WOOD RODGERS

January 26, 2007
Job No. 8233.003

Mr. Lester Messina
County of Glenn
720 North Colusa Street
P.O. Box 351
Willows, CA 95988

Dear Mr. Messina:

Subject: Wilson Creek Hydrogeologic Investigation

Wood Rodgers, Inc. is pleased to provide this technical memorandum summarizing the items of work that have been completed for the Wilson Creek Hydrogeologic Investigation. The purpose of this investigation was to provide a better characterization of the aquifer materials within the study area and the potential for enhancing groundwater recharge with the construction of a detention basin.

The scope of work for this project included the following three tasks:

1.1 Shallow borings to characterize the extent of the surficial gravels underlying Wilson Creek and the proposed Wilson Creek Detention Facility.
1.2 Compilation of hydrogeologic data.
1.3 Evaluation and reporting of hydrogeologic data.

The study area is shown in Figure 1 and is located on the western side of the Sacramento Valley along the eastern flank of the Coast Ranges. The study area is located in Glenn County and is comprised primarily of two ranches: the Big W Ranch (Big W) and Lassen Land Ranch (Lassen Land). Big W is located northwest of Willows and is approximately six miles west of Interstate 5 at the termination of County Road 28. Lassen Land is located in Glenn County as well and borders the Big W property to the north. The size of the study area is approximately 13 square miles.

Wood Rodgers was unable to conduct the site exploration portion of Task 1.1 due to site access problems. Wood Rodgers' characterization of the subsurface geology/hydrogeology began by utilizing test hole exploration data from existing wells in the area. The locations of the existing wells with records that were reviewed for this project are shown in Figure 2.

In order to depict the subsurface geology under the study area, Wood Rodgers prepared a geologic cross section. The data that formed a basis for the preparation of this cross section included regional geologic maps, the lithologic descriptions from water well drillers reports and

geophysical logs (spontaneous potential and resistivity). The location of this geologic cross section is shown in Figure 2. The cross section line (A-A') starts south of Wilson Creek and terminates at the South Fork of Walker Creek, to the north. The geophysical logs were digitized and imported into the cross section utilizing GPS coordinates and the ground surface elevation as the vertical datum. The well data was used to correlate similar lithologic units. Where data control was limited, projections of the formation contacts were made based on the structure of the surrounding formation. These projections are approximate and are identified on the cross section by a dashed line. The wells are identified on the location map and cross section map by a four digit number assigned by the water well driller.

REGIONAL GEOLOGY AND GEOLOGIC STRUCTURE

The Sacramento Valley is situated in the northern Great Valley Province of Central California. The valley is a structural trough, bounded on the east by the Sierra Nevada Mountains and on the west by the Coast Range Mountains. The valley is underlain by marine sedimentary rocks with a relatively thin cover of continental deposits. The continental deposits make up the aquifer materials that supply groundwater for the northern Sacramento Valley.

To the west, the Coast Range Mountains are comprised of several different terrains: the Upper Jurassic eastern belt of the Franciscan Complex, the Upper Jurassic Coast Range Ophiolite, and the Upper Jurassic through Cretaceous Great Valley Sequence (Blake). The Coast Range Mountain terrains are at least 65 million years older than the Tehama Formation, and were uplifted by faulting.

The Sierra Nevada Mountains, on the east side of the Sacramento Valley, are comprised of intrusive igneous granitic material and oceanic material. Ages when these materials were emplaced range from 65 to 215 million years ago. The Sierra Nevada Province rises steeply on the eastern slopes, and dips gently westward toward the Great Valley Province on its western flanks.

Regional tectonic activity is responsible for a majority of deformation encountered in the Sacramento Valley sediments. There are a number of folds and faults that result from compressional stress associated with the overall movement of the North American Plate with the Pacific Plate. From west to east, the prominent faults include the Coast Range Fault, located west of the study area, the Paskenta Fault Zone, the Willows Fault and the Corning Fault. The Coast Range Fault, the Willows Fault, and the Corning Fault are related to compressional tectonic forces and show reverse-type, vertical fault displacement. The Paskenta Fault Zone is a left-lateral strike-slip fault displacing movement between the Willows Fault and the Coast Range Fault.

The structural folds in the valley sediments are associated with the overall tectonic stress, and are caused by the same compressional stresses that are responsible for the faulting in the valley. The axes of these folds are typically parallel to the fault planes. The fold axes trend approximately

north-south. The Greenwood Anticline, the Sites Anticline and the Fruto Syncline are a few of the major folds identified with in the subsurface.

LOCAL GEOLOGY

The Tehama Formation is Pliocene-age and was deposited between 1 and 4 million years ago. The Tehama Formation is a non-marine deposit that originated from the Coast Range Mountains to the west in a series of coalescing alluvial fan deposits, and consists of inter-braided gravel, sand, silt, and clay. The formation dips towards the east with a dip angle of 2 to 4 degrees (200-350 feet/mile). The Tehama Formation is identified in the subsurface by the predominance of metamorphic sediments derived from the Coast Ranges. The Tehama Formation is also marked with a volcanic ash bed called the Nomlaki Tuff. The tuff has a western Sierran source and is a regional marker bed located in the basal section of the Tehama Formation. The Nomlaki Tuff is 3.4 million years old and is thought to have been deposited during the deposition of the Tehama Formation.

