CALIFORNIA
CONSERVATION

Aquifer Exemption
Supplemental Information
Arroyo Grande Oil Field
San Luis Obispo, California

December 2017

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Arroyo Grande Oil Field, San Luis Obispo, California

The information in this document was compiled by the staff of the Division of Oil, Gas and Geothermal Resources (Division), Orcutt Office after reviewing comments received during the public comment period, and in response to questions raised by the U.S. Environmental Protection Agency. Supporting data was also contributed under the supervision of the Division by Freeport-McMoRan Oil & Gas, LLC (FMOG) and Sentinel Peak Resources California, LLC (SPR) staff and consultants.

APPLICATION HISTORY

The Division with concurrence from the State Water Resources Control Board, submitted an application in February 2016 to expand an existing aquifer exemption for the Dollie sands of the Pismo formation in the Arroyo Grande oil field. The United States Environmental Protection Agency (US EPA) in its initial review of the application requested additional information to clarify or expand on the supporting documentation of the criteria prior to making a determination.

The following is provided as a supplement to the State's original aquifer exemption submission for the Arroyo Grande Oil Field. As a result of new data and analysis, the State has reduced the proposed aquifer exemption boundary, and will post this document and accept public comment for a period of 15 days ending at 5 pm on December 22, 2017. Figure 1 shows the revised proposed aquifer exemption boundary for the Arroyo Grande Oil Field.

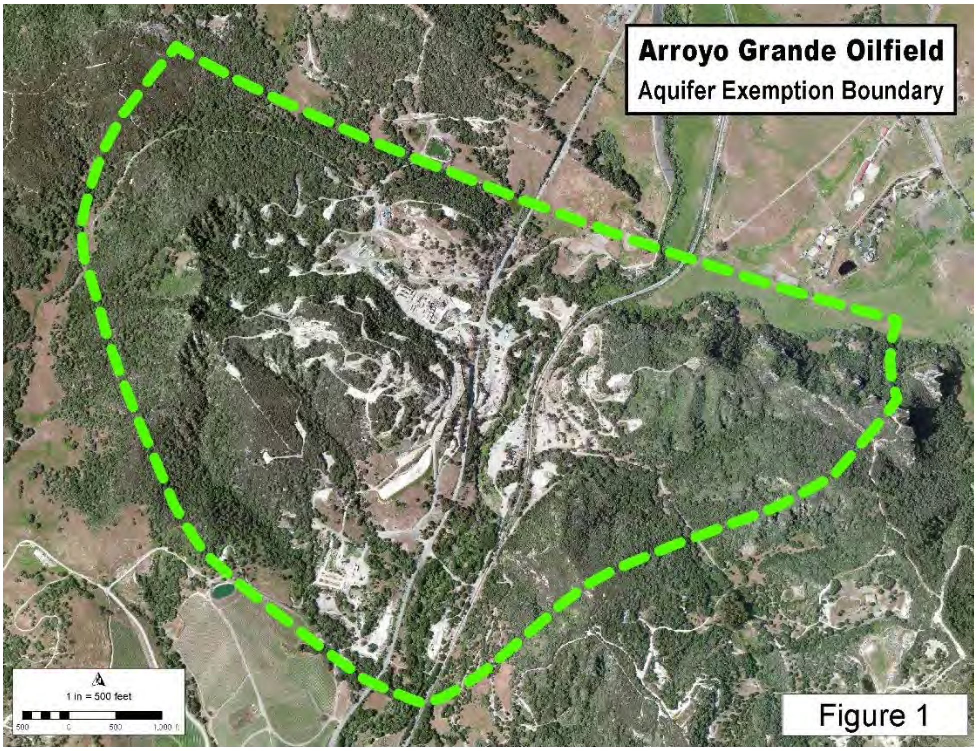


Figure 1

HYDRAULIC ISOLATION

Expanding on the information originally provided to demonstrate hydraulic isolation and to better describe the facies changes and geologic constraints illustrating that injected fluids will not flow beyond the proposed aquifer exemption boundaries described in the application, the Division reviewed an independent study by Cleath-Harris Geologists Inc. (CHG) conducted in 2008 covering the Arroyo Grande oil field (Appendix A). That study contains evidence supporting the assertion that the Arroyo Grande fault acts as a barrier to fluid migration.

In the study, a base flow survey was conducted by CHG. The results of the base flow survey indicated that the fault acted as a barrier. Evidence from the report substantiating that observation are reported as follows:

> "Pismo Creek is gaining stream between the railroad crossing Price Canyon Road and Station 8. The contributions to stream flow are interpreted to come from surfacing ground water. Most of the increase in base flow occurs between Station 4 and Station 6. Station 6 is where the Indian Knob fault is inferred to cross beneath the alluvial deposits. The fault is likely a ground water barrier, where ground water flow backs up and pressure builds, forcing flow up into overlying alluvial deposits, which drain into Pismo Creek. At Station 8, all underflow surfaces as stream flow. Station 8 is at the upstream end of the oil field." See Figure 2.
>
> "The salinity of Pismo Creek increases without an apparent increase in surface flow downstream of Station 8…"

Station 8 is located in the Arroyo Grande Fault Zone (AGFZ). The 2008 base flow survey by CHG demonstrates that multiple faults within the Arroyo Grande oil field serve as barriers to fluid flow and that the AGFZ is the final barrier to the north. The evidence presented in the 2008 study is consistent with the data presented in the Arroyo Grande oil field aquifer exemption application including:

1. The AGFZ main fault and fault splays are identified as liniments on aerial photos and by offset formations in the subsurface as evidenced by well log data.
2. Fault gouge identified on the "Silva" 1 well mud log in the fault zone is evidence of a fault sealing mechanism in the AGFZ.
3. Core samples to the south of the AGFZ show high oil saturations, whereas core samples to the north of the AGFZ show low oil saturations. If the AGFZ was not a barrier to fluid flow, the oil saturations would be consistent across the AGFZ.
4. There is a marked difference between the oil producing wells drilled across the AGFZ. There are 8 uneconomic wells drilled to the north of the AGFZ and hundreds of productive wells to the south. Without the barrier of the AGFZ, the prevalence of the oil accumulation to the north would be far greater.

There are multiple water wells completed to the north of the AGFZ within the Pismo formation sands (same formation as the producing horizon to the south of the AGFZ) at a higher elevation than the Arroyo Grande oil field. Without the AGFZ acting as a barrier to fluid flow, hydrocarbons would have already migrated updip across the AGFZ and would have precluded the Pismo formation from being a water source to the north.

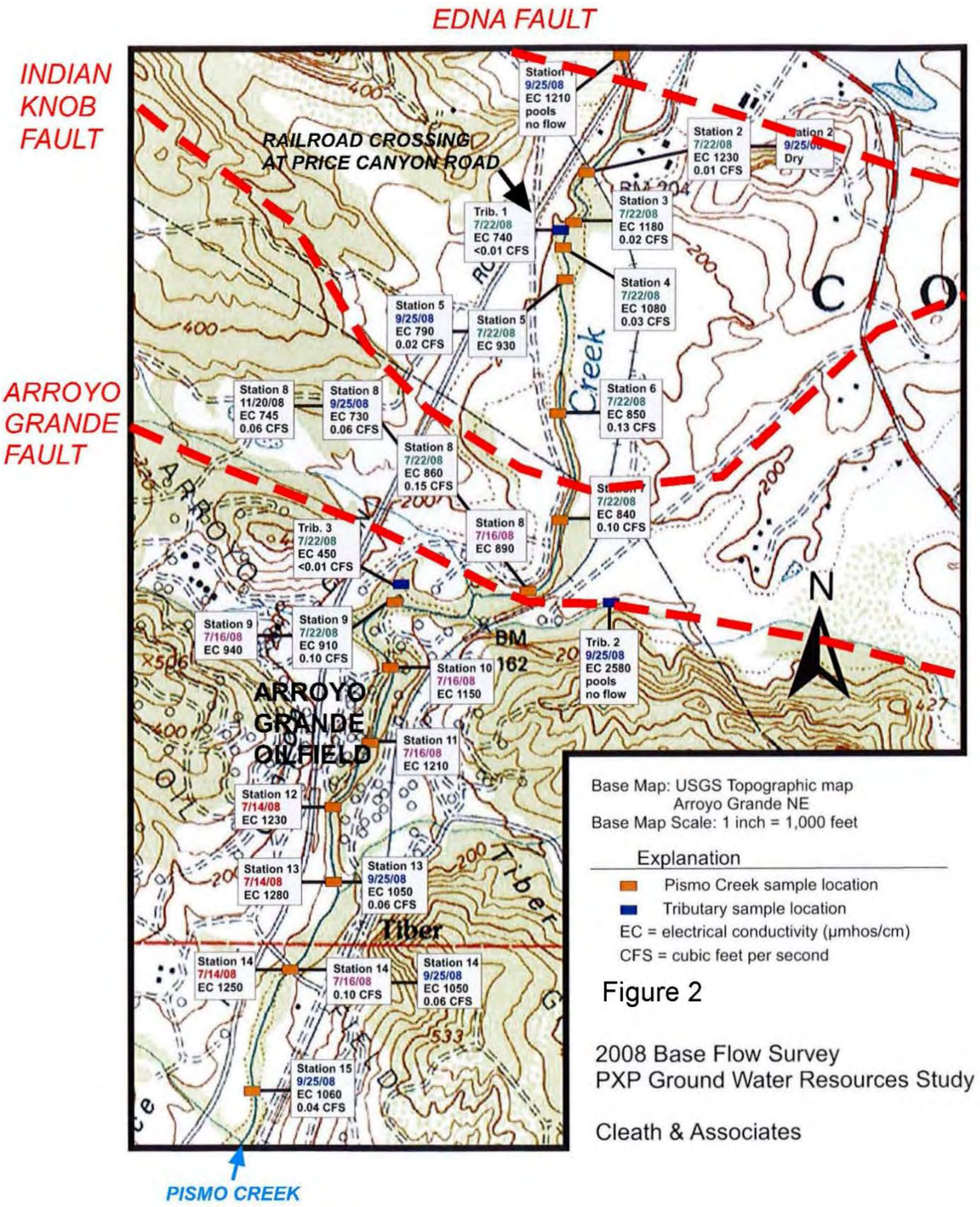


Figure 2

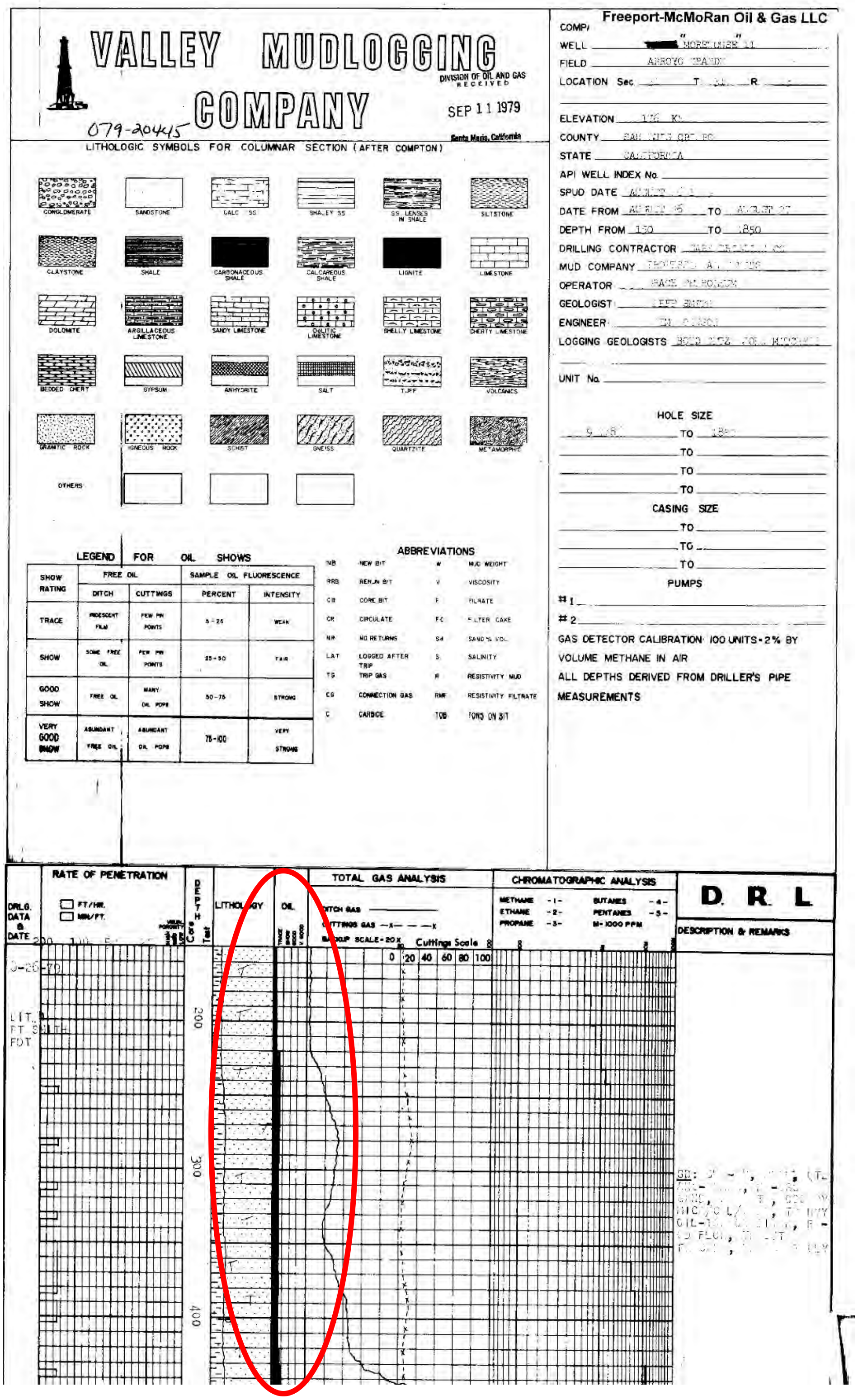
2008 Base Flow Survey
PXP Ground Water Resources Study

Cleath & Associates

The evidence presented in these five examples with the flow and salinity measurement data from the 2008 CHG base flow study provide scientific evidence that the Arroyo Grande fault is in fact a barrier to fluid flow. The referenced report is titled, "*Groundwater Resources Study for PXP, Arroyo Grande Oilfield, December 2008 By Cleath-Harris Geologists Inc.*" (Appendix A)

A comment from the public received during the initial development of the Arroyo Grande aquifer exemption application brought into question the sealing nature of the AGFZ. The commenter provided evidence of a surface breach on property to the north of the AGFZ from injection operations to the south of the AGFZ. The breach occurred on July 10, 1981. Both the Division and staff of FMOG reviewed the incident and the operations in the field that lead to the breach. A technical document was created by FMOG and can be found in Appendix B. The nearest well receiving steam injection at the time of the breach was "Morehouse" 11 (API 079-20445). The operator at that time, Grace Petroleum Corporation (Grace), was injecting into well "Morehouse" 11 at pressures exceeding the fracture gradient. The fracture gradient for the Arroyo Grande oil field is approximately 0.7 pounds per square inch per foot (psi/ft). The maximum allowable surface pressure (MASP) for "Morehouse" 11 would be 376 pounds per square inch (psi). The MASP is the pressure at which injection must not exceed to prevent fracturing the formation. Grace was injecting into "Morehouse" 11 from June 16 to July 10, 1981 at a pressure of 900 psi. Injecting at nearly two and a half times the MASP for over 20 days was required to breakdown the AGFZ and cause the surface breach. Injection over the MASP is not allowed and operators are required to ensure that all injection pressure remain below the MASP at all times. Well "Morehouse" 11 was plugged and abandoned in 1985.

A final analysis of the AGFZ, in relation to the area near well "Morehouse" 11, was performed by the Division and staff of SPR using the mud logs of wells "Morehouse" 11 and Gantry Corporation "Silva" 1 (API 079-20548) (Appendix C). Well "Morehouse" 11 was drilled in August of 1979, and well "Silva" 1 was drilled in October of 1982. The two wells are separated by the AGFZ and are 1,021 feet apart. Both wells have since been plugged and abandoned. During the drilling of both wells, a detailed record of the rock cuttings, a mud log, was completed. The mud log for well "Morehouse" 11 (figure 3) begins at 140 feet below ground surface (bgs) and the mud log for "Silva" 1 (figure 4) begins at 190 feet bgs. Trace amounts of oil are found from the start of the well "Morehouse" 11 mud log and continues throughout the extent of the well. Well "Silva" 1, north of the AGFZ, does not show any oil until a ten-foot section from 330 feet bgs to 340 feet bgs, and again from 390 feet bgs to 405 feet bgs. Consistent oil is not seen until 520 feet bgs. The evidence of a lack of oil for the shallower portion of "Silva" 1 is consistent with the assertion that the AGFZ is sealing. Any oil that may have been present at the shallower depths to the north of the AGFZ has been removed through the percolation and transportation of shallow groundwater that does not proceed south past the AGFZ.



VALLEY MUDLOGGING COMPANY

Santa Maria, California

DIVISION OF OIL AND GAS
RECEIVED
SEP 11 1979

079-20445

Freeport-McMoRan Oil & Gas LLC

COMPANY
WELL [redacted] "MOREHOUSE" 11
FIELD ARROYO GRANDE
LOCATION Sec. [illegible] T [illegible] R [illegible]
ELEVATION 176 KB
COUNTY SAN LUIS OBISPO
STATE CALIFORNIA
API WELL INDEX No.
SPUD DATE [illegible]
DATE FROM AUGUST 26 TO AUGUST 27
DEPTH FROM 150 TO 1850
DRILLING CONTRACTOR [illegible]
MUD COMPANY [illegible]
OPERATOR [illegible] PETROLEUM
GEOLOGIST [illegible]
ENGINEER [illegible]
LOGGING GEOLOGISTS [illegible]
UNIT No.

