The present day mapped boundaries of the Mound Basin are indicated on Figure 1-2. The southern boundary extends from approximately the mouth of the Santa Clara River and trends northeastward toward South Mountain. This boundary approximately coincides with the axis of the subsurface structure consisting of the Montalvo anticline. The northern boundary consists of the Ventura Foothills north of the City of Ventura with the approximate trace of the Country Club fault forming the eastern boundary. The Country Club fault does not have a surface expression and is considered to be a concealed fault. The Pacific Ocean borders the basin to the west. The Oxnard Forebay Basin and Oxnard Plain Basin are directly adjacent to the Mound Basin on the south side and the Santa Paula Basin is directly adjacent on the eastern side.

As evidenced in Figure 1-2, most of the Mound Basin is occupied by the City of San Buenaventura. The city streets and structures occupy approximately 70 percent of the basin. The remainder of the basin is occupied by agricultural lands. Generally, the main crops in the agricultural fields consist of citrus, avocadoes, berries, and row crops. Occasionally celery is grown during the offseason of berry crops. Highway 101 cuts through the Mound Basin in a northwest-southeast direction. One other major highway (Highway 126) cuts through the basin and runs generally east-west.

2 GENERAL GEOLOGY

The groundwater basins managed by United Water are part of the Transverse Ranges geologic province where the mountain ranges and basins are oriented east-west rather than the typical northwest-southeast trend over much of California. These basins are located within the more regional Ventura Basin, which is an elongate east-to-west trending structurally complex syncline within the Transverse Range province (Yeats, et. al., 1981). The Santa Clara River Valley occupies the Ventura Basin, which is one of the major sedimentary basins in the geomorphic province. The total stratigraphic thickness of upper Cretaceous, Tertiary, and Quaternary strata exceeds 55,000 feet (Sylvester and Brown, 1988).

Active thrust/reverse faults border the basins of the Santa Clara River Valley contributing to the uplift of the adjacent mountains and down-dropping of the basins. This configuration creates the elongate mountains and valleys that dominate Santa Barbara and Ventura Counties. The basins are filled with sediments that were deposited in both marine and terrestrial settings. The basins on the coast, including the Mound Basin, are filled with recent sediments deposited on a wide delta complex that formed at the terminus of the Santa Clara River. Figure 2-1 is a regional geologic map showing the general geology of the region. Figure 2-1 shows the local formations which form the mountain ranges, surface geology, and the major faulting in relation to the United Water basins.

As discussed above, the geology associated with the Transverse Ranges is primarily east to west trending folds and faulting (fold axes trend east-west). As per the regional geology, the Mound Basin is characterized by a prominent syncline (Ventura syncline) whose axis trends east-west and plunges to the west.

The surface and shallow materials in the Mound Basin are characterized by Quaternary alluvium (Holocene and late Pleistocene). These are composed of lagoonal, beach, river/flood plain, alluvial fan, terrace, and marine terrace deposits. Underlying the Quaternary alluvium are the upper Pleistocene San Pedro formation (marine and continental clays, silts, sands and gravels) which hosts most of the aquifers in the area; the lower Pleistocene Santa Barbara formation (mudstone, shale and minor sandstone); and the lower Pleistocene Pico formation (marine mudstones, siltstones, sandstones, and conglomerates) (Mukae and Turner, 1975). The Pleistocene deposits outcrop in the hills bordering the Mound Basin to the north. The two mounds located in the south-central part of the basin, the namesake of the basin, are characterized by outcrops of the San Pedro formation.

2.1 MOUND BASIN FOLDING

Figure 2-2 is a generalized geology map of the Mound Basin. The geology as shown in Figure 2-2 is discussed in this section of this report. The Ventura syncline (called the Santa Clara River syncline by some researchers) axis trends through the Mound Basin in an east-west direction and the approximate location of the axis is indicated on Figure 2-2. The syncline plunges gradually to the west. The Montalvo anticline is approximately parallel to the Ventura syncline and is located south of the syncline near the present day southern structural boundary of the Mound Basin (Geotechnical Consultants, Inc., 1972). The southern leg of the Ventura syncline forms the northern leg of the Montalvo anticline. Some workers also place a parallel fault at the location of the Montalvo anticline (Mann, 1959; Fugro West, Inc., 1996). Seismic reflection data from Fisher et al (2005) does confirm that an anticline exists at that location. It is unlikely that the Montalvo anticline is a simple fold. Some faulting is involved on the northern flank of the Montalvo anticline (McGrath fault, Mound NW 3 fault, Mound NW 2 fault, Oak Ridge Fault).

2.2 MOUND BASIN FAULTING

The Mound Basin is characterized by several faults. The faults are discussed in the following sections.

2.2.1 VENTURA AND FOOTHILL FAULTS

The Ventura fault (Figure 2-2) is located in the northern section of the basin and trends east-west. It is a reverse fault that dips to the north at a high angle, with the up-thrown side on the north contributing to the Ventura foothills (Yerkes et al, 1987). Figure 2-3 is a cross-section interpretation showing the Ventura fault. The fault was mapped by the United States Geological Survey (USGS) near the base of the Ventura Foothills. The Ventura fault extends offshore where it is referred to as the Pitas Point fault by Greene et al (1978), however, the USGS and other workers still refer to it as the Ventura fault. The Foothill fault is also mapped as an east-west trending fault in the northeast section of the Mound Basin. It is not referenced in most publications for the geology of the area. However, it was included in the GIS coverage from the USGS website (United States Geological Survey, 2011). Yerkes et al (1987) do show an inferred fault at the approximate location of the Foothill fault where it is shown in Figure 2-2. However it is not shown on Figure 2-3. The assumed motion along the fault is that of a reverse fault with the up-thrown side to the north.

2.2.2 COUNTRY CLUB FAULT

The Country Club fault is an arc shaped fault that trends northwesterly along the eastern edge of the Mound Basin and mainly forms the structural boundary between the Mound Basin and the Santa Paula Basin to the east (Figure 2-2). It is a steeply dipping (almost vertical) reverse fault with some appreciable left-lateral displacement (Turner, 1975). United Water's inspection of oil well data indicate a displacement of 1,600 to 1,800, feet with the south side of the fault displaced upward relative to the northern side which is consistent with the offset reported by other investigators [Fugro West (1996) indicates approximately 2,000 feet of offset; Geotechnical Consultants, Inc. (1972) shows approximately 1,700 feet of offset].

2.2.3 OAK RIDGE FAULT/MCGRATH FAULT/MOUND NW FAULTS

An understanding of the location (Figure 2-3) and nature of the Oak Ridge fault, McGrath fault, Mound NW 2 fault and Mound NW 3 fault share a more complex development in historical literature. The Mound NW 2 fault and Mound NW 3 fault both are located adjacent to a topographic mound referred to as "pressure ridges".

U.S. Geological Survey Bulletin 753 (USGS, 1924) does not extend the overall fault coverage map to the Mound Basin, although they produced a geology map of Los Angeles and Ventura Counties. This suggests that the Mound Basin was not studied at that time. In 1933 the Division of Water Resources Bulletin 46 (California Department of Water Resources, 1933) presents the results of a geological investigation of Ventura County, however, the Oak Ridge fault, McGrath fault, Mound NW 2 fault, or Mound NW 3 fault are not shown pertaining to the Mound Basin. In addition, the Ventura and Montalvo anticlines are not shown. The California State Water Resources Board Bulletin No. 12 (California State Water Resources Board, 1953) contains a geologic map which shows the Oak Ridge fault in the Santa Paula Basin only. It extends to another fault referred to as the Saticoy fault (predecessor in study of the modern Oak Ridge fault) partially extending into the Mound Basin (Figure 2-4). The Saticoy fault is mapped to the east side of the Mound Basin, however, if projected to the west it would trend through or just north of the Mound NW 2 and Mound NW 3 faults (and pressure ridges). The McGrath fault is not shown. The map does show the Montalvo anticline which is depicted as partially coincident with the Santa Clara River.

John F. Mann Jr. and Associates (1959) appears to replace the Montalvo anticline with the "Montalvo fault" on his map. However, he does refer to the Montalvo anticline in his text. The Saticoy fault, as per Bulletin 12, is included in this publication. The McGrath fault or the Mound NW 2 and Mound NW 3 faults (and pressure ridges) are not shown on maps or included in the text. His cross-section shows the Montalvo fault extending to the surface with the up-thrown side to the southeast (Figure 2-5). In 1972 Geotechnical Consultants, Inc. show the Oak Ridge fault extending in a general east-west direction across the entire Mound Basin. It is depicted as touching one Mound NW fault and pressure ridge. There is only one Mound NW fault and pressure ridge shown. The Montalvo anticline is also shown. In map view, they show the McGrath fault approximately coincident with the Montalvo anticline trending approximately parallel to the Oak Ridge fault. GTC's McGrath fault is very similar to the Montalvo fault shown in Mann (1959). No Saticoy fault, or McGrath fault as shown in Figure 2-2, is included. In cross-section, the Oak Ridge fault is shown to partially extend upward into the San Pedro Formation and displaces less than 200 feet of the Santa Barbara formation adjacent to the San Pedro formation at a depth of 2,300 feet.

Turner and Mukae (1975) have the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation north of the pressure ridges (Figure 2-6). They show the

McGrath fault extending from the main part of the Oak Ridge fault. It connects with the Oak Ridge fault east of the pressure ridges. The McGrath fault section is north of the Santa Clara River for its entire length. The Montalvo anticline merges with the McGrath fault in the western portion of the Mound Basin. The Country Club fault also merges with the Oak Ridge fault. In cross-section, both the Oak Ridge and McGrath faults extend into the alluvial deposits in the area (Figure 2-7) with the southern side up-thrown for both faults. The Santa Barbara formation is not shown on their cross-sections as they only address the effective base of fresh water. However, the San Pedro formation and overlying alluvium are shown to extend across both faults for thicknesses between 1,000 and 1,600 feet according to the cross-sections.

Yerkes et al (1987) map the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation located north of the pressure ridges. They also show the McGrath fault as an unnamed fault which connects to the Oak Ridge fault west of the pressure ridges and curves westward extending south of the Santa Clara River (Figure 2-8). An oversize plate from Yerkes et al (1987) also shows the Oak Ridge fault at a different scale. From that scale it can be observed that the Oak Ridge fault is located directly north of the two pressure ridges located adjacent to the Mound NW 3 and Mound NW 2 faults. In fact the Oak Ridge fault actually “touches” the mound (pressure ridge) adjacent to Mound NW 2. Yerkes et al (1987) state that the Oak Ridge is a zone of faulting that forms the southern boundary of the Ventura synclinal trough in the western Ventura Basin (Mound structural basin) rather than the Montalvo anticline as mapped by earlier researchers. They state that the faults in the area are buried and known only from subsurface data. They describe the Oak Ridge as a steeply dipping reverse fault with stratigraphic separation of about 350 meters (1150 feet) at the base of the San Pedro formation. Yerkes et al describe the pressure ridges as two isolated, elongate northwest trending structural uplifts. They are described as compressional features and are compatible with left-lateral slip along the adjacent Oak Ridge fault. It suggests a significant strike-slip component along the Oak Ridge fault as well as a reverse fault uplift on the south side.

Yeats (1988) maps the Oak Ridge fault extending through the Mound Basin in a general east-northeast orientation north of the pressure ridges (Figure 2-9). He refers to the McGrath fault as the “Montalvo” fault and shows the fault extending southwestward in an arcuate shape extending from the Oak Ridge fault. It connects with the Oak Ridge fault west of the pressure ridges and trends south of the Santa Clara River where it goes out to sea. Both faults are mapped as concealed. The Yeats configuration of the Oak Ridge fault and McGrath fault (Yeats’ Montalvo fault) agrees with the Yerkes et al (1987) which is used for Figure 2-2. United Water uses that configuration. Yeats contains two cross-sections (A-A’ and B-B’) over the Oak Ridge fault and McGrath fault (Montalvo fault) (Figure 2-10). Cross-section A-A’ is oriented north-northwest and crosses both the Oak Ridge fault and the McGrath fault. Cross-section B-B’ is also oriented north-northwest and crosses the Oak Ridge fault in the vicinity of the pressure ridges. Cross-section A-A’ shows that the McGrath (“Montalvo”) fault actually merges with the Oakridge fault at a depth of approximately 2 kilometers (6,562 feet) (Figure 2-11). The Oak Ridge fault is shown as a reverse fault with the up-thrown side on the south side. The McGrath fault is also a reverse fault with the up-thrown side on the south side. Therefore, the area between faults as they appear in map view is actually up-thrown in whole. Both cross-sections indicate that the top of the Oak Ridge fault exists at a depth of 1.0 to 1.5 kilometers bgs (3,300 feet to 4,900 feet). Yeats et al (1982) contends that the upper edge of the Oak ridge fault is buried by Quaternary sediment 1,250 meters thick (4,100 feet) in the Ventura Basin near Ventura, California. This is much deeper than the aquifer systems in the San Pedro formation.

Fisher et al (2005) conducted a high resolution and medium resolution marine seismic reflection survey over the Oak Ridge fault and the McGrath fault offshore south of Ventura, California. Using data from Huftile and Yeats (1995), Fisher et al show the Oak Ridge fault upper edge greater than a kilometer (3,300 feet) deep as measured under the continental shoreline where it goes out to sea. Seismic reflection data obtained from approximately 6 kilometers (~19,700 feet or 3.7 miles) as well as 9 kilometers (~29,500 feet or 5.6 miles) offshore image the Oak Ridge fault. These data are interpreted to image an unconformity, at a depth estimated to be approximately 80 meters (265 feet) below the sea floor that is probably at the base of the upper Pleistocene and Holocene strata which is not offset by the Oak Ridge fault. The upper edge of the Oak Ridge fault extends to the unconformity, however, the unconformity and strata above it are not offset. The McGrath (Montalvo) fault is also interpreted by Fisher et al (2005) to be truncated by an unconformity below the sea floor approximately 3 kilometers (9,850 feet or 1.9 miles) offshore.

3 HYDROSTRATIGRAPHY

In the Mound Basin, alluvial deposits and the San Pedro formation represent the principal water bearing strata. Underlying deposits, which include the Santa Barbara and Pico formations, are considered non-water bearing in the Mound Basin area even though they yield a limited amount of water for domestic wells elsewhere in Ventura County.

Figure 3-1 is a schematic cross-section of the Mound Basin taken from Greene (1978). Although the faulting may not be consistent with the latest understanding of the basin, it shows the general formations within the basin discussed in the following paragraphs of this report. It also shows the Montalvo anticline on the right hand side of the figure. Figure 3-2 shows the relationship between the major hydrostratigraphic units (i.e., aquifers and aquifer systems) and the geologic formations and their ages as typically defined for the region. In general the Oxnard aquifer and Mugu aquifer zones comprise the Upper Aquifer System (UAS) with the Lower Aquifer System (LAS) containing the Hueneme, Fox Canyon, and Grimes aquifers. These hydrostratigraphic units extend into the Mound Basin from adjacent basins, however, they change character (e.g., lithology, thickness, degree of interbedding) in places. Generalized conceptual groundwater flow paths are depicted in Figure 3-3. Figure 3-4 is a southwest to northeast cross-section, across the Oxnard Plain, located southeast and adjacent to the Mound Basin. The Grimes Canyon aquifer is not shown on the cross-section.

3.1 UPPER AQUIFER SYSTEM

The UAS is composed of Holocene (Oxnard aquifer) and late Pleistocene (Mugu aquifer) alluvium separated by an unconformity that functions as a clay aquitard (Figure 3-2). The boundary between the UAS and LAS is an unconformity.

Undifferentiated younger alluvium (Holocene Oxnard aquifer zone) and older alluvium (late Pleistocene Mugu aquifer zone) comprise the water bearing alluvial deposits in the UAS in the Mound Basin. The younger alluvium in the Mound Basin is composed of flood plain and active river deposits in the vicinity of the Santa Clara River, and fan deposits which mantle much of the remaining portion of the basin. These deposits are predominately interbedded, lenticular clays with some silts, sands, and gravels. Geotechnical Consultants, Inc. (1972) report a maximum thickness of approximately 290 feet near the southwest corner of the Mound Basin. These deposits unconformably overlie the older, late Pleistocene alluvium. In the nearby Oxnard Plain Basin, the younger alluvium is reportedly nearly 250 feet thick on average (Turner, 1975) and contains a permeable coarse-grained unit at its base (Oxnard aquifer). As the Oxnard aquifer zone in the Mound Basin is dominated by clay deposits, the coarse grained units tend to be more sparse and lenticular in nature.

Undifferentiated older alluvium (late Pleistocene) unconformably overlies the late Pleistocene San Pedro formation. Older alluvium can be divided into an upper and lower portion. The upper portion consists mainly of confining zones (clay and silty clay) with minor amounts of sand and gravel. Interstratified sand and gravel, with variable amounts of clay, comprise the lower portion of these deposits. In the Mound Basin this coarse-grained portion is thickest near the Santa Clara River and becomes generally thinner to the north toward the foothills. The coarse grained strata at the base of the older alluvium in the Mound Basin are considered equivalent to the Mugu Aquifer, which has been traced into the Mound Basin from the Oxnard Plain Basin. Most wells in the Mound Basin contain perforations in the Mugu Aquifer. Older alluvium reported thicknesses are variable ranging from approximately 125 feet (Geotechnical Consultants, Inc., 1972) in the eastern part of the basin to about 450 feet (Turner, 1975) near the coast. Borehole geophysical logs reviewed for this investigation (Figures 3-5, 3-6, and 3-7) suggest Mugu hydrostratigraphic unit thicknesses up to about 425 ft.

3.2 LOWER AQUIFER SYSTEM

The Hueneme and Fox Canyon aquifers are part of the late Pleistocene San Pedro formation with the Grimes Canyon aquifer being part of the early Pleistocene Santa Barbara formation.

The San Pedro formation deposits are upper Pleistocene in age and underlie the alluvial deposits in the Mound Basin along a marked angular unconformity. Exposures of the San Pedro formation occur in the foothills which form the northern boundary of the basin. They attain a maximum thickness of 2,300 feet in this region (Geotechnical Consultants, Inc., 1972). The thickness of the San Pedro formation is considerably less at the southern edge of the Mound Basin as a result of complex folding and faulting and subsequent erosion in that area (Montalvo anticline). This is evidenced in oil well geophysical logs inspected by United Water. The maximum thickness of the San Pedro formation occurs at the axis of the Ventura syncline near the center of the basin. Oil well data show that the maximum thickness is approximately 4,500 feet (Yerkes et al, 1987; Fugro West, 1996).

Upper portions of the San Pedro formation contain variable amounts of clay, silty clay, and sand. A series of interbedded water-bearing sands in this section form the time equivalent of the Hueneme aquifer in the Oxnard Plain Basin. Structural complexities and erosion have removed a portion of these beds in the southern part of the Mound Basin. In the central and northern part of the basin e-log signatures indicate changes in the aquifer units compared to the Oxnard Plain. However, thick sections of the Hueneme aquifer (or its time equivalent) do occur in the Mound Basin, as oil well e-logs interpreted by United Water indicate variable amounts of aquifer materials. Some areas appear to be characterized by significant clays. Most of the deeper wells in the Mound Basin are perforated in the Hueneme aquifer.

Lower portions of the San Pedro formation consist principally of sand and gravel zones with variable thicknesses of interstratified clay and silt. In a northerly direction across the Mound Basin these coarser grained water bearing strata are somewhat lenticular and generally become thinner (Mann, 1959, Geotechnical Consultants, Inc., 1972). This predominantly sand and gravel zone located at or near the base of the San Pedro formation is known as the Fox Canyon Aquifer in the Oxnard Plain Basin and extends into the Mound Basin. These deposits occur at great depths in the Mound Basin and are generally not targeted for water production.

The Fox Canyon Aquifer is continuous and traceable across the Oxnard Plain. As discussed above these beds apparently partially pinch out and become more lenticular in a northerly direction across the Mound Basin. Exposures near the base of the San Pedro formation in the foothills on the north side of the Mound Basin do not indicate the same aquifer thickness, or sediment coarseness, as at the type location of the Fox Canyon zone on the south flank of South Mountain, located several miles southeast of the basin. Nevertheless, in the Mound Basin (and surrounding areas) the distinct borehole geophysical log signature of the Fox Canyon Aquifer can be used as an aid in defining the base of the San Pedro formation.

United Water created several cross-sections by correlating borehole geophysical data from oil wells and some water wells. Figure 3-5 is a location map for two cross-sections that cross the Mound Basin in a general southwest-northeast (Cross-section J-J'; Figure 3-6) and north-south orientation (Cross-section P-P'; Figure 3-7). Both cross-sections illustrate the spatial relationships between the hydrostratigraphic units in the Mound Basin. On Section J-J' the large stratigraphic offset between the second and third well on the southwest side of the profile likely represents the McGrath fault. At that location, there appears to be approximately 700 feet of throw on the top of the Santa Barbara formation with the up-thrown side on the south. It has put some Santa Barbara formation in contact with the San Pedro formation. However, there is still approximately 1,200 feet of San Pedro formation and alluvium above the Santa Barbara formation. Interestingly, offset across the Oak

Ridge fault is not readily apparent which may be a function, at least in part, of the log spacing (i.e., wells are far apart). The Oxnard and Mugu alluvial aquifers do not appear to have been offset by either the McGrath or Oak Ridge faults. Overall, the UAS and a significant portion of the LAS hydrostratigraphic units are continuous across these faults.

On the northeast half of Cross-section J-J', the depth to the bottom of the Hueneme aquifer zone and Fox Canyon aquifer zone (San Pedro formation) in the Ventura syncline are not resolved by the well data (the wells are not deep enough). The Hueneme and Fox Canyon aquifer zones are deeper than the available well log data. The northern leg of the Ventura syncline is very steep on the northeast side of the profile as it extends upward to form the foothills.

On the southern portion of Cross-section P-P' the Fox Canyon aquifer zone extends upward and is in contact with the Mugu aquifer. This is likely the expression of the Montalvo anticline. Part of the extreme upward extension of the Fox Canyon aquifer zone in that area may be due to the Oak Ridge fault. There is approximately 200 feet of offset in the Mugu aquifer zone between wells 02N22W08L01S and 02N22W08P04S which may be caused by the Oak Ridge fault or related splays. Typically the UAS aquifers are not offset by the fault except for this location. The Hueneme aquifer zone is missing between Wells 2N22W17G01S and 2N22W17Q04S. Geotechnical Consultants Inc. (1972) also indicate that structural complexities and erosion have removed the Hueneme aquifer zone in the southern part of the Mound Basin. However, it is present further to the south. The contact between the Fox Canyon aquifer (beneath the Oxnard Plain) and the thick section of Mugu aquifer might serve a source of recharge to LAS aquifers in the Mound Basin.

3.3 IMPACT OF STRUCTURAL FEATURES ON HYDROSTRATIGRAPHY

The hydrostratigraphy of the Mound Basin has been impacted by the development of the structural features such as folding (e.g., Venture syncline, Montalvo anticline) and/or faulting (e.g., Country Club fault, Oak Ridge fault, McGrath fault) that created the Mound structural basin. Some researchers have suggested that the major faults within the basin or basin bounding faults function as impediments to groundwater flow and in some cases as barriers to flow. In most cases, researchers have proposed that low permeability geologic deposits have been uplifted into a juxtaposed position with the aquifers. Review of the readily available literature (Section 2) on the structural geology provided insight into data used to develop the historical perspectives.

The top of the Montalvo anticline has been eroded and the truncated edges of the Hueneme aquifers may be in hydraulic communication with the shallower aquifer zones in that area. Such a contact likely serves as a source of recharge to aquifers in the Mound Basin under certain water level conditions (Fugro West, 1996).

No readily available research on the influence the faults themselves have on groundwater flow has been identified. Their impact on groundwater has not been quantified.

3.3.1 Country Club fault

The Country Club fault has been speculated to be significant barrier to groundwater flow on the eastern boundary of the Mound Basin. However, it only displaces a portion of the low permeability Santa Barbara formation against the aquifer rich San Pedro formation. GTC (1972) shows approximately 1,300 feet of the San Pedro formation and alluvium exists above the up thrown Santa Barbara formation at that location. Fugro West (1996) shows approximately 1,500 feet of San Pedro formation and alluvium on top of the up thrown Santa Barbara formation at that location.

With the San Pedro formation on both sides of the Country Club fault above the displaced Santa Barbara formation, the Country Club fault zone likely conducts groundwater flow. Approximately 1,500 feet of San Pedro formation and younger Quaternary alluvium is continuous across the top of the Country Club fault forming a section that is possible for groundwater flow and recharge to the Mound Basin. The deeper section of the fault where the Santa Barbara formation is in contact with the San Pedro formation may act as a groundwater flow barrier only at depths below a minimum of 1,500 feet. The fault is not considered to extend upward through the alluvium (GTC, 1972).

3.3.2 Oak Ridge fault / McGrath fault / Mound WN faults

Mann (1959) depicts (Figure 2-5) the low-permeability Santa Barbara formation plotted adjacent to the San Pedro formation for approximately 500 feet, at a depth of 900 feet below ground surface (bgs). Therefore, there would be some hydraulic connection in the San Pedro formation (aquifers of the San Pedro formation) for water to recharge or flow on both sides of the "Montalvo fault" for a thickness of 900 feet.

GTC (1972) shows that hydraulic connection could occur for a significant thickness (~2,300 feet) on both sides of the Oak Ridge fault. GTC's McGrath fault extends upward through the San Pedro formation however it does not penetrate the 400 feet of alluvium above it. The fault does displace 500 to 600 feet of Santa Barbara formation adjacent to the San Pedro formation at a depth of 800 to 1,100 feet (depending on which of the cross-sections used). Accordingly, there may be significant hydraulic connection between the aquifers of the San Pedro formation across GTC's McGrath fault. There is a thickness of 800 feet to 1,100 feet of San Pedro formation and alluvium overlying the highest up-thrown section of Santa Barbara formation. Therefore it is likely that there is flow in that zone and recharge to the Mound Basin.

Turner and Mukae (1975) cross sections show the San Pedro formation and overlying alluvium extending across both the Oak Ridge and McGrath faults for thicknesses of between 1,000 and 1,600 feet. Therefore there could be hydraulic connection between the aquifers of the San Pedro formation across both faults. Mapping in the California DMG Open File Report 76-5 (California Division of Mines and Geology, 1975) is very similar to Turner and Mukae (1975) as far as the surface mapping of the faults is concerned. However, the western section of the McGrath fault is located south of the Santa Clara River. In addition, the eastern section of the McGrath fault does not connect with the Oak Ridge fault. It is mapped to end before it merges with the Oak Ridge fault.

Cross-Section D-D' from Yerkes et al (1987) (Figure 2-3) is a full cross-section that extends north-south from the Ventura foothills past the Oak Ridge fault and shows insignificant stratigraphic offset along the Oak Ridge fault (approximately 100 feet). The cross-section shows the San Pedro formation as having a thickness of approximately 1,500 feet on both sides of the Oak Ridge fault overlying the low permeability Santa Barbara formation. This is a significant thickness for possible groundwater flow and recharge.

Yeats et al (1982) depict the San Pedro formation and most of its aquifers as continuous across the top of the Oak Ridge fault and extending between the Oxnard Plain Basin and the Mound Basin unimpeded by the Oak Ridge fault along the southern boundary of the basin. The McGrath fault (Yeats Montalvo fault) extends upward to shallower depths close to the land surface. However, the McGrath fault only traverses a small portion of the southern boundary of the Mound Basin. The shallower aquifer systems of the Oxnard Plain and Forebay Basins extend between the basins across the top of the fault. This configuration, for both faults, suggests hydraulic connection and flow to the Mound Basin from the Oxnard Plain Basin and Forebay Basin.

The seismic data presented in Fisher (2005) suggests that a 265 feet thickness of aquifer materials (below the sea floor) exist continuously across the top of the Oak Ridge fault several miles offshore (3.7 and 5.6 miles).

4 WATER LEVELS

Groundwater elevation records exist for nearly sixty wells located within the Mound Basin. A number of key wells have water levels dating to the late 1920s, allowing an evaluation of long-term water level trends within the basin. However, the distribution of wells is heavily skewed towards the southern half of the basin, with relatively few wells existing north of Telephone Road. In the western portion of the basin wells are concentrated along Olivas Park Drive and near the railroad tracks south of Highway 101. This distribution of active and historic wells complicates the assessment of potential mountain-front recharge to the basin from the north. The southern and eastern boundaries of the basin are defined by structural features, and water level records from adjacent areas help assess the nature of the basin boundaries in these areas. Water level trends for many wells within the basin are similar, with evidence of recharge from adjacent basins to the east and south. The main groundwater flow pattern is down the axis of the basin from east to west. The slope of the potentiometric surface within the basin is quite flat during dry periods and the gradient increases somewhat following periods of above-average rainfall. During dry periods, groundwater elevations in many wells fall below sea level.