Five formation types were identified in the cross section. These formations are summarized in Table 1, and discussed in more detail below:

TABLE 1

Geologic Age	Map Symbol	Formation	Rock Type	Description
Holocene	Qa	Alluvium	Gravel, Sand and Silt	Recent deposits by streams and rivers; unsaturated
Pliocene	Pt (w/ hash pattern)	Tehama Formation	Clay	Low permeability formations
Pliocene	Pt (w/ dotted pattern)	Tehama Formation	Gravel and Sand	Permeable formation; aquifer material where saturated
Pliocene	Pt (solid color)	Undifferentiated Tehama Formation	Unknown	Insufficient lithology/geologic data
pre-Pliocene	Tupt	Undifferentiated pre-Tehama Formation	Sandstone and Clay	Low permeability and poorer water quality

The Tehama Formation outcrops in the low foothills of the Coast Ranges at the western edge of the Sacramento Valley. With in the creek beds, the Tehama Formation is overlain by recent alluvial sediments (Qa) which are comprised primarily of reworked Tehama material. Toward the center of the Sacramento Valley, near the Sacramento River, the Tehama Formation interfingers with the Sierra Nevada- and Cascade Mountains-sourced Tuscan and Modesto Formations, but the nature of this interaction remains unclear. Within the Tehama Formation, the gravel, sand, and silt (Pt w/ dotted pattern) materials are separated into distinct zones by impermeable and semi-permeable layers of clay (Pt w/hash pattern) and other fine-grained materials. The gravel and sand zones vary in thickness, from tens of feet to up to 200 feet thick, but may lack lateral continuity. The Tehama Formation was deposited unconformably on top of older, east dipping Cretaceous-age material, creating an angular unconformity. The Cretaceous-age material was deposited under marine conditions.

Although the Tehama Formation is the principal water-bearing formation in the western half of the Sacramento Valley, the units of the Tehama Formation have not been studied in detail. The Tehama Formation begins between the ground surface (in the outcrop areas) to 200 feet below ground surface and becomes thicker toward the center of the Sacramento Valley, extending to a depth of up to 1,700 feet below ground surface east of the study area. There are units within the Tehama Formation that are moderately permeable, and these units can yield moderate to high volumes of water to wells.

Within the study area, the deposition of the Tehama Formation was predominantly via alluvial fans. Alluvial fans are continental, non-marine sedimentary deposits derived from a mountain front with relatively high relief. Sediments on alluvial fans are typically poorly sorted and include abundant gravel size clasts. In many cases, alluvial fans form downslope from major fault scarps (Boggs). In cross section, alluvial fans are wedge-shaped or lens-shaped as shown in Figure 3. Sediments deposited on an alluvial fan decrease in size with distance from the source. The Tehama Formation resembles a braided fluvial fan model.

With in the study area, the Tehama Formation exhibits the convex upward geometry typical of alluvial fans. The Tehama Formation is deformed by tectonic stress and strain related to the Willows Fault Zone. Structural folding in the form of an anticline was identified in cross section.

Wood Rodgers' interpretation of the well logs suggests that at least two faults are located within the cross section A-A' (Figure 4). The faults appear to dip toward each other and each show reverse motion, emplacing older material adjacent to younger material. The southern fault appears to have offset of approximately 200 feet, emplacing a thick succession of permeable gravel and sand adjacent to low permeable clays. Offset along the northern fault appears to be approximately 100 feet. Offset along the faults was inferred where dramatic differences in correlatable lithologic unit elevations could not be explained. Surface expressions of the faults were not observed and their locations were inferred based solely on borehole data. There is also likely some lateral displacement associated with the faults. The two faults shown in the cross

section are likely part of the Willows Fault Zone; however, cross section A-A' suggests that the major fault traces are further north than previously shown on geologic maps that include the study area.

Cross section A-A' depicts the elevation and lateral extent of permeable zones within the subsurface. Cross section A-A' also identifies the pre-Tehama formations (Tupt) that likely contain poor water quality. This detailed cross section, in combination with the regional geologic cross section Z-Z' (Wood Rodgers), shown in Figure 5, helps to characterize the occurrence of the Tehama Formation within this portion of Glenn County.

SITE HYDROGEOLOGY

Within parts of the study area, coarse-grained materials within the Tehama Formation outcrop at ground surface. These areas are capable of accepting recharge to the Tehama Formation. The Tehama Formation is likely recharged locally at the study area by surface water flowing over these permeable zones. A zone of permeable Tehama gravels and sand intersects Wilson Creek in cross section A-A'. This location provides an opportunity for direct recharge into the Tehama Formation. The deeper portions of the Tehama Formation, which are overlain by less permeable materials with in the study area, likely receive recharge from outcrops further west and north and from the percolation of surface water and applied irrigation water.

Groundwater elevation data for two monitored wells (21N/04W-16J01 and 22N/04W-27Q01) was obtained from the California Department of Water Resources Water Data Library. The data was plotted, depicting hydrographs of the groundwater elevation over time as shown in Figure 5. The two monitored wells were located in the vicinity of the cross section, as shown in Figure 2.

Hydrographs of the two wells indicate that seasonal water level fluctuations of at least 45 feet, and possibly more, occur in the study area. Water levels are lower during the summer, when pumping generally increases and available recharge decreases. Conversely, water levels are higher during the winter and spring when pumping generally decreases and available recharge generally increases. The fact that water levels recover after seasonal lows indicates that the aquifer zones underlying the study area are receiving annual recharge. Over the five-year period of record, both wells showed declines in seasonal-high groundwater elevations in most years, but both wells had at least one year where seasonal-high water levels were higher than the previous year. Both wells show an overall decline in groundwater elevations over the period of record. In well 21N/04W-16J01, spring groundwater levels declined by an average of 4-5 feet per year for the period from 2002 to 2005. In well 22N/04W-27Q01, spring groundwater levels declined by 3-4 feet per year for the period from 2003 to 2006. Although the period of record for groundwater levels is limited within the study area, these declines are an indication that groundwater pumping exceeded recharge during the period of record. Ongoing monitoring will be required to determine if this is a short-term condition or indicative of over pumping.

Within the study area, spring depth to water has ranged from approximately 120-150 feet below ground surface.