HOLE SIZE
9 5/8 TO 1850
TO
TO
TO

CASING SIZE
TO
TO
TO

PUMPS
#1
#2

GAS DETECTOR CALIBRATION: 100 UNITS = 2% BY VOLUME METHANE IN AIR

ALL DEPTHS DERIVED FROM DRILLER'S PIPE MEASUREMENTS

LITHOLOGIC SYMBOLS FOR COLUMNAR SECTION (AFTER COMPTON)

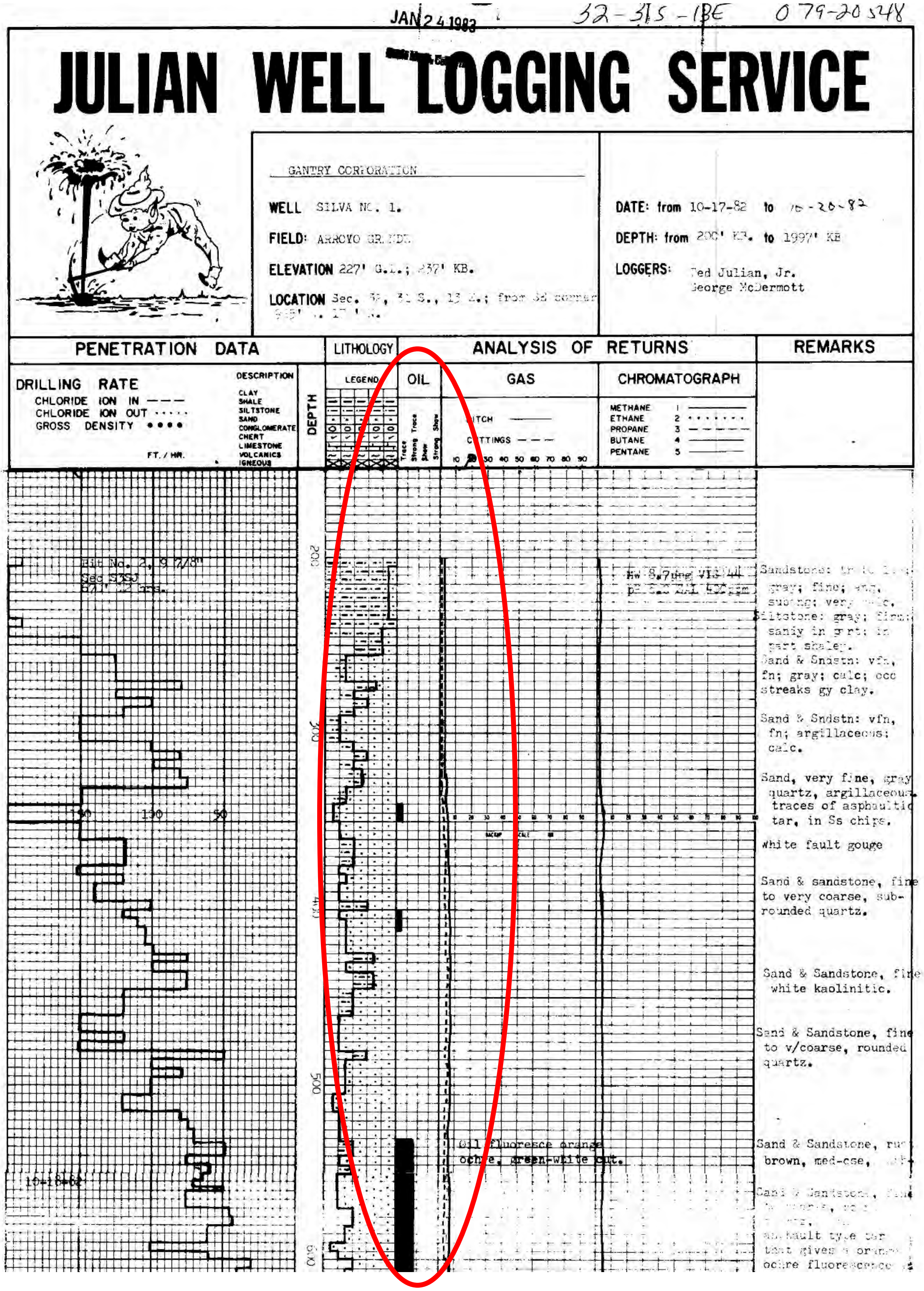
LEGEND FOR OIL SHOWS

SHOW RATING	FREE OIL		SAMPLE OIL FLUORESCENCE	
	DITCH	CUTTINGS	PERCENT	INTENSITY
TRACE	IRIDESCENT FILM	FEW PIN POINTS	5 - 25	WEAK
SHOW	SOME FREE OIL	FEW PIN POINTS	25 - 50	FAIR
GOOD SHOW	FREE OIL	MANY OIL POPS	50 - 75	STRONG
VERY GOOD SHOW	ABUNDANT FREE OIL	ABUNDANT OIL POPS	75 - 100	VERY STRONG

ABBREVIATIONS

NB	NEW BIT	W	MUD WEIGHT
RRB	RERUN BIT	V	VISCOSITY
CB	CORE BIT	F	FILRATE
CR	CIRCULATE	FC	FILTER CAKE
NR	NO RETURNS	Sd	SAND % VOL.
LAT	LOGGED AFTER TRIP	S	SALINITY
TG	TRIP GAS	R	RESISTIVITY MUD
CG	CONNECTION GAS	RMF	RESISTIVITY FILTRATE
C	CARBIDE	TOB	TONS ON BIT

Figure 3 – Mud log for “Morehouse” 11, 140 feet bgs to 430 feet bgs. Evidence of oil circled in red. (Mud Log available online at: https://secure.conservation.ca.gov/WellSearch/Details?api=07920445&District=&County=&Field=&Operator=&Lease=&APINum=07920445&address=&ActiveWell=true&ActiveOp=true&Location=&sec=&twn=&rge=&bm=&PgStart=0&PgLength=10&SortCol=0&SortDir=asc&Command=Search



JAN 24 1983

32-31S-13E 079-20548

JULIAN WELL LOGGING SERVICE

GANTRY CORPORATION

WELL SILVA NO. 1.

FIELD: ARROYO GRANDE

ELEVATION 227' G.L.; 237' KB.

LOCATION Sec. 32, 31 S., 13 E.; from SE corner [illegible]

DATE: from 10-17-82 to 10-20-82

DEPTH: from 200' KB. to 1997' KB

LOGGERS: Ted Julian, Jr.
George McDermott

Bit No. 2, 9 7/8"
Sec S3SJ
671' 22 hrs.

Mw 8.7ppg VIS 44
pH 8.2 [illegible] 450ppm

Sandstone: [illegible]
gray; fine; [illegible]
subang; very [illegible]
Siltstone: gray; firm;
sandy in part; in
part shaley.
Sand & Sndstn: vfn,
fn; gray; calc; occ
streaks gy clay.

Sand & Sndstn: vfn,
fn; argillaceous;
calc.

Sand, very fine, gray
quartz, argillaceous.
traces of asphaltic
tar, in Ss chips.

White fault gouge

Sand & sandstone, fine
to very coarse, sub-
rounded quartz.

Sand & Sandstone, fine
white kaolinitic.

Sand & Sandstone, fine
to v/coarse, rounded
quartz.

Oil fluoresce orange
ochre, green-white cut.

Sand & Sandstone, [illegible]
brown, med-cse, [illegible]

Sand & Sandstone, [illegible]
[illegible]
asphault type tar
that gives [illegible] orange
ochre fluorescence [illegible]

Figure 4 – Mud log for "Silva" 1, 190 feet bgs to 595 feet bgs. Evidence of oil circled in red. (Mud Log available online at: https://secure.conservation.ca.gov/WellSearch/Details?api=07920548&District=&County=&Field=&Operator=&Lease=&APINum=07920548&address=&ActiveWell=true&ActiveOp=true&Location=&sec=&twn=&rge=&bm=&PgStart=0&PgLength=10&SortCol=0&SortDir=asc&Command=Search

The proposed southwestern aquifer exemption boundary is based on the formation facies change. That facies change acts as a barrier to fluid movement. The proposed boundary was determined using a variety of well tests and logs. The variety of tests and logs included analysis of mud logs, striplogs, and electric logs, run at the time the wells were drilled. These tests and logs can be used to determine the lithology and characterization of the formations drilled through. The west side of the Arroyo Grande oil field between cross sections E-E’ and B-B’ is part of the Indian Knob area geologically. The further west you go, the less economic the area becomes. It is very heavy oil with little to no mobile oil and only immobile tar within the pore space of the Edna member sands. The interpretation of the geologic model depends on the wells that have been drilled in the area, and because of the lack of mobile oil, there have not been a lot of wells drilled to delineate the facies change. Phillips Petroleum Co. well “Guidetti A” 4 (API 079-20566) is the furthest well to the west that can be used for interpretation of the subsurface. The log for well “Guidetti A” 4 shows that there are Edna member sands to a depth of approximately 600 feet deep (measured depth) with Miguelito siltstones and claystones underlying the Edna member, and the Monterey formation underlying the Miguelito formation.

The Edna member sands this far west are also water sands with immobile tar. The prevalence of the tar seal seen to the west and the evidence that there is only mobile oil to the east of the tar seal indicates that the tar seal serves as a barrier for fluid migration. If there was no barrier, the oil being produced from the Arroyo Grande oil field would have migrated up and out of the syncline to the west as the formation trends up in subsurface elevation towards the west.

The proposed boundary to the south of the Arroyo Grande oil field is based upon the permeability data that is associated with the facies change. The Edna Member sands transition into the Miguelito member siltstone and claystones. This transition is an example of a fluid barrier because of the change in permeability. Within the Arroyo Grande oil field, the Edna member sands have laboratory verified permeability values from core samples ranging from several hundred millidarcys (md) to well over a darcy. The permeability values of the Miguelito member in the area of the facies change is less than 10 md. Permeability values of less than 100 md are typically seen as an efficient seal for fluid flow. In addition to the facies change and lack of permeability moving south of the Arroyo Grande oil field, there is a distinct lack of oil saturation within the Miguelito member. The lack of oil saturation is additional evidence that the facies change prevents fluid flow to the south.

The oil in the Arroyo Grande oil field is contained because of tar seals that act as barriers to fluid movement. The characteristics of tar seal defined oil fields are well known and common throughout California and the world. The oil fields of San Ardo, King City, Santa Paula, Los Angeles City, McKittrick, South Belridge, and Coalinga are all examples of oil fields in California with tar seals as prominent geologic features. In 1980, the Division published technical report 25, “*Unconventional Petroleum Resources in California*” (TR25) by Fred O. Hallmark (Appendix D). In publication TR25, the Division reported that “the Edna deposit of San Luis Obispo County is probably the largest surface occurrence of tar sand in California.” These extensive tar sands are the original producing horizon of the Arroyo Grande oil field. The oil contained within the tar sands is so immobile that it has to be extracted through mining operations.

The tar seal for the Arroyo Grande oil field was developed through eons of geologic and biologic activity. The original native formation fluids when deposited were more saline than what is seen today. As the Pismo formation sands were uplifted through geologic forces, the formation was exposed to meteoric water from the environment, improving the originally deposited saline fluid to today’s total dissolved solids (TDS) value of less than 3,000 parts per million. Hydrocarbons tend to stay stable when in contact with a highly saline water but will begin to biodegrade from light-oil hydrocarbons to heavy-oil and/or bitumen (tar, asphalt) in the presence of freshwater. The cause of this biodegradation is from anaerobic bacteria found in fresh water consuming the oil to obtain energy. The greatest level of biodegradation is found at the surface evidenced by the vast amounts of tar sands and along the outer edges of the Arroyo Grande oil field in the form of the tar seal. The anaerobic bacteria has degraded the oil from what can be seen within the producing area of the Arroyo Grande oil field with an API gravity of 13 degrees and viscosity in the range of 2,500 – 3,500 centipoise (cp) to bitumen and tar sands with an API gravity of less than 10 degrees and viscosity in the range of 10,000 cp to over 100,000 cp. Biodegradation concentrates the longer hydrocarbon chains found in lighter oil to create the tar and asphalt. Frequently found in the biodegraded tar are higher levels of metals, such as nickel and vanadium, and nonmetallic inorganic elements, such as nitrogen, oxygen, and sulfur. See Figure 5.

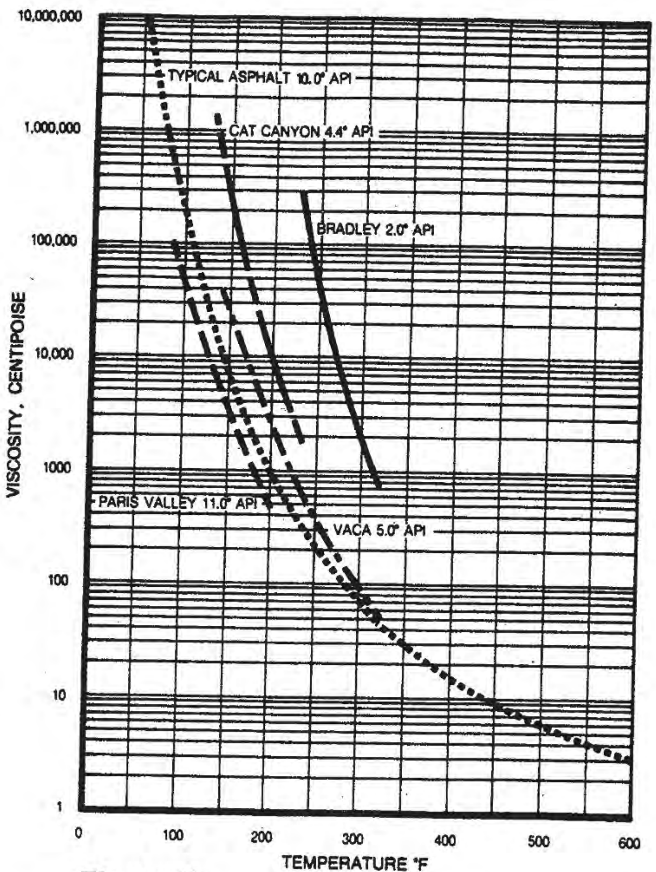
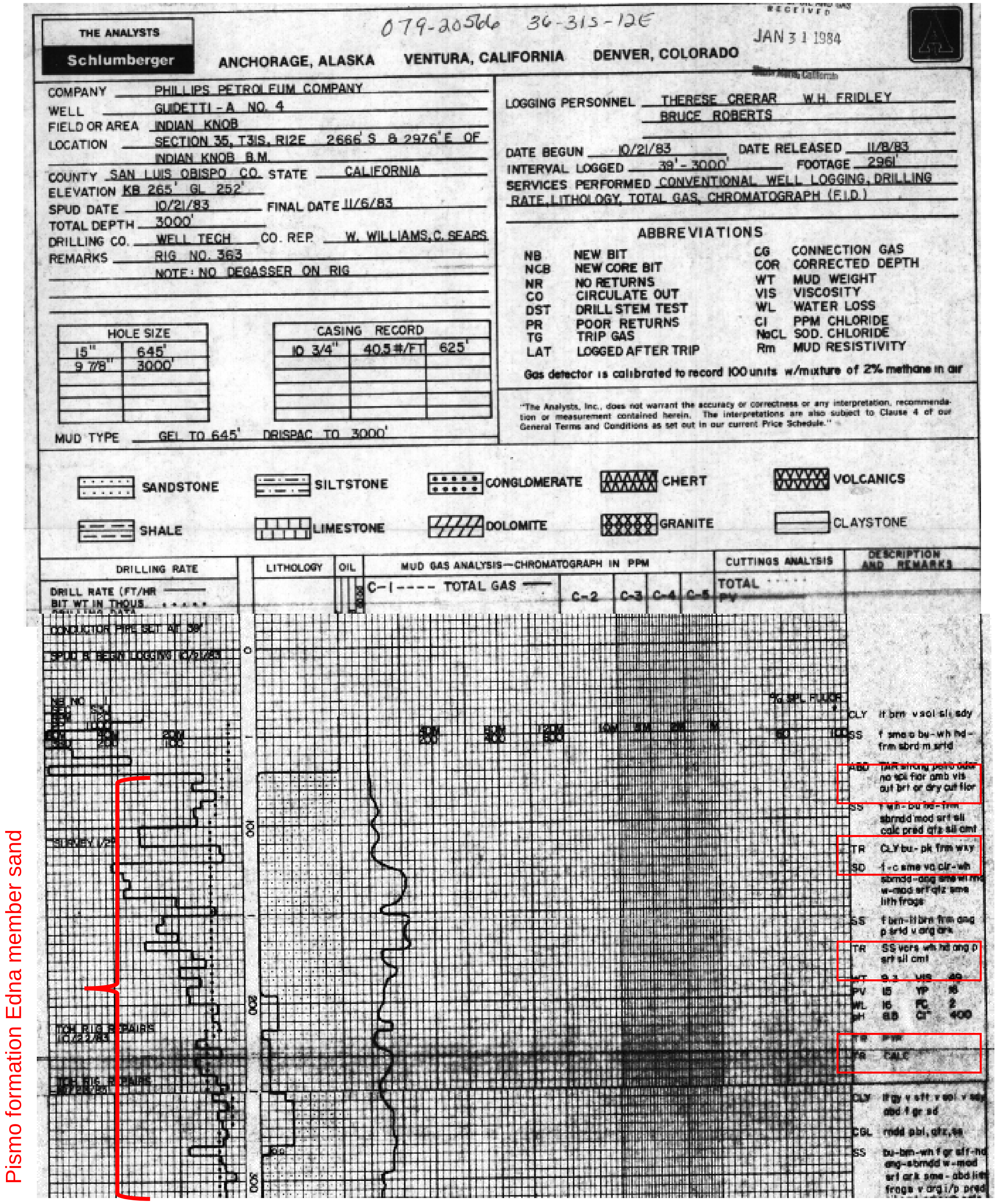


Figure 5
Viscosity temperature characteristics of asphaltic crude oils.