A major structural feature of the Mound Basin is the Ventura syncline, with the axis following an alignment similar to that of Highway 126. Several wells are located near the axis of this syncline, providing water level information in the center of the basin. Recharge on the north flank of the structure is believed by some to be likely, where the San Pedro formation crops out in the foothills (Geotechnical Consultants, Inc., 1972). The influence of faulting along the northern margin of the basin is undetermined, but may limit the potential for recharge from the adjacent uplands. Water level records are known to exist for only one well in the northern portion of the Mound Basin (well 02N23W01P01S, total depth 300 feet). Water level records are only available for the mid-1970s, when recorded water levels were about 100 feet higher than in other wells from the central portion of the basin. Monitoring well 02N22W07M03S was constructed in 1995, located near the intersection of Highways 101 and 126, and screened from 210-270 feet below grade. Groundwater elevations in this well are similar to those recorded earlier in well 02N23W01P01S, and show very little seasonal or annual variability (Figures 4-1 and 4-2). Samples from the monitoring well show water quality to be consistently very poor, supporting the water level record as evidence of a perched groundwater system (of unknown extent) in this vicinity. Water levels in the aquifer units that may exist on the north flank of the Ventura syncline are not known to exist. Test holes drilled near the mouth of Lake Canyon (near Foothill Road and Victoria Ave) in the early 1970s apparently did not penetrate productive aquifer units and were not completed as production wells.

The eastern boundary of the Mound Basin sits adjacent the western Santa Paula basin. This boundary between sub-basins of the Ventura Central basin is generally defined by the concealed trace of the Country Club fault (Turner, 1975 and Geotechnical Consultants, Inc. 1972). The geology of the western Santa Paula basin is structurally complex, and faulting and folding in this vicinity may complicate groundwater flow within the regional groundwater flow system down the Santa Clara River valley. Groundwater elevations in the western Santa Paula basin generally range from 80 to 140 feet above sea level, and individual wells in this area exhibit somewhat muted water level variability, common to groundwater discharge areas of the other sub-basins of the valley. Groundwater elevations in three wells (02N22W09K05S, -09L03S and -09L04S) near Kimball Road in the eastern Mound Basin are similar to those recorded in the western Santa Paula basin, and are some 40 to 80 feet higher than other nearby wells (Figure 4-4). The high heads in these three deep wells may suggest some aquifer zones have a better connection to the Santa Paula basin. A fourth well located south of the Oak Ridge fault and in section 02N22W09 has a record of groundwater elevations in the 1970s approximately 20 to 30 feet higher than nearby wells. However, recorded groundwater elevations in shallower wells in the eastern Mound Basin are often 80 to more than 100 feet lower than those in western Santa Paula. This differential in head produces a large hydraulic gradient across the basin boundary, and likely results in groundwater flow from the Santa Paula to the Mound Basin. The magnitude of this flow, however, remains unquantified.

Along its southern margin, the Mound Basin sits adjacent to the Oxnard Forebay in the east and the Oxnard Plain to the west. A number of past researchers adopted the Montalvo anticline as the southern boundary of the Mound Basin, and this same feature has been mapped by others as the Montalvo fault or McGrath fault (Mann, 1959 and Geotechnical Consultants, Inc. 1972). More recently, others have refined the existence and location of the Oak Ridge fault about 4,000 feet to the north (Figure 2-2 geology section), and argue this is a more appropriate southern boundary for the Mound “structural” basin (Yerkes et al, 1987, Yeats et al, 1988). This more northern interpretation of the basin structural boundary leaves few production wells in the central portion of the Mound Basin. Historic water level records exist for a few wells located in the area north of the Oak Ridge fault, but the amount of water produced from these older wells is unknown. In the early

1980s municipal pumping in section 02N22W08 increased rapidly, reaching 3,000 acre-feet in 1984 and averaging slightly more than this amount annually through the end of 2010. Groundwater elevations around 40 feet above sea level were common in this area throughout the 1970s, but rare in years since (Figure 4-1). Regardless of this change in pumping in the area, a long-term profile of groundwater elevations from selected wells located near the axis of the basin shows a fairly consistent and gradual decline in heads from east to west [from the Kimball Road area to the coast near Ventura Harbor (Figures 4-5 and 4-6)]. Significant agricultural pumping also exists in the areas east and northeast of the harbor.

The annual water level responses for the wells located south of the Oak Ridge fault are similar, with the more eastern wells (up-gradient wells) having higher heads than the wells closer to the coast (Figures 4-7 and 4-8). Deeper wells throughout the basin tend to have lower groundwater elevations, but recorded water levels in most Mound Basin wells tend to converge during dry periods. In periods of drought, water elevations in many wells in the central portion of the basin fall below sea level. Contouring of water levels in the central portion of the basin is difficult given the poor distribution of wells and a common variability in water levels among nearby wells of up to 20 feet.

Comparison of water level records from the northern Forebay/Oxnard Plain and the area between the Montalvo Anticline and the Oak Ridge fault of Yerkes and Yeats appear to support the appropriateness of the more-northern boundary. Contouring of available groundwater elevations from wells south of the Oak Ridge fault generally show a relationship with those from adjacent areas to the south, namely, the former “Zone C” area north of the Santa Clara River and the northern Oxnard Plain in areas south of the Santa Clara River (Figures 4-7 and 4-8; Appendix B). Wells located north of the Montalvo anticline and closest to the Forebay (e.g., well 02N22W16K01S) predictably exhibit the greatest annual variability, but the range of recorded water levels is less than that in wells in the main recharge areas of the Forebay. Groundwater flow to the Mound basin from the Forebay and northern Oxnard Plain has been noted in older reports, but also noted was reduced opportunity for recharge north across the Montalvo anticline during times of depressed groundwater elevations on the Oxnard Plain (GTC, 1972; Fugro, 1996). United Water’s contouring of water levels north of the Montalvo anticline support these prior findings, showing good agreement with water levels in the northern Forebay and Oxnard Plain in the spring of some recent wet years (e.g., 2001, 2005). Contouring also suggests that during drier periods the southern strip of the Mound basin (located south of the Oak Ridge fault and north of the Montalvo anticline) exhibits heads that are commonly 5 to 15 feet lower than those to the south, with the head differential between the basins increasing towards the coast.

The contouring of past water level conditions is complicated at times by sparse data. Increased collection of water level records is recommended in this greater area in order to better define groundwater gradients between these adjacent basins. The recent installation of monitoring wells north of the Santa Clara River near the northwestern margin of the Forebay should be helpful in better defining the flow of groundwater from the Oxnard Forebay to areas north of the Montalvo anticline. However, relatively few wells exist along the southeastern portion of the Mound basin, an area of sparse well records and known structural complexity. In recent times no active production wells have been located within a mile of the coast, so in 1995 United Water and the City of Ventura jointly funded the installation of three monitoring wells at Marina Park near the north side of Ventura Harbor to assess groundwater conditions near the ocean. Artesian conditions are common in the shallowest of these wells, screened 170 to 240 feet below the land surface. Heads 20 feet above the land surface are commonly recorded, suggesting recharge from the Ventura foothills to the north. In fall 2004 water levels in most wells in the western Mound Basin were below sea level, but heads in this well remained high. No active wells in the area are screened in this shallow aquifer zone. A deeper well at Marina Park (screened 480-660' deep) commonly displays weak artesian conditions, and recorded heads six feet below sea level in 2004. The deepest well at this site rarely has artesian flow, but often has groundwater elevations above sea level. In the agricultural area east of Ventura Harbor, production wells record water levels below sea level in dry periods (Figure s 4-9 and 4-10). Heads of 25 feet below sea level were recorded here in 1991, and 14 feet below sea level in 2004.

As discussed in this chapter and the hydrostratigraphy chapter (Section 3), the Mound Basin is structurally complex. The current distribution of wells and water level records within and surrounding the basin allows an imperfect understanding of groundwater source and movement in some locations. Available information indicates the Mound Basin receives groundwater recharge from both the Santa Paula basin to the east and the Oxnard Forebay/ Oxnard Plain to the south. Overall, water levels in many wells respond in similar fashion to wet and dry periods. Gradients within the basin remain fairly flat most of the time. Water levels tend to vary among nearby wells, with deeper wells often having lower groundwater elevations. Groundwater production is concentrated in several areas with the basin, creating the potential for pumping interference in some water level measurements. In some production wells, the large distance to water may lead to occasional errors in water level measurement.

5 GROUNDWATER EXTRACTION

Much of the Mound groundwater basin lies within the boundaries of the City of Ventura. The Downtown, Midtown and West Side areas of the City fall within the boundaries of Casitas Water District, and water supplied to these areas source from Lake Casitas and various City wells located near the community of Casitas Springs. Areas south and east of Midtown Ventura fall within the boundary of United Water Conservation District. The City chose to concentrate Mound Basin pumping in the area near the Ventura County Government Center. Deep municipal wells were constructed here in 1975, 1994 and 2000, and since 1982 the great majority of municipal pumping in this central portion of the basin has been from the City's wells. The City also operates high-capacity production wells near the San Buenaventura Golf Course on the Oxnard Plain, and pumps water north to businesses and residents located in the Mound Basin. Other areas in the eastern portion of the City receive water from a production well in the Santa Paula basin.

Historically, agricultural pumping has been the majority water user in the Mound Basin, and agricultural pumping totaled nearly 70 percent of reported pumping in calendar year 2010. Agricultural pumping is concentrated in three main areas of the basin: farmland near Olivas Park Drive in the south, the agricultural areas east of Ventura Harbor, and the so-called Serra area extending southeast from the southern terminus of Kimball Avenue (Figure 5-1). A fourth agricultural area, located north of Hwy 126 and west of Kimball Avenue, is served by water imported from the Santa Paula basin. These areas of agricultural land use have not been incorporated by the City and are not served by the City's potable water system.

The distribution of historic pumping between agricultural and municipal uses in the Mound Basin is displayed in Figure 5-2. The city's pumping generally increased through the 1980s, and was variable in the 1990s. Municipal pumping peaked in 2003 at over 5,500 acre-feet, and has declined fairly steadily in recent years. Since the mid-1980s agricultural pumping has averaged nearly 4,200 acre-feet per year, with peak annual production of 5,850 AF recorded in 1990. The above pumping totals are for the Mound Basin defined as the area north of the Montalvo anticline. If the Mound Basin were defined as the area north of the Oak Ridge fault, pumping along Olivas Park Drive would be included with Oxnard Plain pumping totals. In this case, 2010 pumping would total 4,630 AF, with agricultural usage totaling 64 percent of the reported pumping.

6 WATER QUALITY

While the quality of the groundwater produced by most wells within the Mound Basin is suitable for municipal and agricultural uses, the basin is not known for the high quality of its groundwater. The Geotechnical Consultants, Inc. (1972) investigation of the Mound Basin noted structural complexity and the lenticular nature of many San Pedro Formation sediments within the basin, and suggested connate waters continue to impair water quality in many zones. Structural deformation and the less-continuous nature of highly permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin. Water quality is variable between wells, and many records indicate somewhat elevated concentrations of TDS, sulfate, hardness and other analytes. Water quality appears to be relatively stable among many of the Mound basin wells having long-term water quality records. Available records from wells near the coast do not show evidence of saline intrusion.

Relatively few dedicated monitoring wells exist in the Mound Basin. Six monitoring wells, jointly funded by United Water and the City of Ventura, were installed in 1995. One nest of wells exists at Marina Park, at the north side of the Ventura Harbor. Water quality in these three wells has been fairly stable since the wells were installed. The deepest well, screened 970 to 1070 feet bgs, routinely records TDS concentrations near 1,300 mg/l and sulfate concentrations of approximately 500 mg/l. A shallower well, screened between 480 and 660 feet below the surface, records slightly better water quality, with TDS around 900 mg/l and sulfate around 400 mg/l. The shallowest well at this location, well 02N23W15J03S, is screened from 170 to 240 feet bgs has the poorest water quality. In this shallow well TDS concentrations are above 3,000 mg/l and chloride values average nearly 100 mg/l. As noted in the previous section on water levels, strong artesian heads are consistently recorded in this well. The high heads in this well suggest offshore groundwater gradients in this vicinity. Near-shore submarine canyons, such as those that exist near Port Hueneme and Point Mugu, do not incise the offshore portion of the Mound groundwater basin. The absence of near-shore canyons, high heads in coastal wells and the lack of active production wells near the coast results in a minimal threat of saline intrusion under current basin conditions.

A second cluster of three monitoring wells was installed at Camino Real Park in the central portion of the basin. Sampling of these wells has resulting in the only water quality records known to exist for wells located north of Highway 126. As with the Marina Park wells, mineral content is slightly higher in the deeper San Pedro unit (screened 1,200 to 1,280 feet bgs) than in a shallower zone (screened 710 to 780 feet bgs). In the deeper screened interval TDS concentrations of 1,100 mg/l are commonly recorded. TDS is generally less than 1,000 mg/l in the shallower screened well CP-780 (Figure 6-1). Sulfate anions account for about half of the total mineral content of the water as is typical for other wells in the basin.

The shallowest of the three wells at the Camino Real Park site (screened 210 to 280 feet bgs) records some of the worst groundwater quality in the basin. TDS in this well sometimes exceeds 5,000 mg/l. Chloride and nitrate are also found at high concentrations in this well. These analytes are rarely elevated in other Mound Basin wells. Groundwater elevations are very stable in this well and are also much shallower than in other nearby wells. The anomalous groundwater elevations and water quality from this well suggest perched groundwater conditions, or an aquifer zone otherwise isolated from aquifer units utilized for groundwater production elsewhere in the basin.

The two newest monitoring wells in the Mound Basin were installed near Kimball and Telegraph Roads in 2008 as part of a siting study for a potential new production well for the City of Ventura (Hopkins Groundwater Consultants, Inc., 2008). Limited samples exist for these wells to date. The shallower well (screened 480 to 510 feet bgs) records very poor water quality. A recent sample recorded TDS of 6,300 mg/l, sulfate of 3,700 mg/l and hardness of 2,650 mg/l. Nitrate and chloride concentrations were also high. The deeper well (screened 890 to 950 feet bgs) records water quality more typical of wells within the basin. Both of these wells have groundwater levels higher than some other surrounding wells. It is unclear at this time whether the higher heads are related to groundwater recharge from the nearby Santa Paula basin, or associated with aquifer zones that are poorly connected with other permeable zones within the stratigraphic section that are currently utilized for groundwater production.

Municipal pumping in the Mound basin is concentrated in section 02N22W08 with production wells located around the perimeter of the Ventura County Government Center. The City's Victoria 1 well was constructed in 1975 with five screened intervals within the depth range of 460 to 1,405 feet below ground surface. Water quality was very consistent in this well from the early 1980s through the 1990s, with TDS commonly measured near 1,500 mg/l. In the late 1990s production shifted to the new Victoria 2 well and sampling of Victoria 1 became infrequent as the well was maintained in standby status. A few samples in 2001 and 2002 did however show a distinct increase in dissolved mineral content, with TDS peaking above 2,000 mg/l and sulfate approaching 1,200 mg/l. The nearby Victoria 2 well (02N22W08F01S) has two screened intervals (580-640 and 900-940 feet bgs). Water quality records from this well show a steady long-term decline. Early TDS concentrations of less than 1,000 mg/l slowly increased to values of 1,400 to 1,800 mg/l common to recent samples (Figure 6-2). A third well, Mound 1, was constructed in 2000 (screened 580 to 650 feet bgs) and began reporting production in 2003. Water quality records from 2006 to 2011 show fairly consistent TDS concentrations of around 1,800 mg/l, with some samples exceeding 2,000 mg/l. The cause of the water quality changes in this vicinity is not readily apparent. The multiple screened intervals in the Victoria 1 well do however provide an opportunity for depth-dependent water quality sampling. Sampling devices are now available to measure both water quality and groundwater production from various depths within an active production well. This type of information might assist the designers of future wells in this area in avoiding aquifer zones of poor water quality.

Water quality samples from wells in an area of former municipal pumping, the Montalvo area in the southern portions of Section 02N22W17, record a period of significant deterioration in water quality. Quality problems began in the early 1970s and continued through the 1980s. Pumping records are not available prior to 1980, so it is unclear if water quality changes in this vicinity were related to an increase in groundwater pumping in the 1970s. A peculiarity of these records is that chloride concentrations rose along with TDS and sulfate.

A map showing recorded TDS concentrations in Mound basin wells from 2011 is shown as Figure 6-3. The map plots TDS (by summation) from production well samples collected by the Groundwater Section of the Ventura County Watershed Protection District, as well as TDS (by residue) as sampled by United Water and the City of Ventura. It is easily seen that without the sampling by the County's Groundwater Section, coverage in the basin would be very poor. The distribution of sampled wells within the basin for 2011 is better than in most prior years. TDS in the production wells ranged from 1150 to over 2,200 mg/l. Also shown is sulfate sample results from 2011 (Figure 6-4). These two maps show that sulfate commonly contributes roughly half the TDS in these samples, and water quality results are often variable among nearby wells.

Mapping the maximum values of all available water quality samples for Mound basin wells reveals that many of the highest chloride concentrations are recorded in wells located near mapped faults in the southern portion of the basin (Figure 6-5). Many of these high values are likely associated with times of drought, but some may be outlier records from individual wells. The maximum-recorded chloride concentrations from the 2011 calendar year are shown in Figure 6-6. One production well located near the intersection of highways 101 and 126 recorded chlorides above 100 mg/l, a target water quality threshold for many agricultural operations.

Many of the active wells in the basin are operated for agricultural water supply and sampling of these wells tends to be less consistent than in the public supply wells. If samples are collected, the results often are not shared with regulators or water management agencies. A good water quality record does exist for well 02N22W16K01S. This well is located east of Harmon Barranca and just north of the mapped location of the Montalvo anticline axis. Water quality records for this well exist for the years 1953 through 1997. The water quality record shows some variability (upward deflections) but no clear trending over the period of record. This well is screened from approximately 290 to 350 feet bgs. Water quality in this well is relatively good, with most recorded TDS concentrations less than 1,200 mg/l. In the western basin near Ventura Harbor, well 02N23W14K01S provides another example of a well with good water quality for the period of record from 1933 to 1981. Concentrations for most analytes are fairly stable, with TDS concentrations averaging less than 1,200 mg/l (Figure 6-7). This agricultural well is screened from 475 to 915 feet bgs. One outlier record of elevated chloride exists from 1962. This outlier of 376 mg/l is shown just inland of Ventura Harbor in Figure 6-5. Otherwise the records from this coastal production well show no evidence of saline intrusion.

7 DISCUSSION

There are a limited number of wells within the Mound Basin. Wells are absent along the northern portions of the basin, and the western extent of the basin also lacks wells as this area is supplied by surface water and groundwater from Ventura River valley. Some public supply wells exist in the central portion of the Mound basin but significant quantities of groundwater are imported from Oxnard Plain to the south, in part due to the better water quality associated with those wells. The amount of data available for characterization of basin conditions is somewhat limited. The water supply scenario for the Mound Basin is atypical for the region, with groundwater imports from three adjacent basins. The other basins managed by United Water are dominated by agricultural land use with some urban environment. The Mound Basin is dominated by the urban environment of the City of San Buenaventura and surrounded by some agricultural lands. Pumping records indicate that agricultural pumping often exceeds municipal pumping in the Mound basin.

The Mound basin is a complex basin due to its physical and geologic setting. Characteristics of the Mound Basin are different than most of the other basins that are managed by United Water. Despite its unique characteristics the Mound Basin shares similar hydrogeologic dynamics and processes with the other basins in the Santa Clara River Valley and Oxnard Plain.

The present day boundaries of the Mound Basin consist of: the Ventura foothills/Ventura fault to the north, the Country Club fault to the east, the Pacific Ocean to the west, and the Montalvo anticline to the south. The Oak Ridge fault runs sub-parallel to the Montalvo anticline approximately one half to one mile north of the anticline. Although the Montalvo anticline is presently used for the southern boundary it has been suggested that perhaps the Oak Ridge fault should be used for the southern basin boundary. Yerkes et al (1987) state that the Oak Ridge is a zone of faulting that forms the southern boundary of the Ventura synclinal trough in the western Ventura Basin (Mound groundwater basin) rather than the Montalvo anticline. Since the basin is characterized by faults along the northern and eastern boundaries it is arguable that the southern boundary should be defined by a fault, forming a consistent structural architecture to the basin rather than a geographical basin for groundwater management. Groundwater elevations in the zone between the

Oak Ridge fault and the Montalvo anticline are responsive to water levels in the Oxnard Forebay, especially during periods of above-average recharge in the Forebay.

There are some appreciable offsets of geologic formations across the faults bounding the Mound Basin. Several previous studies by others and recently reviewed borehole geophysical data suggest that the low-permeability Santa Barbara formation does not extend to sufficiently shallow depths to impede groundwater flow across the faults or above the faults. In most cases the faults do not extend close enough to the surface to disturb San Pedro or alluvial sediments. In those cases, there is a significant thickness of the San Pedro formation (aquifer materials) existing on both sides of the faults. The degree of aquifer offset is site-specific along the trace of the faults, however, there are significant data to suggest that the UAS and to a somewhat lesser degree the LAS, are continuous across most of the basin-bounding faults. This implies that the hydrogeological boundaries of the basin are not necessarily coincident with its' structural boundaries and that there is hydrologic connection between the Mound basin and the adjoining groundwater basins.

The nature of the faults themselves as an impedance to groundwater flow is not known. However, groundwater flow and basin recharge across these zones is most probable. Recharge from the Oxnard Plain basin, Forebay basin, and Santa Paula basin into the Mound Basin is likely occurring across the geologic features that currently delineate the Mound basin. Groundwater flow within the basin is generally east-to-west, and groundwater flows from recharge areas to surrounding down-gradient areas. These recharge and flow dynamics are consistent with the accepted and well-documented groundwater flow systems in the Oxnard Forebay/Oxnard Plain and other coastal California basins.

In the Mound Basin water levels in many wells respond in similar fashion to wet and dry periods. Gradients within the basin remain fairly flat most of the time and water levels tend to vary somewhat among nearby wells. Deeper wells often have lower groundwater elevations. Records of groundwater samples from Mound basin wells reveal that salt concentrations are somewhat elevated compared to adjacent basins, but the water is generally suitable for municipal and agricultural uses. Although groundwater flow may occur through areas where interconnected or continuous aquifer materials exist, the less-continuous lens-like nature of some highly-permeable deposits within the basin (compared to nearby basins) have likely inhibited the flushing of poor-quality waters from the basin (possible connate waters). Active production wells are not currently located near the coast, and available records from coastal wells do not show evidence of saline intrusion.

Since there is somewhat limited data for characterization of the Mound basin, it is recommended that some additional studies be performed to better define basin conditions. One study would be to assess and better characterize the Country Club fault. Geophysical surveys (TDEM) can be utilized across the assumed location of the Country Club fault. Since the Santa Barbara formation is easily recognizable in electric logs (very low resistivity), its depth along a profile or profiles extending from the Santa Paula Basin into the Mound Basin may be defined using this technique. From that data the actual location of the Country Club fault and the throw on the fault might be resolved. This would provide information regarding the thickness of the San Pedro formation above the up-thrown Santa Barbara formation. Once those data are resolved a pump test could be conducted with a pumping well on one side of the fault and observation wells on both sides of the fault. This type of study can furnish information on flow dynamics on both sides of the fault and across and/or over the fault. A similar study could also be conducted in the vicinity of the Oak Ridge fault.

Additional study is also warranted in the southern portion of the basin, in the greater area surrounding the Montalvo anticline and the Oak Ridge fault. This area of geologic complexity likely provides significant recharge to the Mound basin. The complexity of the zone appears to influence water quality as well, with some of the basin's highest historical chloride concentrations located in this area. A number of active wells currently exist in this area, but data collection from these wells has been poor or inconsistent to date.

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9 APPENDIX A – GENERAL FIGURES

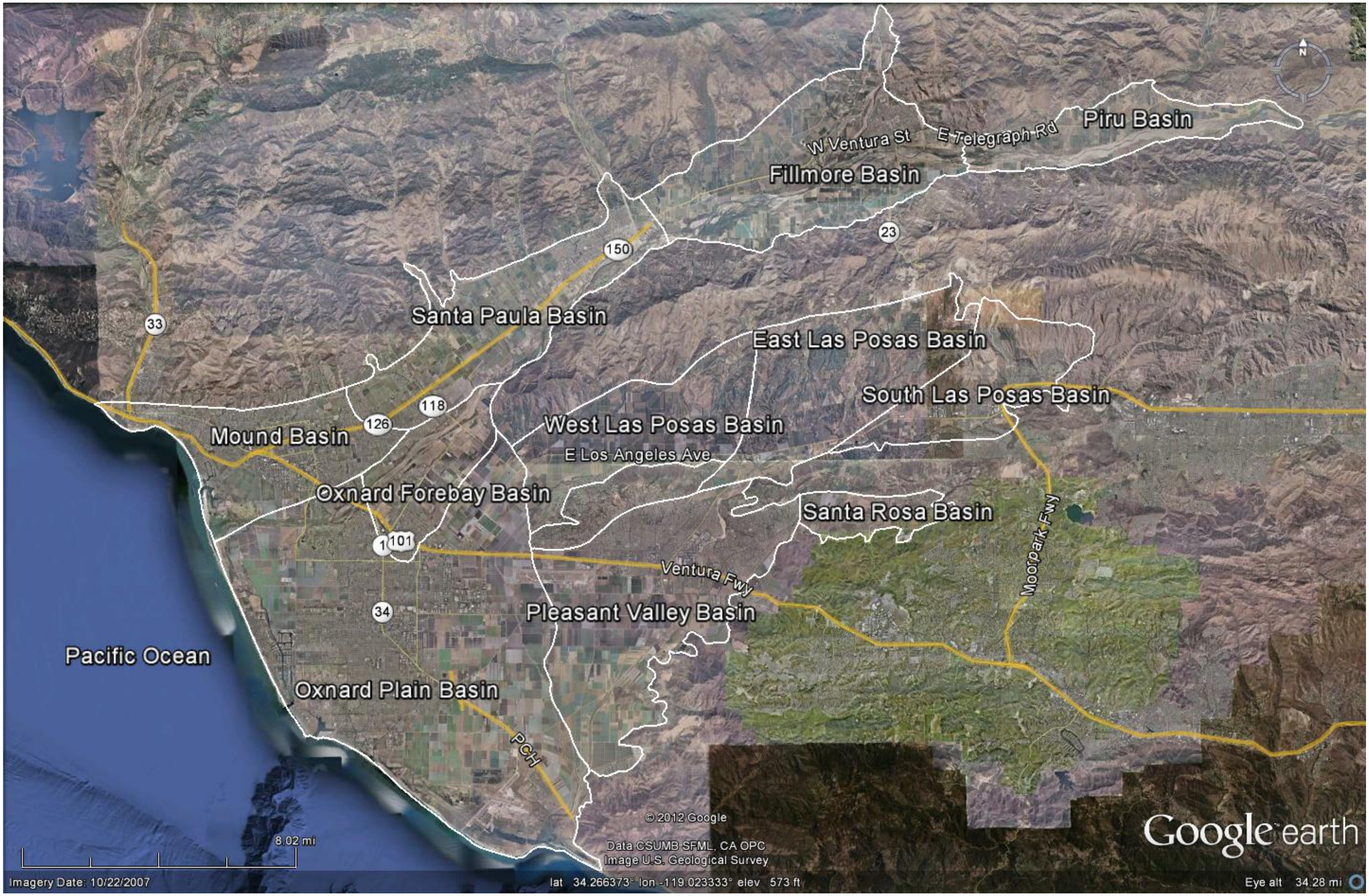


Figure 1-1: Map of Basins Managed by United Water Conservation District.

Figure 1-2: Map Showing Boundaries of the Mound Basin.