In December 2002, a report of abnormal groundwater levels was filed with the Glenn County Water Advisory Committee by Lassen Land. A one-year study conducted by the DWR and Glenn County reported an average groundwater level decline within the Lassen Land property of 3.96 feet (California DWR). It should be noted that one-year observations are not a good indication of long term trends. This short term study was an attempt to determine if a decline is occurring and to provide long term recommendations for continued monitoring.

Groundwater in the Tehama Formation generally yields acceptable water quality. Poorer water quality is expected within the undifferentiated pre-Tehama. Within the study area, the elevation of poorer water quality varies due to faulting and geologic structure in the area. The cross section provides a useful tool for predicting the depth at which poor water quality would be expected across the study area.

CONCLUSIONS

The geology within the study area is complicated because of the presence of faulting, combined with the already-complex alluvial fan depositional environment. Significant thicknesses of aquifer material underlie the study area, and the limited period of record shows annual recharge to the aquifer zones underlying the study area. However, water levels have shown an average decline of 3-5 feet per year over the last five years; which indicates that pumping is exceeding recharge over that period. Ongoing monitoring of groundwater levels will be required to determine if this is a short term condition or if this area is experiencing overdraft.

The study area includes areas where coarse-grained Tehama material is exposed at the ground surface, which may provide excellent opportunities to enhance groundwater recharge in this vicinity.

RECOMMENDATIONS

Recommendation 1 – Implement a "Target" Groundwater Monitoring Program for the Study Area

In order to better understand the movement and occurrence of groundwater within the study area, a monitoring program should be implemented. The monitoring program should include data from multiple, representative wells on the property. The study area has many wells available for observation, with the majority being irrigation wells. A program should be set up to monitor seasonal fluctuations of the groundwater elevation as well as influences created by pumping irrigation wells. Additional monitoring wells should be selected in the Tehama Formation. These wells should ideally be non-pumping wells to provide true static water levels. Measurements should be made with such frequency to observe seasonal highs and lows, and before and during the irrigation season.

Recommendation 2 - Install Dedicated Monitoring Wells

Dedicated monitoring wells are designed to target specific aquifer zones for monitoring and provide subsurface geologic exploration and characterization. Glenn County has an extensive network of monitoring wells. Consideration of data gaps within the existing network should be used to locate new monitoring wells. This investigation has determined an area southeast of the study area that could benefit from the addition of a new dedicated monitoring well.

Wood Rodgers recommended area for a dedicated monitoring well is shown in Figure 7 and Figure 8. The dedicated monitoring well should be deep enough to penetrate the basal portion of the Tehama Formation. The monitoring well location, along Wilson Creek, will create a triangle with dedicated monitoring wells 21N/4W-12A1 and 21N/3W-31R. The location is south of Road 28 and west of Road C. It is recommended that the monitoring well be completed in the surficial gravels and significant aquifer zones within the Tehama Formation. At this location the surficial gravels and Tehama Formation aquifer materials will likely be encountered.

To assist the County with future planning, Wood Rodgers has also identified a second recommended area for a new monitoring well, if funds become available. This area is located north of the study area and is shown in Figure 7, and would complement Glenn Counties existing dedicated monitoring wells.

To avoid pumping interference, new monitoring wells should be located at least 500 feet away from pumping wells, if possible.

Wood Rodgers looks forward to future work on this project. If you have any questions, or require additional information, please contact Larry Ernst at (916)-341-7447 or Sean Spaeth at (916) 326-5368

Sincerely,

Lawrence H. Ernst

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Sean J. Spaeth

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Hydrogeologist

REFERENCES

Blake, M.C., Jr., Helley, E.J., Jayko, A.S., Jones, D.L., Ohlin, H.N., "Geologic Map of the Willows 1:100,000 Quadrangle, California", U.S. Geological Survey Open-File Report 92–271, 1992

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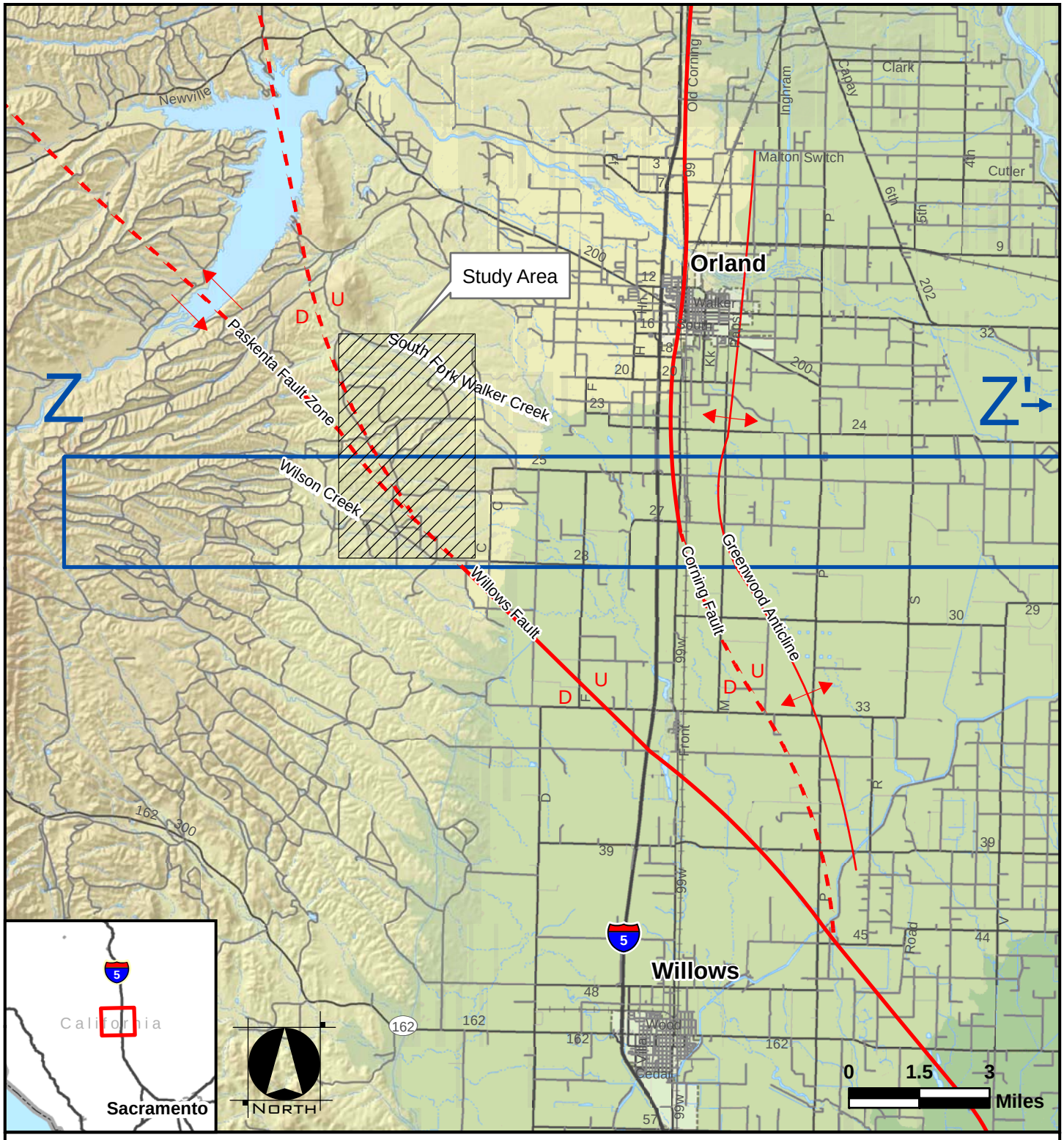