CALIFORNIA DIVISION OF OIL AND GAS

Figure 6a. Surface to 300 ft. Tar accumulation observed by Well Site Geologist captured in red



079-20566   36-31S-12E

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JAN 31 1984

THE ANALYSTS
Schlumberger

ANCHORAGE, ALASKA   VENTURA, CALIFORNIA   DENVER, COLORADO

COMPANY PHILLIPS PETROLEUM COMPANY
WELL GUIDETTI - A NO. 4
FIELD OR AREA INDIAN KNOB
LOCATION SECTION 35, T31S, R12E 2666' S & 2976' E OF INDIAN KNOB B.M.
COUNTY SAN LUIS OBISPO CO. STATE CALIFORNIA
ELEVATION KB 265' GL 252'
SPUD DATE 10/21/83 FINAL DATE 11/6/83
TOTAL DEPTH 3000'
DRILLING CO. WELL TECH CO. REP. W. WILLIAMS, C. SEARS
REMARKS RIG NO. 363
NOTE: NO DEGASSER ON RIG

HOLE SIZE	
15"	645'
9 7/8"	3000'

CASING RECORD		
10 3/4"	40.5 #/FT	625'

MUD TYPE GEL TO 645' DRISPAC TO 3000'

LOGGING PERSONNEL THERESE CRERAR W.H. FRIDLEY
BRUCE ROBERTS
DATE BEGUN 10/21/83 DATE RELEASED 11/8/83
INTERVAL LOGGED 39' - 3000' FOOTAGE 2961'
SERVICES PERFORMED CONVENTIONAL WELL LOGGING, DRILLING RATE, LITHOLOGY, TOTAL GAS, CHROMATOGRAPH (F.I.D.)

ABBREVIATIONS

NB	NEW BIT	CG	CONNECTION GAS
NCB	NEW CORE BIT	COR	CORRECTED DEPTH
NR	NO RETURNS	WT	MUD WEIGHT
CO	CIRCULATE OUT	VIS	VISCOSITY
DST	DRILL STEM TEST	WL	WATER LOSS
PR	POOR RETURNS	Cl	PPM CHLORIDE
TG	TRIP GAS	NaCL	SOD. CHLORIDE
LAT	LOGGED AFTER TRIP	Rm	MUD RESISTIVITY

Gas detector is calibrated to record 100 units w/mixture of 2% methane in air

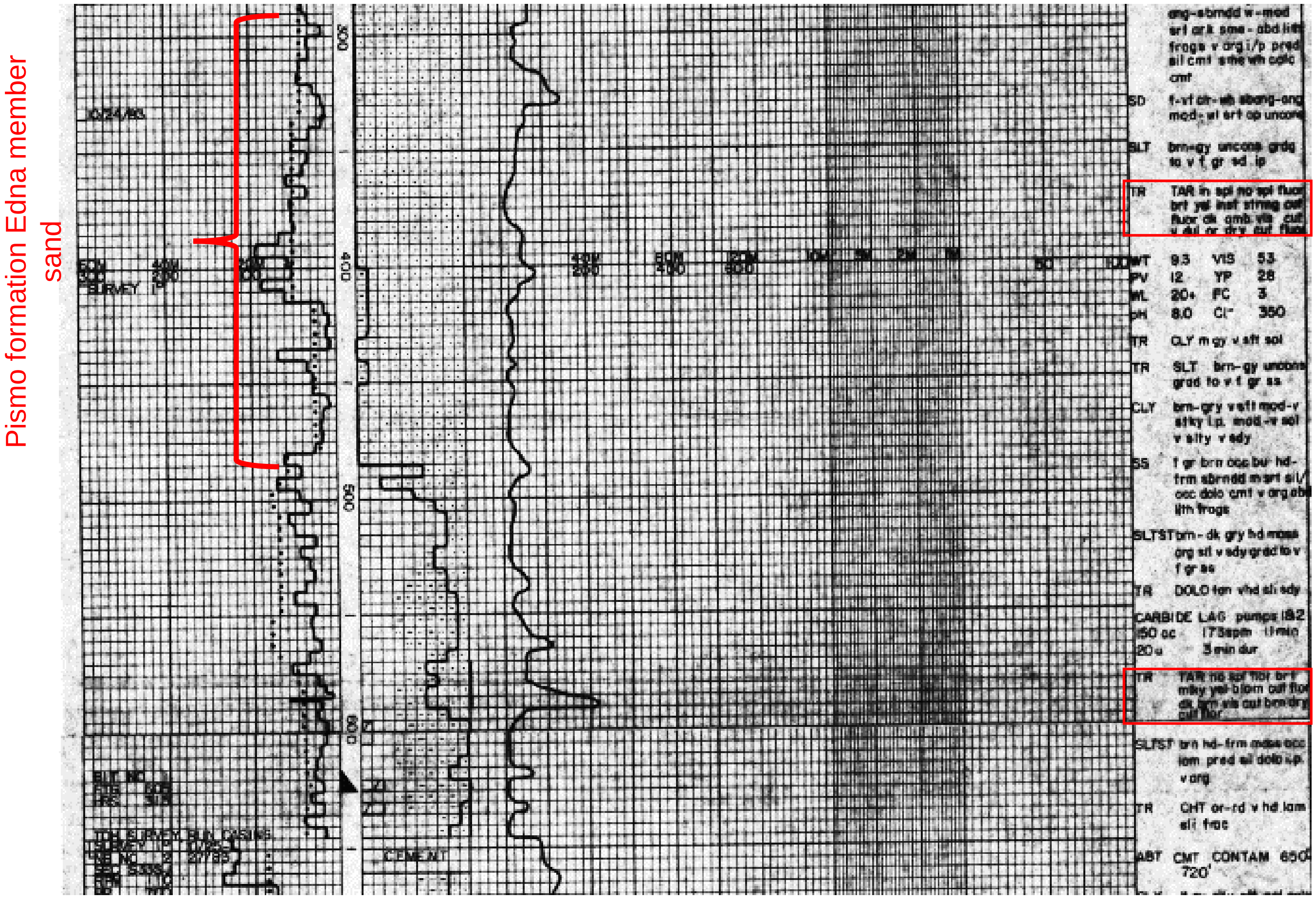
"The Analysts, Inc., does not warrant the accuracy or correctness or any interpretation, recommendation or measurement contained herein. The interpretations are also subject to Clause 4 of our General Terms and Conditions as set out in our current Price Schedule."

CLY lt brn v sol sl sdy
SS f sme o bu-wh hd-frm sbrd m srtd
ABD TAR strong petro odor no spl flor amb vis cut brt or dry cut flor
SS f wh-bu hd-frm sbrndd mod srt sil calc pred qtz sil cmt
TR CLY bu-pk frm wxy
SD f-c sme vc clr-wh sbrndd-ang sme wl rnd w-mod srt qtz sme lith frags
SS f brn-lt brn frm ang p srtd v ang grs
TR SS vers wh hd ang p srt sil cmt

WT	9.3	VIS	49		
PV	15	YP	16		
WL	16	FC	2		
pH	8.5	Cl⁻	400		

TR PYR
TR CALC
CLY ltgy v sft v sol v sdy abd f gr sd
CGL rndd pbl, qtz, ss
SS bu-brn-wh f gr sft-hd ang-sbrndd w-mod srt ark sme-abd lith frags v ang i/p pred

Figure 6b. From 300 ft to 700 ft. Tar accumulation observed by Well Site Geologist captured in red.



(Mud Log available online - https://secure.conservation.ca.gov/WellSearch/Details?api=07920566&District=&County=&Field=&Operator=&Lease=&APINum=07920566&address=&ActiveWell=true&ActiveOp=true&Location=&sec=&twn=&rge=&bm=&PgStart=0&PgLength=10&SortCol=0&SortDir=asc&Command=Search)

The outer and surface tar seals have insulated the producing horizon of the Arroyo Grande oil field from the anaerobic bacteria biodegradation. Because of the high viscosity and low mobility of the tar and bitumen, the fluid from the Arroyo Grande oil field is effectively prevented from migrating out through the porous Pismo Formation sands. The mudlog for well Phillips Petroleum Co. “Guidetti A” 4 (API 079-20566) validates this geologic description and can be found in the cross section B – B’ at the west of the proposed aquifer exemption area. There are multiple occurrences of tar within the mudlog description and remarks. See Figure 6a and Figure 6b.

The tar seals in the cross sections of the aquifer exemption application are depicted as single lines however, the tar seals represent significant thickness in the Arroyo Grande oil field.

The 1999 California Drinking Water Source Assessment and Protection Program (DWSAPP) says that a highly confined aquifer has “Presence of continuous, unfractured, confining strata (clays, glacial till, shale, siltstone).” In addition to the tar seals found in “Guidetti A” 4, the mud log in Figures 6a and 6b shows multiple instances of clay and siltstone throughout the shown interval. Similar mud logs can be found across the field. The data in the original proposed aquifer exemption application and the data provided in this supplement show multiple lines of evidence to support the assertion that this is a confined aquifer.

The Division, through regulation and oversight of the project approval and individual well permitting process, limits the field operations. These limitations ensure that the operator maintains a low reservoir pressure and tight control of the reservoir temperature. A number of temperature observation wells have been installed and monitored. To date, none of the current monitoring wells have shown a rise in temperature from the active steam injection above the background temperature levels (Appendix E). Additional monitoring wells are expected in strategic locations to broaden the ability to monitor reservoir conditions within the Arroyo Grande oil field. The continued review of existing monitoring wells, as well as establishing additional monitoring wells ensures a comprehensive program to safeguard aquifer exemption expectations.

All six cross sections (Appendix A 7 a 1 {A – A'} through Appendix A 7 a 7 {E – E'}) in the aquifer exemption application illustrate that the Miguelito member underlays the Edna member (Dollie) sands throughout the Arroyo Grande oil field. Within the Arroyo Grande oil field, the Miguelito member is comprised of siltstones and claystones with very low permeability (<10 md) and forms a consistent barrier to fluid flow. There are some Edna member (Dollie) sands that continue laterally into the Oak Park basin as depicted in cross section E – E'. Only the M-12, or basal Edna member sand, has been productive. The upper portion of the syncline of the Arroyo Grande oil field acts as a ridgeline between the Arroyo Grande oil field and Oak Park basin and is a barrier to fluid flow**.** This distribution as depicted in the cross sections, and extremely low permeability of the Miguelito member from field data, is the technical justification for the lower hydraulic isolation.

The proposed aquifer exemption is from 250 feet bgs to the base of the Edna member (Dollie) sands. The portion of the aquifer above 250 feet bgs is comprised of shallow tar sands and serves as the final upper barrier to fluid flow. Evidence to the assertion that the surface is comprised of tar sands/tar seal can be found in the 1944 USGS study "*Geology of the bituminous sandstone deposits near Edna, San Luis County, California"* on map 16, in multiple Division technical reports in "California Oil and Gas Fields", and in the numerous logs and cores from the Arroyo Grande oil field. This evidence is justification for the upper hydraulic isolation.

With hydraulic confinement illustrated above, how is the point at which spill over from the syncline to the surrounding area determined? A detailed hydraulic analysis was conducted for the proposed aquifer exemption application in 2015. Because of the synclinal nature of the reservoir, a spill point was determined for a subsurface elevation that would allow fluids to fill up to and spill out. However, the use of the spill point is not the sole measure of confinement, it is just a level of confinement within the proposed aquifer exemption boundary. The hydraulic analysis used field pressure data from February 2013 before the reverse osmosis plant was put into service, and from June 2015 after the reverse osmosis plant was put into service. The analysis shows that with the continued use of the reverse osmosis plant and the removal of water and oil from the reservoir, that a spillover of fluids over the spill point is not possible.

To find the most conservative (lowest) spill point, the focus of the hydraulic analysis was on the west side of the Arroyo Grande oil field. The vast majority of the water disposal occurs there and the subsurface elevation of the syncline is at its lowest point. The sands were mapped for six wells to determine the spill over point of 275 feet bgs. The geologic marker used as the spill point is the top of the M-2 of the Dollie sands, and the well that was used was “Signal-Guidetti” 2 (API 079-00744). This well is directly inside the proposed aquifer exemption boundary. Since the original application was submitted, an additional cross section was developed utilizing a well log from Phillips Petroleum Co. well “PPG” 21 (API 079-20204), which lies outside the proposed aquifer exemption boundary in section 36 Township 31S Range 12E M.D. B&M. This cross section confirms the syncline configuration and illustrates further vertical containment to the west (Appendix F).

Since the hydraulic analysis was performed, the operator has commissioned a wet electrostatic precipitator (WESP) for use of removing hydrogen sulfide. Prior to the WESP, hydrogen sulfide gas was reinjected into the reservoir contributing to increased reservoir pressure. With the operation of the WESP, there has been a significant reduction in gas injection thereby reducing the reservoir pressure. As more and more water, oil, and gas are being removed in daily operations, the reservoir pressure is decreasing and prevents fluid from migrating outside of the proposed aquifer exemption boundary. For every 20 psi decrease in reservoir pressure, approximately 15% safety margin is added versus the spill point hydraulic head. The originally submitted application discusses the hydraulic analysis and the data used in calculations on pages 9 – 14.

The Edna Valley groundwater basin is recognized as being separated by geologic formations and faulting from the proposed aquifer exemption area by the California Department of Water Resources and other geologic and hydrogeological authorities.

The California Department of Water Resources limits the extent of the San Luis Obispo Valley Groundwater Basin and does not include any of the area within the proposed aquifer exemption boundary, recognizing that these are distinctly separate areas that do not have significant groundwater connectivity (Appendix G). This is supported by the findings in a Balanced Hydrologics, Inc. report from 2008 (Appendix H). This report details how groundwater, when present in sufficient quantities, undergoes upwelling along the various fault traces that cross Pismo Creek up-gradient of the aquifer exemption area. This upwelling water feeds into Pismo Creek as surface water because it cannot continue to flow as groundwater across the fault traces. This presupposes what other research has found (Appendix I), which is that general groundwater flows are from the northeast to southwest, but illustrates that the groundwater does not flow significantly in a subsurface manner across the various faults. It flows as a surface water when there is sufficient water to support upwelling into Pismo Creek, but when groundwater is insufficient to support upwelling, the fault traces act as a dam, holding back groundwater from flowing into the area of the aquifer exemption. This is consistent with the interpretation from the technical document (Appendix J) from CHG in Appendix G 1-1 of the aquifer exemption application package which states, "The subsurface hydraulic connection between the Edna subbasin and Price Canyon water-bearing zones is restricted by faulting and folding, which act as barriers to groundwater flow."

Likewise, little to no groundwater flow can be expected through the area of the proposed aquifer exemption in a downstream direction. A 2007 report by WZI, Inc. (Appendix K) states, "... the Pismo Creek drainage was observed to be incised directly into the Edna Member of the Pismo

Formation bedrock." It goes on to state that “... no extensive or continuous alluvial deposits are present along the Pismo Creek drainage through the PXP property." Since no extensive or continuous alluvial deposits exist in the area, the only possibility for groundwater flow would be through fractures in the bedrock. Since the bedrock in the area is saturated with oil, any groundwater flowing from the area of the aquifer exemption to the south would be accompanied by crude oil, but this has not been observed in any down gradient wells.

These multiple references from independent sources all indicate that water flow across the various fault zones separating the Edna sub basin of the San Luis Obispo Valley Groundwater Basin is insignificant under average conditions. In addition, there is insignificant groundwater flow within the area of the aquifer exemption, and there is no groundwater flow out of this area to the south. Instead, all flows into and out of the area of the aquifer exemption are limited to the surface flows in Pismo Creek.

To explain the effects of saturation in the aquifer within the Arroyo Grande oil field, it is helpful to understand the business process that will drive operations. The Arroyo Grande oil field, to remain economic, depends upon using the recently constructed reverse osmosis plant combined with the new WESP to dewater and lower the pressure of the reservoir. With continued reduction in water volume and reservoir pressure, all injected fluids will be contained within the proposed aquifer exemption boundary. The actions of the reverse osmosis plant will reduce the water cut ratio per barrel of produced fluid. Buoyance-driven fluid movement is not evident or expected as the heavy oil and water remain interspersed and in emulsion.

The installation of the reverse osmosis treatment facility and WESP, along with oil extraction are major operational factors in the Arroyo Grande oil field. Appendix L contains the production and injection volumes, and the net volume removed from the aquifer for the Arroyo Grande oil field from January 2010 through December 2016. The data contained in Appendix L details the factors that dramatically contribute to hydraulic confinement and illustrates that all fluid will be contained within the Arroyo Grande oil field, not only through geologic and stratigraphic containment, but through the daily operation and ongoing pressure reduction in the field.

ADDITIONAL INFORMATON AND ANALYSIS REGARDING WHETHER THE PROPOSED AQUIFER EXEMPTION AREA IS A CURRENT SOURCE OF DRINKING WATER

Update Regarding Inventory of Water Wells within 1-Mile Radius

In an effort to provide the most comprehensive water well analysis for the area, the aquifer exemption proposal submitted in February 2016 included data that was extracted from a previous water well study developed for San Luis Obispo County. That study used a 1-mile radius from the active oil field and provided a solid starting point. The technical memorandum presenting this extracted data may be found in Appendix G 1-1 in the original Arroyo Grande aquifer exemption application and has also been added to this report in Appendix J. In response to the letter from the US EPA dated April 19, 2016, the State conducted an enhanced review of that water well study to improve the reliability of the data, adding information for any new wells within a ¼-mile radius of the proposed aquifer exemption boundary. In addition to adding any new wells, a water well capture analysis was performed on the ¼-mile radius and was presented in a reply to the US EPA dated August 18, 2016. After consultation with the US EPA, CHG, and local landowners, the updated ¼-mile radius water well capture analysis presented in this report was developed. Capture zone analysis was not performed on wells outside of the ¼-mile radius because at a lifetime of 30 years and a flow rate of 10 gallons per minute (GPM), the capture radius of a water well is less than a ¼-mile. There is no one agency in California that is responsible for all of the records on water wells, and as such, multiple iterations of the water well study have been performed as new information has been gathered through the public comment period and through review by multiple government agencies.