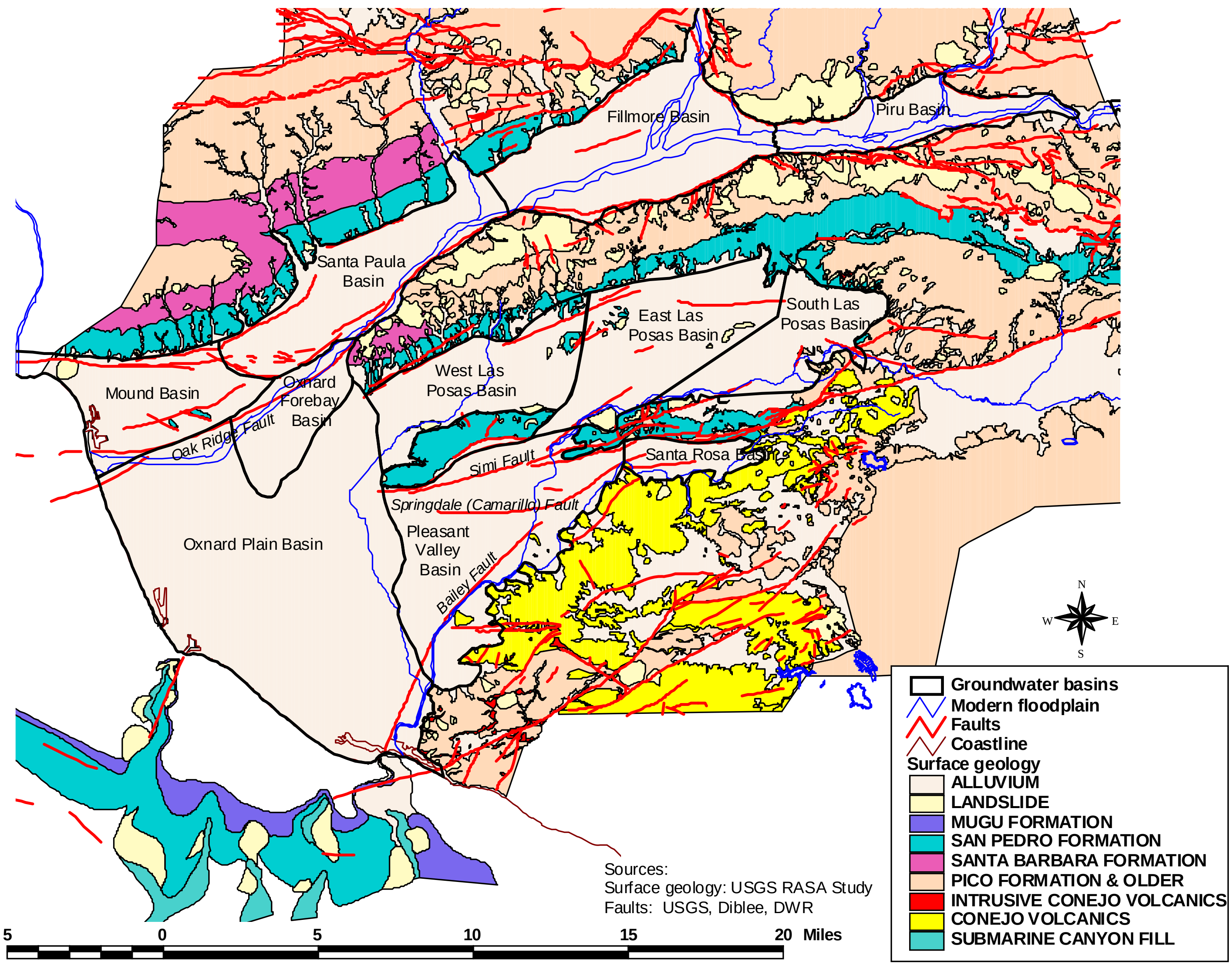


Figure 2-1: Overall geologic map showing groundwater basins including the Mound Basin.

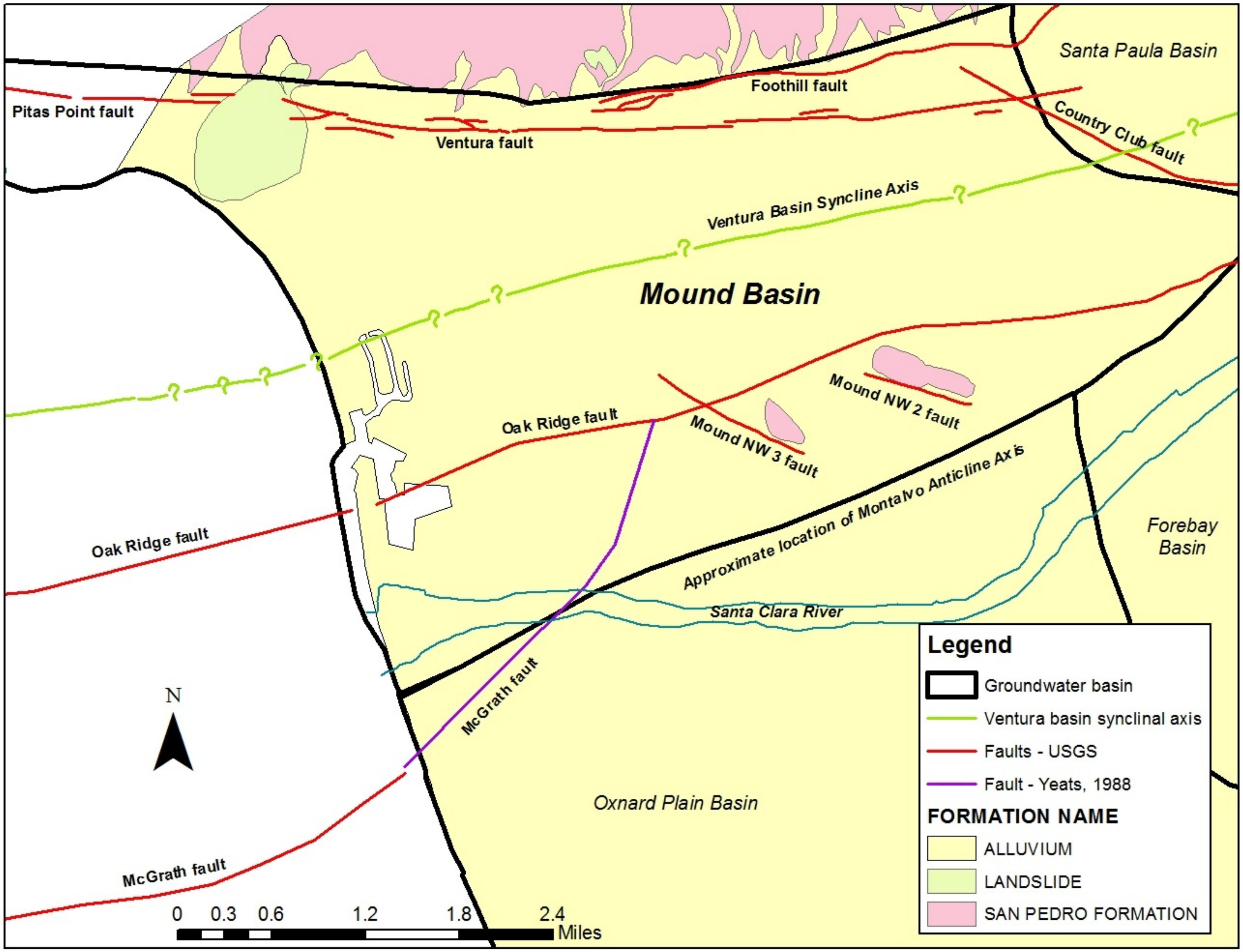


Figure 2-2: Generalized geologic map of the Mound Basin.

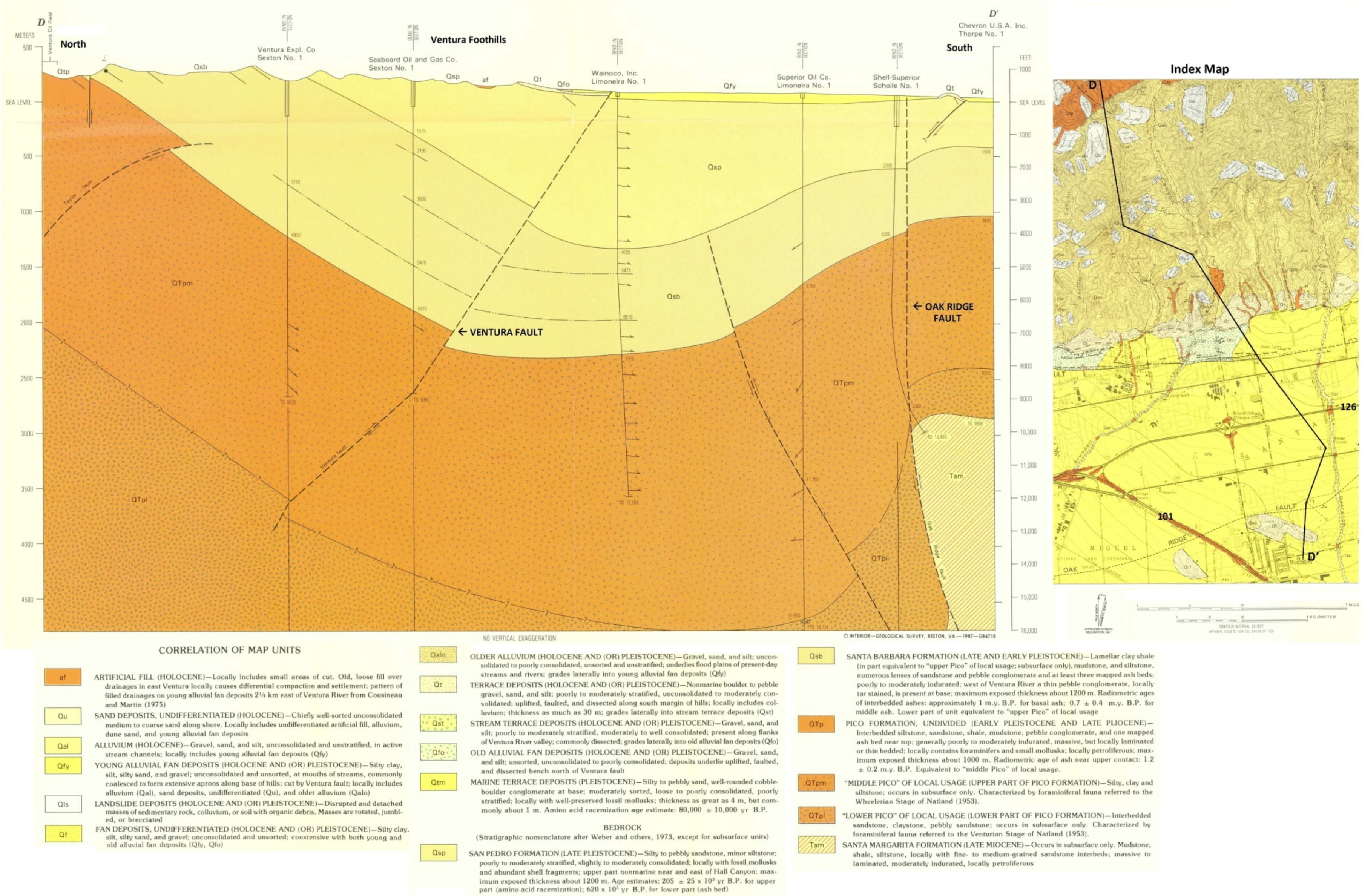


Figure 2-3: Cross-section of the Mound Basin showing the Ventura fault and Oak ridge fault interpretations (Yerkes et al, 1987).

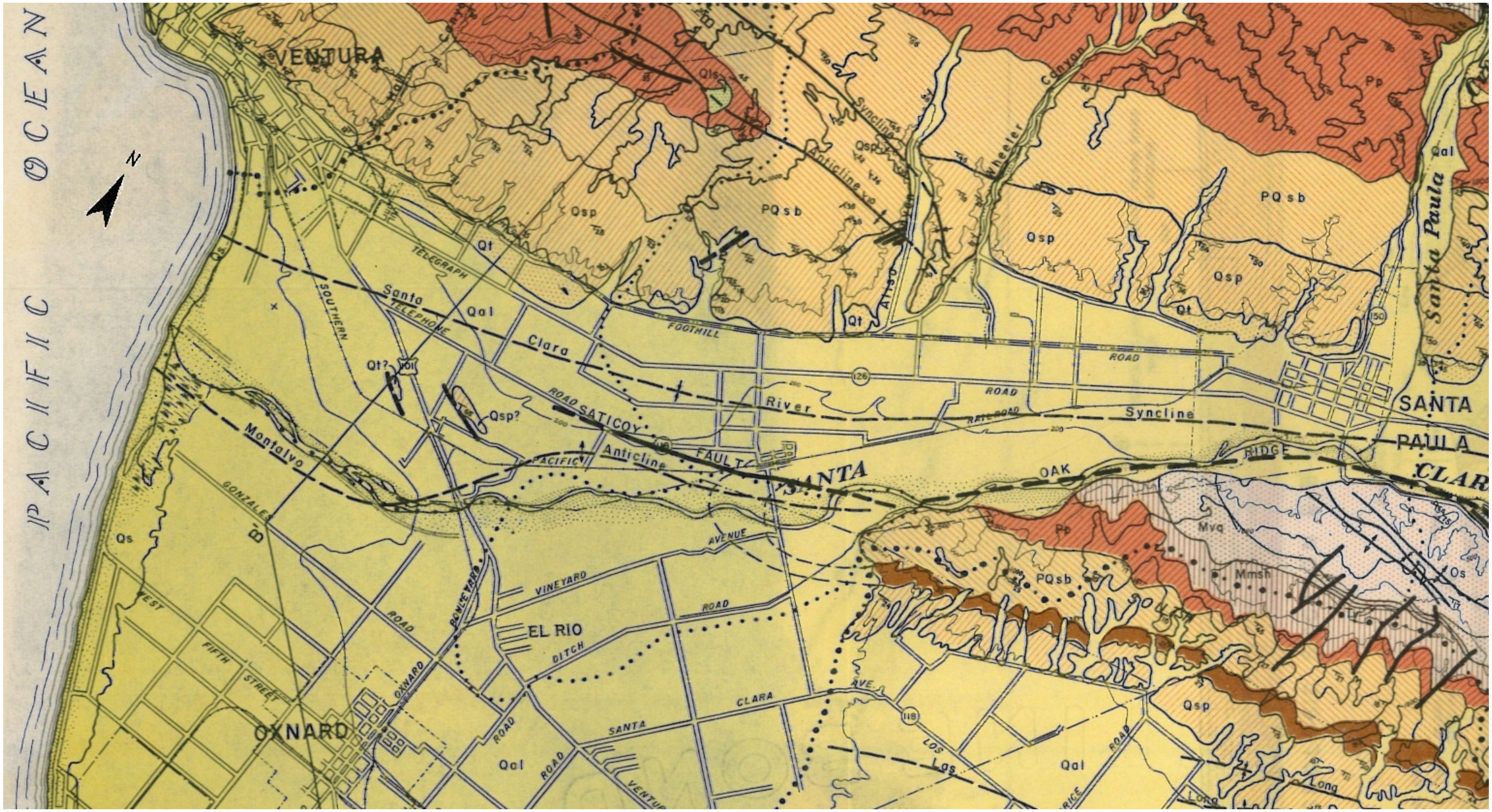
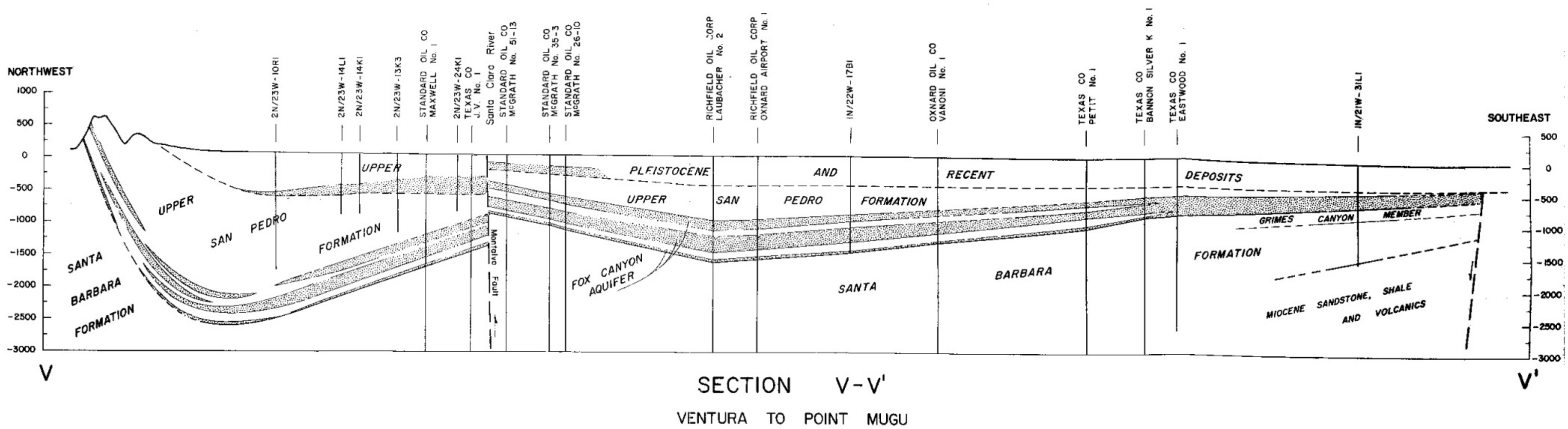


Figure 2-4: Map showing Oak Ridge fault near Santa Paula leading to the "Saticoy Fault" on the eastern side of the Mound Basin (California State Water Resources Board, 1953).



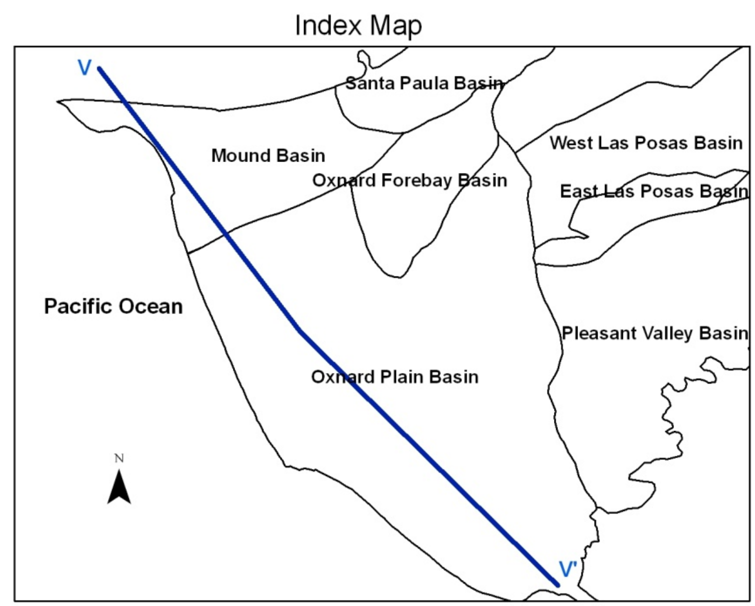


Figure 2-5: Cross-section taken from Mann (1959). The Montalvo fault is shown to form the southern boundary of the Mound Basin. Note that the Ventura fault is not shown.

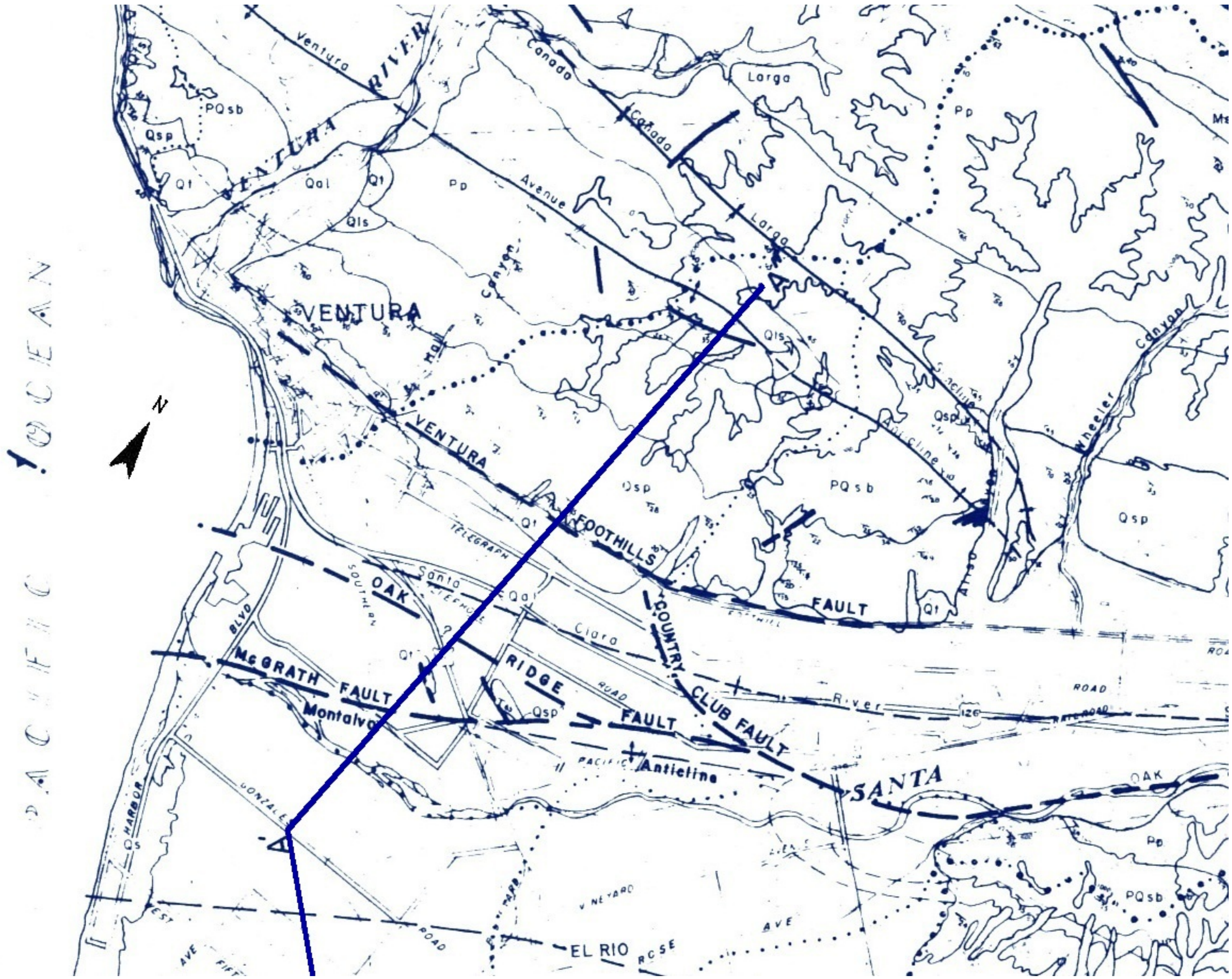


Figure 2-6: Turner and Mukae (1975) map showing Oak Ridge fault and McGrath fault. The Montalvo anticline is shown which forms the southern boundary of the Mound Basin. The location of cross-section A-A' is also shown.

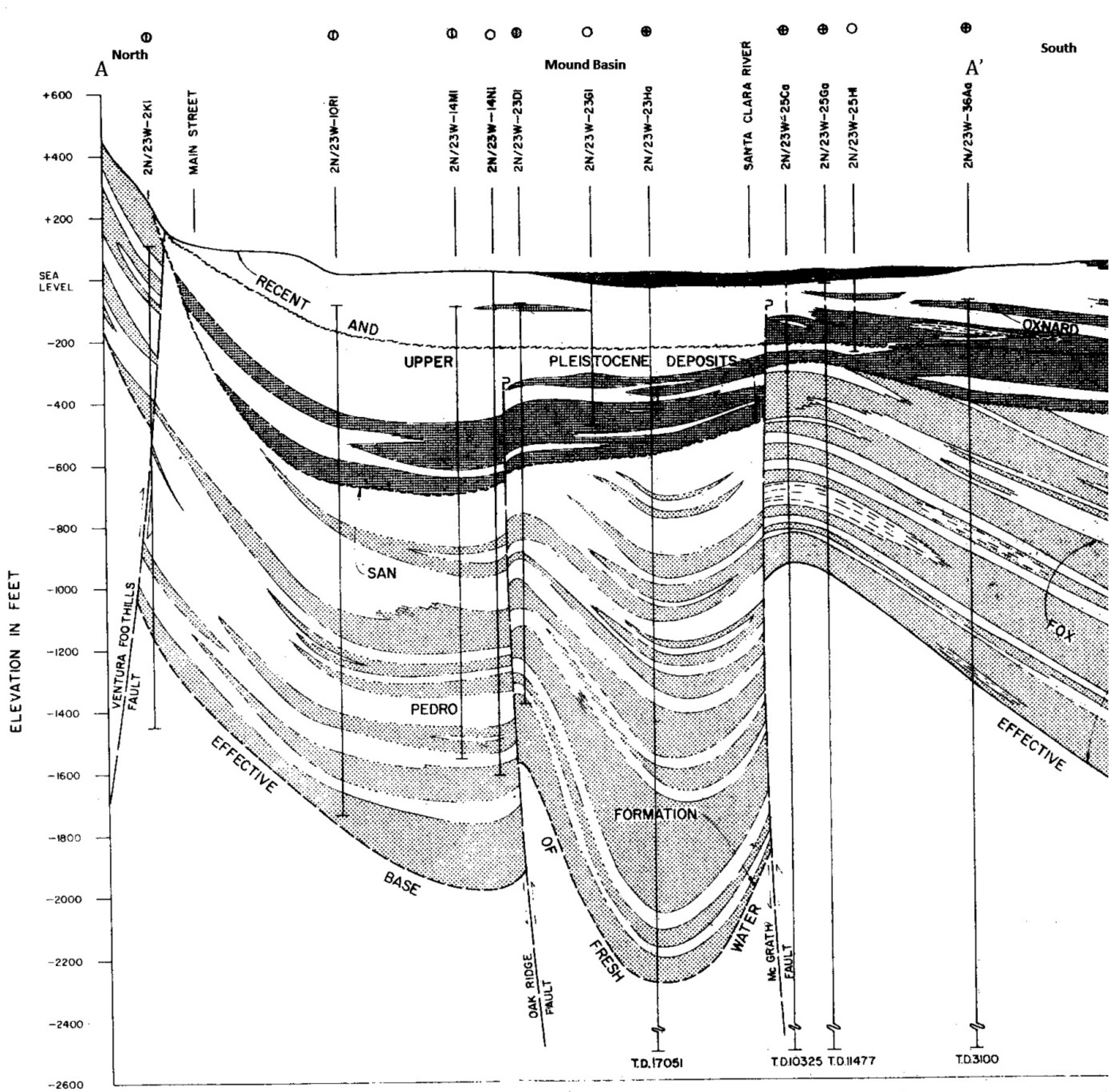


Figure 2-7: Turner and Mukae (1975) cross-section A-A' of Mound Basin near the coast showing the Oak Ridge fault and McGrath fault.