Figure 1
Wilson Creek Hydrogeologic Investigation
Project Location Map

Study Area

Z-Z' Cross Section Location

Fault Location & Offset; Dashed where inferred

U / D Fault Offset; U , upthrown side; D , downthrown side

Anticline

Source: USGS

3301 C St, Bldg. 100-B
Sacramento, CA 95816
Tel 916.341.7760
Fax 916.341.7767
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J:\Jobs\8233.001-Glenn\8233.003 GW Monitoring\Wilson Creek Investigation\GIS\Figure 1 Location Map.mxd

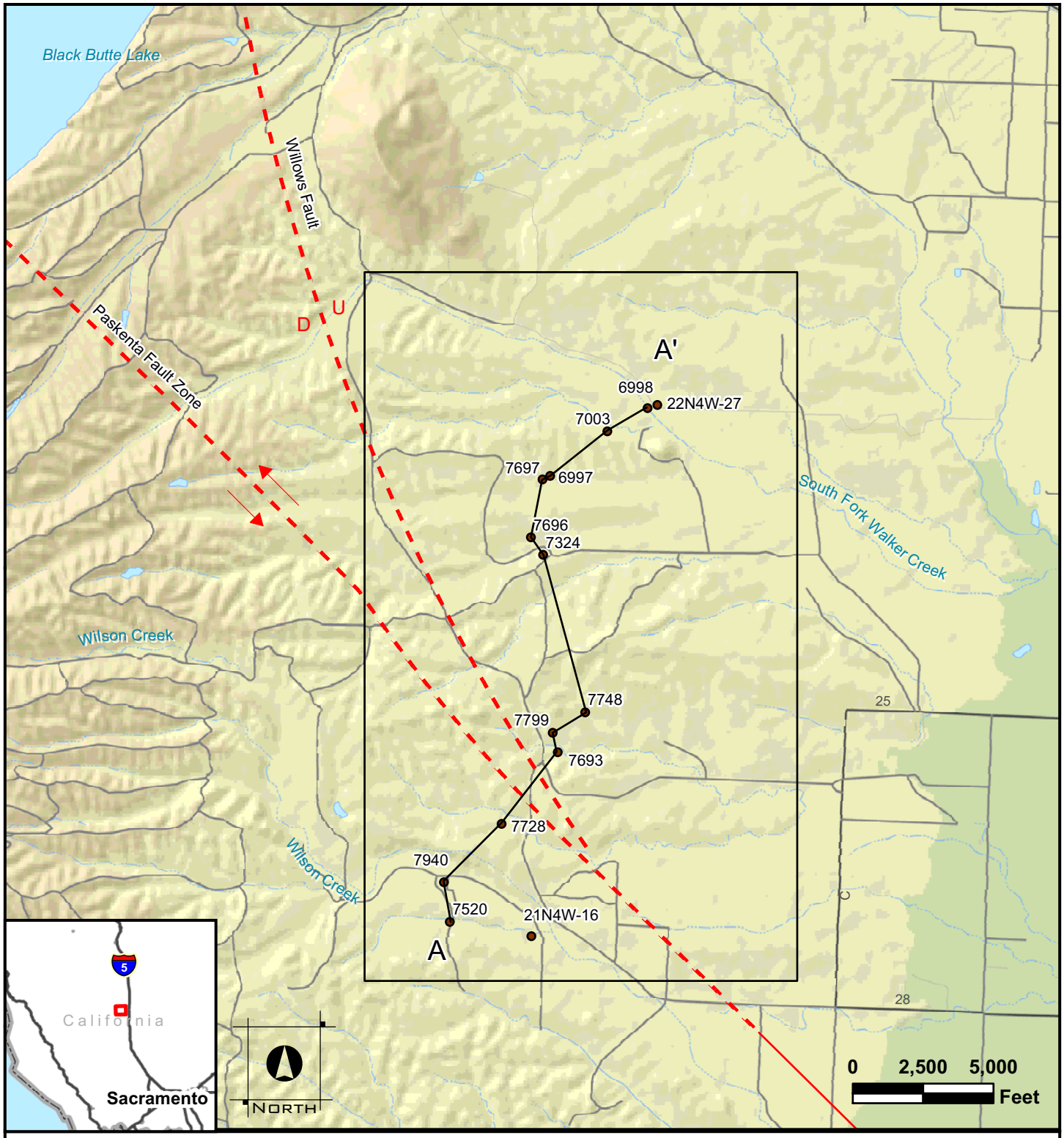

Figure 2
Well Location and Cross Section Map

Study Area

Well Location

Fault Location & Offset; Dashed where inferred

U / D — Fault Offset; U , upthrown side; D , downthrown side

Source: USGS

3301 C St, Bldg. 100-B
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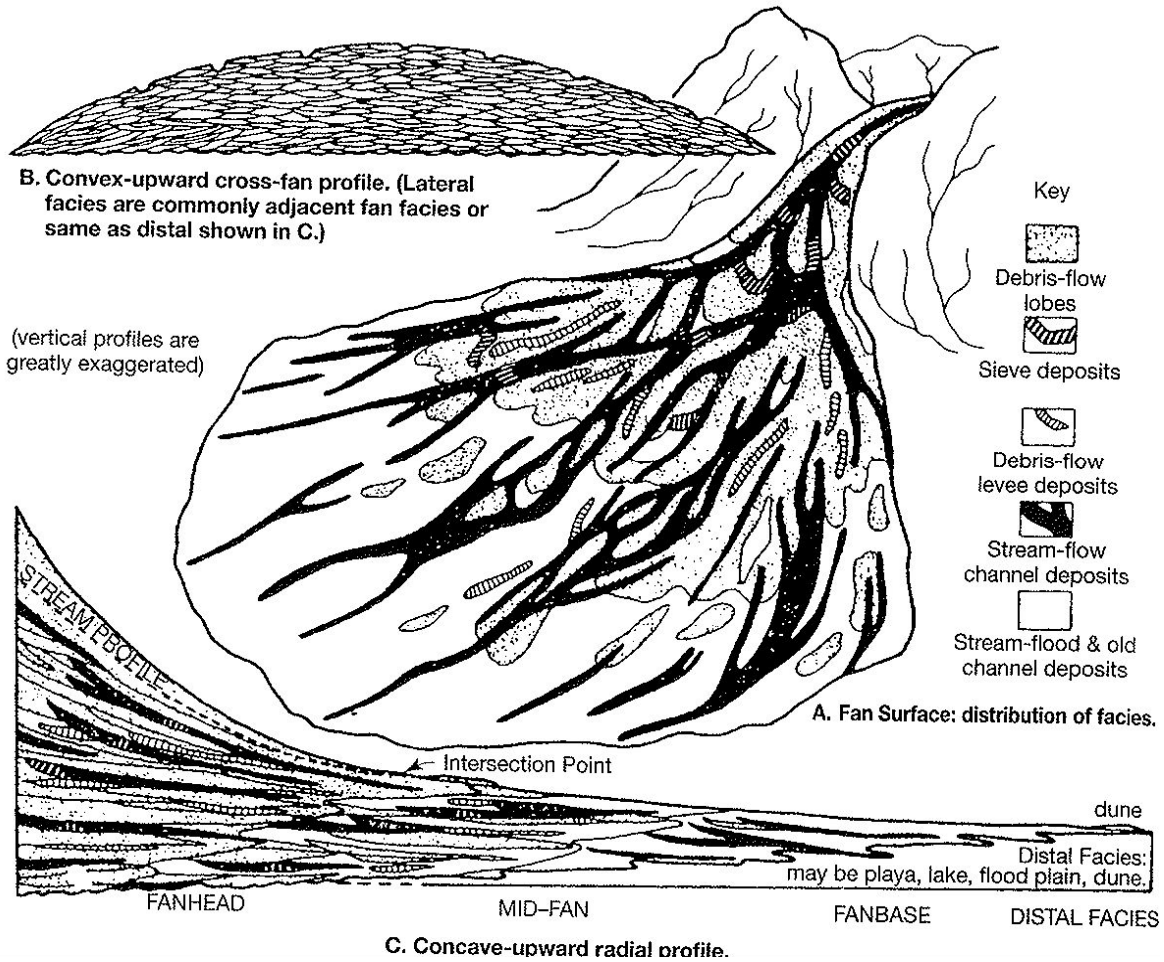

Figure 3 - Surface Features and Cross-sectional profiles of alluvial fans (Boggs, p. 272)

Wilson Creek Hydrogeologic Investigation

Glenn County, Ca.