One public comment that aided in the revised water well study was submitted by the Center for Biological Diversity. The Center for Biological Diversity presented the Division with a separate survey of water wells completed by Matt Hagemann, a certified hydrogeologist and a California professional geologist and co-founder of Soil/Water/Air Protection Enterprise (SWAPE). The Hagemann water well survey identified more wells within a 1-mile radius from the active oil field than were identified in the original aquifer exemption proposal. CHG was retained by the operator of the field, FMOG, to resolve the discrepancies and determine the validity of the additional wells. Because of the sheer number of wells inferred by the Hagemann report, CHG only validated wells within 2,250 feet of the proposed aquifer exemption boundary, which is the minimum zone of protection for wells in a porous media pumping continuously for 10 years as suggested by the California Drinking Water Source Assessment and Protection Program. Within that 2,250 foot area, the Hagemann report identified 35 wells. Fifteen of these 35 Hagemann-identified wells were captured by the original survey included in the initial aquifer exemption proposal. Five more of the Hagemann-identified wells are located on parcels where the existence of the well could not be verified through the review of water well records or by an on ground survey. As a result, the five wells were added to the water well survey to ensure the safety of all drinking water wells. A further ten of the Hagemann-identified wells are on lots already captured to have a well by the water well study and are considered duplicates. As such, they were not added to the water well survey. The final five Hagemann-identified wells are in fact not wells at all, but frost protection wind machines (Figure 7) in the vineyard to the south of the Arroyo Grande oil field.

Figure 7. Frost protection wind machine and associated equipment

Figure 7 is a photograph taken at the location listed in the Hagemann report and identified as water well H-97. A site inspection verified that H-97 was the location of a wind machine used for frost protection. Similar devices were located in the Hagemann report and listed as wells H-98, H-99, H100, and H101.

Update Regarding Capture Zone Analysis for Drinking Water Wells within ¼-Mile Radius

In an August 18, 2016 letter to the US EPA, the Division presented a water well capture zone analysis for the 13 drinking water wells that were identified to be within a ¼ mile radius of the proposed aquifer exemption area. After further research, as explained below, the State has determined that 8 of these 13 wells were either wells used for agricultural purposes, no longer in use, or not wells at all. The calculated capture zone analysis values for the remaining 5 wells are presented in Appendix M. The lifetime of any given well cannot be predicted, but based on consultation with the US EPA and input from CHG, a conservative estimate for water wells of this type and size is 30 years. Appendixes N, O, and P are three letters from adjacent landowners attesting to the status of their respective wells.

The following is a summary of the State's determination regarding each of the 13 wells.

Water Wells #38, #40, and #41 –

These water wells are located east of the original proposed aquifer exemption boundary and south of the Arroyo Grande Fault Zone. As referenced in the letters in Appendix O and Appendix P, well #38 was incorrectly placed north of the Arroyo Grande Fault Zone and is now in the proper location. Well #40 was misidentified as a well using aerial photography. As stated in the letter in Appendix O, well #40 is not a well and is no longer included in the water capture analysis. The estimated 30-year capture zone of wells #38 and #41 crosses the original proposed aquifer exemption boundary. The revised aquifer exemption boundary, as noted in green in Figure 9, has been adjusted to not overlap the calculated capture zones. The Division does not have evidence that the capture zone actually crosses the tar seals to the east of the proposed aquifer exemption area. Wells #38 and #41 are not expected to draw water from the Arroyo Grande oil field due to the impermeable nature of the seals. It is the tar seal boundary that prevents oil from the Arroyo Grande oil field from migrating further east into the pore space of these water wells. The effectiveness of the seal is demonstrated by the lack of free oil in these domestic wells that allow their use for domestic drinking water. Absent the existence of the tar seal, free oil would have migrated into these wells. The aquifer exemption boundary proposed in this supplement avoids overlap with the calculated capture analysis to ensure the protection of the drinking water wells. Protection of the area between the original proposed boundary (tar seal) and the calculated capture zone would be achieved through hydraulic confinement with the reduction in field pressure.

Water Wells #43, #46, #47 and #48 –

These water wells are located north of the original proposed aquifer exemption boundary and north of the main trace of the Arroyo Grande Fault Zone. Wells #46, #47, and #48 have been removed from the capture analysis. As documented in the letter found in Appendix N, wells #46 and #47 are in fact not wells at all, but rather are storage tanks. Well #48 was at one time used to supply water for an agricultural nursery, is not currently in use, and has been out of use for many years. Accordingly, the capture analysis was performed on the only domestic water well, well #43. The capture analysis used a flow rate

> of 5 gallons per minute based on a pump test performed on the well in 2012. The test, as seen in Appendix Q, was performed at 5 gallons per minute and the fluid level stayed static for the final 2 hours of the 4 hour test showing that the well flow rate had achieved equilibrium. The Division's research does not support that the calculated capture zone for well #43 crosses the fault because the Arroyo Grande fault is an aquiclude and prevents any migration of water across it. Therefore, the capture analysis, as shown in Figure 9, for well #43 does not cross the proposed aquifer exemption boundary.

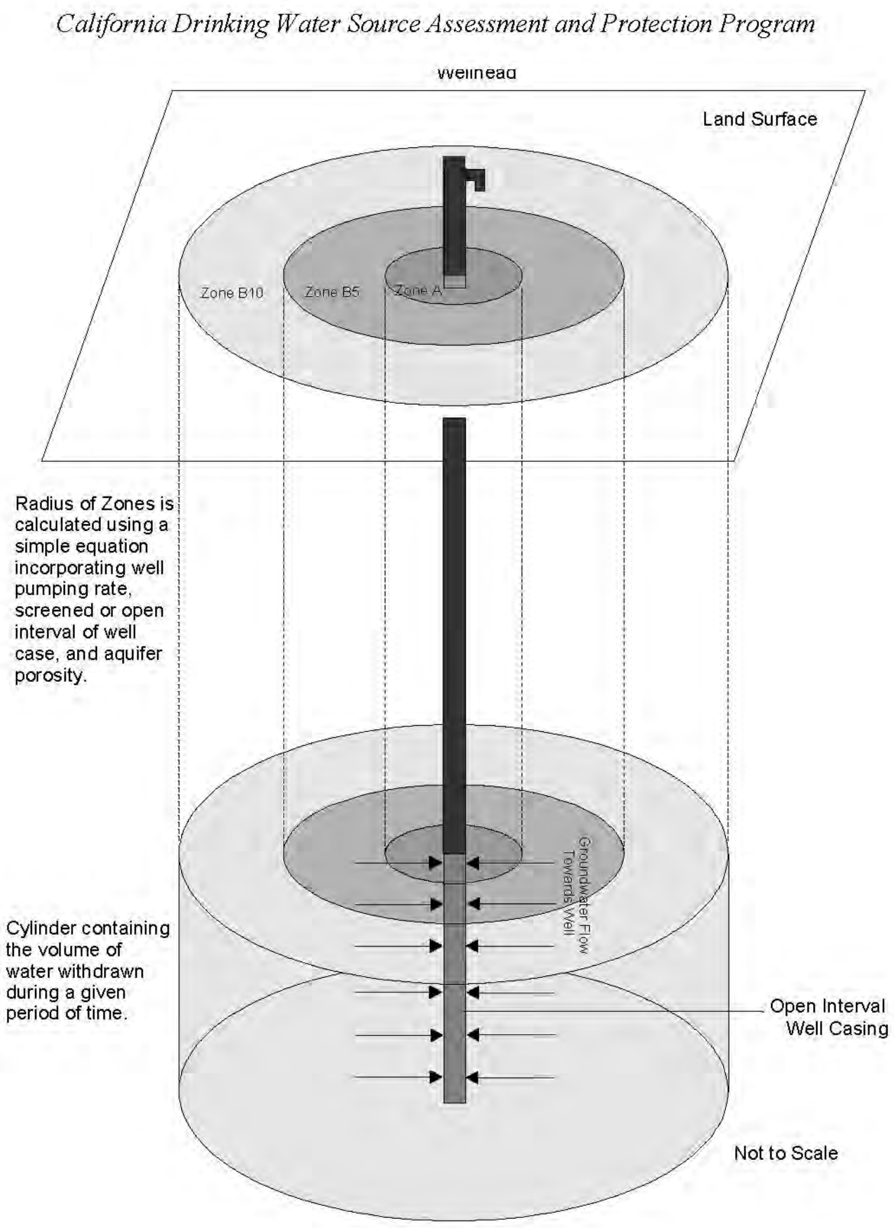
Water Wells #50, #51, #52, and #54 –

> These water wells are located southeast of the proposed aquifer exemption boundary on the north flank of the Oak Park structural basin, which is an entirely separate and distinct hydrologic basin from the Arroyo Grande oil field. As outlined in the data included in the original aquifer exemption document, the basins are isolated from each other by tar seals and the geologic structure. In addition to the data indicating that these wells are within a separate structural basin, the only well with the capture analysis overlapping the proposed aquifer exemption boundary, well #51, is located on a vacant lot and has not been developed to serve as a source of drinking water. For the aforementioned reasons, wells #50, #51, #52, and #54 were removed from of the map.

Water Wells #84 and #86 –

> These South Ranch water wells are completed in a thin alluvium (QAL) layer within Pismo Creek which overlies the Miguelito member of the Pismo formation, consisting of siltstone and claystone. The South Ranch wells are hydrologically isolated from the proposed aquifer exemption area. In addition, two of the four Phase IV monitoring wells, MW 3A and MW 3B completed in 2006, are located about 1000 feet north of these water wells along Pismo Creek, in between the Arroyo Grande oil field and the South Ranch property, and have shown no evidence of change in the last ten years of oil field operations.

For each of the remaining 5 wells identified to be within the ¼ mile radius of the proposed aquifer exemption area (Water Wells #38, #41, #43, #84, and #86), CHG calculated the capture zone using the 1999 California Drinking Water Source Assessment and Protection Program (DWSAPP) capture zone equation as shown in Figure 8. In the absence of real world data, a conservative well flow rate of 10 gallons per minute (gpm) was used. Capture zone analysis was not performed on wells outside of a ¼ mile because at a lifetime of 30 years and a flow rate of 10 gpm, the capture radius is less than a ¼ mile.



$$r = \sqrt{\frac{Q\,t}{\pi\,n\,H}}$$

Where
Q = Pumping Rate of Well
n = Effective Porosity (0.2)
H = Open Interval or Length of Screen
t = Travel Time to Well (2, 5, 10 years)

Figure 8. Calculated fixed radius delineation method (Adapted from Washington State, "Wellhead Protection Program Guidance Document," 1995)

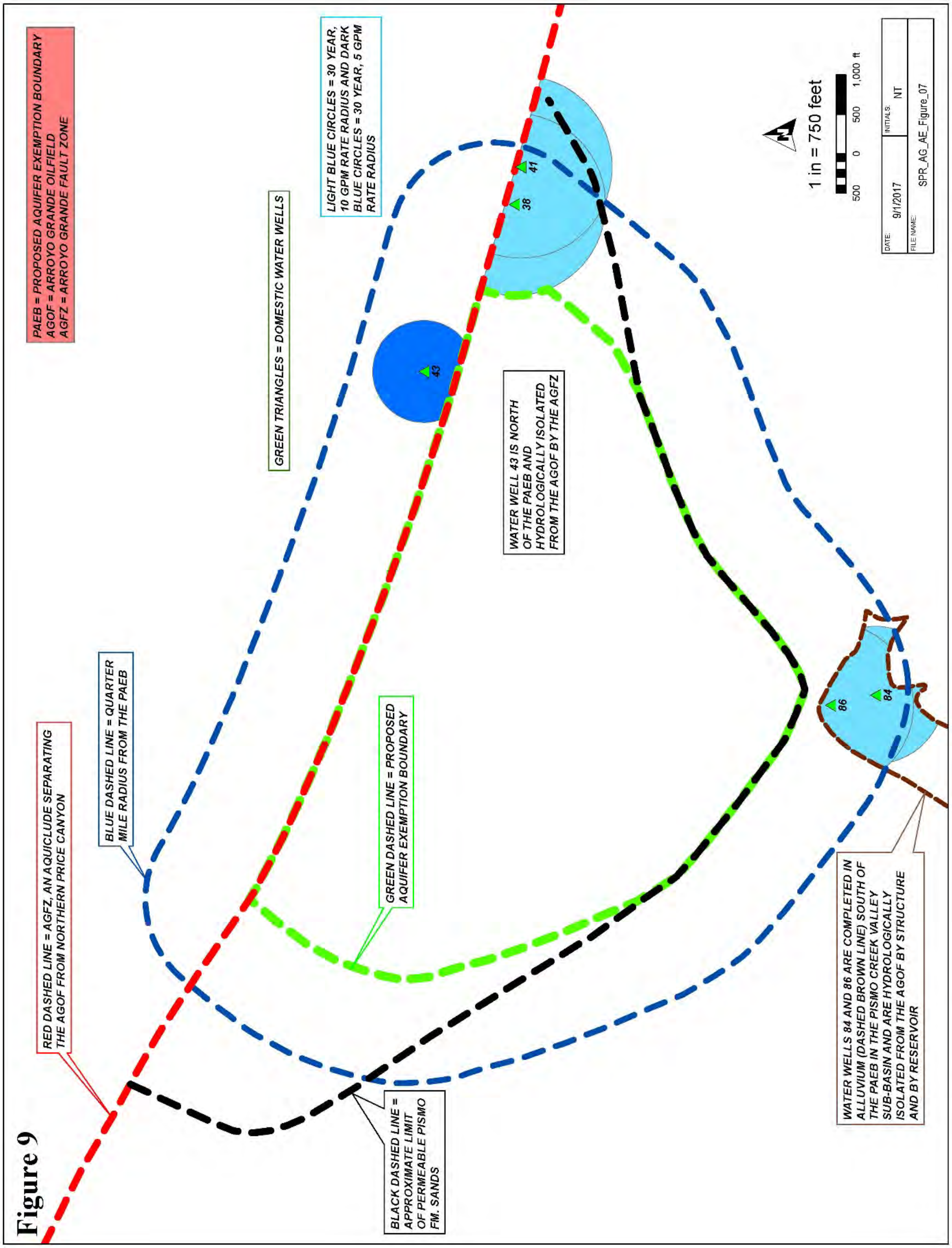


Figure 9

Figure 9 shows a graphical representation of the calculated capture zones for these 5 wells, in relationship to the proposed aquifer exemption boundary.

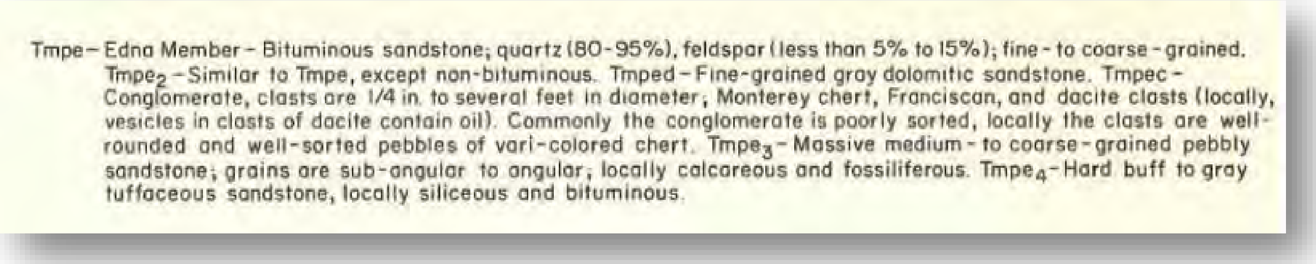
GEOLOGIC DESCRIPTION

The Dollie sands discussed in the aquifer exemption proposal are a subset of the Edna member of the Pismo formation. In Appendix A1 of the original proposed aquifer exemption application is a stratigraphic column of the Arroyo Grande oil field (Appendix R). The column on the left is from the "*Geology of the Arroyo Grande 15' quadrangle, San Luis Obispo County, California*" (Hall, C.A. 1973), and the column on the right is from the Division's technical report 12, "*California Oil and Gas Fields, Volume II"* (1991). In its report, the Division identifies the bituminous sandstone portion of the Edna member of the Pismo formation as the Dollie sands. The Dollie sands are the producing horizon for the Arroyo Grande oil field.

Outside of the Arroyo Grande oil field, the water production is from the Edna member. A more detailed mapping of the area can be found in the "*Preliminary Geologic Map of the Arroyo Grande NE 7.5' Quadrangle, San Luis Obispo County, California: A Digital Database"* (Wiegers, O'Neal 2013). See Figure 10, Figure 10b, and Figure 10c.

The Dollie sands would be represented by the "Tpeb" designation on the map delineating the bituminous sandstone of the Edna member. The hydrocarbon laden Dollie sands are a subset of the Edna, but are not hydraulically connected to the freshwater producing Edna sands because of the multitude of barriers discussed in the application.

Clarence A. Hall in 1973 mapped and described the Edna member as follows:



Tmpe – Edna Member – Bituminous sandstone; quartz (80-95%), feldspar (less than 5% to 15%); fine- to coarse-grained. Tmpe_2 – Similar to Tmpe, except non-bituminous. Tmped – Fine-grained gray dolomitic sandstone. Tmpec – Conglomerate, clasts are 1/4 in. to several feet in diameter; Monterey chert, Franciscan, and dacite clasts (locally, vesicles in clasts of dacite contain oil). Commonly the conglomerate is poorly sorted, locally the clasts are well-rounded and well-sorted pebbles of vari-colored chert. Tmpe_3 – Massive medium- to coarse-grained pebbly sandstone; grains are sub-angular to angular; locally calcareous and fossiliferous. Tmpe_4 – Hard buff to gray tuffaceous sandstone, locally siliceous and bituminous.

THREE-DEMENSIONAL REPRESENTATION

After receiving the initial aquifer exemption proposal, the US EPA requested three-dimensional coordinates that would delineate the proposed aquifer exemption boundaries. A three-dimensional representation can be inferred using the surface boundary of the proposed aquifer exemption boundary, cross sections that bisect each other, the vertical restriction of 250 feet below the surface of the proposed aquifer exemption boundary, and the structural contour map of the top of the Miguelito (Figure 11).