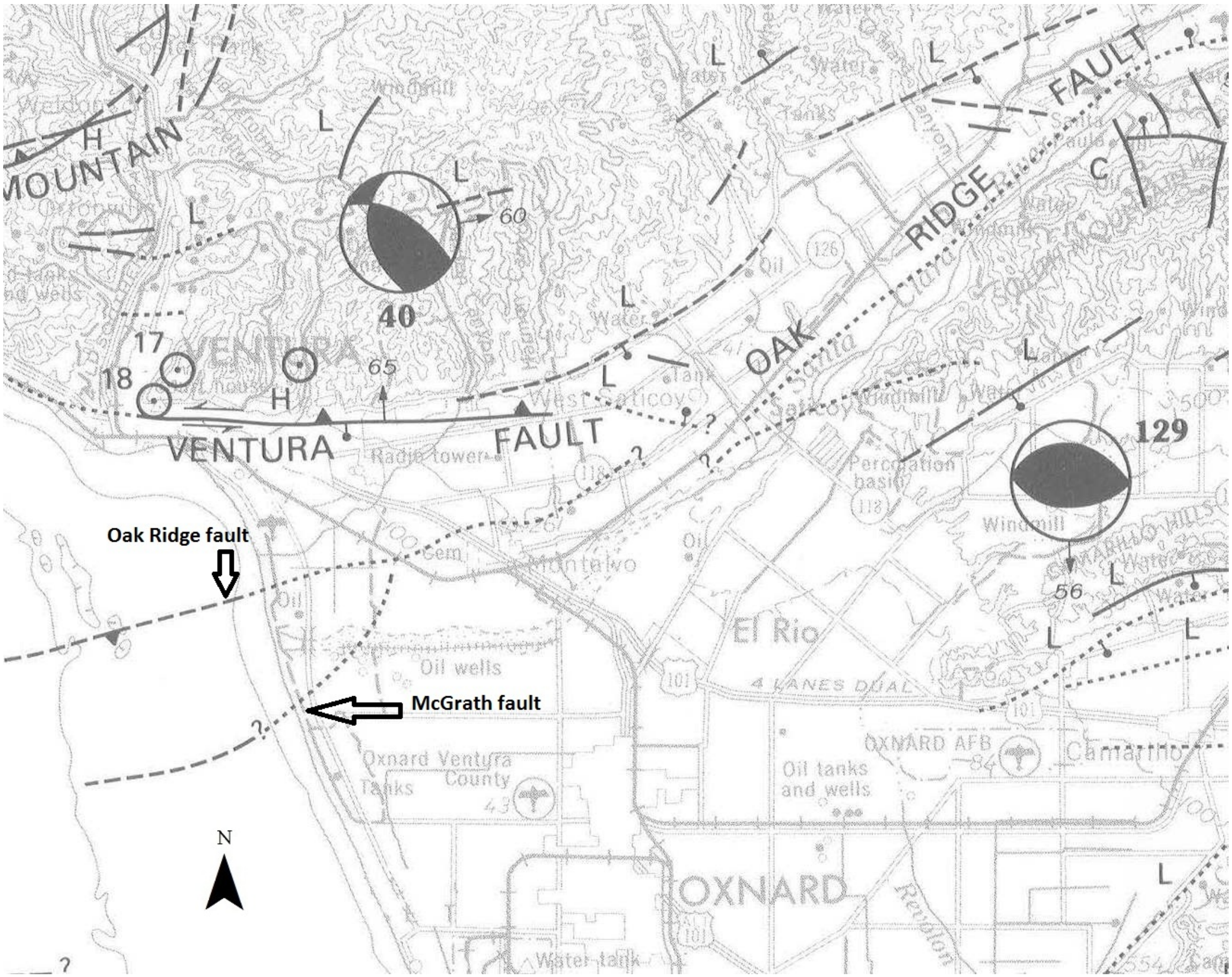


Figure 2-8: Yerkes et al (1987) map showing the Oak Ridge fault and McGrath fault.

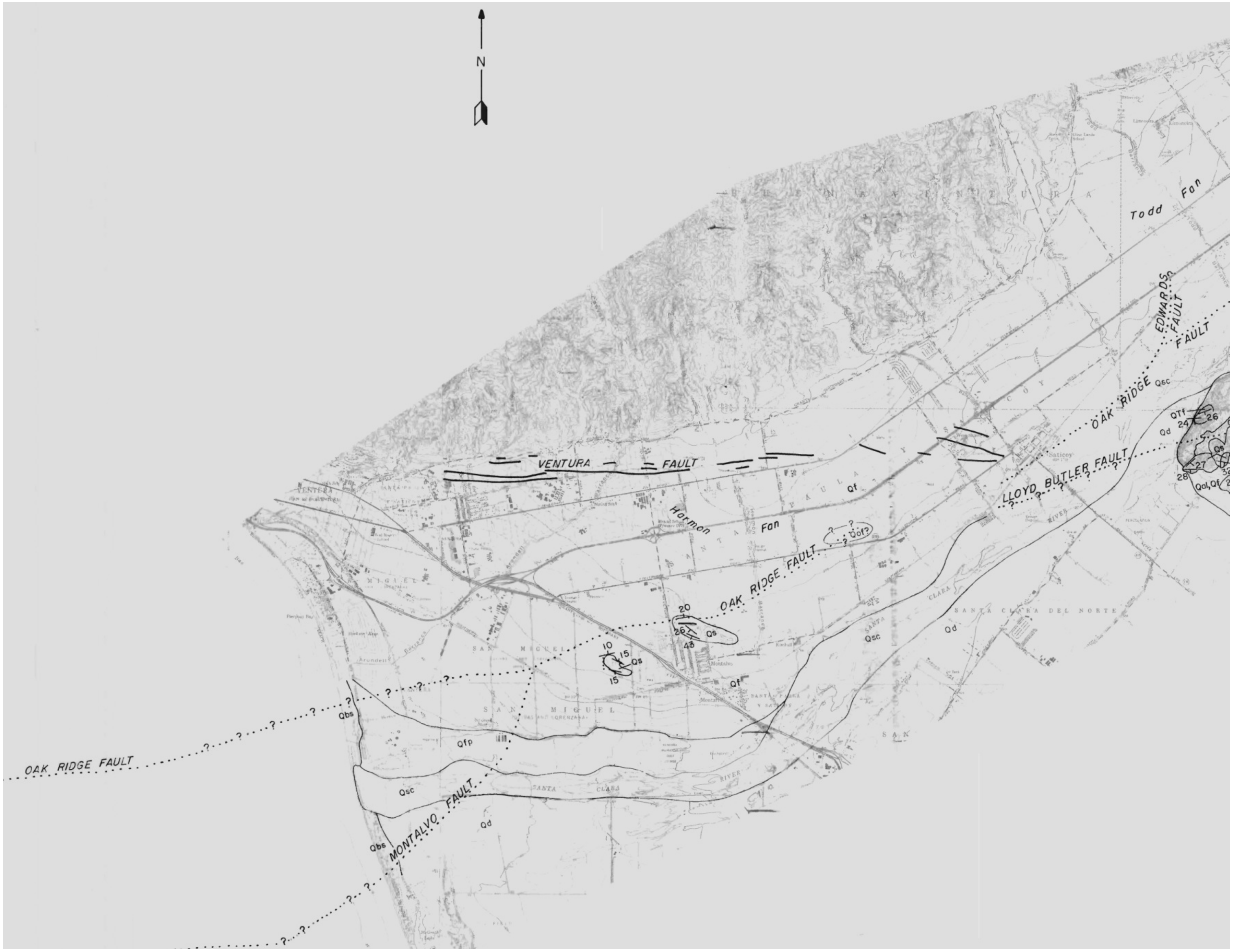


Figure 2-9: Yeats et al (1988) map showing the Oak Ridge fault and McGrath fault. Yeats refers to the McGrath fault as the "Montalvo" fault.

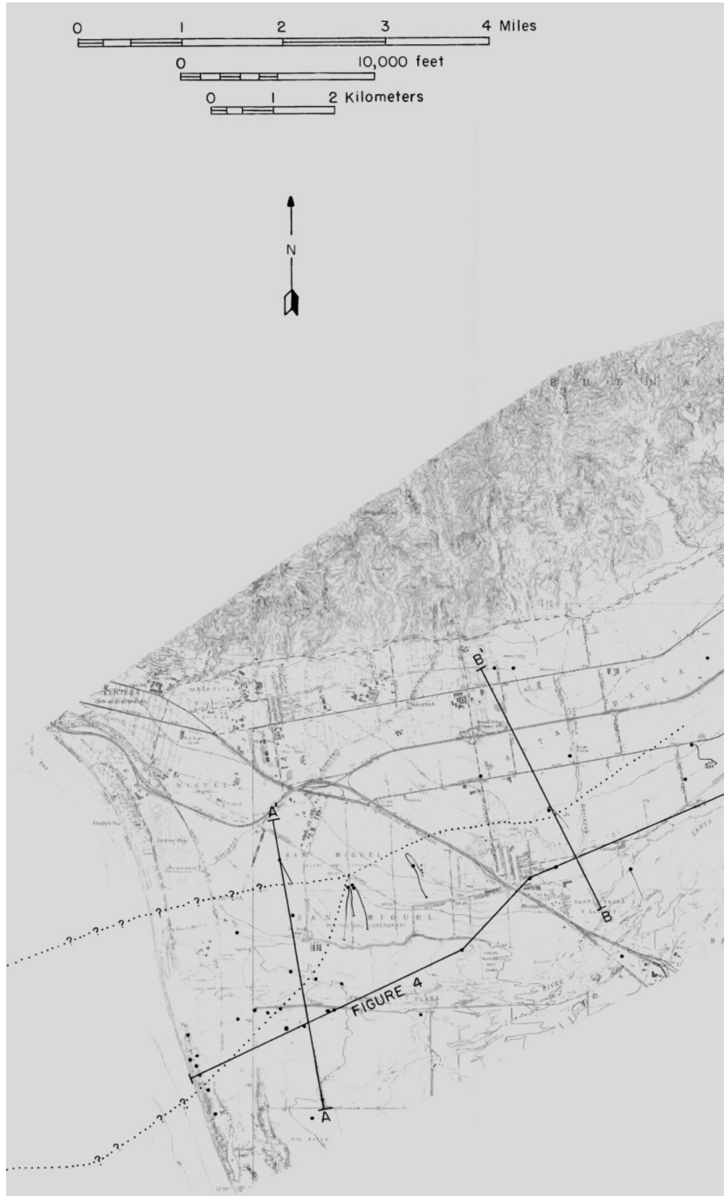


Figure 2-10: Yeats et al (1988) map showing Cross-sections A-A' and B-B' locations over the Oak Ridge fault and McGrath fault ("Montalvo" fault).

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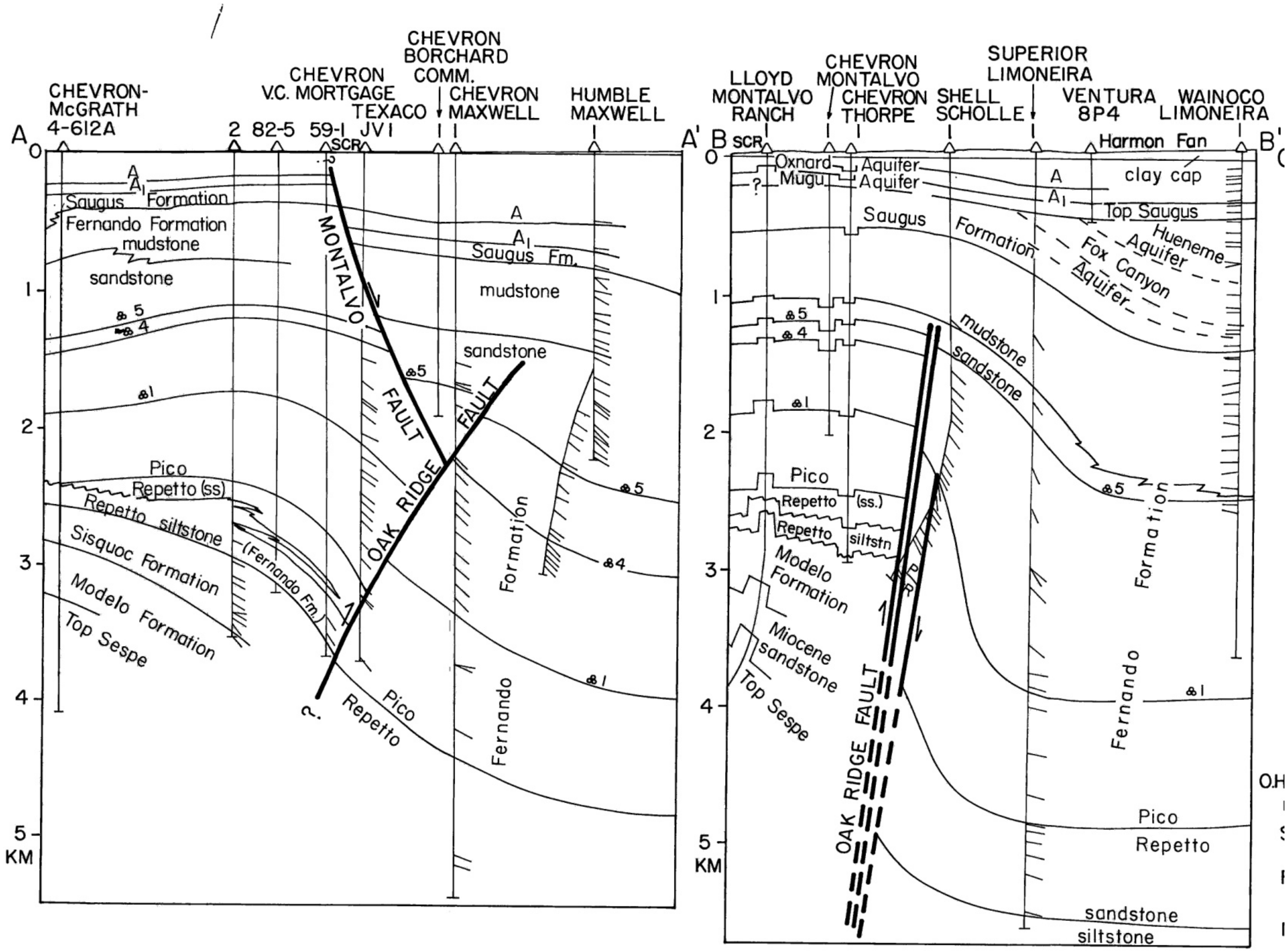
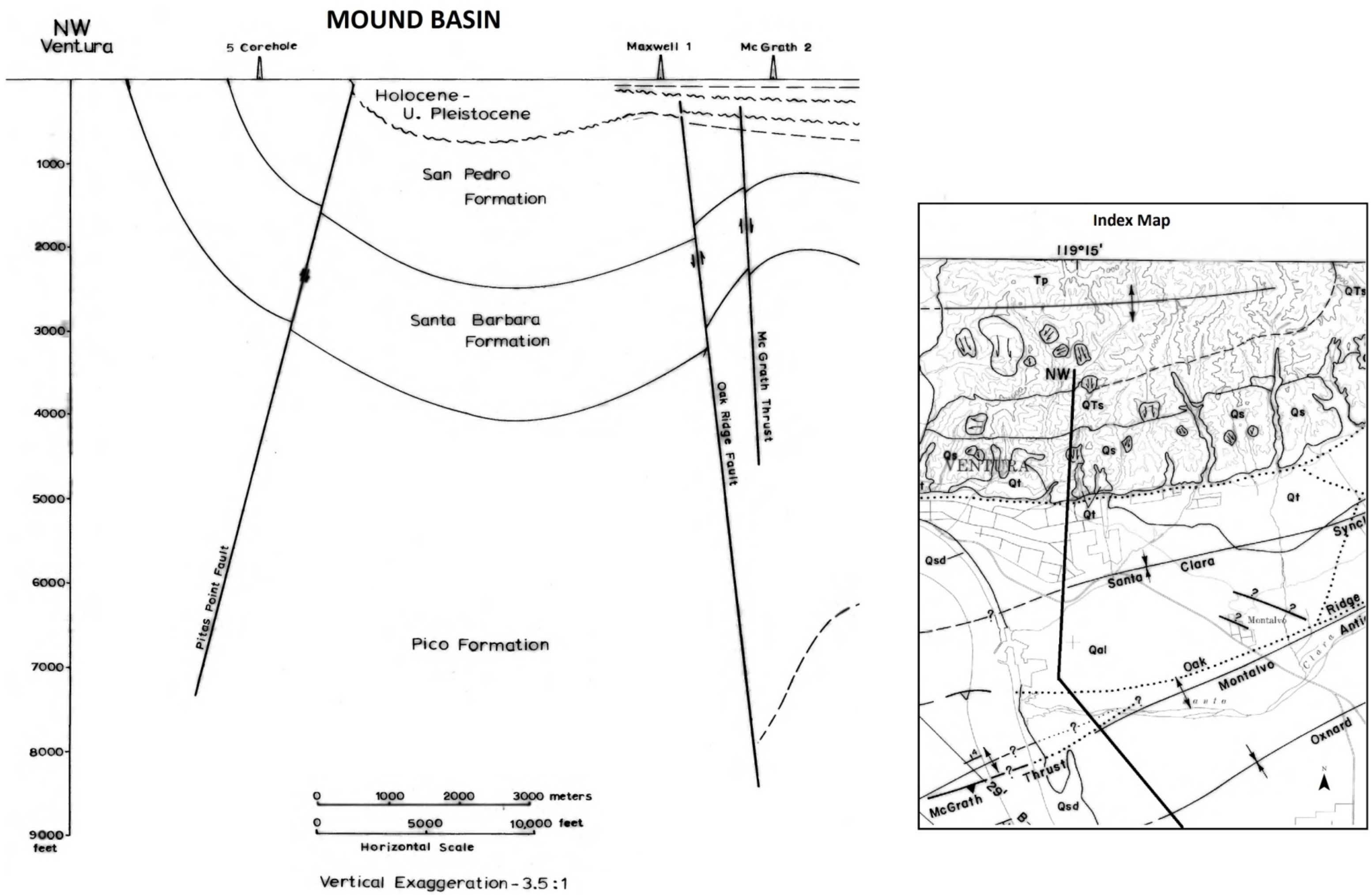


Figure 2-11: Yeats et al (1988) Cross-sections A-A' and B-B' over the Oak Ridge fault and McGrath fault ("Montalvo" fault).



Generalized onshore stratigraphic cross-section across the coastal portion of Oxnard Plain. See Plate 2 for areal extent and orientation of cross-section. (Modified after Paschall and others, 1956; State of California, 1965; Ogle, 1969; Turner, 1971, oral commun.)

Figure 3-1: Schematic Cross-Section of the Mound Basin taken from Greene et al (1978).

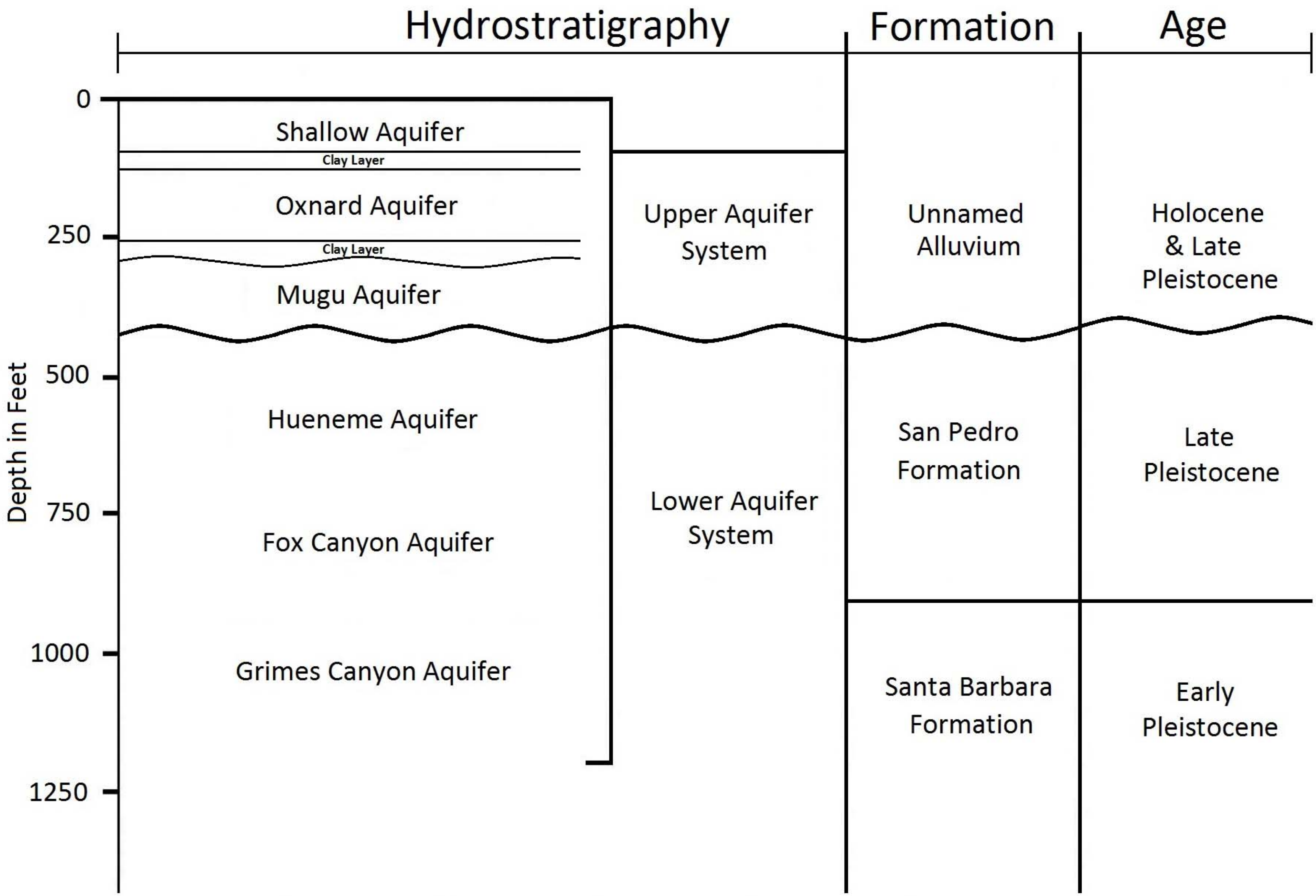


Figure 3-2: Schematic diagram of general aquifer systems.

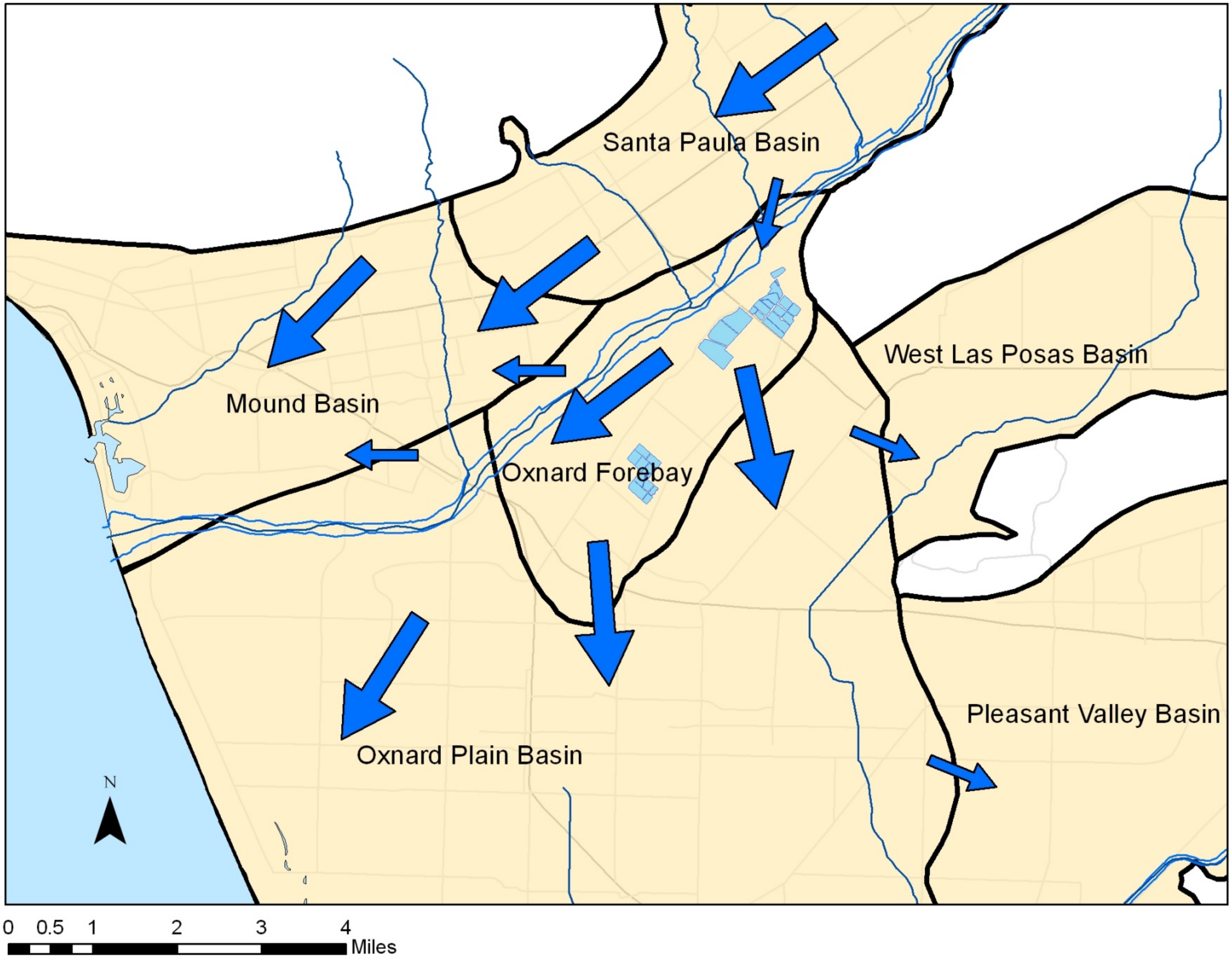


Figure 3-3. Generalized conceptual groundwater flow paths.

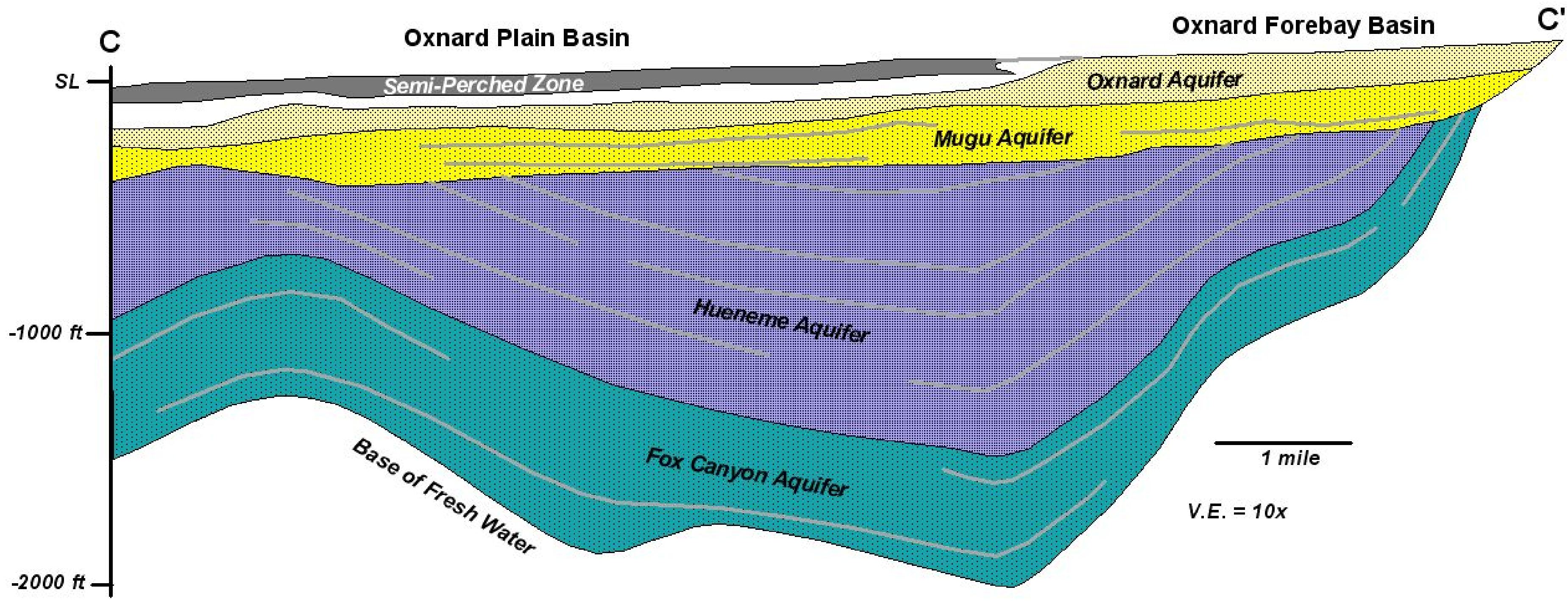


Figure 3-4: Schematic Cross-Section of Aquifer Systems in the adjacent Oxnard Plain south of the Mound Basin.