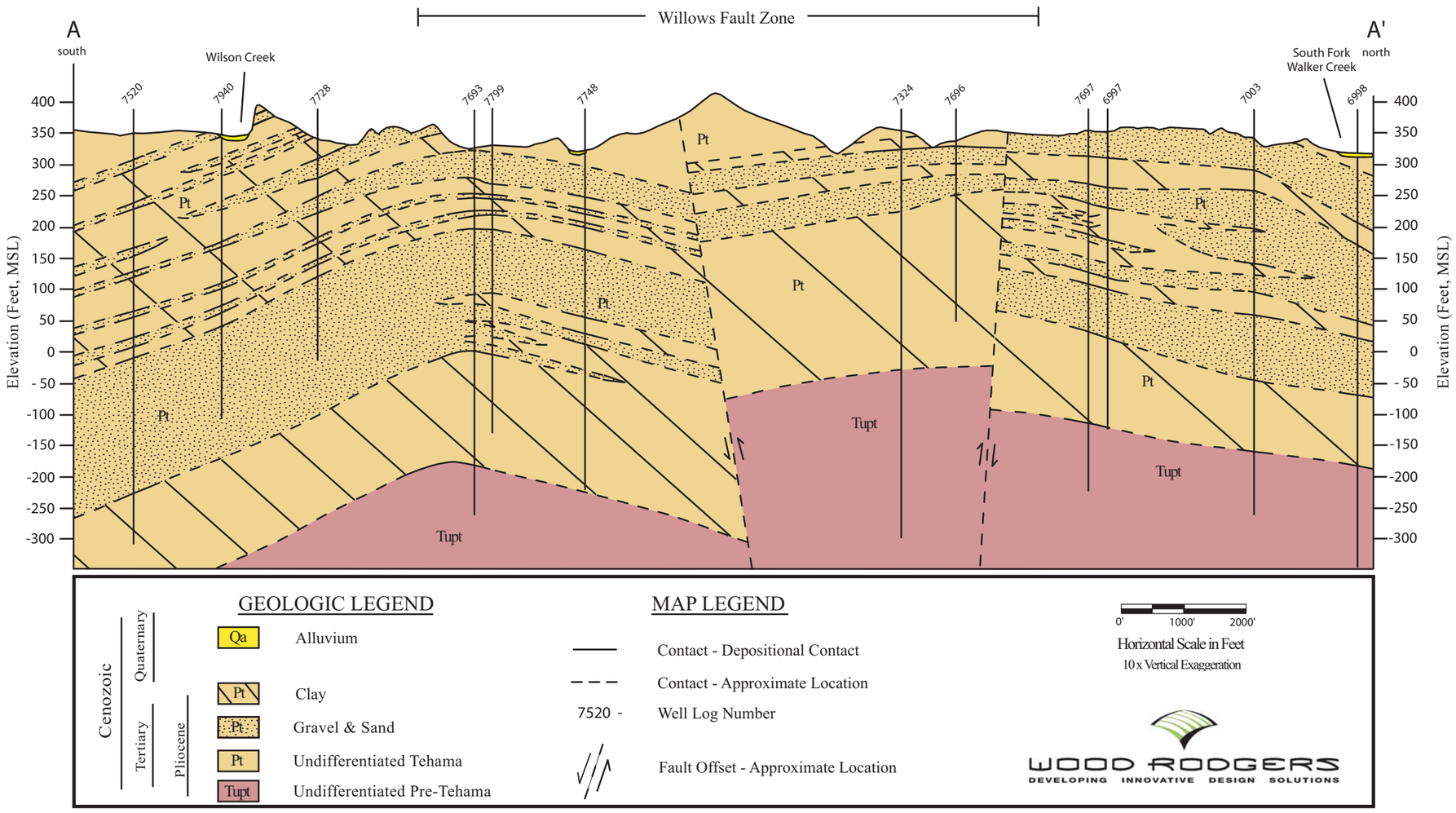

Figure 4

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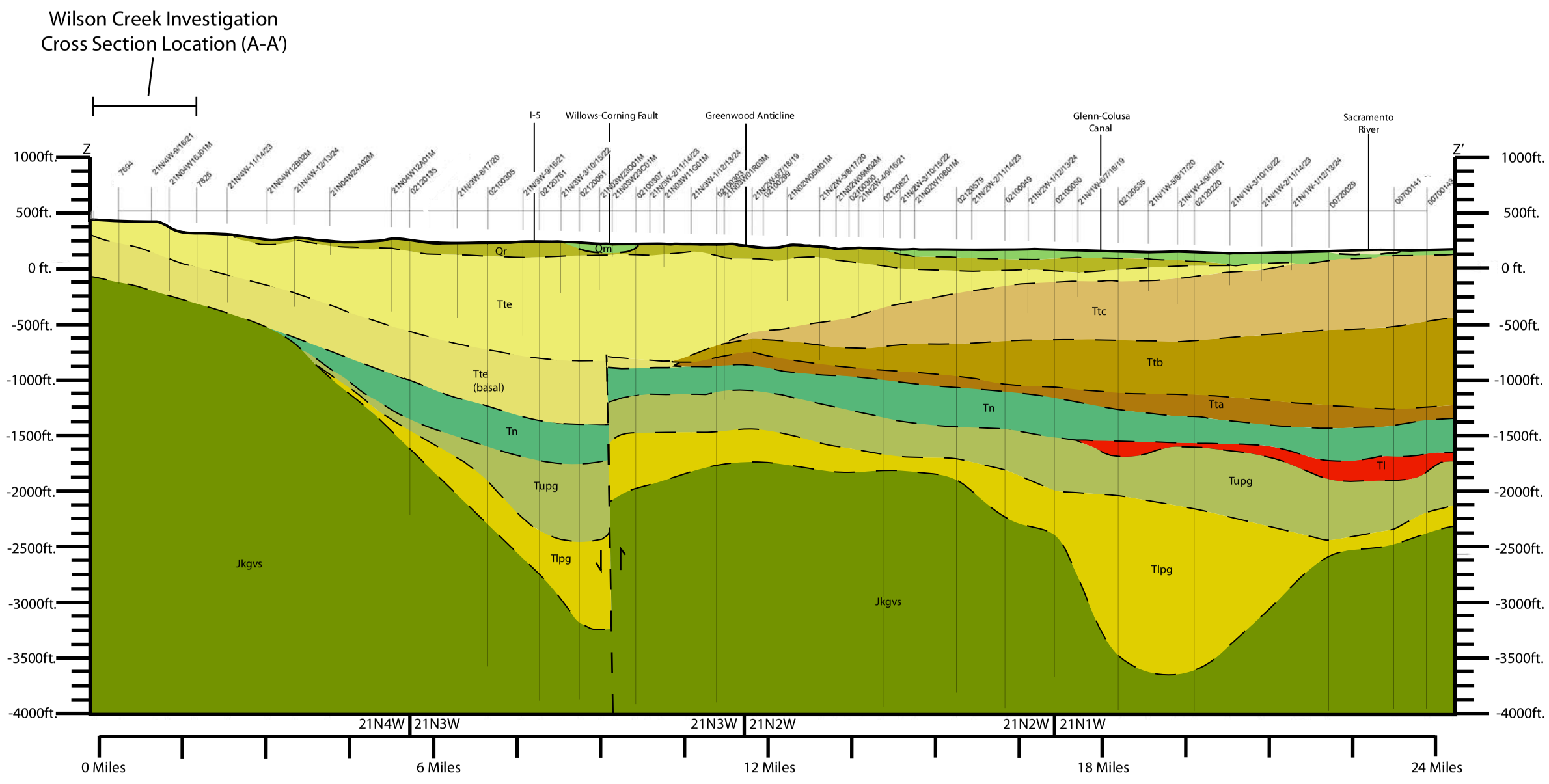