Figure 10

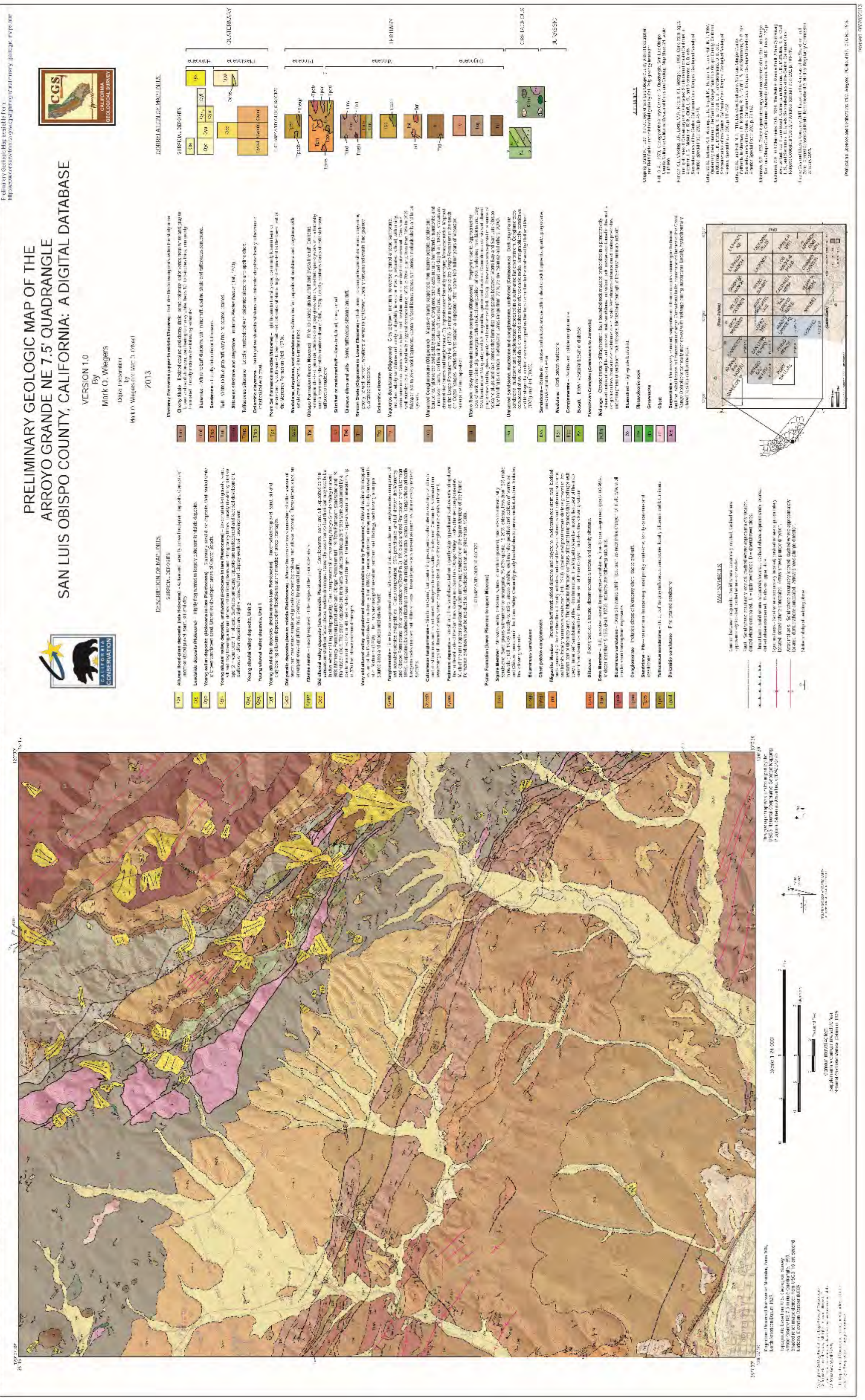
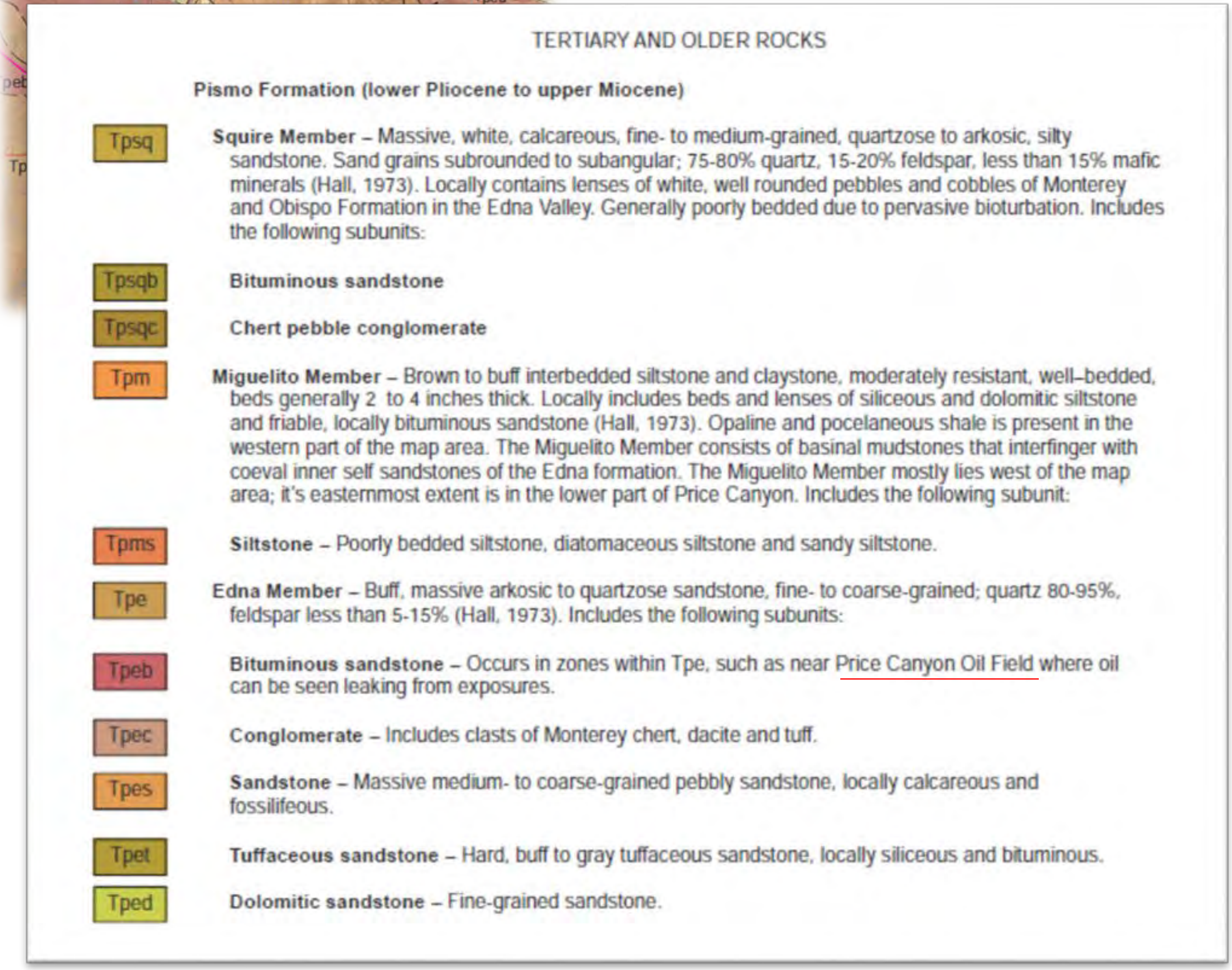

PRELIMINARY GEOLOGIC MAP OF THE
ARROYO GRANDE NE 7.5' QUADRANGLE
SAN LUIS OBISPO COUNTY, CALIFORNIA: A DIGITAL DATABASE
VERSION 1.0
By
Mark O. Wiegers
2013
CGS
CALIFORNIA GEOLOGICAL SURVEY
CALIFORNIA CONSERVATION

Figure 10b – Enlargement taken from the Preliminary Geologic Map of the Arroyo Grande NE 7.5' Quadrangle

Figure 10c – Description of formations



TERTIARY AND OLDER ROCKS

Pismo Formation (lower Pliocene to upper Miocene)

Tpsq	**Squire Member** – Massive, white, calcareous, fine- to medium-grained, quartzose to arkosic, silty sandstone. Sand grains subrounded to subangular; 75-80% quartz, 15-20% feldspar, less than 15% mafic minerals (Hall, 1973). Locally contains lenses of white, well rounded pebbles and cobbles of Monterey and Obispo Formation in the Edna Valley. Generally poorly bedded due to pervasive bioturbation. Includes the following subunits:
Tpsqb	**Bituminous sandstone**
Tpsqc	**Chert pebble conglomerate**
Tpm	**Miguelito Member** – Brown to buff interbedded siltstone and claystone, moderately resistant, well–bedded, beds generally 2 to 4 inches thick. Locally includes beds and lenses of siliceous and dolomitic siltstone and friable, locally bituminous sandstone (Hall, 1973). Opaline and pocelaneous shale is present in the western part of the map area. The Miguelito Member consists of basinal mudstones that interfinger with coeval inner self sandstones of the Edna formation. The Miguelito Member mostly lies west of the map area; it's easternmost extent is in the lower part of Price Canyon. Includes the following subunit:
Tpms	**Siltstone** – Poorly bedded siltstone, diatomaceous siltstone and sandy siltstone.
Tpe	**Edna Member** – Buff, massive arkosic to quartzose sandstone, fine- to coarse-grained; quartz 80-95%, feldspar less than 5-15% (Hall, 1973). Includes the following subunits:
Tpeb	**Bituminous sandstone** – Occurs in zones within Tpe, such as near Price Canyon Oil Field where oil can be seen leaking from exposures.
Tpec	**Conglomerate** – Includes clasts of Monterey chert, dacite and tuff.
Tpes	**Sandstone** – Massive medium- to coarse-grained pebbly sandstone, locally calcareous and fossilifeous.
Tpet	**Tuffaceous sandstone** – Hard, buff to gray tuffaceous sandstone, locally siliceous and bituminous.
Tped	**Dolomitic sandstone** – Fine-grained sandstone.

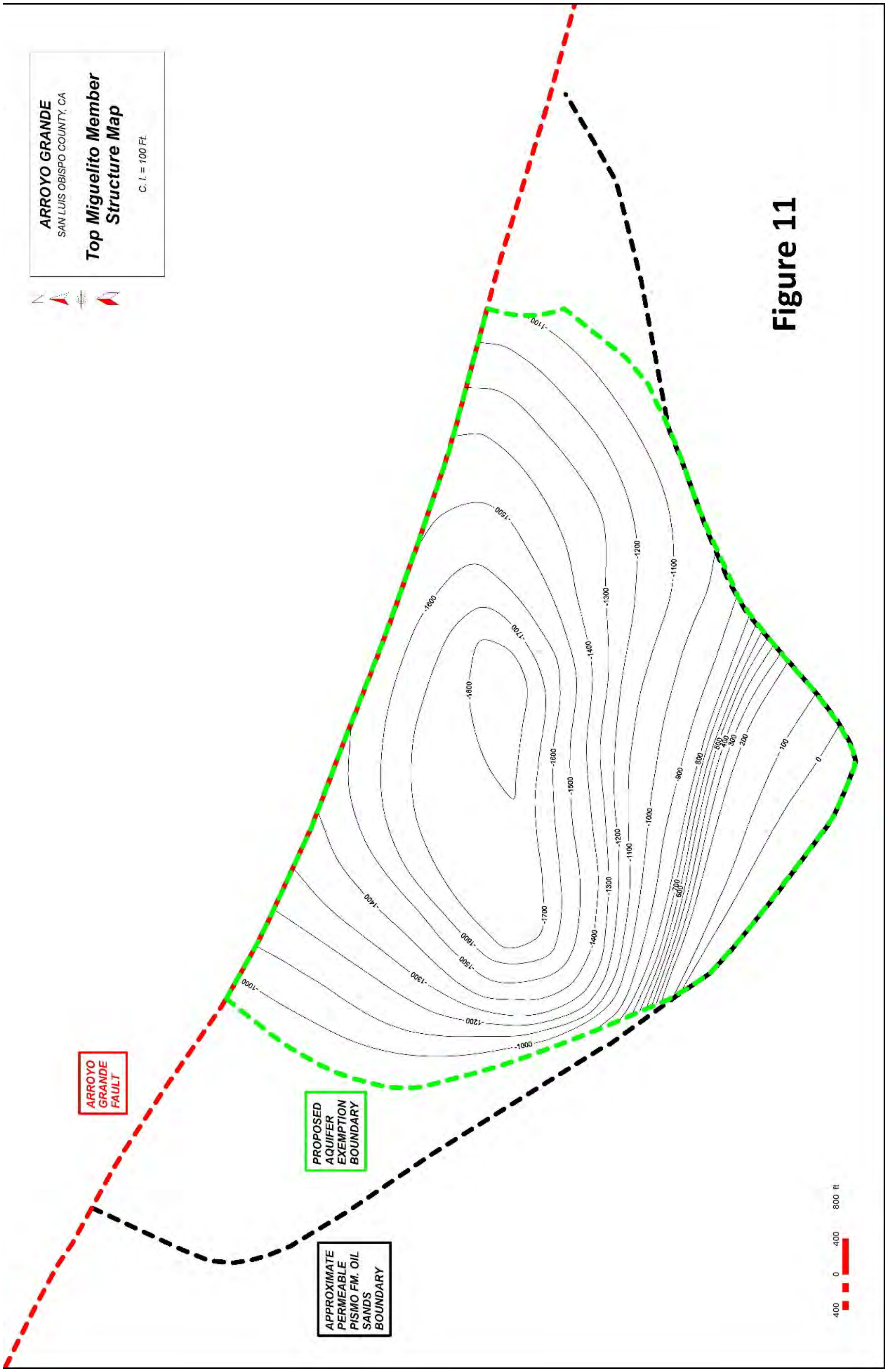
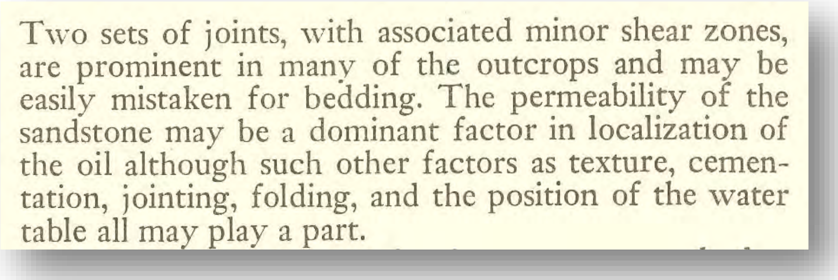

ARROYO GRANDE
SAN LUIS OBISPO COUNTY, CA
Top Miguelito Member Structure Map
C. I. = 100 Ft.
ARROYO GRANDE FAULT
PROPOSED AQUIFER EXEMPTION BOUNDARY
APPROXIMATE PERMEABLE PISMO FM. OIL SANDS BOUNDARY
-1000
-1100
-1200
-1300
-1400
-1500
-1600
-1700
-1800
-900
-800
-700
-600
-500
-400
-300
-200
-100
0
400
0
400
800 ft

Figure 11

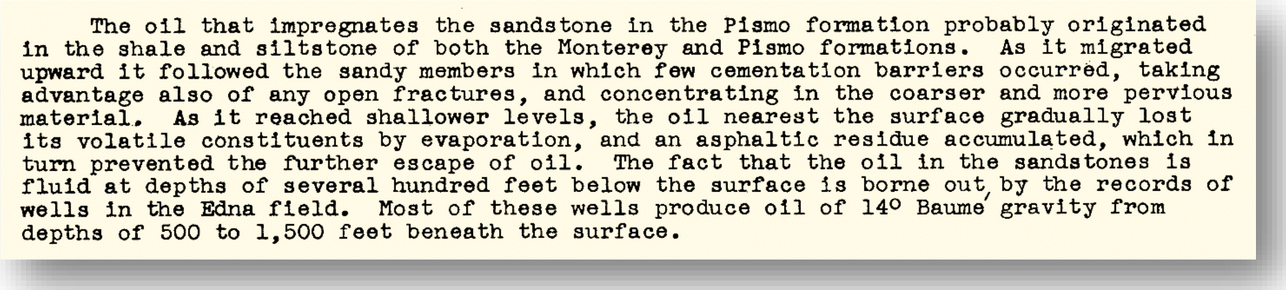
SUMMARY

The sum of the recent geology and engineering studies compiled for the proposed Arroyo Grande aquifer exemption package point to the conclusion that the proposed area is hydraulically isolated. Prior studies of the Arroyo Grande oil field have reached similar conclusions. Clarence A. Hall in 1973 concluded that permeability values were possibly the dominant factor in localization of the oil within the Arroyo Grande oil field:



Two sets of joints, with associated minor shear zones, are prominent in many of the outcrops and may be easily mistaken for bedding. The permeability of the sandstone may be a dominant factor in localization of the oil although such other factors as texture, cementation, jointing, folding, and the position of the water table all may play a part.

Prior to Hall's report in 1973, the United States Geologic Survey published "Geology of the Bituminous Sandstone Deposits near Edna, San Luis Obispo County, California" in 1944 by Benjamin M. Page, M.D. Williams, E.L. Henrickson, C.N. Holmes, and W.J. Mapel. In the report, the authors claim that the oil in the area probably originated in the Monterey and Pismo and migrated to the surface through sandy members. A tar seal was created when the volatile components of the oil evaporated near surface and in turn prevented the further escape of oil from the formation:



The oil that impregnates the sandstone in the Pismo formation probably originated in the shale and siltstone of both the Monterey and Pismo formations. As it migrated upward it followed the sandy members in which few cementation barriers occurred, taking advantage also of any open fractures, and concentrating in the coarser and more pervious material. As it reached shallower levels, the oil nearest the surface gradually lost its volatile constituents by evaporation, and an asphaltic residue accumulated, which in turn prevented the further escape of oil. The fact that the oil in the sandstones is fluid at depths of several hundred feet below the surface is borne out by the records of wells in the Edna field. Most of these wells produce oil of 14° Baumé gravity from depths of 500 to 1,500 feet beneath the surface.

The State submits the information included in this supplemental study to further validate the assertion in the original aquifer exemption submittal and to propose the revised aquifer exemption boundary and accompanying new or updated data.