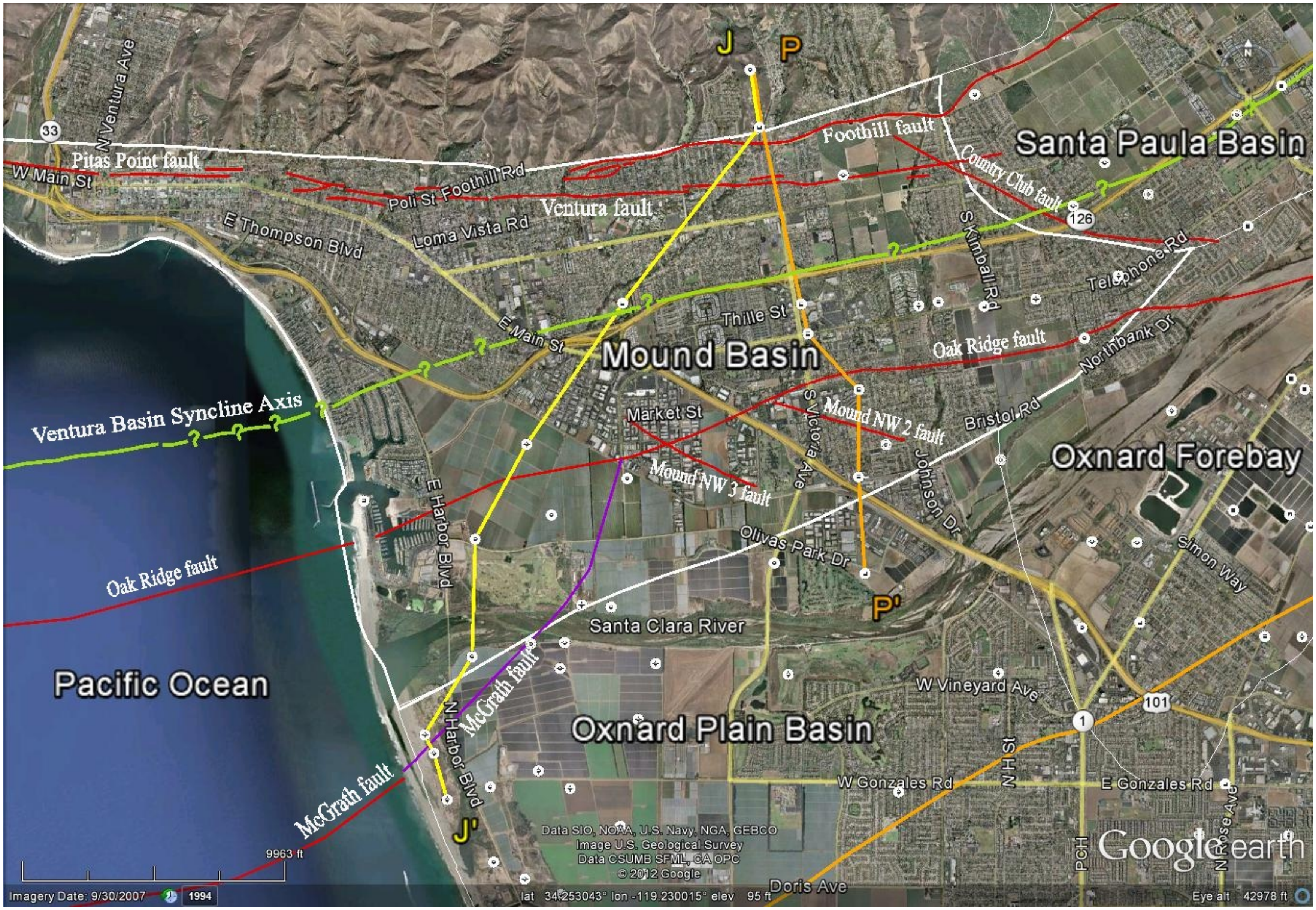


Figure 3-5: Location Map for United Water Cross-Sections J-J' and P-P'.

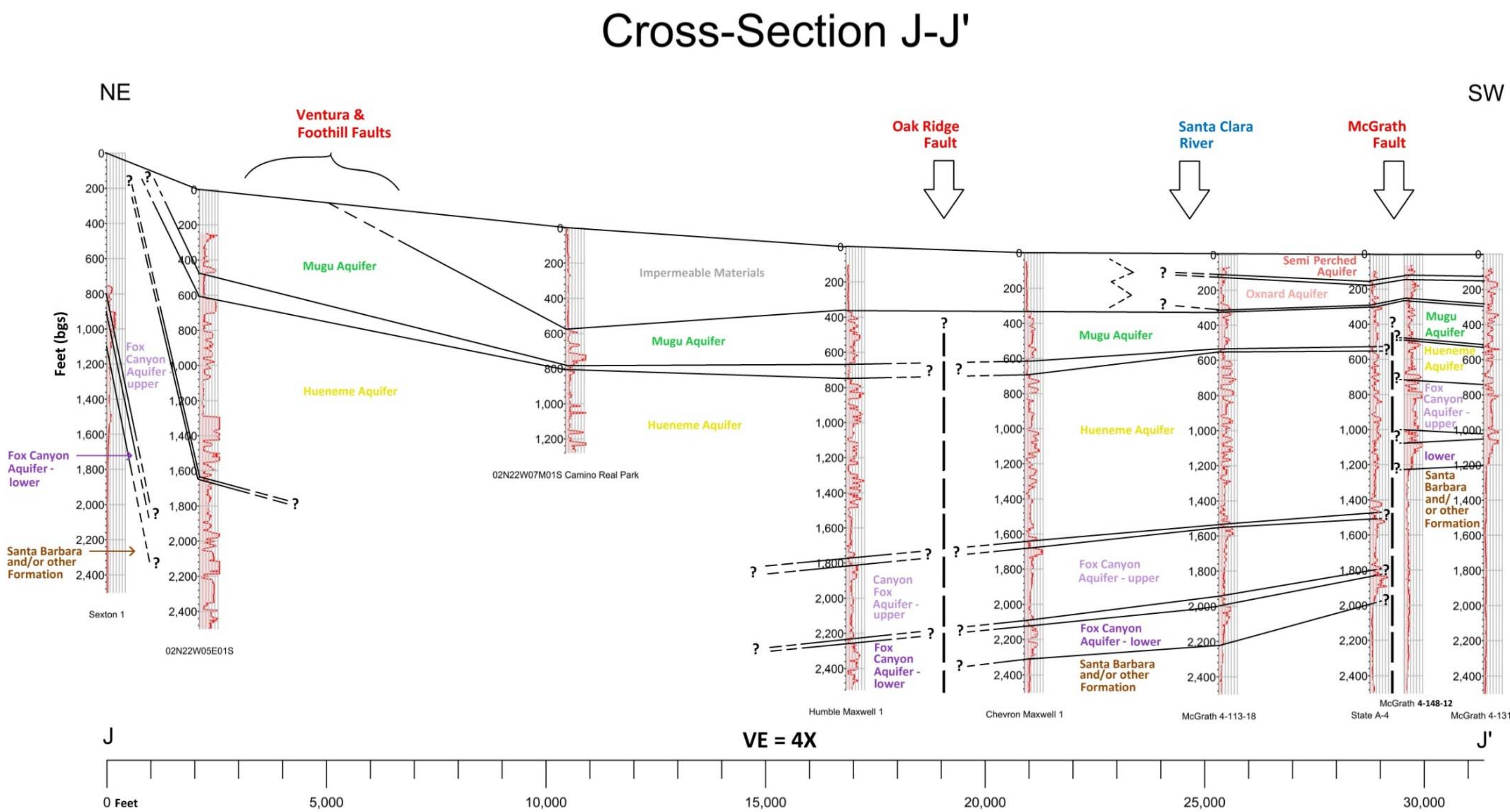


Figure 3-6: United Water Cross-Sections J-J'.

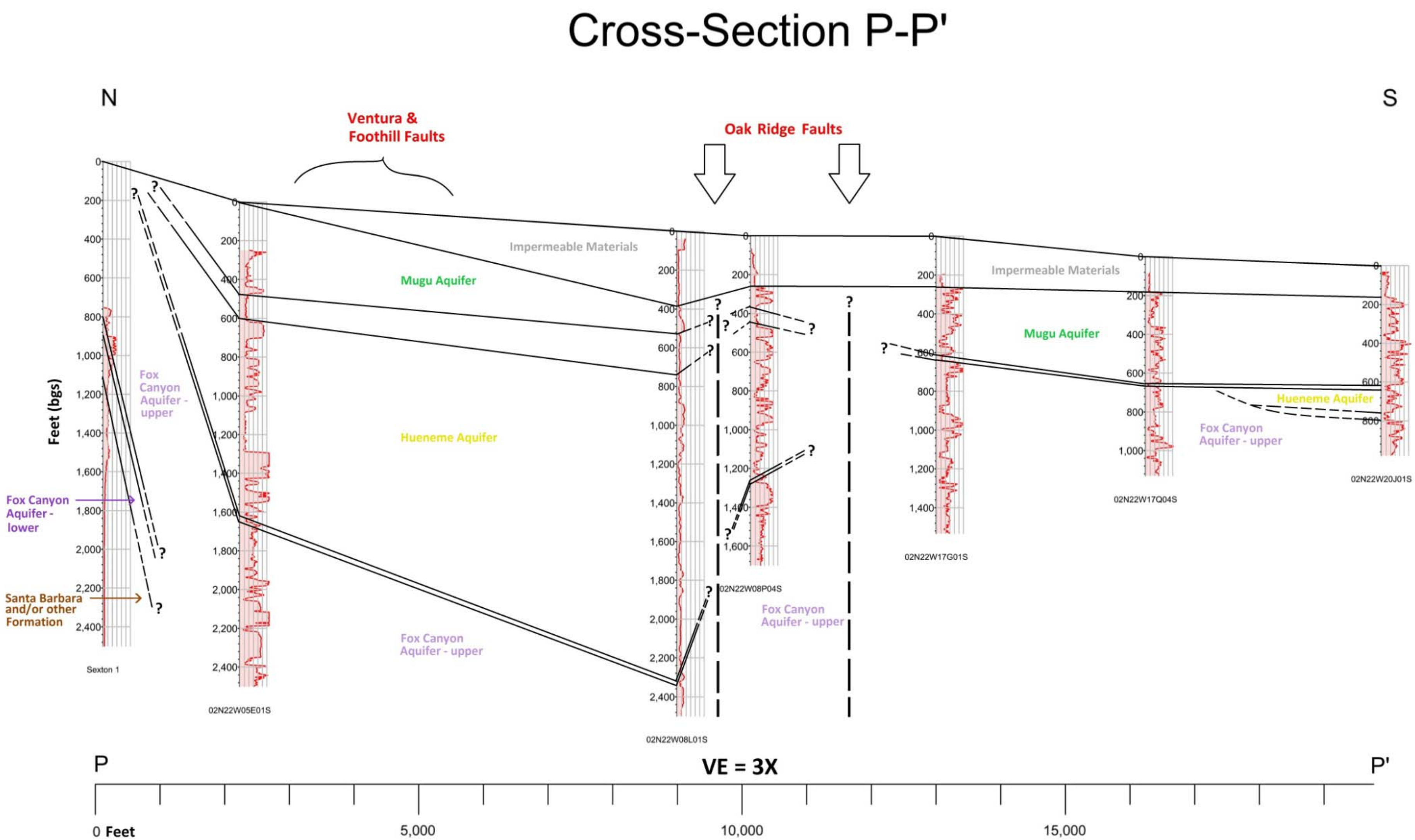


Figure 3-7: United Water Cross-Sections P-P'.

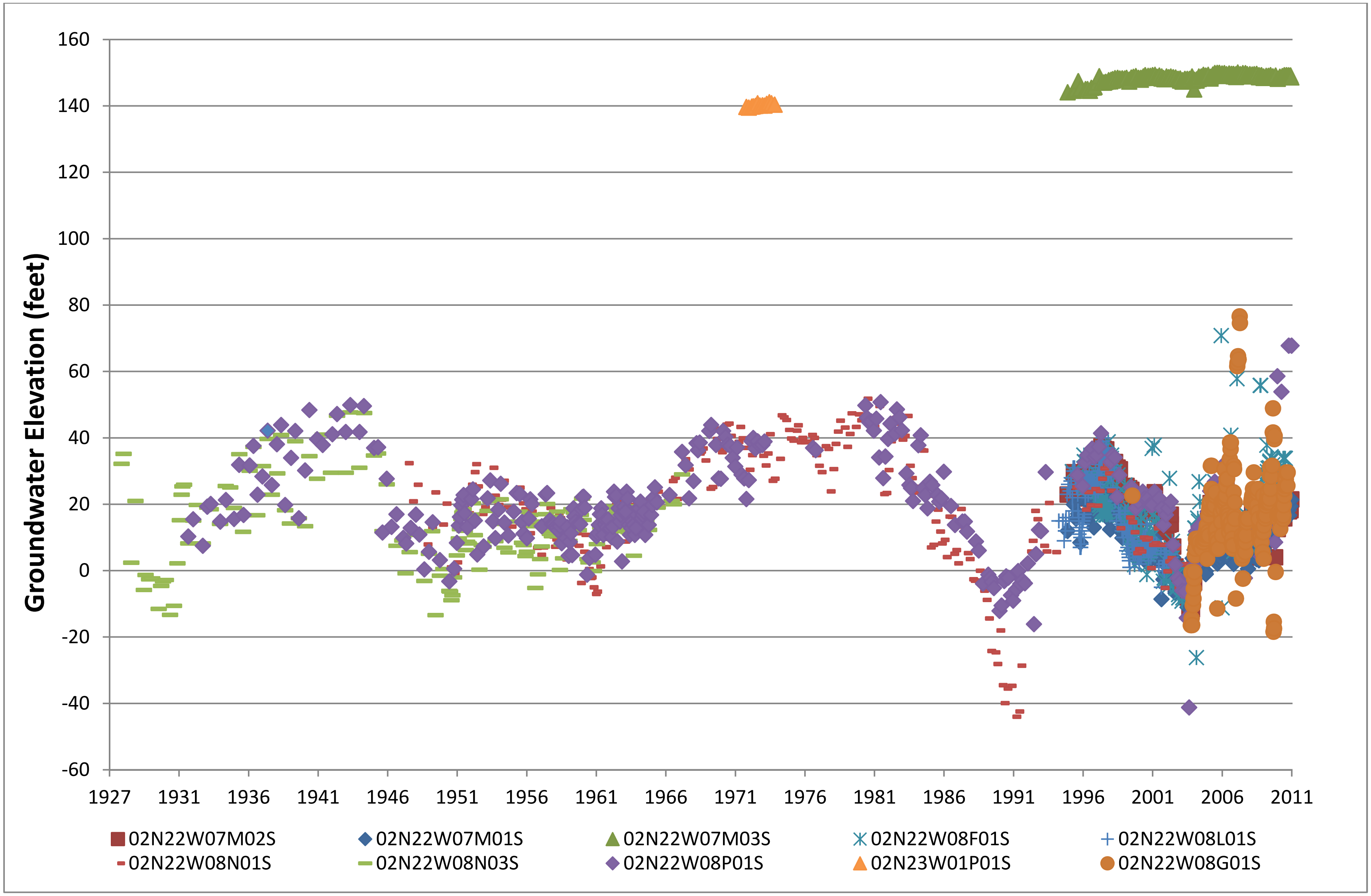


Figure 4-1. Recorded groundwater elevations, north and central Mound basin.

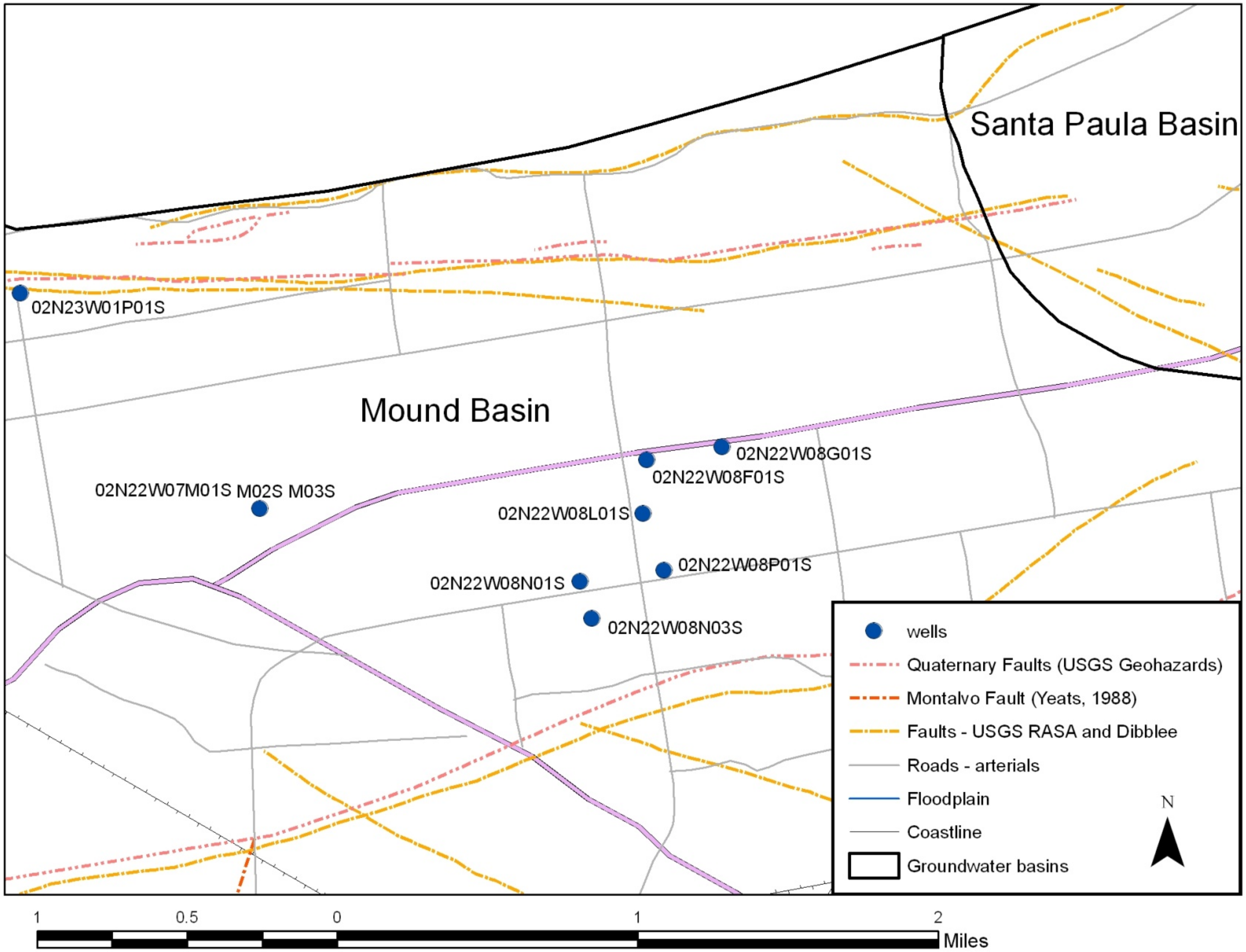


Figure 4-2. Location map for north and central Mound basin wells with WLE records.

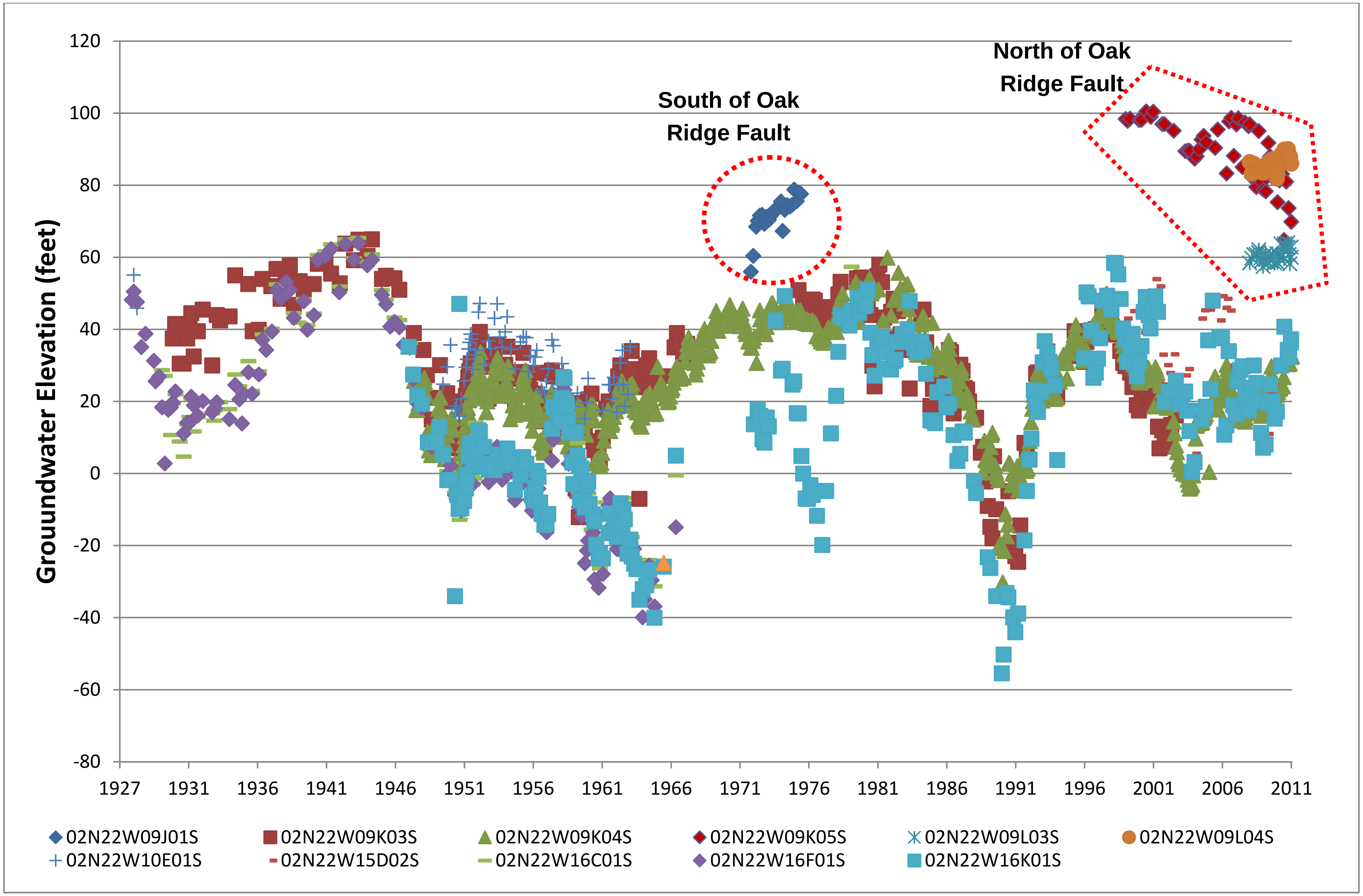


Figure 4-3. Recorded groundwater elevations, eastern Mound basin.

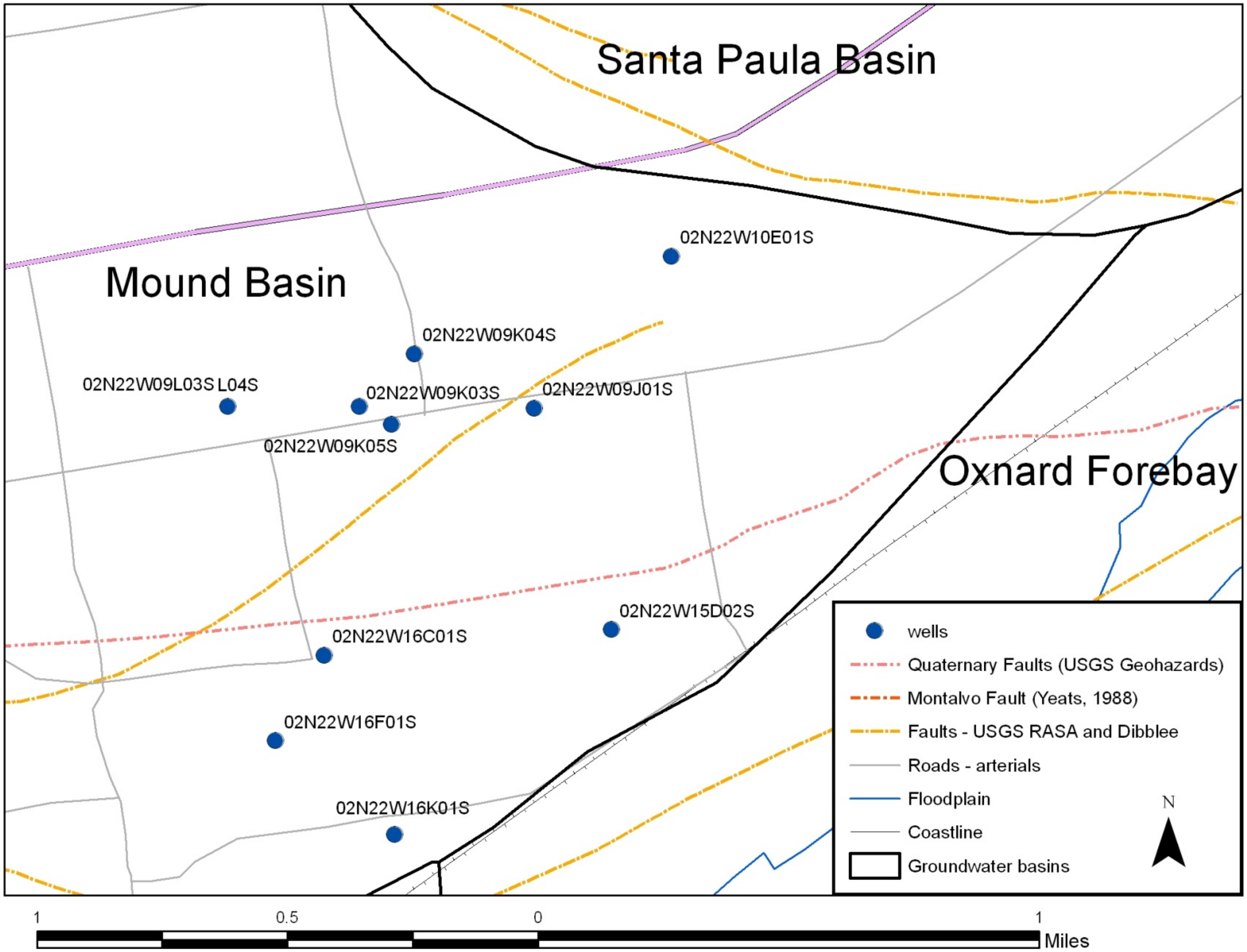


Figure 4-4. Location map for eastern Mound basin wells with WLE records.

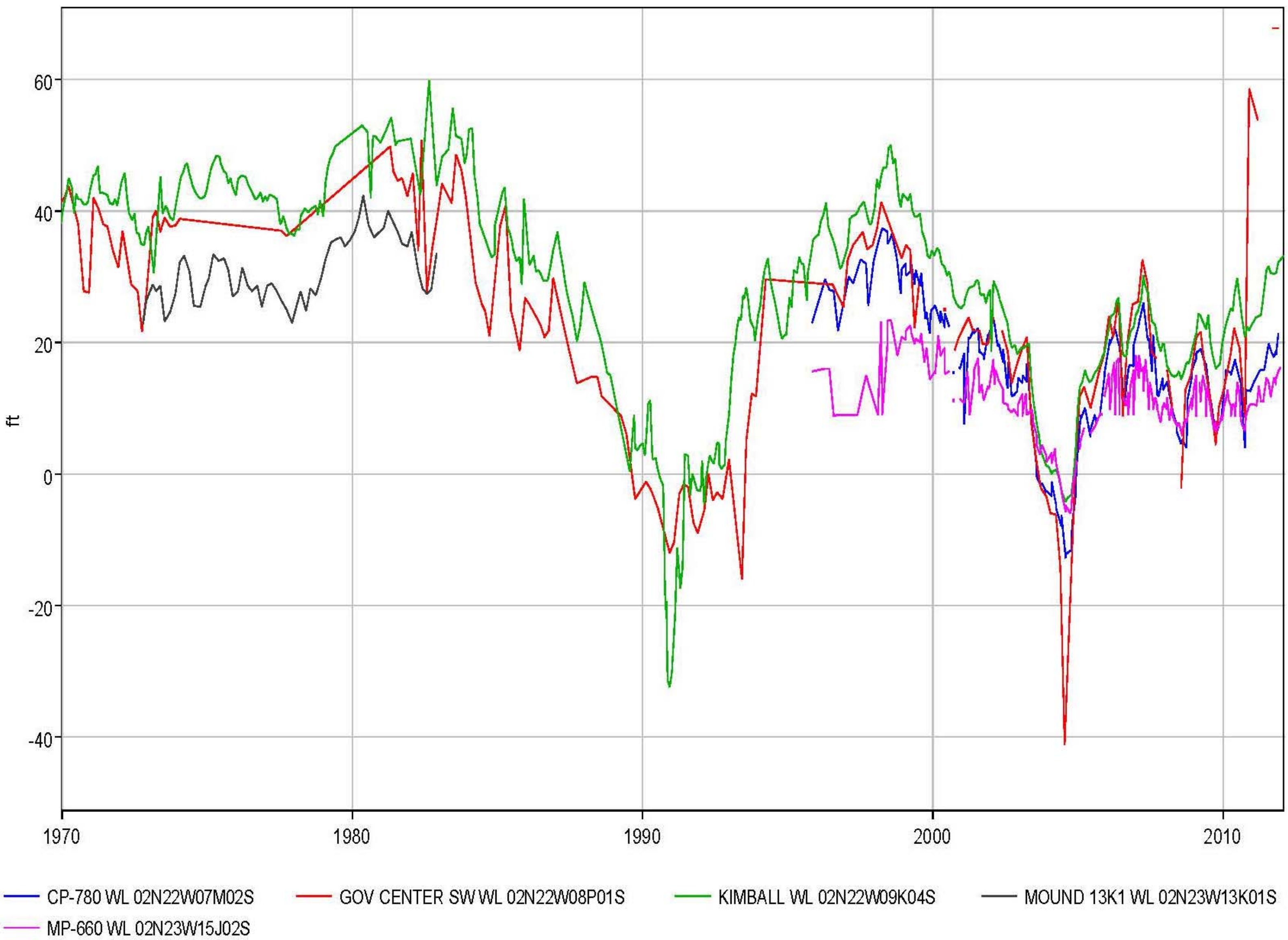


Figure 4-5. Recorded groundwater elevations, central Mound basin.