(6 X Vertical Exaggeration)

Note:
1. Vertical lines indicate locations and depths of wells used for geologic control.
2. Dip angle on fault appears steeper due to vertical exaggeration.

Well Identifier:
1. Division of oil and gas- API # 's 007 & 021
2. State well # 's 21N 4,3,2,1W

Cross-Section Scale

Vertical: 1000 ft. / 500 ft. / 0 ft.

0 Miles — 1.5Miles

Horizontal

Map Units

Cenozoic

- **Quaternary**
  - Holocene
  - Pleistocene
    - Qa — Alluvium
    - Qm — Modesto Formation
    - Qr — Riverbank Formation
- **Tertiary**
  - Pliocene
    - Ttc — Tuscan Unit C
    - Ttb — Tuscan Unit B
    - Tta — Tuscan Unit A
    - Tte — Tehama Formation
    - Tte — Tehama Formation (Basal Deposits)
  - Miocene
    - Tn — Neroly Formation
    - Tl — Lovejoy Basalt
  - Oligocene
    - Tupg — Upper Princeton Gorge
  - Eocene
    - Tlpg — Lower Princeton Gorge

Mesozoic

- Jurassic | Cretaceous
  - Jkgvs — Great Valley Sequence

Map Legend

Geologic contact- dashed where inferred.

Fault- dashed where inferred

GLENN COUNTY WATER ADVISORY COMMITTEE

PRELIMINARY PLAN FOR GROUNDWATER AND COORDINATED WATER MANAGEMENT
TASK E. COMPREHENSIVE GROUNDWATER MONITIORING PROGRAM

GEOLOGIC CROSS SECTION

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DEVELOPING INNOVATIVE DESIGN SOLUTIONS

J:\Jobs\8233.001 - Glenn\8233.003 GW Monitoring\GIS\ArcMap\Final Figures\Figure 3 - Glenn County Geologic Cross-Section 1/02/2007