Appendix A

Groundwater Resources Study for PXP, Arroyo Grande Oilfield, December 2008 By *Cleath-Harris Geologists, Inc.*

DRAFT REPORT

GROUND WATER RESOURCES STUDY
PXP - ARROYO GRANDE
SAN LUIS OBISPO COUNTY, CALIFORNIA

prepared for

Plains Exploration and Production Company

December 2008

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

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INTRODUCTION

Plains Exploration and Production Company (PXP) retained Cleath & Associates to study the ground water resources on approximately 1,050 acres of land along Price Canyon. The purpose of the study is to present a hydrogeologic overview of local water resources, to evaluate how much ground water would be available to existing or new water wells developed on the property, and to characterize the relationship between on-site and off-site water resources.

The PXP study area includes eight parcels along Price Canyon, beginning approximately 100 feet downstream of the Pacific Railroad bridge over Pismo Creek and ending approximately 600 feet downstream of the Ormonde Road bridge (Figure 1).

The main body of the report is organized into three main sections, Hydrology, Regional Hydrogeology, and Site Hydrogeology. Hydrology is focused on Pismo Creek flow, and includes a detailed base flow survey. Regional Hydrogeology presents an overview of regional features, including the San Luis-Edna ground water basin, the Santa Maria ground water basin (Pismo Creek Valley subbasin) and the San Luis-Pismo structural block (Indian Knob Valley and Oak Park subbasins). Site Hydrogeology revises the extent of the Pismo Creek Valley ground water subbasin on PXP land, identifies the main structural controls for water resource characterization areas on PXP, and focuses on characterizing the aquifer zones with the greatest potential for on-site development.

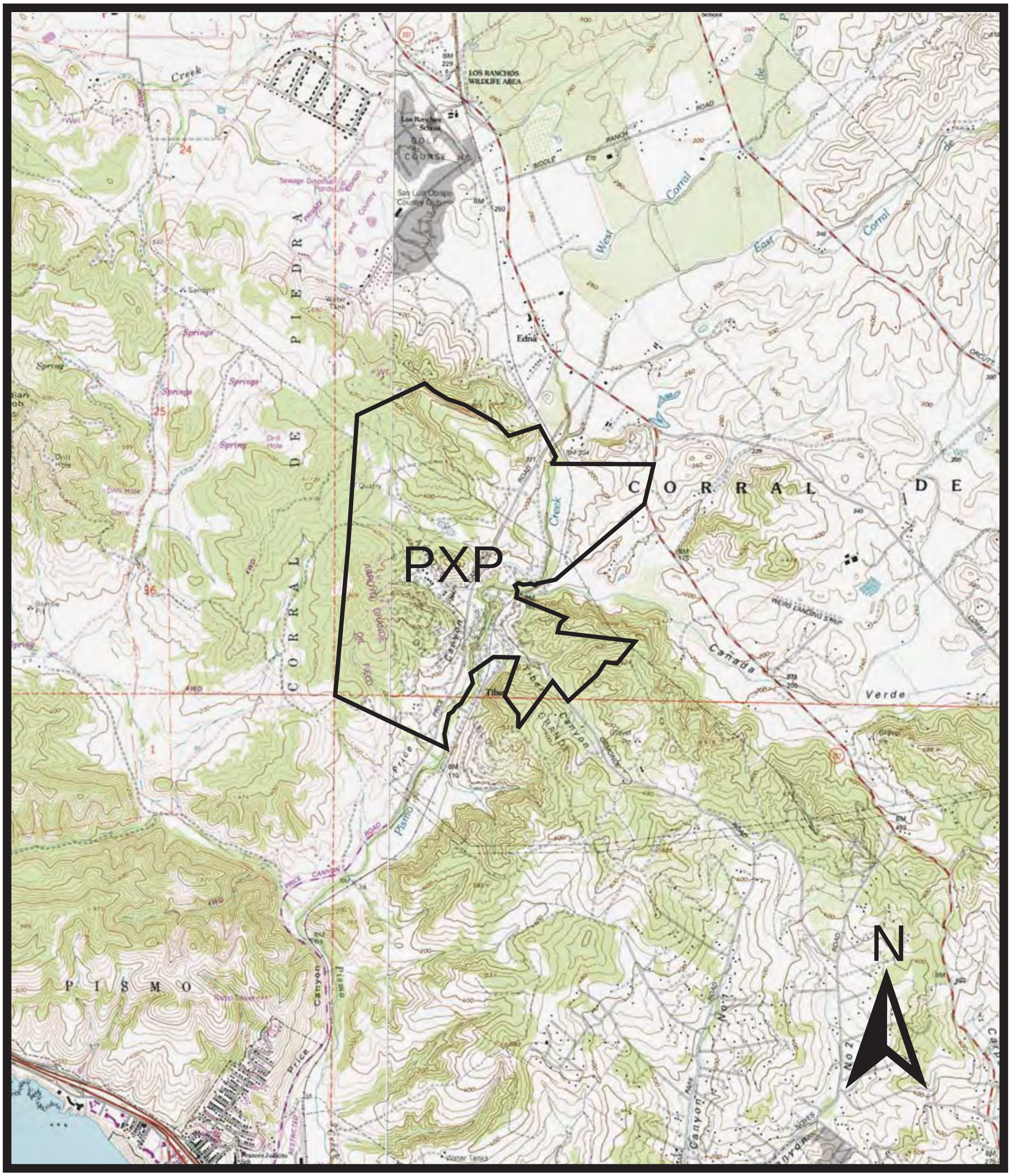
HYDROLOGY

Price Canyon is within the Pismo Creek watershed, which encompasses a total area of approximately 38 square miles, of which approximately 15 square miles drain to the entrance of Price Canyon. Upstream of Price Canyon, Pismo Creek branches into two main tributaries, East Corral de Piedra and West Corral de Piedra. A third tributary, Canada Verde Creek, drains approximately 9.6 square miles and flows into Price Canyon about 3,500 feet downstream of the confluence of the other two tributaries. These tributaries cross the Edna Valley to the southern slopes of the Santa Lucia Range.

Historical Stream Flow Data

There is no permanent stream flow gage on Pismo Creek. Historical data include flows measured at the City of Pismo Beach wastewater treatment plant between 1989 and 1992, and also in 2006 (Balance Hydrologics, 2006), flows measured on PXP property in 2006 (Entrix 2006a), and flow measured at various locations within the watershed in 2007 (Balance Hydrologics, 2008).

Total surface flows at the wastewater treatment plant measured 80 acre-feet in the 1990 water year, 2,040 acre-feet in the 1991 water year, and 4,640 in the 1992 water year. Peak flows were recorded at 3,300



Base Map: USGS Topographic Maps:
Pismo Beach, Arroyo Grande NE
Base Map Scale: 1 inch = 4,000 feet

Figure 1
Study Area
PXP Ground Water Resources Study

Cleath & Associates

cubic feet per second (cfs) on February 15, 1992. Using this historical data, the estimated mean annual flow for Pismo Creek at the wastewater treatment plant was estimated at 5.3 cfs, equivalent to about 3,800 afy (Balance Hydrologics, 2006).

The Entrix flow data at PXP includes base flow measurements ranging from 0.9 to 1.76 cfs, and peak flow measurements of storm runoff at 98 cfs. Hydraulic flow modeling was performed which calculated a bankfull flow of 530 cfs. Mean annual flow for Pismo Creek was estimated by Entrix at 5,800 acre-feet, along with mean monthly and daily flows based on proportioning the records for Toro Creek stream flow by the size of the respective water sheds (Entrix, 2006a).

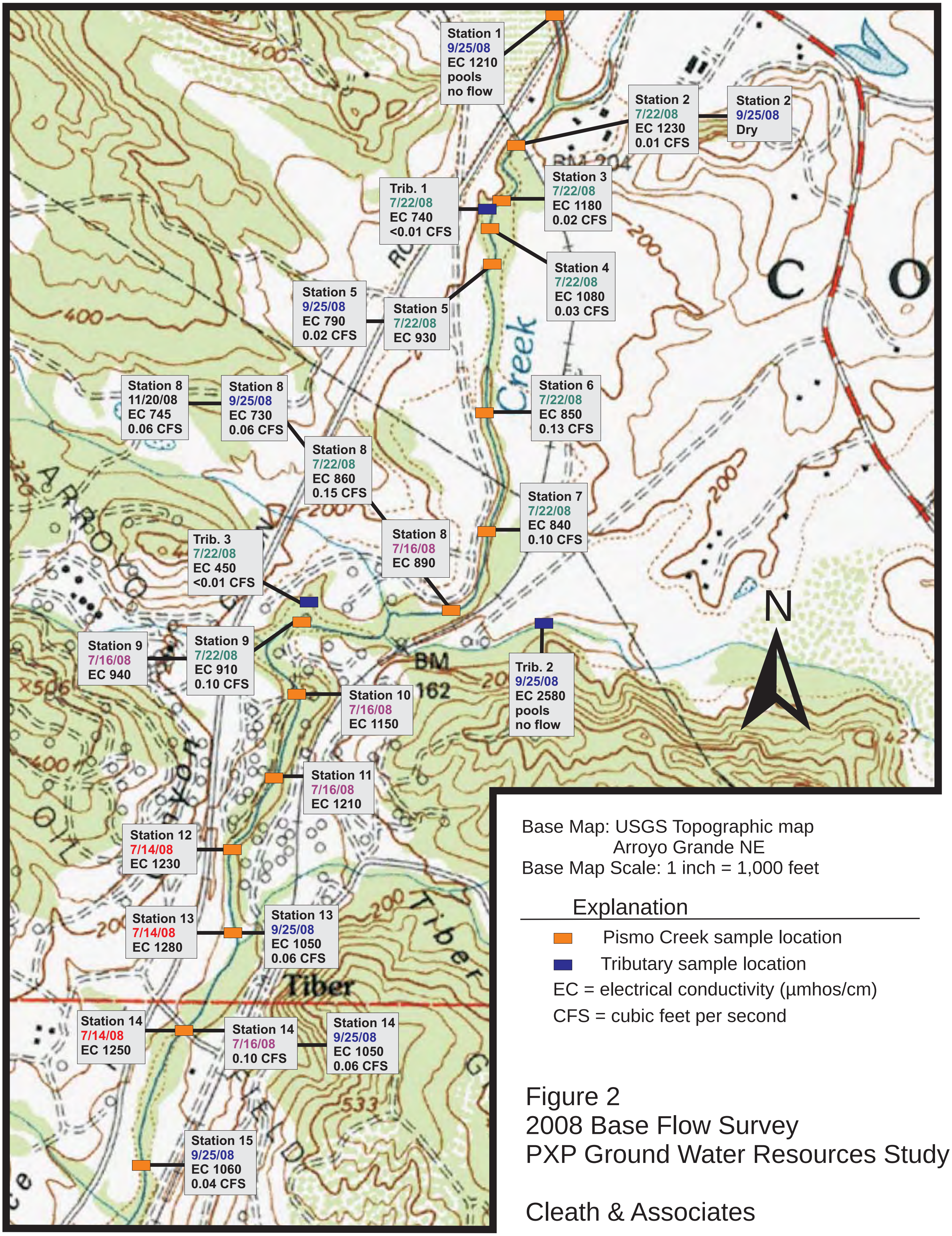
More recently, Balance Hydrologics performed flow modeling to estimate low flow and high flow events on Pismo Creek using a correlation developed between the Pismo Creek watershed and the Upper Lopez Creek watershed (Balance Hydrologics, 2008). The estimated total annual runoff in the Pismo Creek watershed averaged 11,780 afy (mean annual flow), with a median annual flow of 5,300 afy.

2008 Base Flow Survey

Cleath & Associates conducted a creek base flow survey consisting of stream flow and electrical conductivity (EC) measurements along Pismo Creek. The results of the survey with measurement station locations are shown in Figure 2 and summarized in Table 1. Measurements were collected at fifteen locations on Pismo Creek and three tributary locations. Several locations were visited on more than one date. A graph of survey data for July 2008 is shown in Figure 3.

The initial creek survey was conducted July 14 and 16, 2008. Stream flow was measured at the Ormonde Road bridge and EC measurements were collected between Station 14 and Station 8. This reach brackets the published extent of the Pismo Creek Valley ground water subbasin on PXP property.

On July 22, the creek survey was continued upstream to Station 2, with stream flow measurements and EC measurements at regular intervals. Two small tributary inflows were also noted and measured. On September 25, additional stream flow and EC measurements were collected to evaluate changes in base flow over time. A final visit was made to measure stream flow and EC at Station 8 on November 20.



Base Map: USGS Topographic map
Arroyo Grande NE
Base Map Scale: 1 inch = 1,000 feet

Explanation

🟧 Pismo Creek sample location
🟦 Tributary sample location
EC = electrical conductivity (µmhos/cm)
CFS = cubic feet per second

Figure 2
2008 Base Flow Survey
PXP Ground Water Resources Study

Cleath & Associates

Table 1
2008 Base Flow Survey
Pismo Creek at PXP

Location	Distance (feet)	Electrical Conductivity Measurements (µmhos/cm)					Stream Flow Measurements (cfs)			
		7/14/2008	7/16/2008	7/22/2008	9/25/2008	11/20/2008	7/16/2008	7/22/2008	9/25/2008	11/20/2008
Station 1	0				1210				no flow	
Station 2	1000			1230				0.01	dry	
Station 3	1450			1180				0.02		
Station 4	1700			1080				0.03		
Station 5	1950			930	790				0.02	
Station 6	3100			850				0.13		
Station 7	4000			840				0.1		
Station 8	4700		890	860	730	745		0.15	0.06	0.06
Station 9	5850		940	910				0.1		
Station 10	6550		1150							
Station 11	7200		1210							
Station 12	7800	1230								
Station 13	8400	1280			1050				0.06	
Station 14	9200	1250			1050		0.1		0.06	
Station 15	10250				1060				0.04	
Trib. 1	1550			740				<0.01		
Trib. 2	5250				2580				no flow	
Trib. 3	5850			450				<0.01		

Notes:
See report Figure 2 for map locations
EC measured with Hydac Model 910 calibrated using 1,413 µmhos/cm standard
EC measurements are as specific conductance at 25 degrees Celsius
Flow measurements >0.03 cs performed using Global Water digital velocity meter and cross-sectional area (lower flows estimated visually)

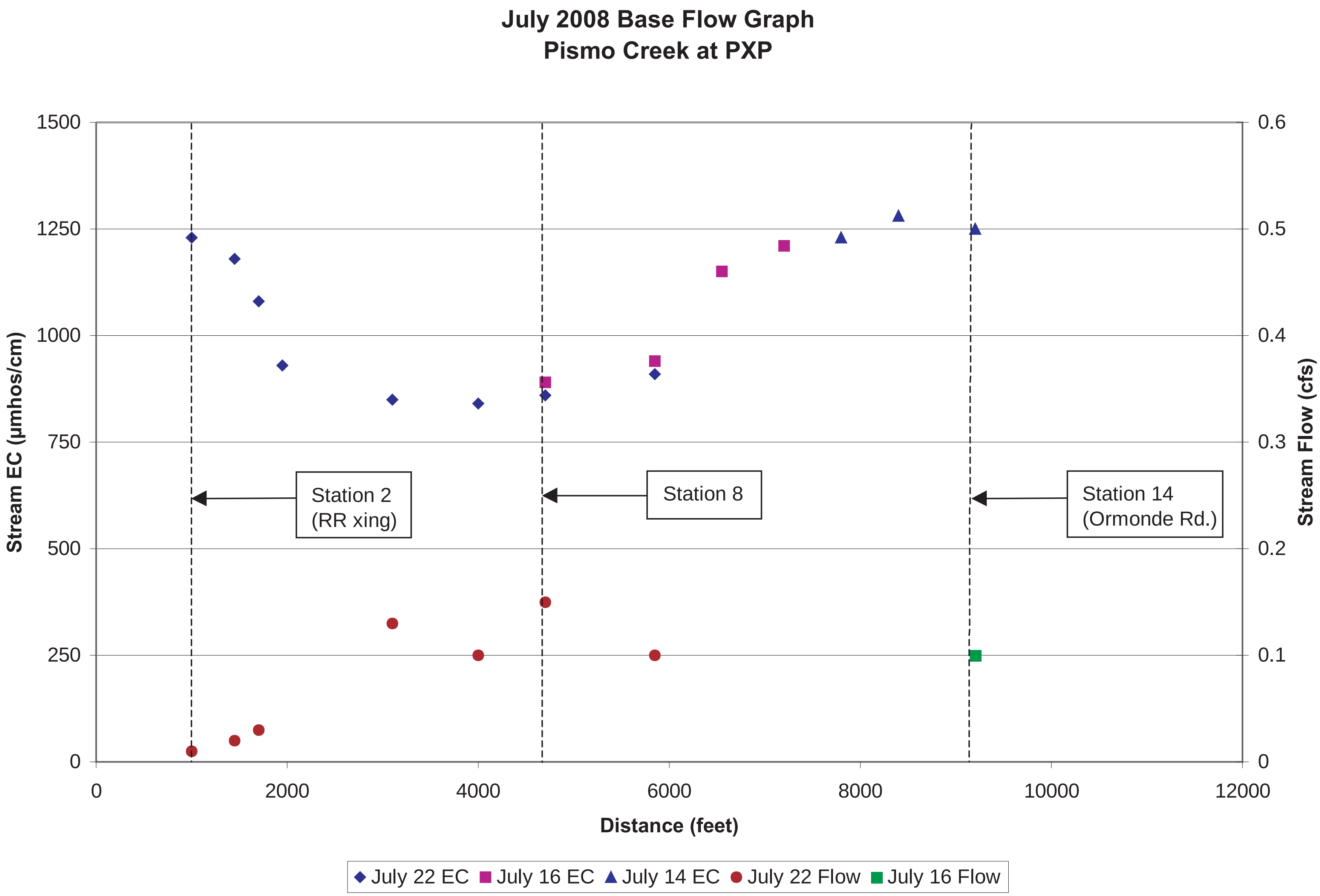


Figure 3
July 2008 Base Flow Graph
PXP Ground Water Resources Study

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Hydrologic Setting

Local rainfall over the last two years has been below average. County Station #147 in Arroyo Grande, where the average rainfall since 1955 has been 16.33 inches per year, recorded 6.68 inches for precipitation year 2006-07 and 12.33 inches for 2007-08. County precipitation station #205.4 at San Luis Obispo County airport, where the average annual rainfall since 1982 has been 21.80 inches, recorded 8.97 inches for 2006-07 and 13.87 inches for 2007-08. PXP lies between these two precipitation stations, with an estimated annual rainfall similar to the county airport (22 inches), based on the 1956-1998 county isohyetal map.