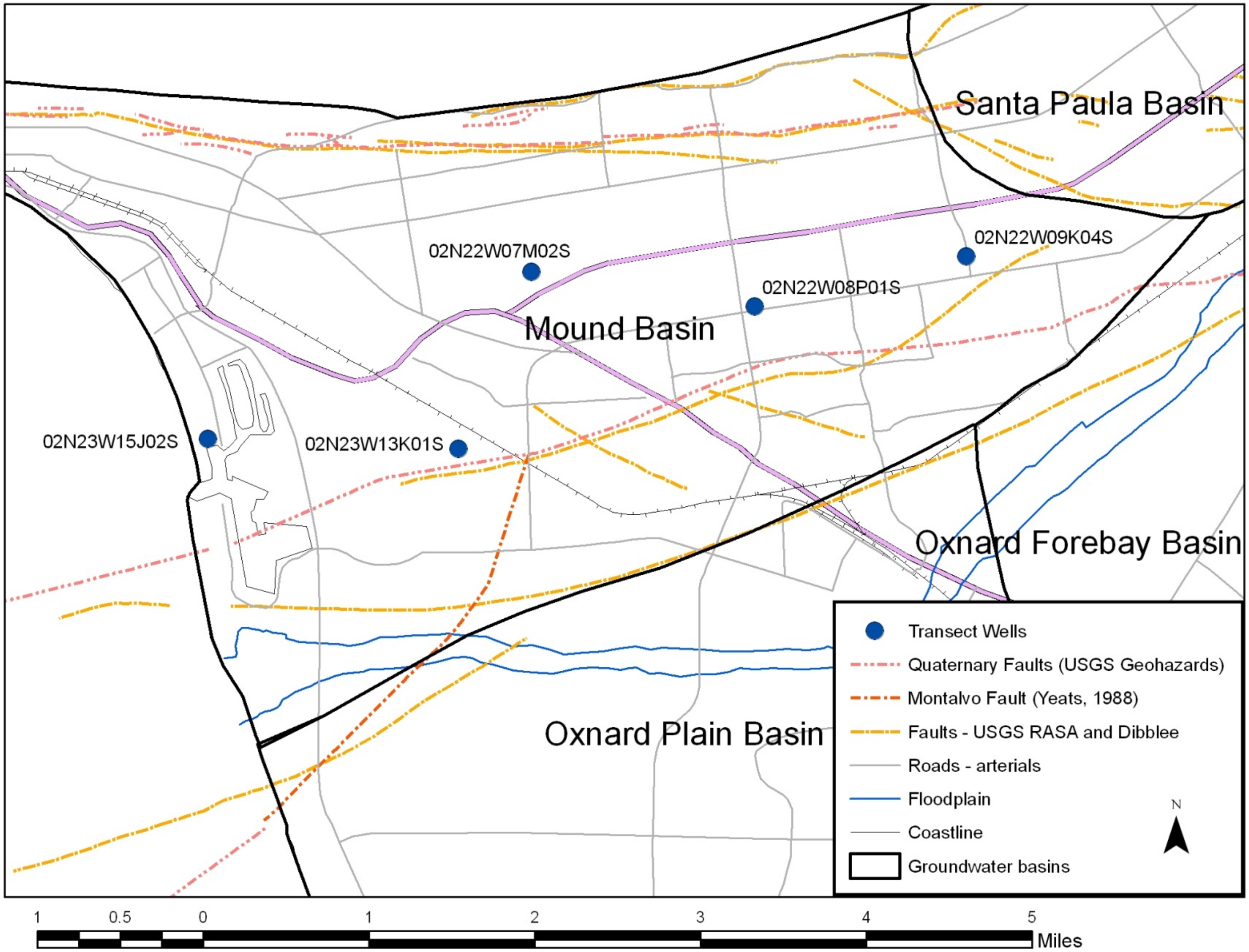


Figure 4-6. Location map for central Mound basin wells with WLE records.

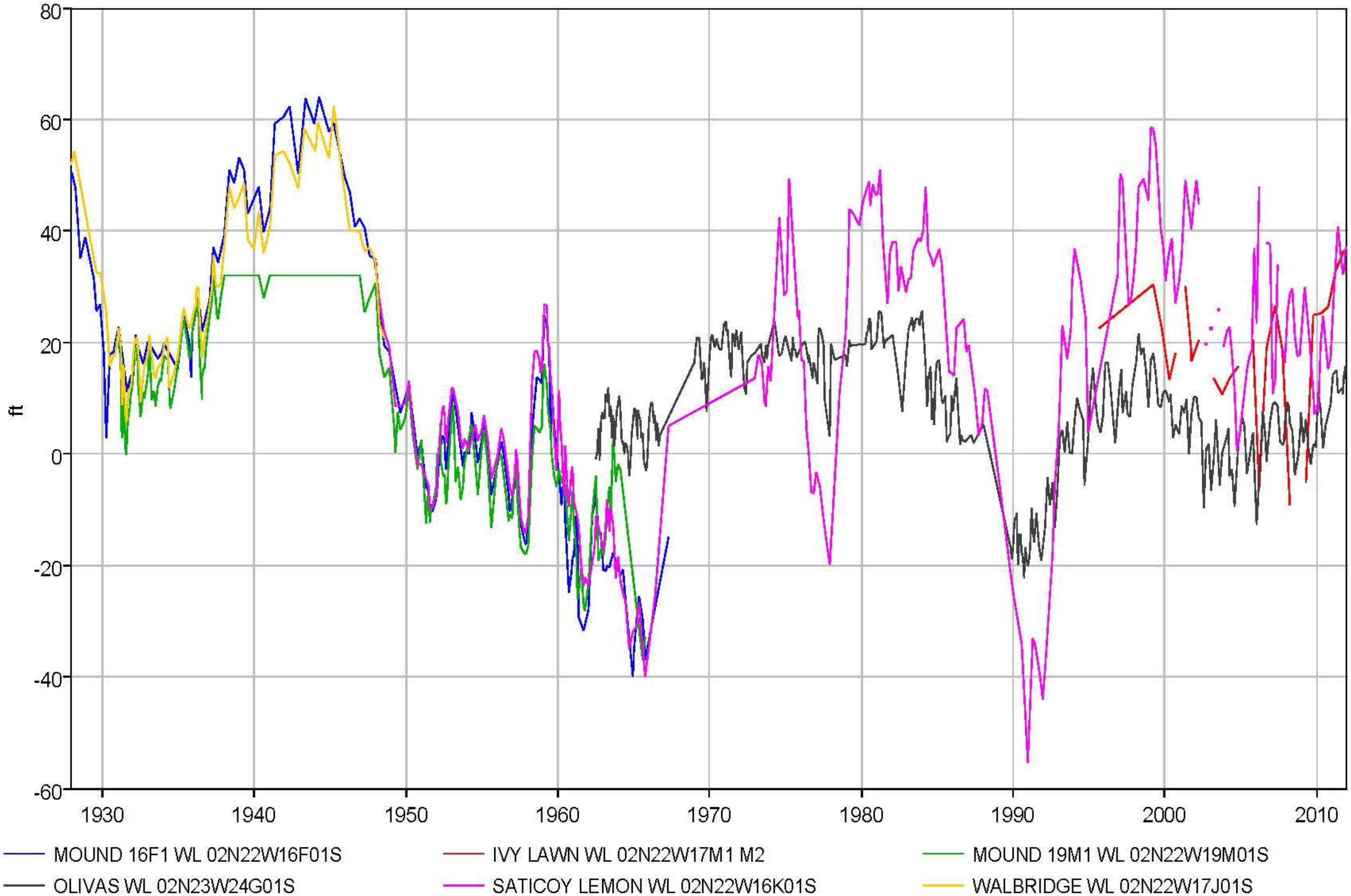


Figure 4-7. Recorded groundwater elevations, southern Mound basin.

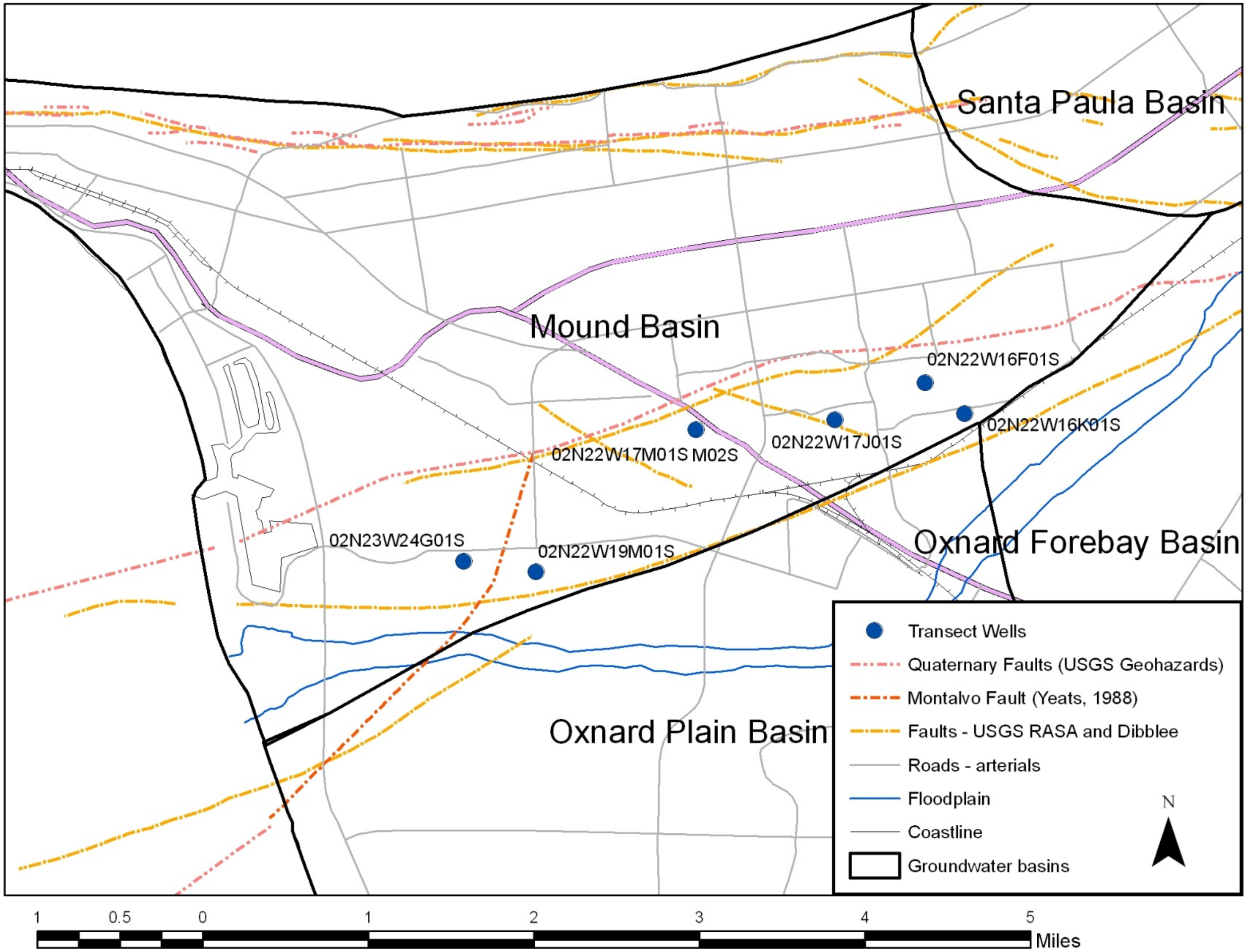


Figure 4-8. Location map for southern Mound basin wells with WLE records.

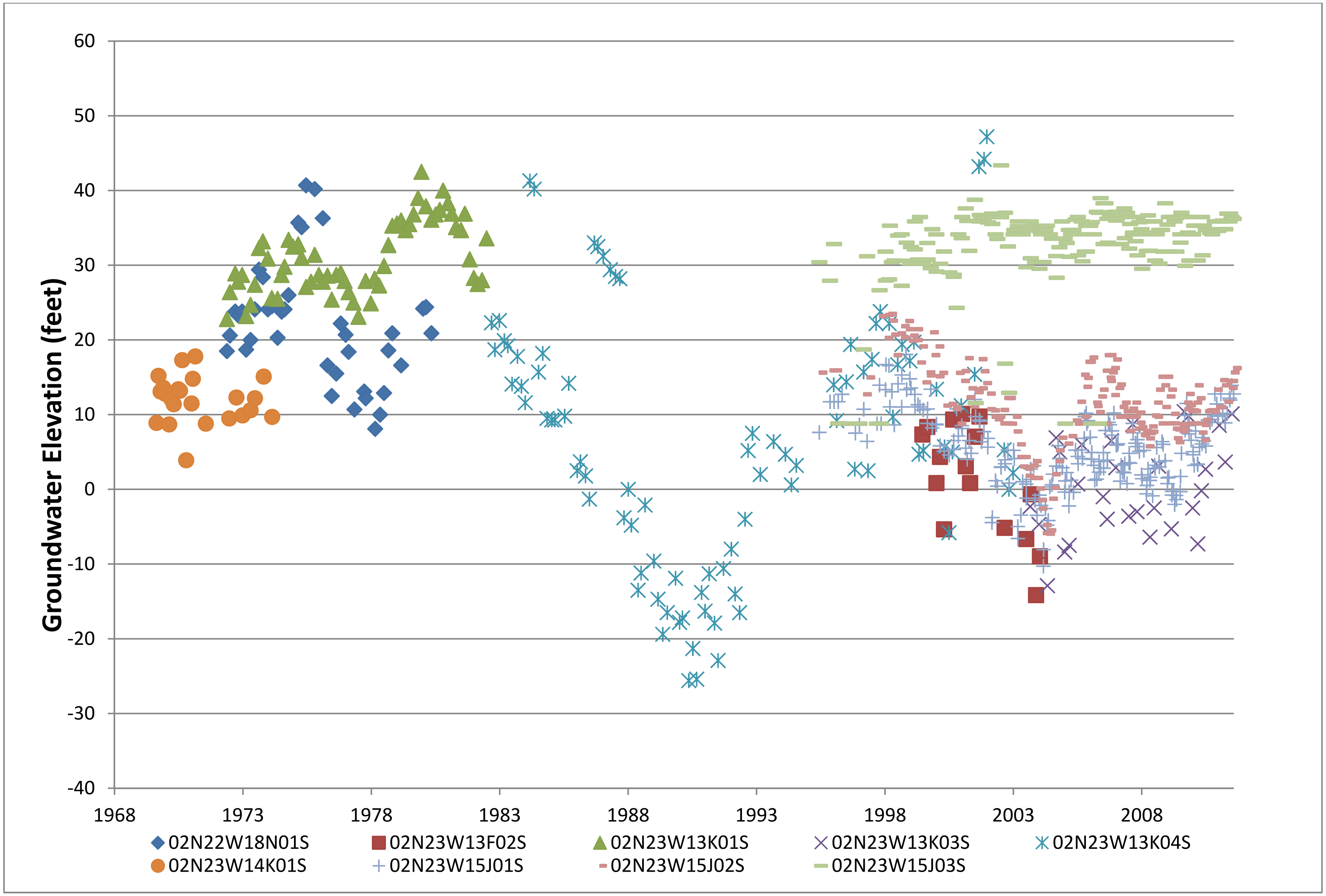


Figure 4-9. Recorded groundwater elevations, western Mound basin.

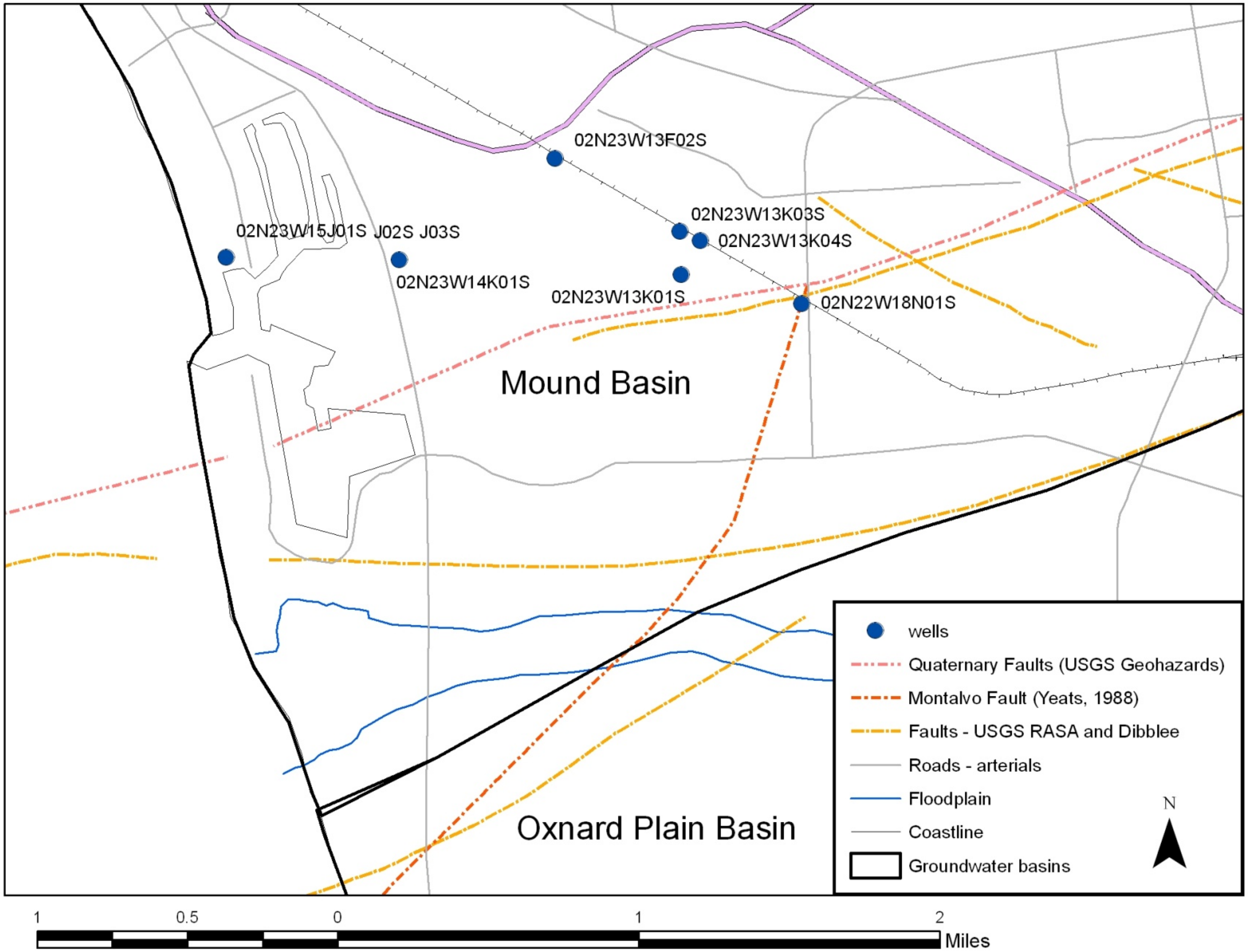


Figure 4-10. Location map for western Mound basin wells with WLE records.

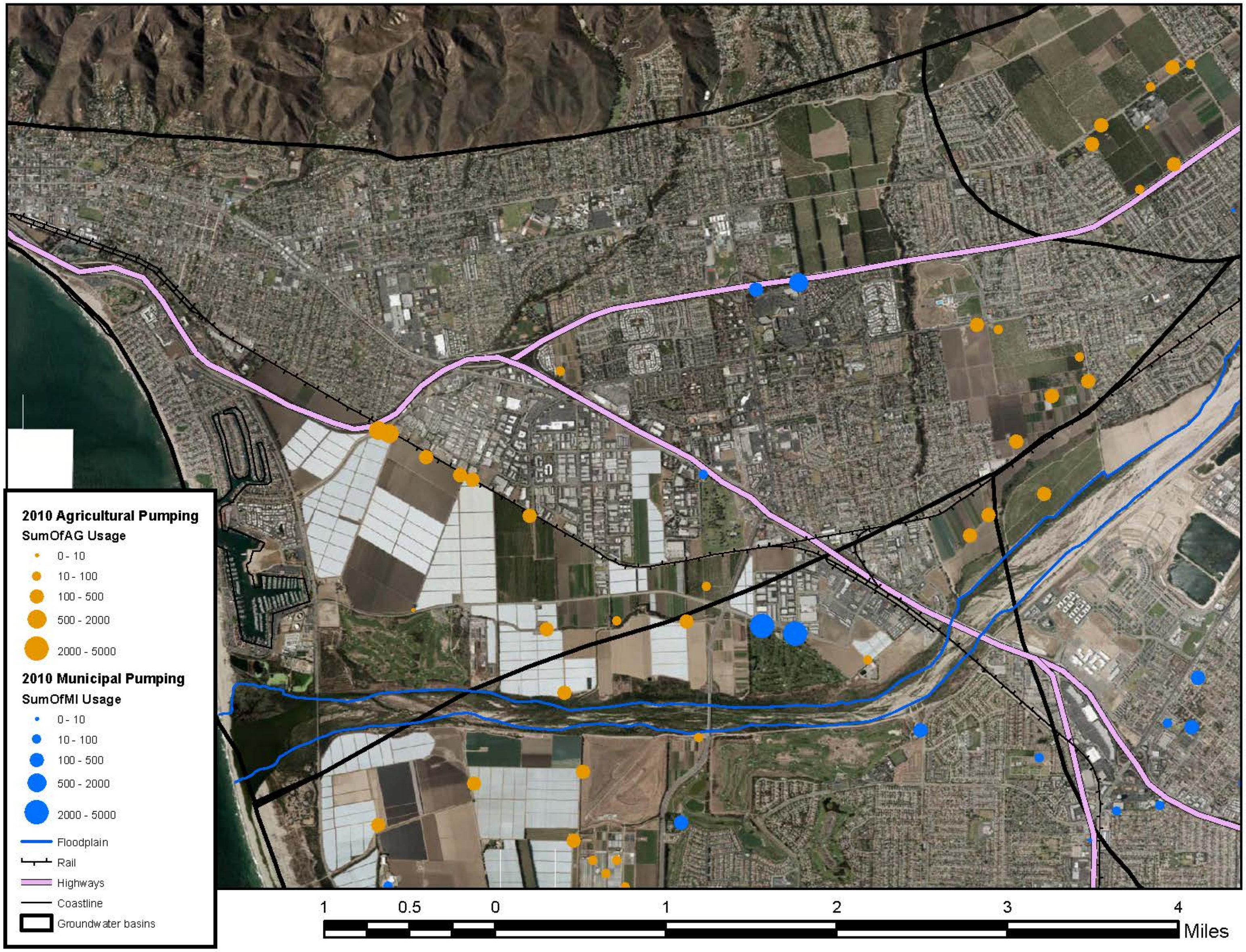


Figure 5-1. Distribution of Mound basin pumping, 2010 calendar year.

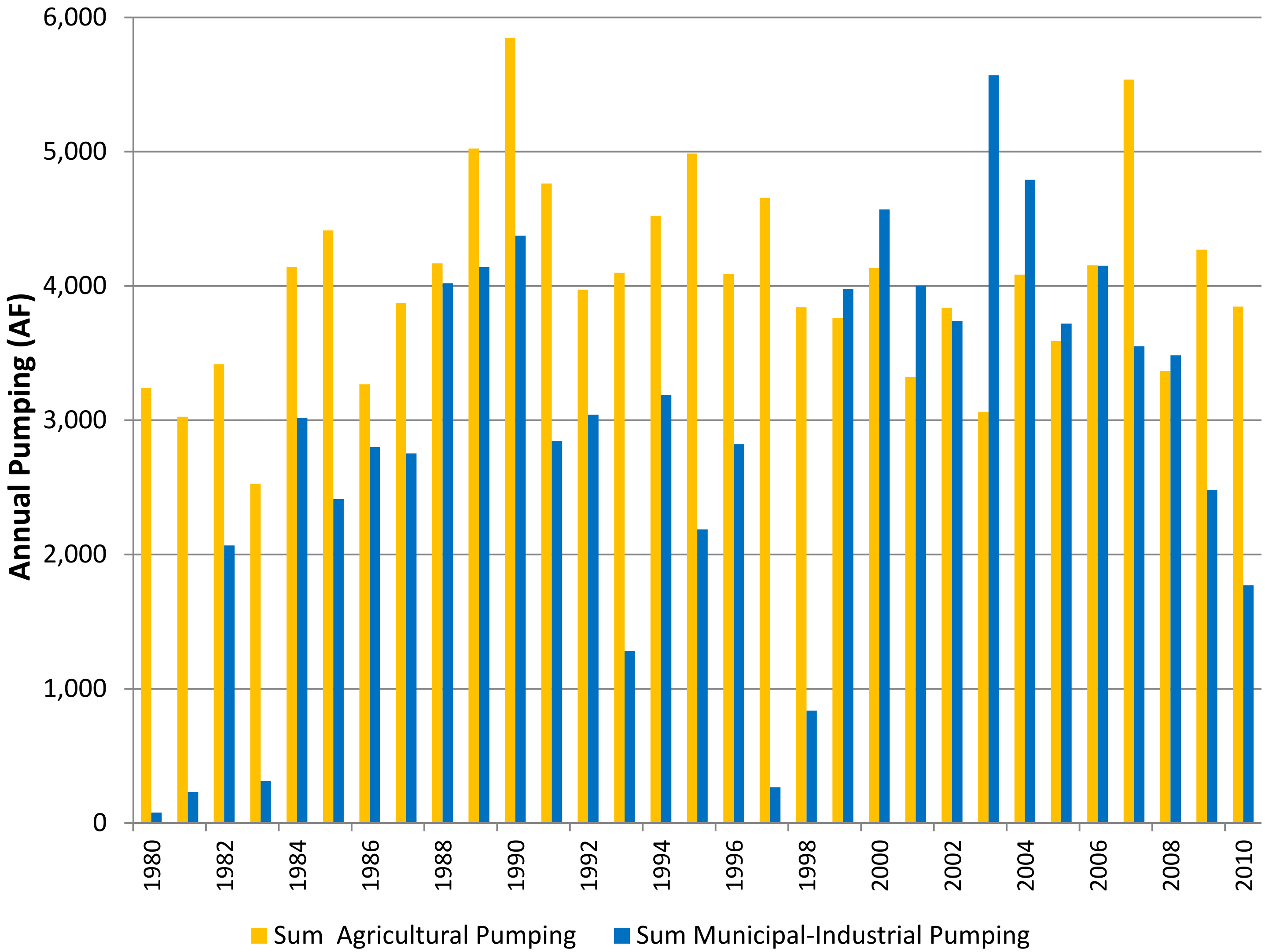


Figure 5-2. Annual Mound basin pumping totals by water use.