FIGURE 5

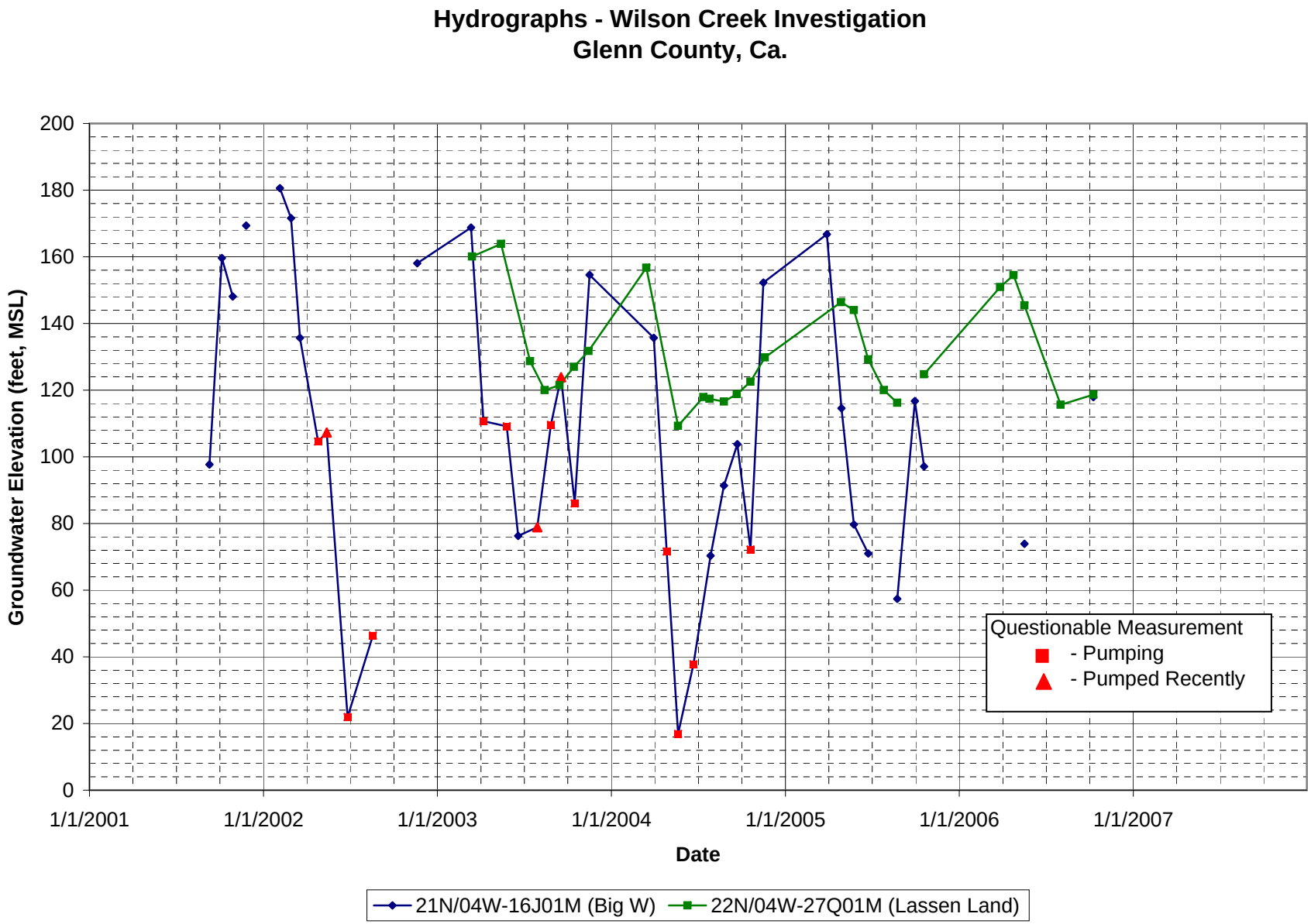
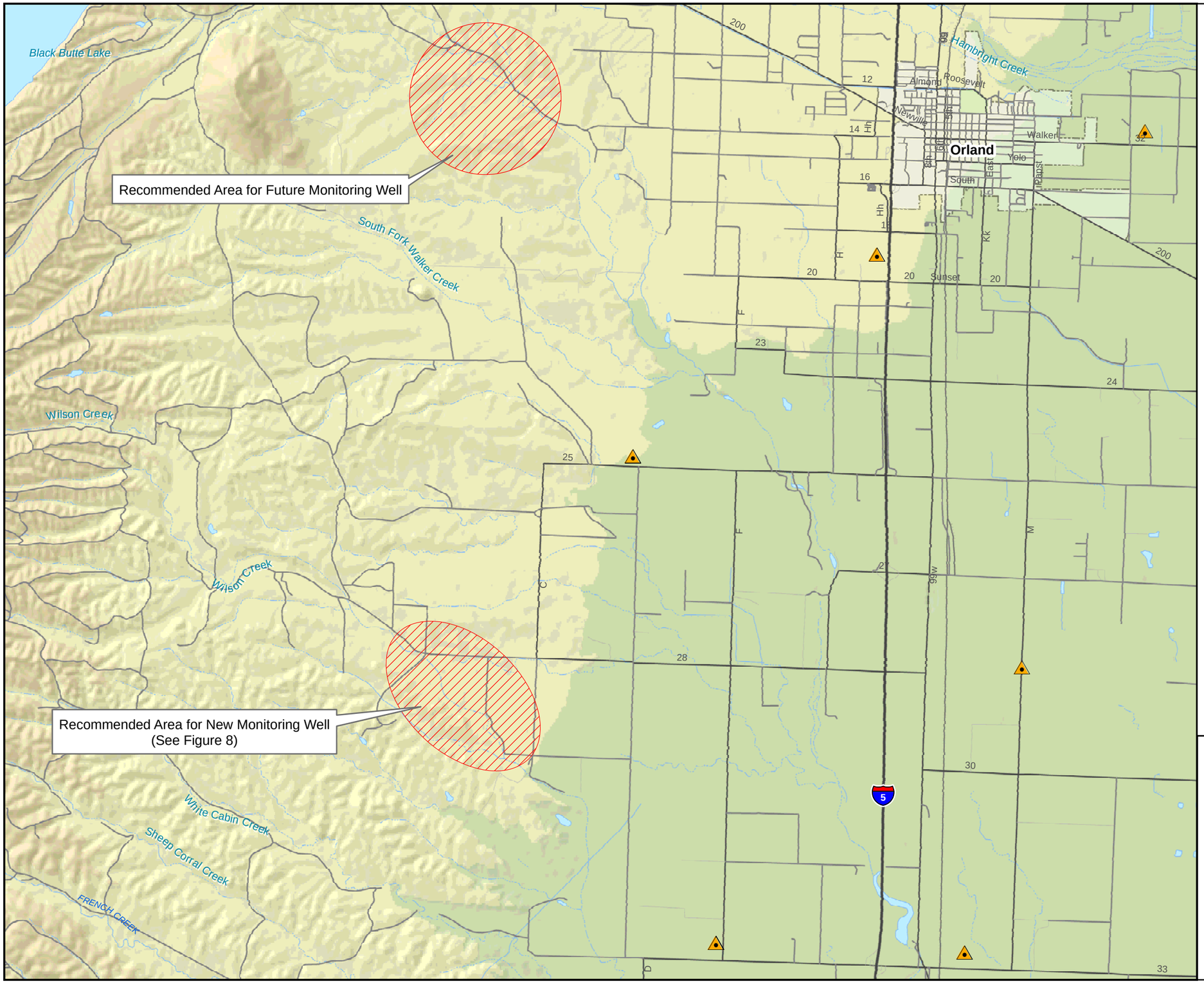


Figure 6 - Hydrographs of DWR Monitored Wells



LEGEND

- Existing Nested and/or Clustered Monitoring Wells (All have completions in the Tehama Formation)
- Recommended Monitoring Well Area

SOURCES: USGS, DWR, GLENN COUNTY

0 1 2 Miles

Figure 7
Wilson Creek Hydrogeologic Investigation

Recommended Monitoring Well Areas

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LEGEND

Recommended Area for Monitoring Well

SOURCES: USGS

0 1,000 2,000 Feet

Figure 8
Wilson Creek Hydrogeologic Investigation

Recommended Monitoring Well Area

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J:\Jobs\8233.001-Glenn\8233.003 GW Monitoring\Wilson Creek Investigation\Final Figures\Figure 8 Recommended MW Area.mxd