The combined rainfall total for the past two years is one of the lowest two-year precipitation on record. At County station #147, precipitation years 2006-07 to 2007-08 recorded 19.01 inches combined. By comparison, drought years 1975-76 to 1976-77 recorded a total of 19.73 inches, and 1988-89 to 1989-90 recorded 18.31 inches. At County station #205.4, precipitation years 2006-07 to 2007-08 recorded 22.84 inches combined, while the 1988-89 to 1989-90 years recorded 22.71 inches (precipitation records in Appendix A). Therefore, the 2008 base flow measurements could be considered as representative of severe drought conditions.

Pismo Creek flows over sandstone bedrock with no stream channel deposits at Station 1 (Figure 2). At Station 2, the creek flows over a concrete ledge with a 10-foot drop and a fish ladder. Between Station 1 and Station 7, the creek bed consists of stream channel deposits which are incised into valley alluvial deposits. At Station 8, Pismo Creek flows over a sandstone ledge with no stream channel deposits. Downstream of Station 8, through Station 13, the creek flows over stream channel deposits incised into bedrock. Downstream of Station 13 through the south PXP property boundary, the stream flows over stream channel deposits incised into valley alluvial deposits.

Stream Flow/Salinity Measurements

Stream flow entering PXP land at the Pacific Railroad bridge was estimated at 0.01 cfs on July 22, increasing to 0.03 cfs at Station 4. There was a marked increase in flow to 0.13 cfs between Station 4 and Station 6, with a maximum of 0.15 cfs at Station 8. Downstream of Station 8, flow declined to 0.10 cfs at Station 9 and (based on measurement a week earlier at Station 14) remained at approximately 0.10 cfs through the Ormonde Road bridge.

The EC of stream flow entering PXP land at Station 2 was measured at 1,230 micromhos per centimeter (µmhos/cm) on July 22. The surface water salinity decreased, as flow increased, through Station 8, where EC was measured at 860 µmhos/cm. Downstream of Station 8, stream flow salinity increased to 910 µmhos/cm at Station 9, and continued to increase (based on a measurement a week earlier at Station 14) to 1,250 µmhos/cm through the Ormonde Road bridge.

On September 25, flow increased from no flow (pools) at Station 1 to 0.06 cfs at Station 8, and then remained constant through Station 14 (Ormonde Road bridge). EC decreased from 1,210 µmhos/cm in pools at Station 1 to 730 µmhos/cm at Station 8, and then increased to 1,050 µmhos/cm through Station 14. A final measurement at Station 8 was performed on November 22, with flow at 0.06 cfs and EC at 745 µmhos/cm.

Stream Flow/Ground Water Interaction

Pismo Creek is a gaining stream between the railroad bridge and Station 8. The contributions to stream flow are interpreted to come from surfacing ground water. Most of the increase in base flow occurs between Station 4 and Station 6. Station 6 is where the Indian Knob fault is inferred to cross beneath the alluvial deposits. This fault is likely a ground water barrier, where ground water flow backs up and pressures build, forcing flow up into the overlying alluvial deposits, which drains into Pismo Creek.

The main source of the base flow is not interpreted to come from Edna Valley underflow, where ground water is more mineralized than beneath the northern PXP parcels. The EC of ground water from PXP wells near Stations 4 and 5 has been measured between 350 µmhos/cm and 600 µmhos/cm (Appendix B), compared to EC values greater than 770 µmhos/cm in Edna Valley ground water near the entrance to Price Canyon.

Static water levels at PXP wells were also measured above the adjacent creek invert elevation, which is incised an estimated 25 feet below the alluvial plain. Depth to water in PXP Well 3 measured at 18.9 feet on September 25, 2008. This inflow of local ground water to the creek results in increasing flow and lower salinity through Station 8.

At Station 8, all underflow surfaces as stream flow. Station 8 is at the upstream end of the oil field. Oil seeps and tar can be observed issuing from the Pismo Formation sandstone at Station 8 and at points downstream. The salinity of Pismo Creek increases without an apparent increase in surface flow downstream of Station 8, although stream channel deposits in the creek bed are present, so there could be an increase in the net volume of water moving downstream (including underflow) without an observed increase in surface flow.

Potential sources of salt loading downstream of Station 8 include Canada Verde Creek inflow (Tributary 2 on Figure 2; 2,580 µmhos/cm EC) and water seeps from bituminous sandstone zones. Historical mineral analyses of oil field wastewater show an EC range of 1,200 to 1,900 µmhos/cm in T31S/R13E Section 31, and 7,352 µmhos/cm in a sample from T32S/R13E Section 6, which is south of Ormonde Road (DWR, 1969). The higher salinity in oil field produced water on the south side of the oil field may be a result of tapping older, less permeable deposits. Data from shallow sentry wells near the Ormonde Road bridge show EC's of 1,100 µmhos/cm to 1,700 µmhos/cm (Entrix, 2006b). PXP oil-field produced water EC was reported at 3,000 µmhos/cm in 2006 (Entrix, 2007). Tributary 3, a small drainage on the west side of Pismo Creek, is a source of decreasing salinity to Pismo Creek, based on a measurement of 450 µmhos/cm during the July 22 survey.

In July, there was a decrease of 370 µmhos/cm in stream flow EC between Station 2 and Station 8, then an increase of 360 µmhos/cm through Station 14, resulting in a net decrease in stream flow EC of 10 µmhos/cm across PXP land. In September, there was a decrease in surface water EC of 480 µmhos/cm between Station1 and Station 8, then an increase of 320 µmhos/cm through Station 15, for a net decrease of 160 µmhos/cm EC across PXP land.

There was a greater net decrease in stream flow EC in September, compared to July, because Pismo Creek stopped flowing onto PXP land from the Edna Valley in September. This also resulted in a lower overall stream EC at the Ormonde Road bridge, which declined from 1,250 µmhos/cm in July to 1,050 µmhos/cm in September.

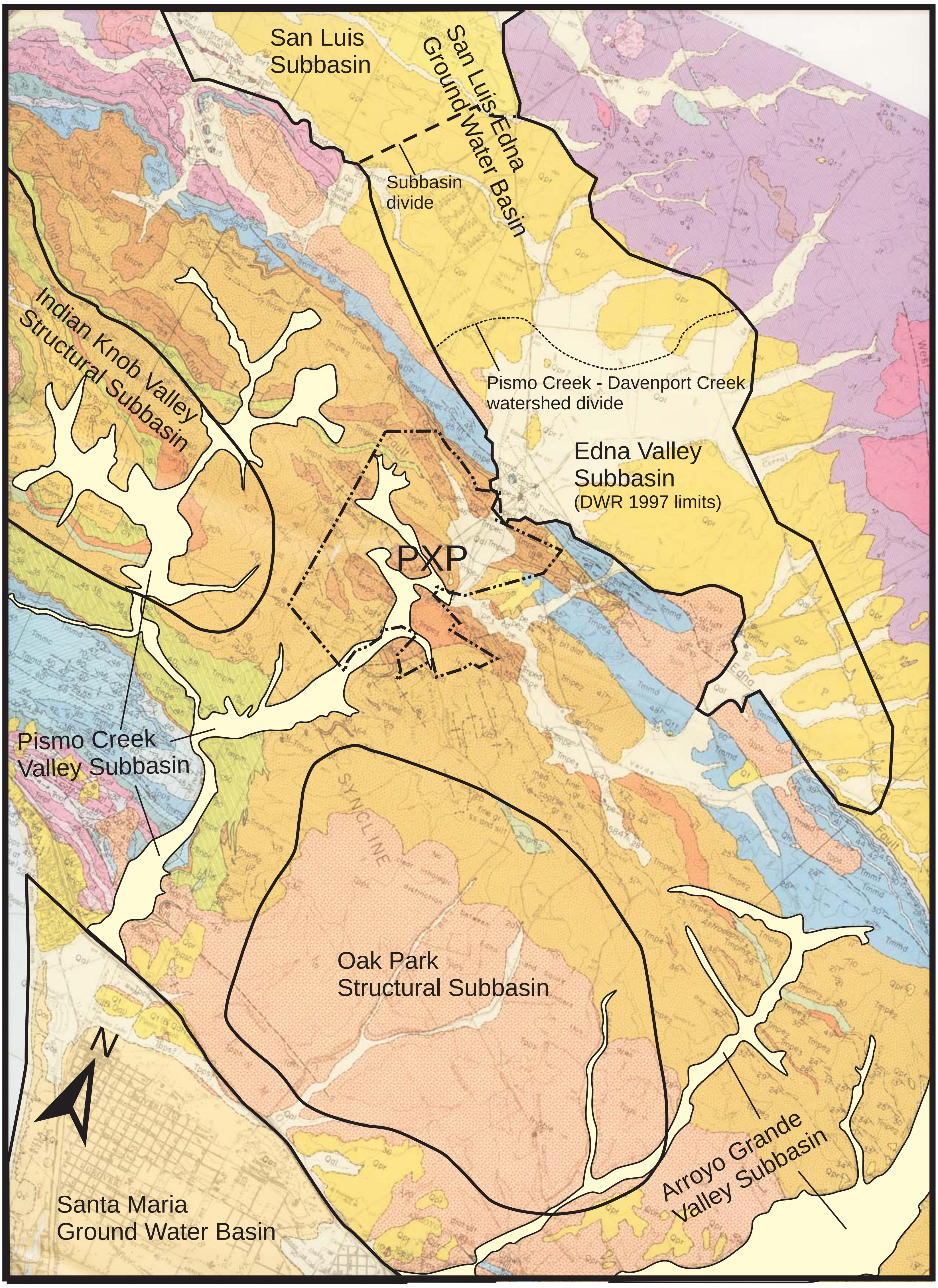
The watershed for Canada Verde Creek is 9.6 square miles, which is approximately five square miles less than West Corral de Piedra and East Corral de Piedra combined. Deep pools were observed in Canada Verde Creek, but no perceptible flow. No increase in base flow was observed on Pismo Creek attributable to Canada Verde.

REGIONAL HYDROGEOLOGY

Regional hydrogeologic features surrounding PXP land are shown in Figure 4. These features include ground water basins and subbasins recognized by the California Department of Water Resources (DWR), along with two structural subbasins which have been defined by Cleath & Associates in prior work. The structural subbasins are areas where ground water aquifers have been identified and characterized, and are within the San Luis-Pismo block, part of the Pismo structural basin.

San Luis-Edna Ground Water Basin

This ground water basin, also referred to as the San Luis Obispo Valley ground water basin, is DWR basin number 3-9. The division between the San Luis and the Edna subbasins is a subsurface divide just south of the County airport. Originally, the Edna subbasin was called the Pismo basin (DWR, 1958, Bulletin 18), and included the alluvial deposits in upper Price Canyon (on PXP land) through the confluence with Canada Verde Creek. By 1975, outlines of basin 3-9 had eliminated the portion entering PXP land (DWR Bulletin 118), and in 1997, the DWR released a draft report which further constrained the subbasin limits by considering that significant portions of the Paso Robles Formation formerly within the subbasin were unsaturated. These revised subbasin limits encompass approximately seven square miles (Figure 4).



Base Map: Hall, 1973, Geology of the Arroyo Grande Quadrangle
Base Map Scale: 1 inch = 4,000 feet

Legend:

Qal = alluvial deposits
Qt = terrace deposits
Qpr = Paso Robles Formation
Tpps = Squire sandstone (Pismo Fm.)
Tmpm = Miguelito Member (Pismo Fm.)
Tmpe = bituminous Edna sandstone (Pismo Fm.)
Tmpe2 = non-bituminous Edna sandstone
Tmpe3 = coarse grained Edna sandstone
Tmpe4 = hard buff to gray Edna sandstone
Tmpec = Edna conglomerate
Tmped = dolomitic Edna sandstone
Tmmd = mostly diatomite (Monterey Fm.)
Tmmc = cherty shale (Monterey Fm.)
Tmot = tuff (Obispo Fm.)
Tmor = resistant tuff (Obispo Fm.)
s = serpentinite and ultrabasic rocks
Jf = Franciscan Formation

Figure 4
Regional Hydrogeologic Features
PXP Ground Water Resources Study

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The more productive irrigation wells in the Edna subbasin produce mainly from Paso Robles Formation terrestrial deposits to approximately 150 feet depth and from an underlying marine sand facies with shell hash zones that extends up to 500 feet depth and may correlate to Careaga Formation deposits in other areas. Well capacities from these aquifers can be up to several hundred gallons per minute (gpm).

The ground water in storage in the Edna Valley portion of the basin was estimated to range from 28,000 to 32,000 acre-feet during the period from 1969 through 1993, with the average for the entire period at 31,000 acre-feet. The average total surface inflow entering the Edna Valley portion of the basin is estimated at 2,400 acre feet per year (afy). The long-term dependable yield of the subbasin was originally estimated at 2,000 afy (DWR, 1958) and most recently estimated at 4,000 to 4,500 afy (DWR, 1997 Draft Report).

The subsurface hydraulic connection between the Edna subbasin and PXP water-bearing zones is restricted by faulting, which acts as a barrier to ground water flow. When the aquifers of Edna Valley are fully saturated, subsurface flow into Price Canyon may occur through the alluvial deposits.

Santa Maria Ground Water Basin

The Santa Maria ground water basin (DWR basin 3-12) covers approximately 288 square miles, of which approximately 184 square miles are within San Luis Obispo County. The main basin lies between the Pacific Ocean and the Wilmar Avenue fault, which generally parallels Highway 101. One of the three subbasins in San Luis Obispo County, the Pismo Creek Valley subbasin, is shown extending onto PXP land (DWR, 2002).

There has been some confusion regarding hydrogeologic information for the Pismo Creek Valley subbasin, which appears to stem from the use of Pismo basin in the 1958 DWR Bulletin 18 to describe the Edna subbasin. In 1975, DWR Bulletin 118 listed values for the Pismo Creek Valley Subbasin (DWR subbasin 3-10) that do not correspond to the subbasin as mapped in lower Price Canyon. For example, the area of the subbasin was listed as 10 square miles, with 30,000 acre-feet of storage capacity and wells averaging 350 gpm. These values have been quoted for the subbasin as recently as this year in the PXP Produced Water Reclamation Facility Subsequent Final EIR (Padre, 2008).

The 2002 DWR Southern District report on the Water Resources of the Arroyo Grande-Nipomo Mesa Area cleared up the confusion by identifying 1.9 square miles of alluvial deposits in Price Canyon and tributary canyons as comprising the Pismo Creek Valley subbasin of the Santa Maria ground water basin. The previous erroneous subbasin information has been removed from the current DWR Bulletin 118 (2003, updated 2004).

Information developed to date by the DWR for the Pismo Creek Valley subbasin includes surface area (1,220 acres), average weighted specific yield of the deposits (11.2 percent), storage capacity (2,000 acre-feet), and average annual subsurface inflow to the main Santa Maria ground water basin across the Wilmar Avenue fault (100 afy).

As noted above, portions of the subbasin extent into the study area (Figure 4). More details of the Pismo Creek Valley subbasin on PXP property are developed below under Site Hydrogeology.

San Luis-Pismo Structural Block

The San Luis-Pismo structural block is one of several horst-graben like structures in the Pismo basin, a regional tectonic feature. The block trends northwest-southeast between the Hosgri and Huasna fault zones and is flanked by the Wilmar Avenue fault to the south and the Edna fault zone to the north in the Price Canyon area. The structural subbasins identified herein are developed along the Pismo syncline, which is the dominant structural feature in the block.

Indian Knob Valley Subbasin

The "Indian Knob Valley" is not a formal name but has been assigned in recent studies to the topographic depression due south of Indian Knob, east of Gragg and Squire Canyons and west of Price Canyon. Within the valley, the beds have been folded, forming a syncline that plunges to the west into the San Luis Obispo Creek watershed. The syncline is bounded on the northeast by the Indian Knob fault.

Water-bearing beds within Indian Knob Valley include the Gragg and nonbituminous Edna members of the Pismo Formation. Also included in the valley are non water-bearing claystones and siltstones of the Miguelito member of the Pismo Formation, bituminous sandstone of the Edna member, and diatomite and shale of the Monterey Formation. To the west, the Squire member sandstone crops out along the synclinal axis, but this sandstone is much less permeable than the Gragg and Edna members.

Both the Gragg member and the Edna member have sufficient permeability and thickness locally to provide greater than 50 gpm capacity wells. By comparison, the Squire member typically provides less than10 gpm capacity to wells. Springs issue out of these two members of the Pismo Formation and contribute to the flow in the tributary to Pismo Creek and associated alluvial deposits. The Indian Knob Valley subbasin is structurally and hydraulically isolated from water-bearing zones beneath PXP.

Oak Park Subbasin

This subbasin encompasses approximately 6,200 acres, and is defined by the areal extent of a 300-foot thick fine to medium quartz sand aquifer. The subbasin is developed along the Pismo Syncline, where a plunging and then rising fold axis forms a bowl structure centered in the Arroyo Grande Oak Park area.

There are two or three shallower (and thinner) sand aquifers overlying the main zone, with thick clayey interbeds. The main (deep) aquifer has only been tapped by wells along the subbasin margins, as it reaches depths in excess of 1,000 feet beneath much of the subbasin interior. Wells completed in the deep aquifer provide capacities in excess of 50 gpm to wells. The Oak Park subbasin is structurally and hydraulically isolated from water-bearing zones beneath PXP.

SITE HYDROGEOLOGY

Water bearing deposits within the study area include younger (Holocene) alluvium on the canyon floor and the lower Pliocene sandstone of the Pismo Formation, which underlies the alluvium and is laterally extensive. The younger alluvium is not saturated at depth in all locations where it has been mapped, and forms a thin veneer covering less permeable sandstones throughout the oil field area. Site geology is shown in Figure 5.