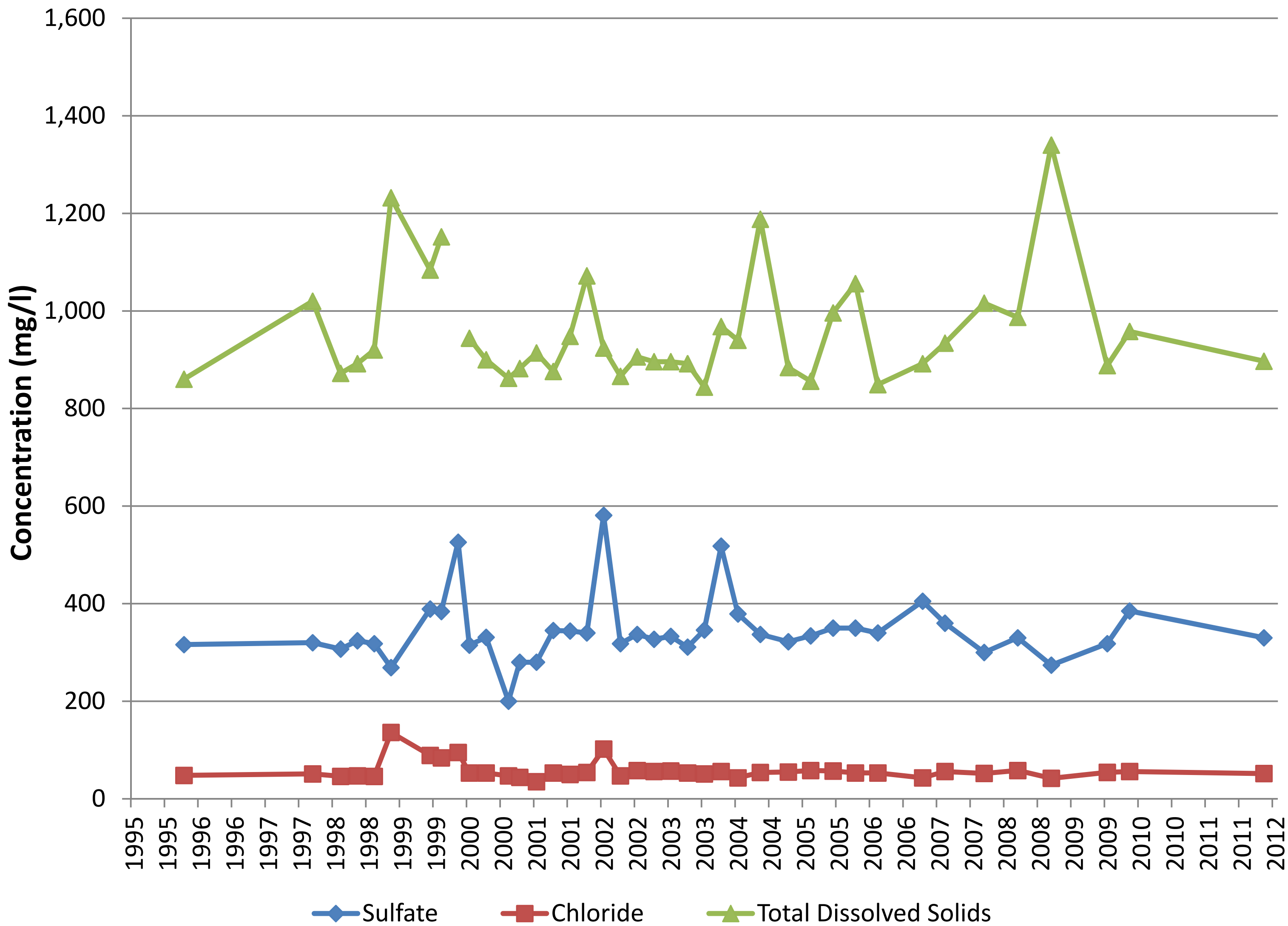


Figure 6-1. Well 02N22W07M02S water quality records (monitoring well CP-780).

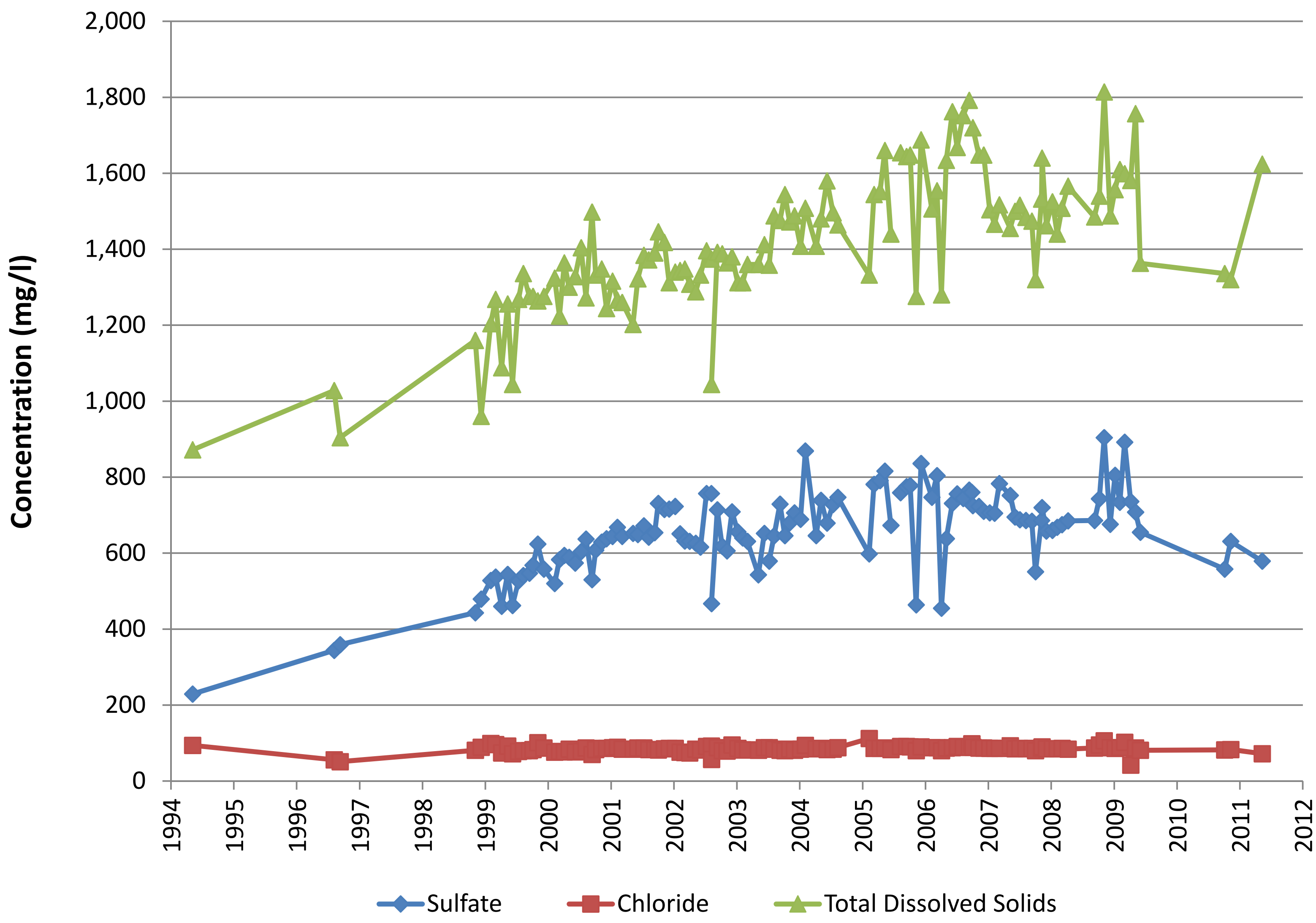


Figure 6-2. Well 02N22W08F01S water quality records (Victoria 2).

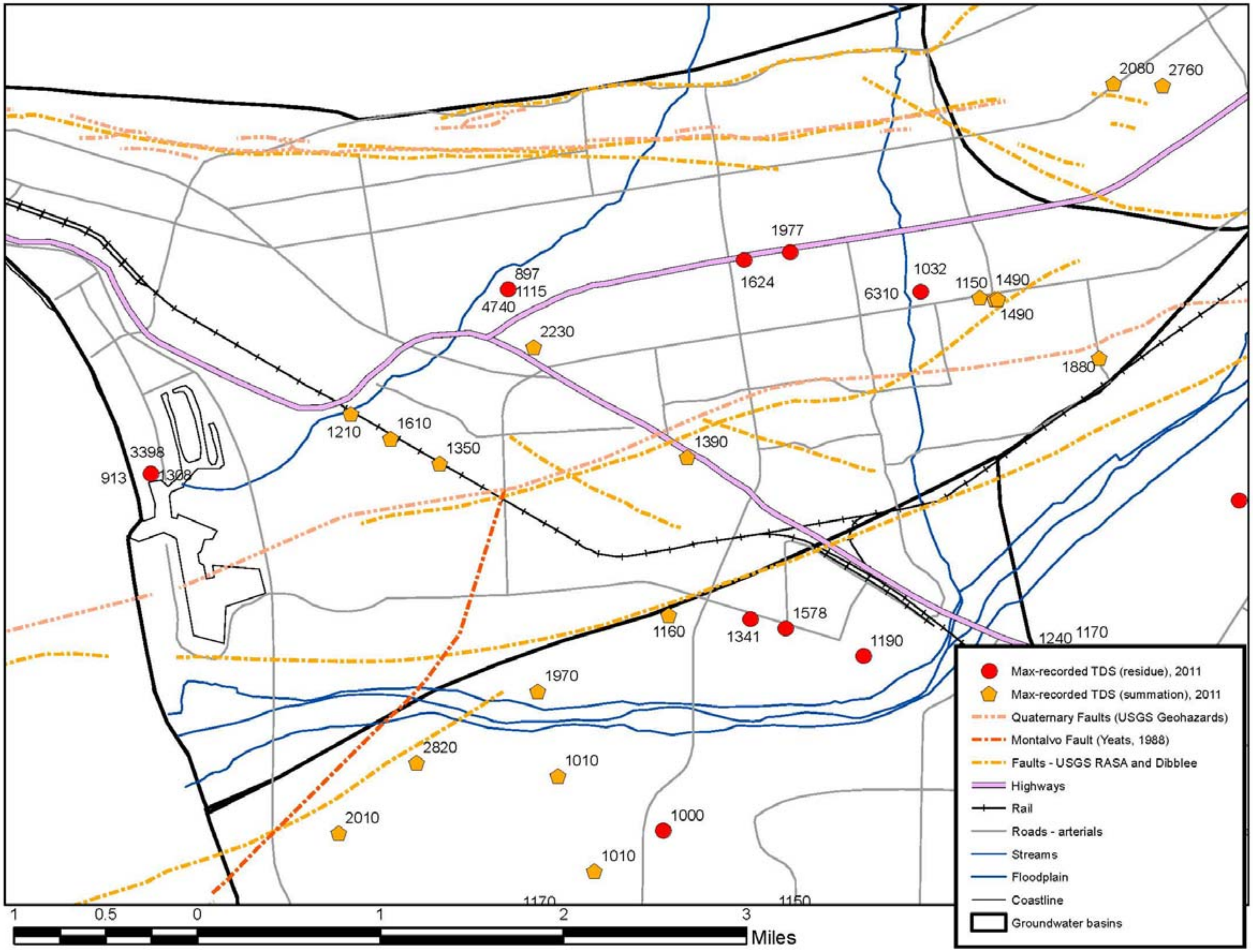


Figure 6-3. Maximum-recorded Total Dissolved Solids in 2011.

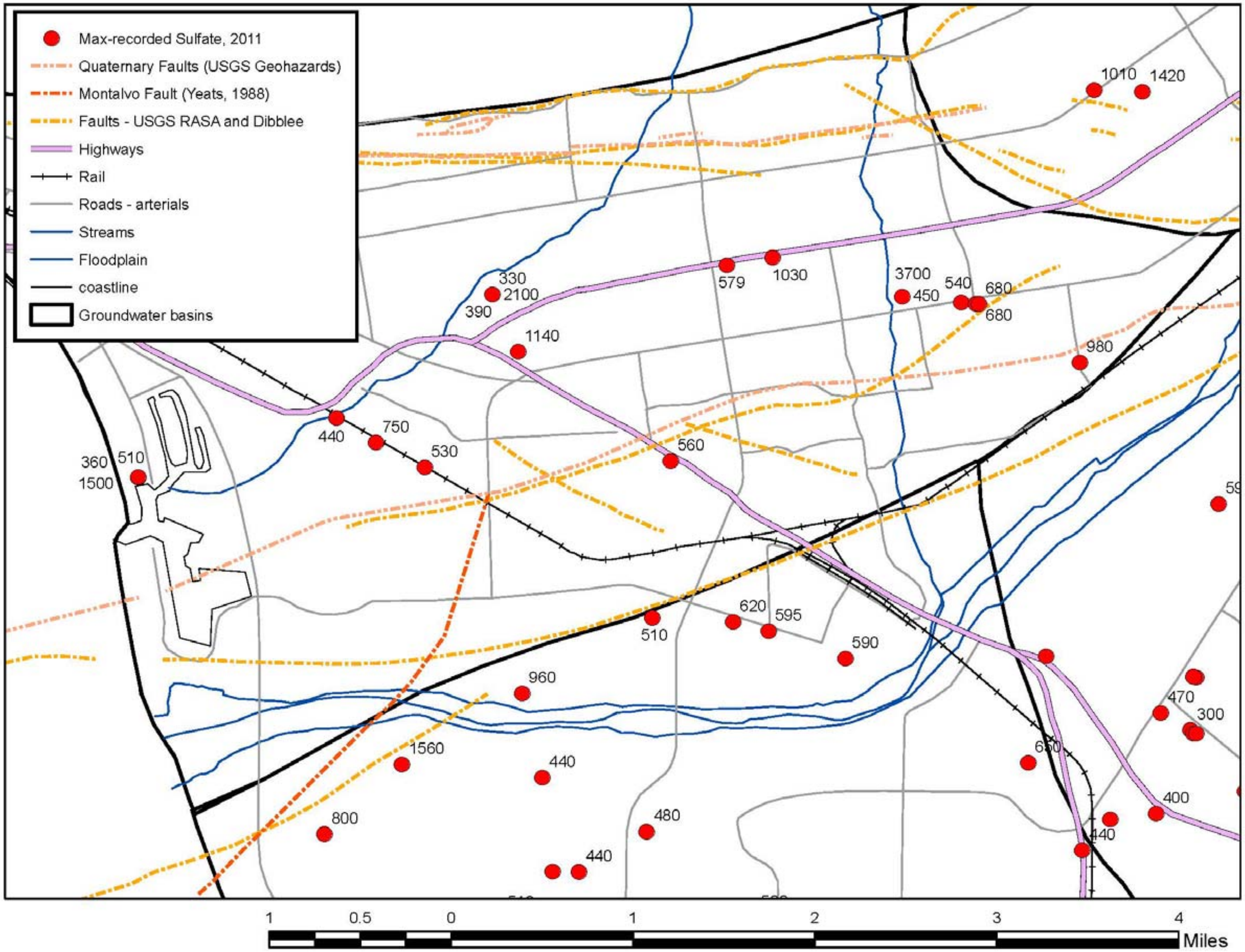


Figure 6-4. Maximum-recorded sulfate concentration in 2011.

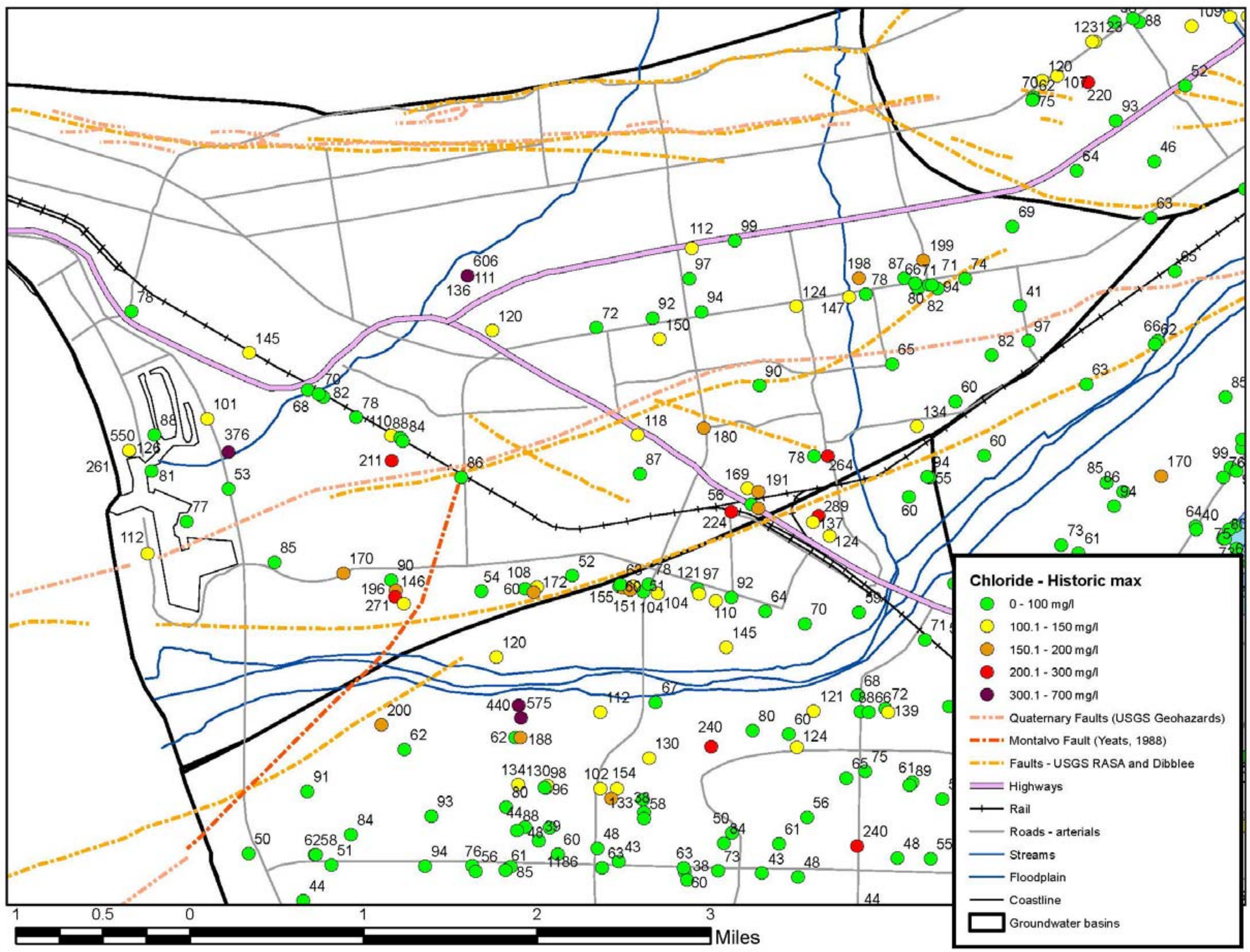


Figure 6-5. Maximum-recorded chloride concentration, all historic records.

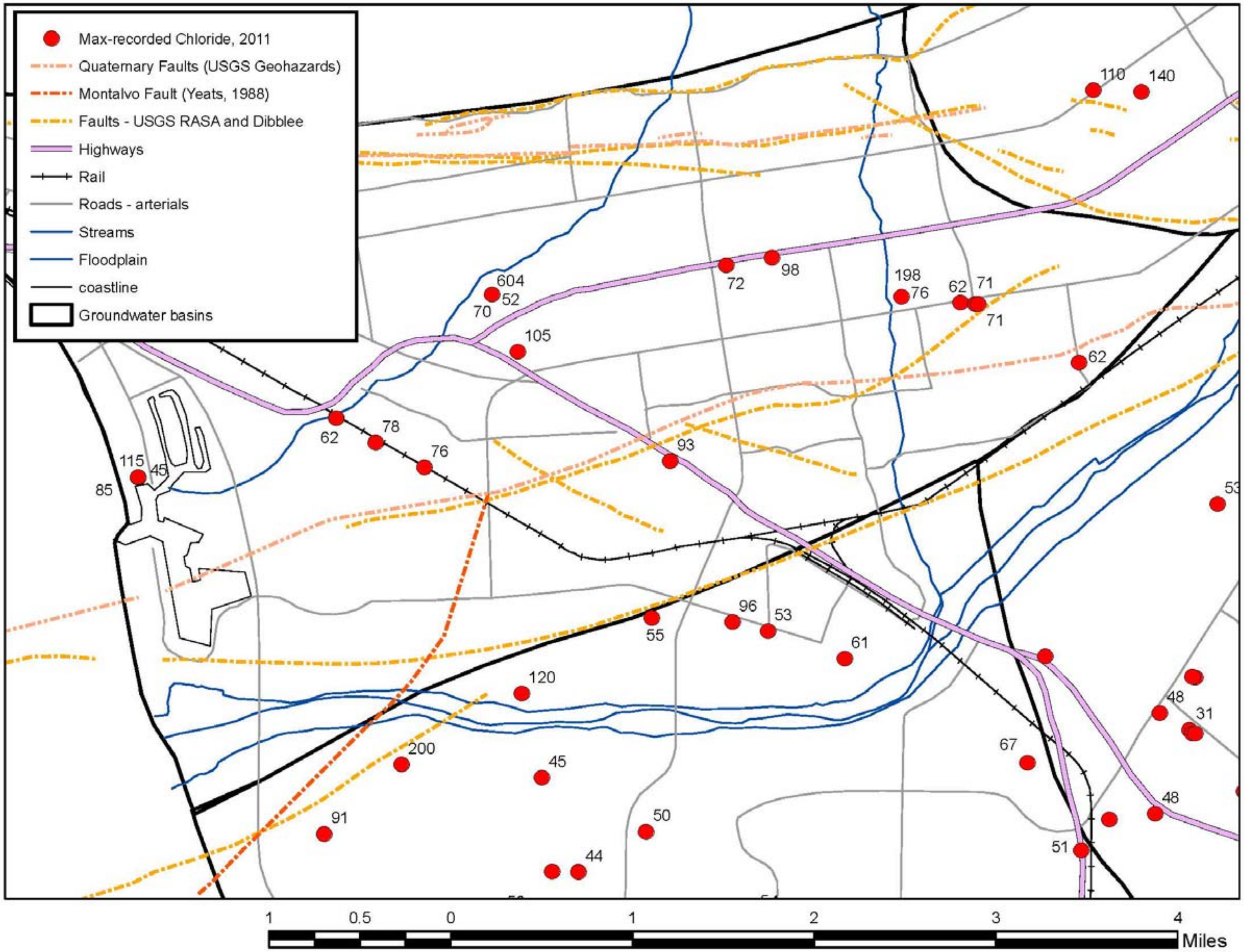


Figure 6-6. Maximum-recorded chloride concentration in 2011.

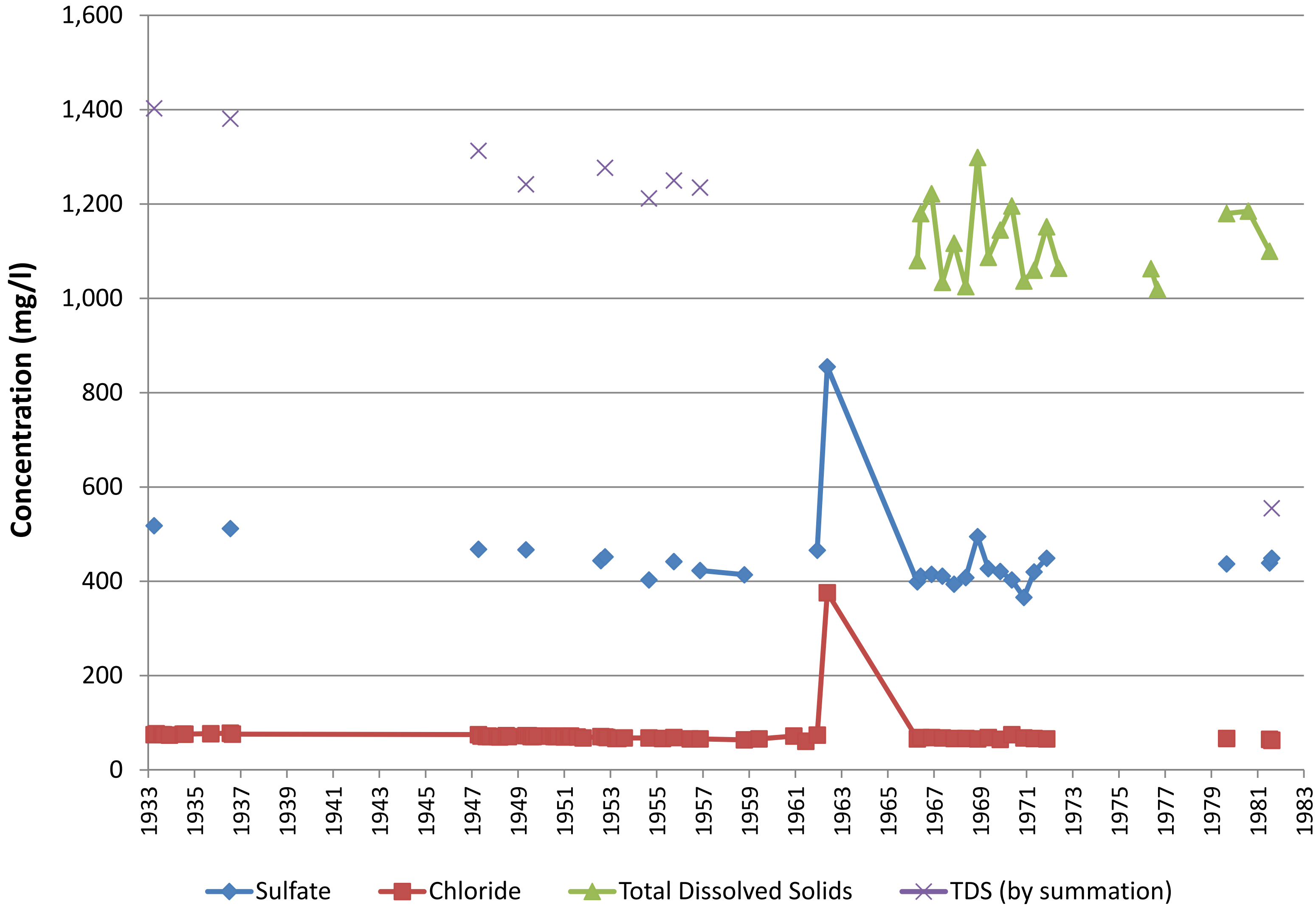
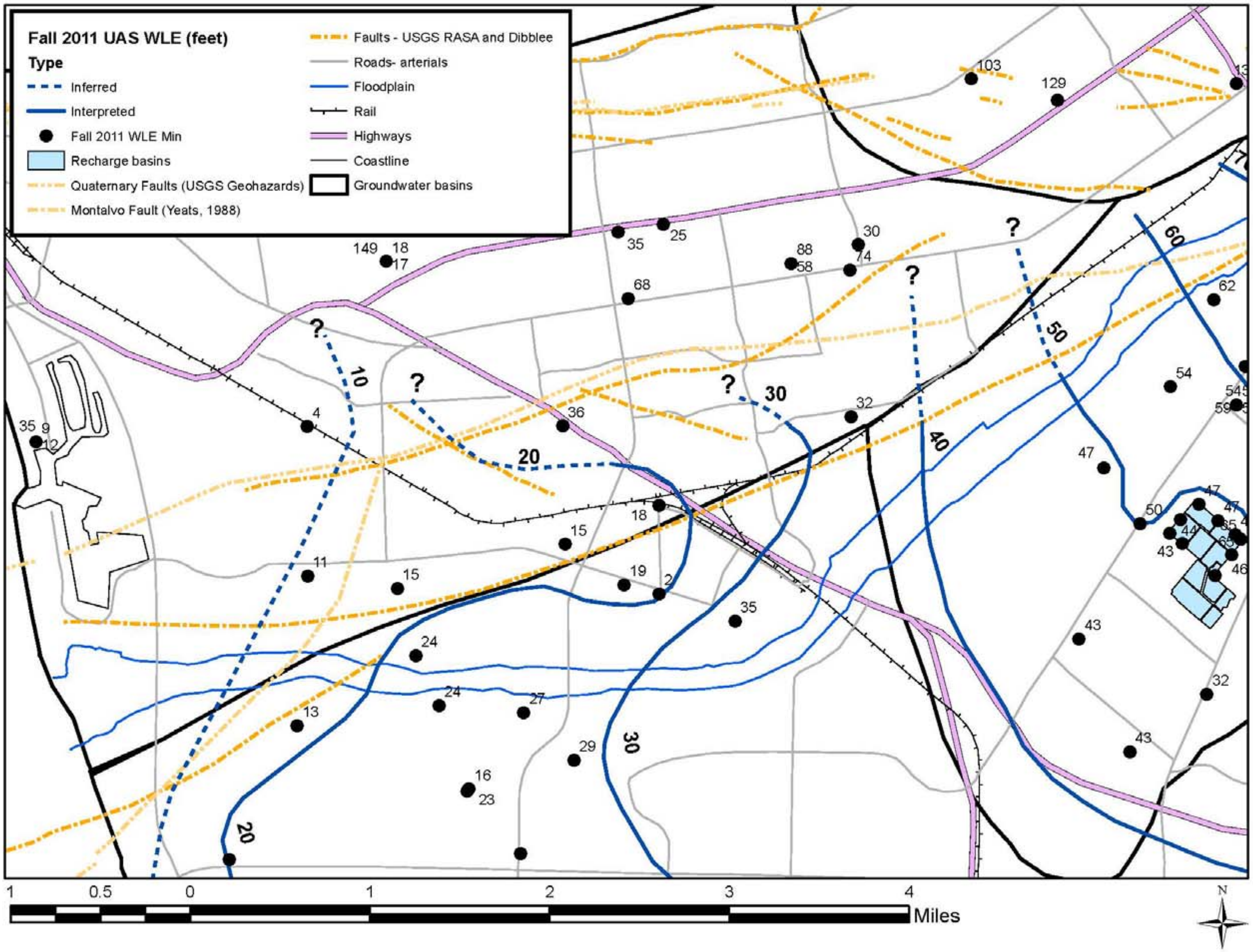
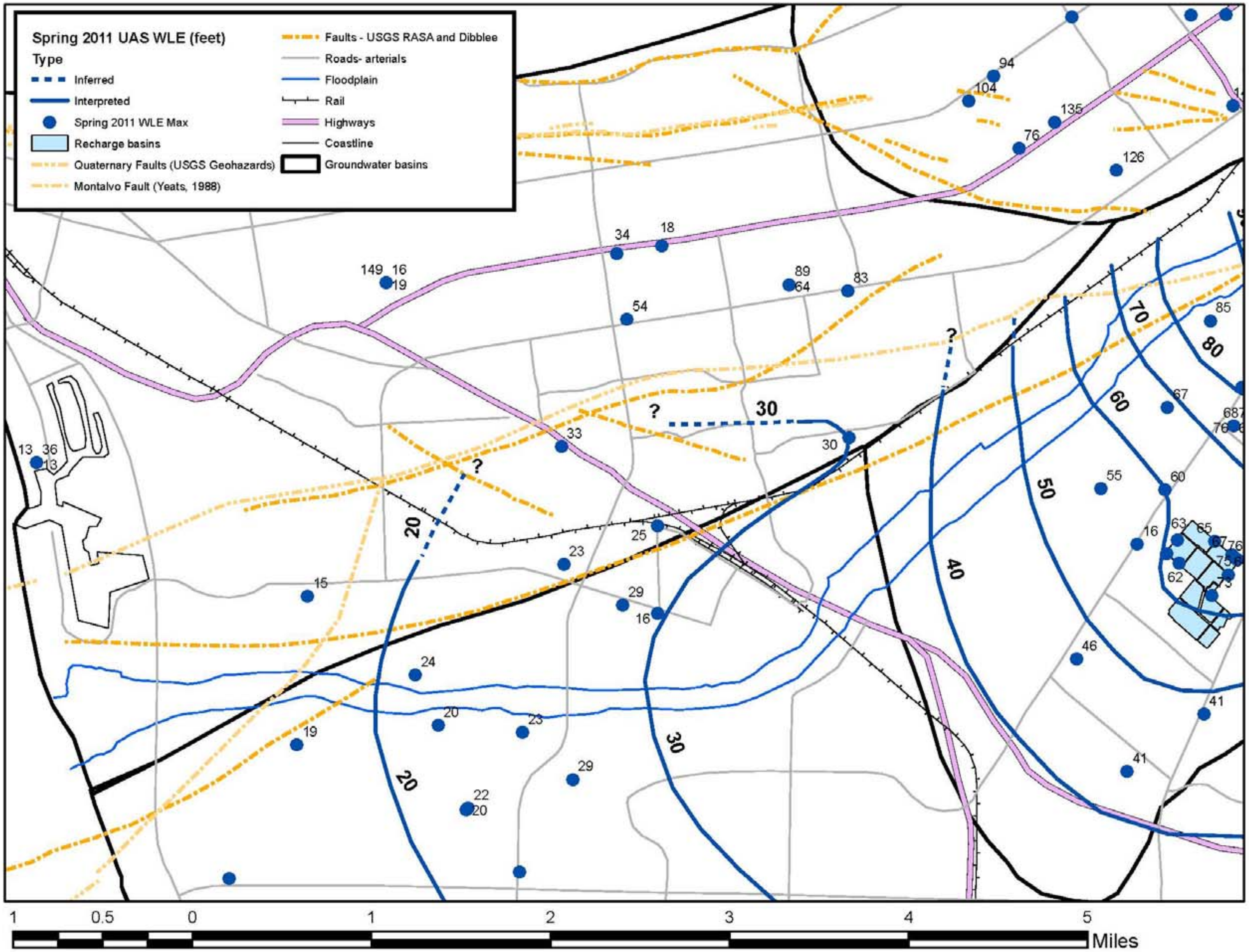


Figure 6-7. Well 02N23W14K01S water quality records.

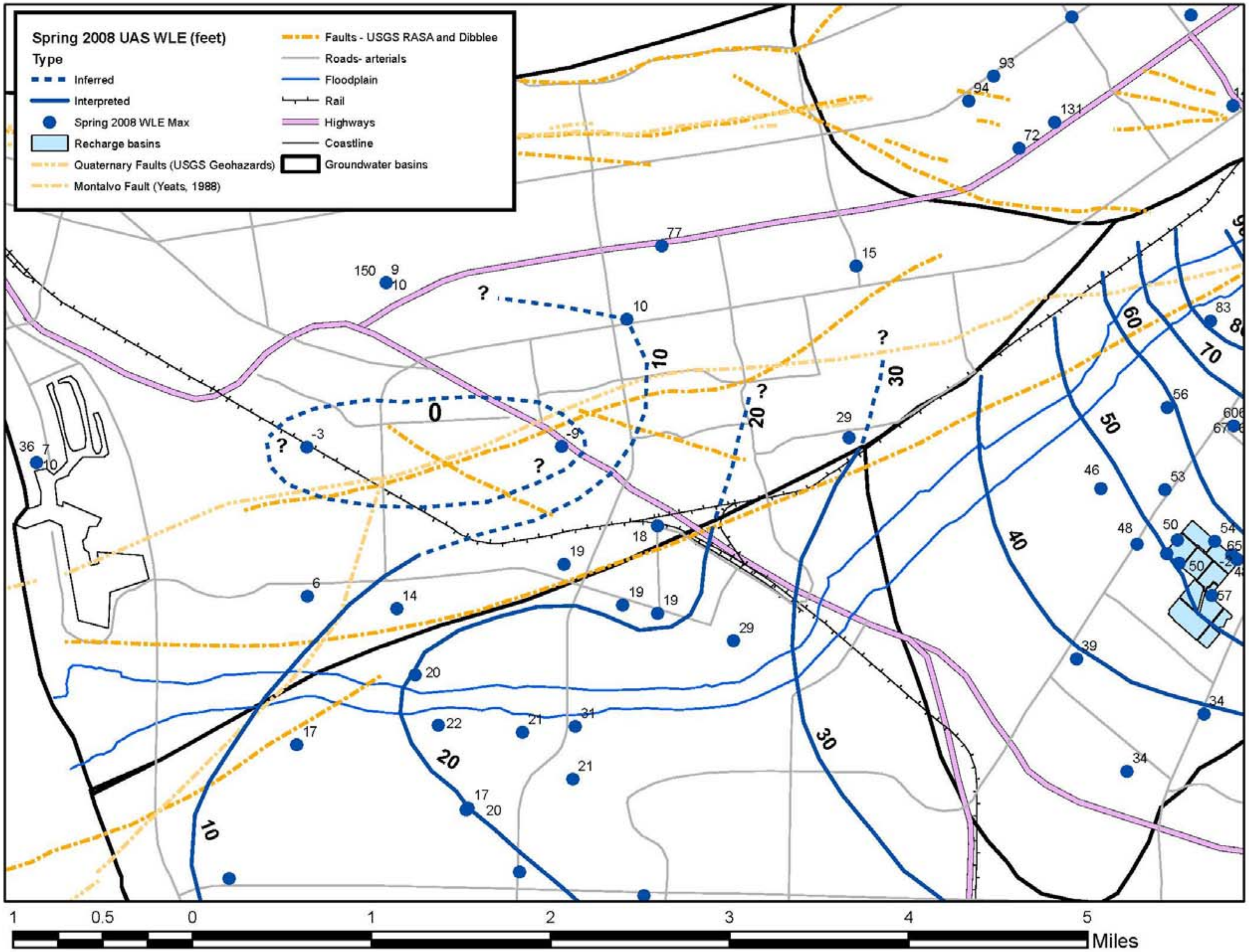
10 APPENDIX B - GROUNDWATER ELEVATION MAPS

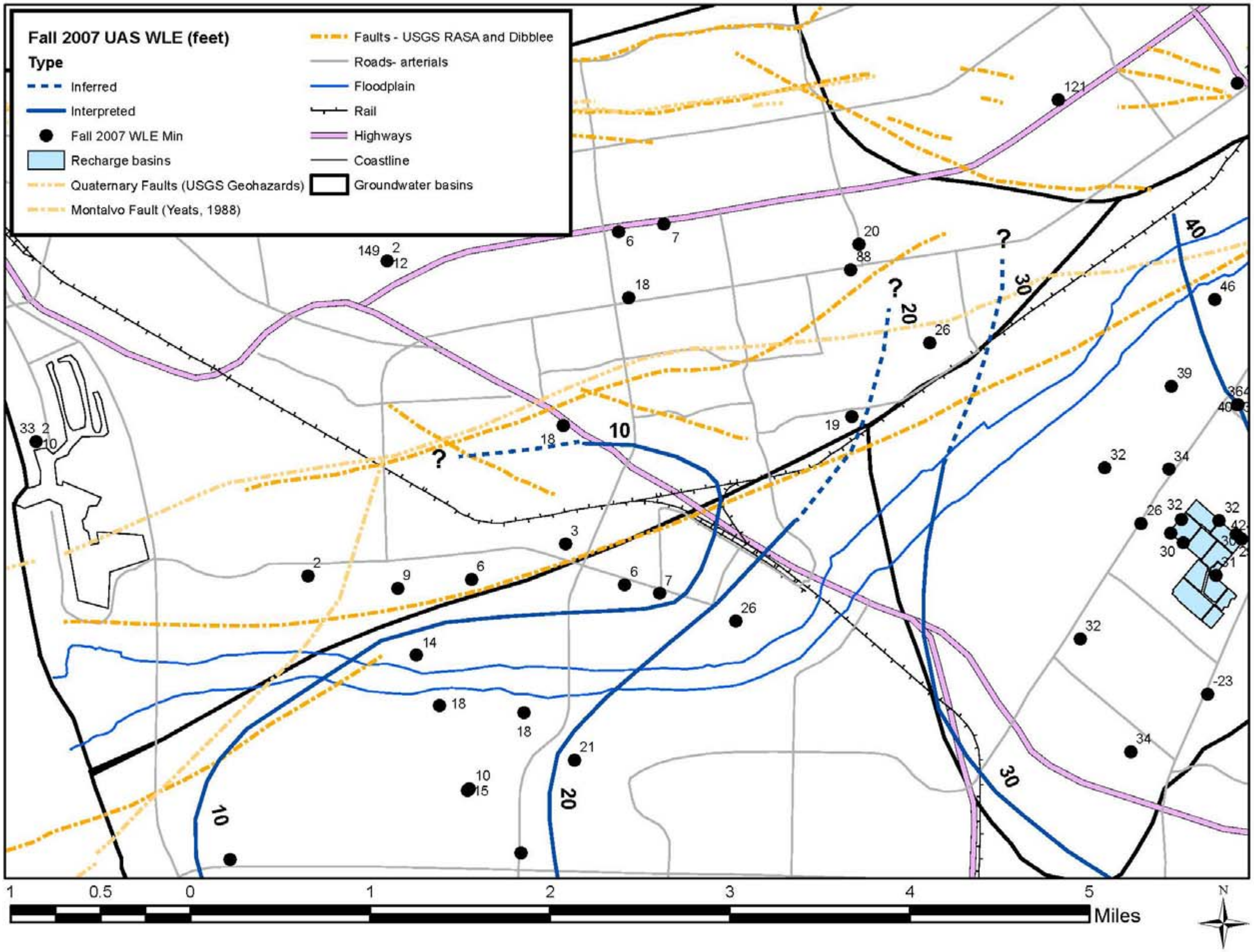
Appendix B contains representative groundwater elevation maps for 2001-2001. If sufficient data were available, both spring and fall groundwater elevation maps are included.


Fall 2011 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2011 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
10
20
30
40
50
60
Miles
N

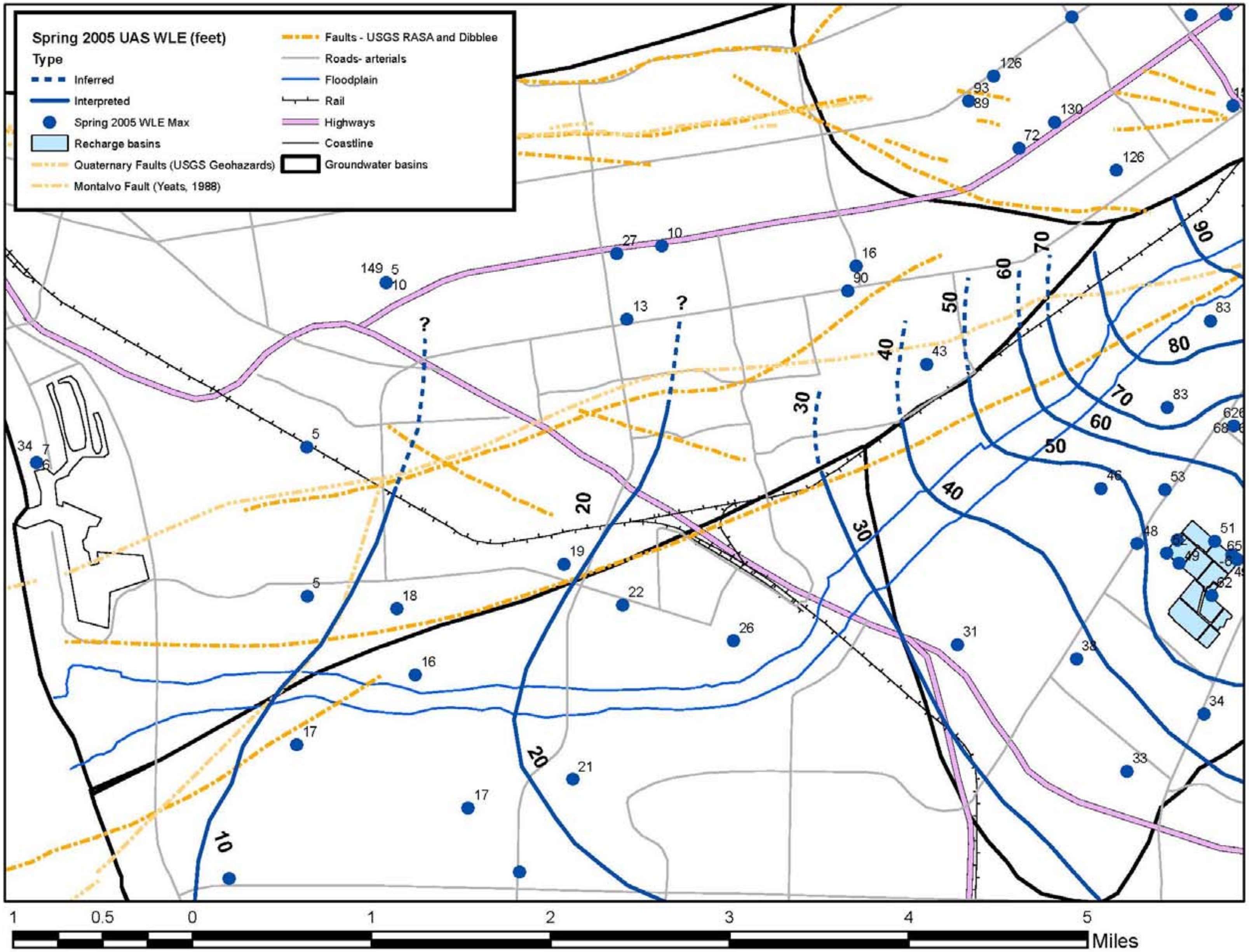


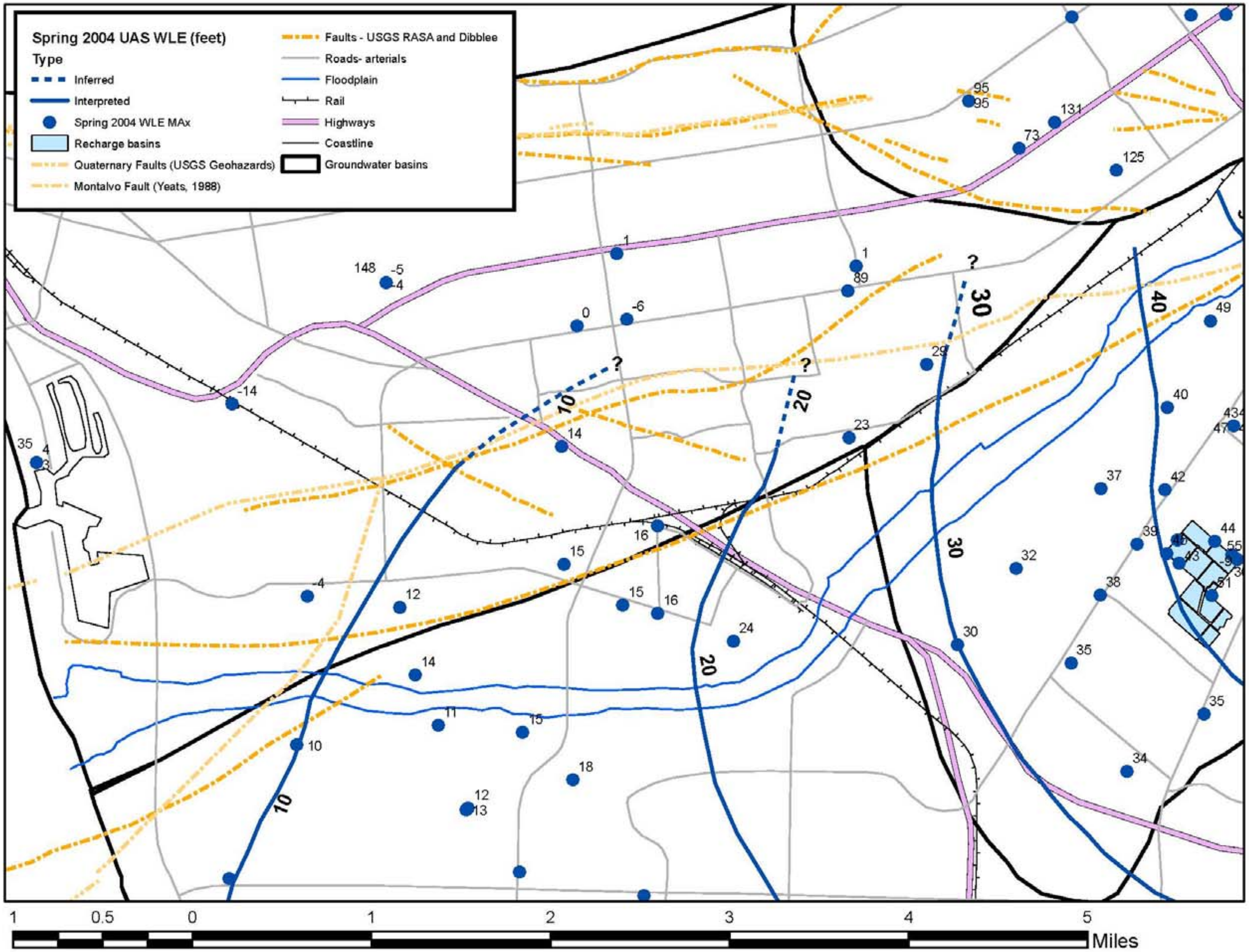
Spring 2011 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2011 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles

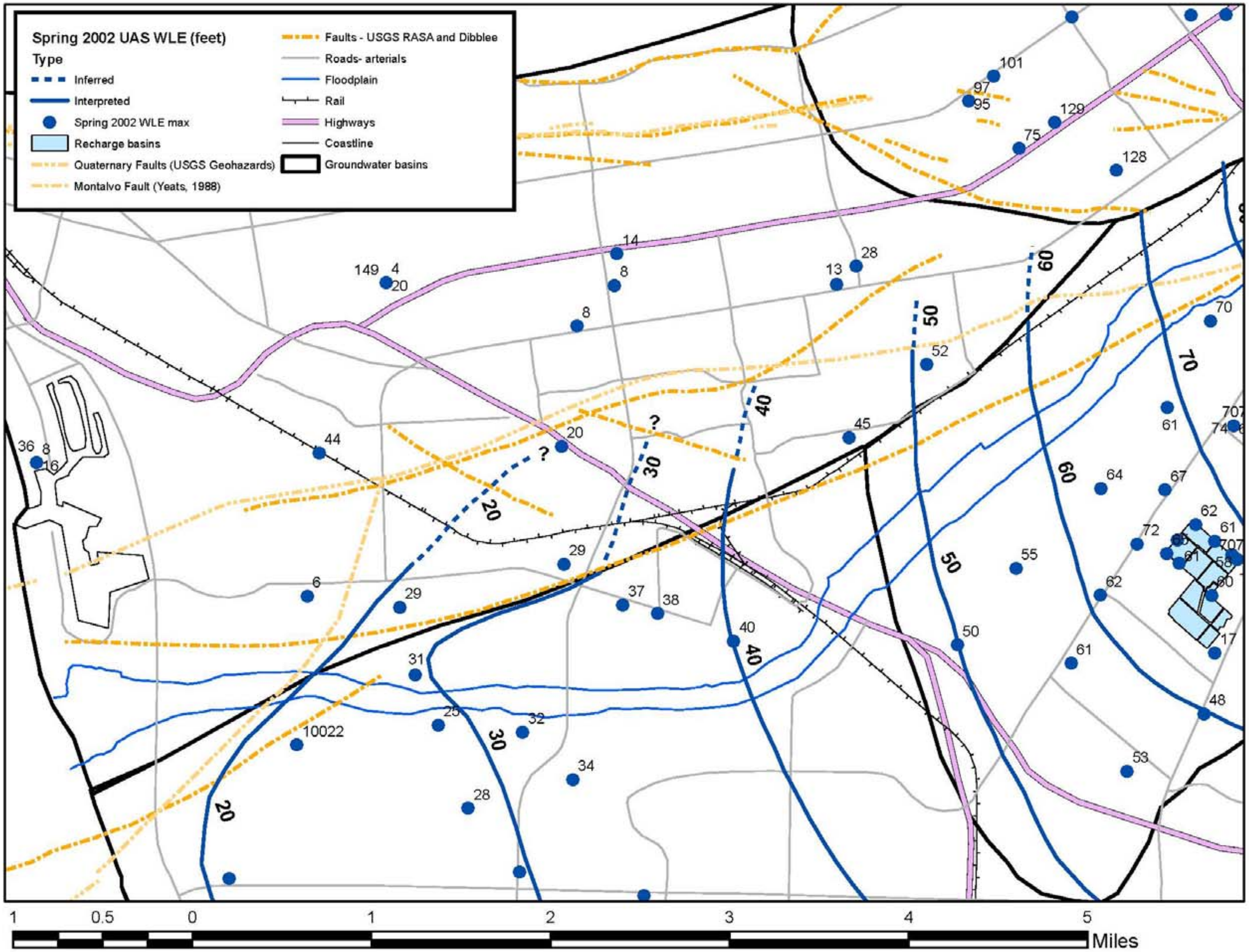

Spring 2008 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2008 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles

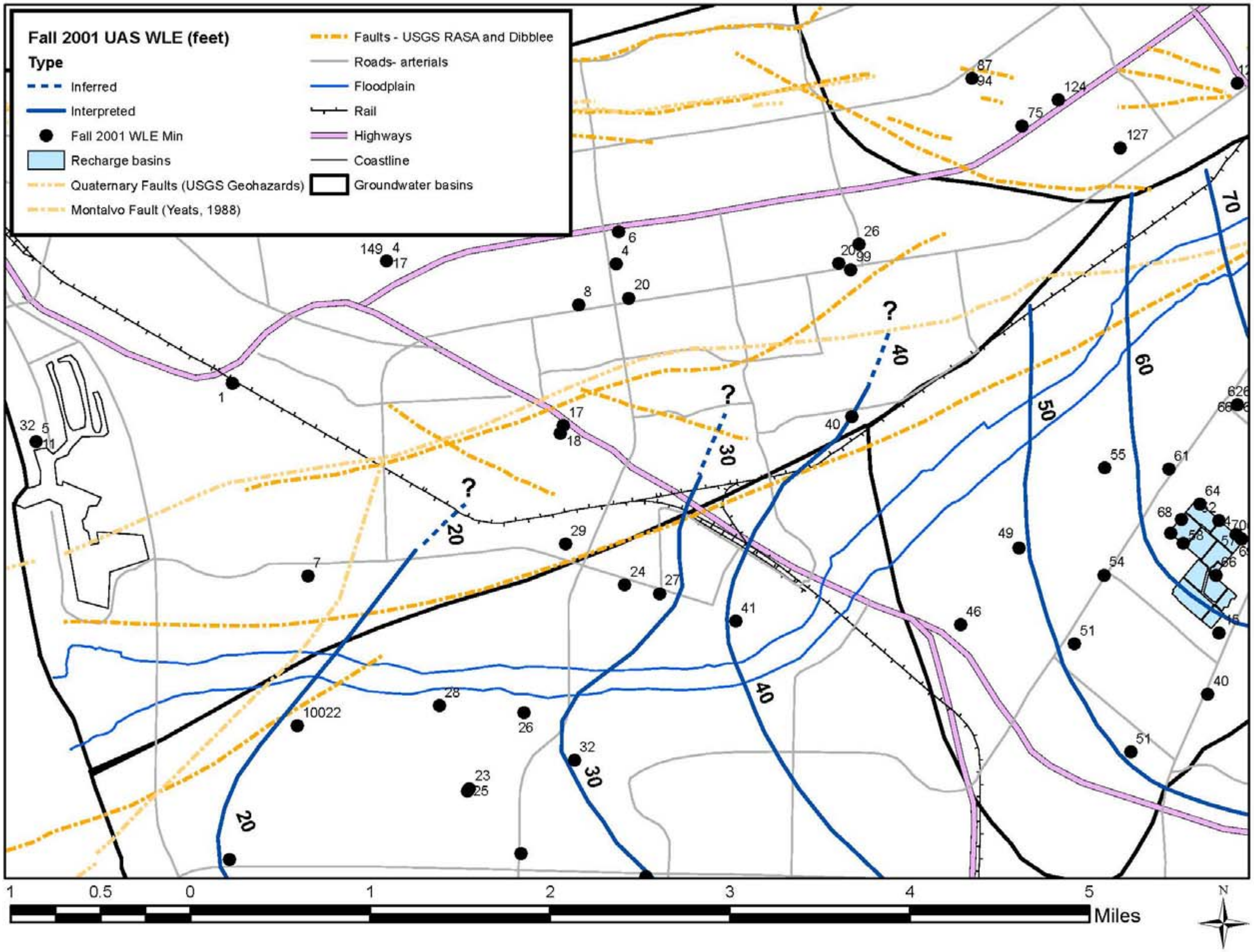


Fall 2007 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2007 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
10
20
30
40
1 0.5 0 1 2 3 4 5
Miles
N


Spring 2005 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2005 WLE Max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
10
20
30
40
50
60
70
80
90
?
1
0.5
0
1
2
3
4
5
Miles


Spring 2004 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2004 WLE MAx
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Spring 2002 UAS WLE (feet)
Type
Inferred
Interpreted
Spring 2002 WLE max
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles


Fall 2001 UAS WLE (feet)
Type
Inferred
Interpreted
Fall 2001 WLE Min
Recharge basins
Quaternary Faults (USGS Geohazards)
Montalvo Fault (Yeats, 1988)
Faults - USGS RASA and Dibblee
Roads- arterials
Floodplain
Rail
Highways
Coastline
Groundwater basins
1 0.5 0 1 2 3 4 5
Miles
N