Both heavy oil and water are produced from the Edna member of the Pismo Formation. Bituminous tar sands crop out at ground surface throughout the oil field area, and oil seeps are present in Pismo Creek. Historically, portions of the bituminous sandstone were mined from surface pits. Current oil field production taps sandstone zones between approximately 500 and 1,400 feet depth. The ratio of produced water to produced oil from the oil-bearing zones of the Edna sandstone is approximately 8:1 (Padre, 2008). Oil field produced water is currently heated and re-injected into the subsurface to enhance oil recovery. Current PXP Plans for improving oil recovery efficiency (along with oil field expansion) include treatment and alternate surface disposal for produced water. The development, treatment and disposal of produced water has been evaluated by others and is not the focus of this report.

Pismo Creek Valley Subbasin Alluvial Deposits

The limit of the Pismo Creek Valley subbasin in Price Canyon, as mapped by the DWR (2002), has been challenged by prior investigators. In 2007, WZI conducted an evaluation of the Pismo Creek alluvium and concluded that no alluvial aquifer appears to be present within the Pismo Creek drainage in the area of PXP's property.

One of the objectives of this study was to assess the potential ground water resources of the subbasin available to PXP. The DWR subbasin limits are mapped as the alluvial deposits of Pismo Creek and tributaries between the Wilmar Avenue fault at Highway 101 to the confluence of Canada Verde, which on PXP property roughly corresponds to the alluvial deposits downstream of creek survey Station 8.

As noted earlier, Pismo Creek flows over stream channel deposits incised into bedrock downstream of Station 8 through Station 13. The isolated stream channel (fluvial) deposits, which are perhaps a few feet thick and are restricted to the active creek bed, are not be considered part of the subbasin alluvium.

Base Map: Hall, 1973, Geology of the Arroyo Grande Quadrangle
Base Map Scale: 1 inch = 2,000 feet

Legend:

Qal = alluvial deposits
Qpr = Paso Robles Formation
Tpps = Squire sandstone (Pismo Fm.)
Tmpm = Miguelito Member (Pismo Fm.)
Tmpe = bituminous Edna sandstone (Pismo Fm.)
Tmpe2 = non-bituminous Edna sandstone
Tmpe3 = coarse grained Edna sandstone
Tmpe4 = hard buff to gray Edna sandstone
Tmpec = Edna conglomerate
Tmped = dolomitic Edna sandstone
Tmmd = mostly diatomite (Monterey Fm.)
Tmmc = cherty shale (Monterey Fm.)

Figure 5
Site Geology
PXP Ground Water Resources Study

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Downstream of Station 13 (near sentry Well MW-1) and through the south PXP property boundary, the stream flows over stream channel deposits incised into alluvial deposits. The effective limits of the Pismo Creek Valley subbasin on PXP land is shown in Figure 6.

Available subsurface information has been used to construct geologic cross-section A-A' (Figure 7). As shown in the cross-section, the Pismo Creek alluvial deposits are unsaturated upstream of sentry Well MW-2. Based on the creek observations and the available subsurface information, the effective upstream limit of the Pismo Creek Valley subbasin is near the Ormonde Road bridge.

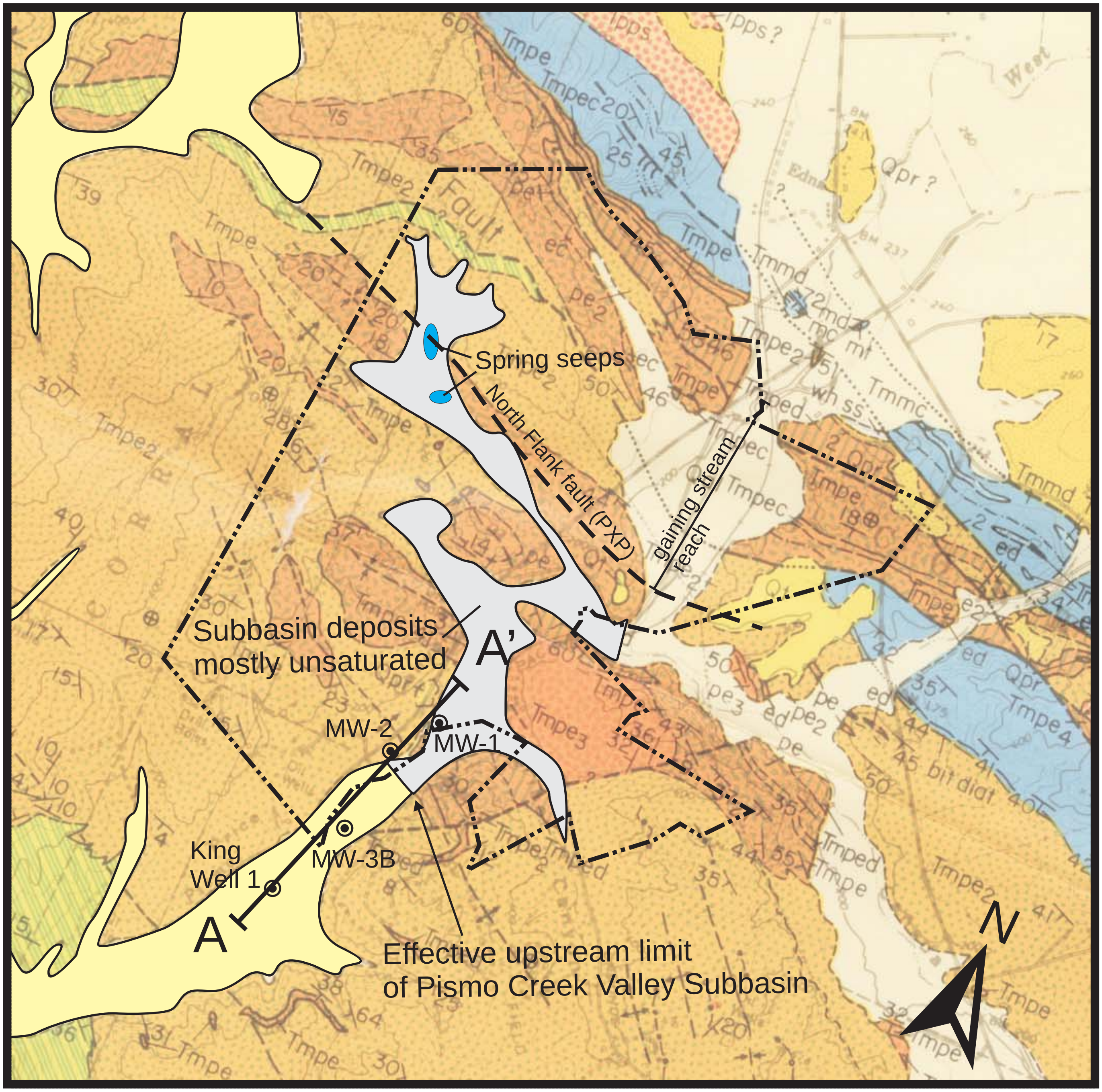
Ground water well installation and monitoring reports for Sentry Wells 3A and 3B indicate both oil and water are present in the alluvial between the Ormonde Road bridge and the southern property line (Entrix, 2006b). There is no viable ground water resource development potential in the Pismo Creek Valley subbasin on PXP property.

Northern Alluvial Deposits

Price Canyon begins at a narrows near the railroad bridge over Pismo Creek, which is formed by a resistant dolomitic sandstone. Below this narrows, the canyon widens significantly on the northern portion of PXP land, where the existing ground water wells are located. The creek is estimated to be incised approximately 25 feet into alluvial deposits in this area (Station 2 through Station 7). Historical photos show a road crossing in1947 which was interpreted to indicate that the creek was not substantially incised in the past (Balance Hydrologics, 2008). During the 2008 creek survey, however, the old road was found and used to walk down to the current creek invert, indicating the creek was already substantially incised when the road was built.

Resistivity logs for the wells and other test holes completed in this area suggest a change in lithology, formation, and/or water quality at approximately 75 feet depth beneath the canyon floor (Appendix B and Appendix C). Drillers logs for some of these holes also suggest a change in formation or penetration rates between about 60 and 80 feet depth. While not conclusive, the information is interpreted to indicate that deep, saturated alluvial deposits are present in the vicinity of the PXP water wells.

Development of these alluvial deposits appears possible, as sands and gravels are identified in the drillers lithologic logs. For practical purposes, given the relatively good capacity and ground water quality of existing wells completed in the deeper sandstone unit, development of ground water resources in the overlying alluvial deposits would probably be unnecessary and redundant in terms of overall yield, because the alluvium and underlying sandstone aquifer are hydraulically connected. Nevertheless, a discussion of potential alluvial well yield is helpful to understanding the dynamics of ground water resources at PXP.



Base Map: Hall, 1973, Geology of the Arroyo Grande Quadrangle
Base Map Scale: 1 inch = 2,000 feet

Figure 6
Limits of Pismo Creek Valley subbasin on PXP
PXP Ground Water Resources Study

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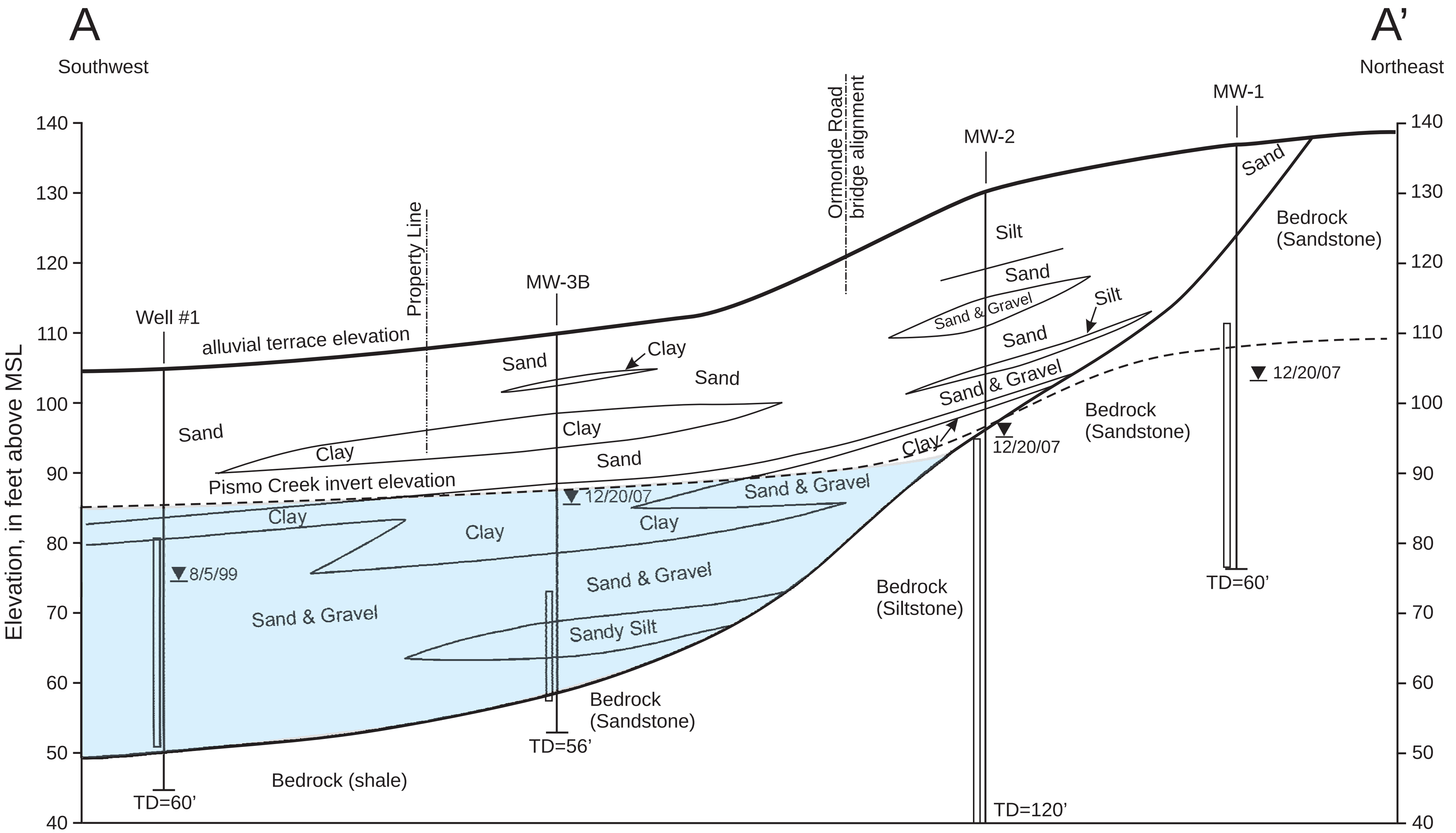

Explanation

▼12/20/07 Static ground water level with date of measurement

Well location showing perforated sections

▨ Saturated alluvial deposits of Pismo Creek Valley subbasin (below creek invert elevation)

Scale:
1 inch = 400 feet horizontal
1 inch = 20 feet vertical

Figure 7
Geologic Cross-Section A-A'
PXP Ground Water Resources Study

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Base Flow

As previously shown, the last two precipitation years (2006-07 and 2007-08) qualify as severe drought years. Base flows in Pismo Creek were measured in 2007 by Balance Hydrologics (Appendix D) and 2008 by Cleath & Associates (Table 1). A review of the flow data indicates that on June 6, 2007, the base flow originating on PXP from the northern alluvial deposits was approximately 0.13 cfs (Balance Hydrologics map point 13 flow minus map point 16 flow; Appendix D). On July 22, 2008, the base flow from these alluvial deposits was approximately 0.14 cfs (Station 8 flow minus Station 2 flow). By September 25, and through November 20, base flow over the reach had declined to 0.06 cfs.

For yield calculations, the base flow data is interpreted to indicated that over a two-year severe drought period, there would be at least 0.1 cfs base flow average, equivalent to 70 afy. This value may also be considered the minimum base flow for longer droughts, based on the 1989-90 Pismo Creek stream flow measurements, and considering that average annual rainfalls increase with longer drought periods. The 1986-87 through 1989-90 four-year drought averaged 10.97 inches per year at Station #147, compared to 9.51 inches per year for 2006-07 and 2007-08.

As recorded by Balance Hydrologics, 80 acre-feet of flow was measured at the wastewater treatment plant gaging site in 1989-90. Additional base flow (minus outflow from pumping) between PXP and the Price House, approximately 2,000 feet upstream of the wastewater treatment plant, was 0.03 cfs in June 2007 (Balance Hydrologics map point flow 20 minus map point 13 flow; Appendix D). Assuming a proportionately lower value of 0.02 cfs for the average additional base flow downstream of PXP during severe drought, the total flow at the Price House in June 1989-1990 would be estimated at 86 afy (0.12 cfs average flow), very close to the actual record at the wastewater treatment plant.

Alluvial Water in Storage

The alluvial area between the narrows and the oil field encompasses close to 80 acres. Assuming an average saturated thickness of 25 feet (between 0 and 50 feet saturated thickness), and a nominal specific yield of 15 percent, there would be approximately 300 acre-feet of ground water in storage, although only a fraction of this storage would be available to shallow alluvial wells. Well capacities could vary significantly, and may approach 75 gpm, based on records of alluvial wells downstream in the canyon.

Recharge to the alluvial deposits currently occurs from percolation of precipitation and subsurface inflow from the underlying Pismo Formation. Following resource development, as water levels are lowered, stream seepage would also contribute to recharge.

Sustainable Yield

A nominal 20 percent deep percolation of precipitation is estimated over approximately 80 acres of alluvial deposits. Assuming precipitation similar to County Station #205.4, the total percolation of precipitation for the alluvial deposits in severe drought year 2006-2007 would have been approximately 12 acre-feet.

Subsurface inflow from Pismo Formation sandstone would contribute at least 70 acre-feet, based on the 0.1 cfs minimum average annual base flow. Since this base flow was issuing from the alluvial deposits, it would be available for capture by shallow wells.

Capture of stream inflow from the Edna Valley would also be a component of recharge. Given the continuing development of the Edna Valley, during severe drought this value is considered to be negligible.

A fourth consideration on sustainable yield for the alluvial deposits would be utilization of ground water in storage during drought. Only a fraction of the 300 acre-feet of alluvial water in storage could be drained by wells. With diminishing return on pumping as water levels decline, up to 100 acre-feet may be available from storage during drought. If this is spread over two consecutive years of severe drought, the storage yield would be 50 acre-feet per year. Periods of more than two years without significant surface inflow from the Edna Valley are unlikely.

In summary, with 12 acre-feet per year percolation of precipitation, at least 70 acre-feet per year subsurface inflow from the Pismo Formation, and 50 acre-feet per year of available storage during severe drought, the northern alluvial deposits on PXP parcels could reliably be developed to provide an estimated **130 afy** per year. Outside of drought, the aquifer could yield significantly more water on an annual basis, however, as the underlying Pismo Formation is developed at PXP, the alluvial deposits yield will decline proportionately. Construction and testing of shallow alluvial wells would be necessary to confirm these estimates.

Pismo Formation Aquifers

Ground water flow in the more permeable members of the Pismo Formation (the Gragg and Edna sandstones, and in some areas, the Squire sandstone) is typically through primary permeability, or a combination of primary and secondary permeability, rather than only through fractures. Cementation of the sandstones reduce both the potential for ground water flow and the amount of water in storage. The softer and more friable the zone, the greater potential for successful development with wells. Tar and oil sands within the Edna member also interferes with ground water flow. Oil sands are predominantly found at greater depth than tar sands. Bitumen content does not necessarily correlate with the local stratigraphy due to faulting and lateral variations in permeability.

Ground water aquifers within the Edna sandstone have the greatest potential for development at PXP. The existing PXP water wells tap one of these zones, although the current level of ground water production is only a few acre-feet per year.

The PXP property has been divided into five areas for the purposes of water resource characterization within the Edna sandstones (Figure 8). Area 1 lies within the Edna fault zone. Area 2 lies between the Edna fault zone and the Indian Knob fault (as mapped by Hall, 1973). Area 3 lies between the Indian knob fault and the North Flank fault, the latter of which is located based on information provided by PXP. These two faults are inferred to intersect northwest of PXP. The eastern boundary of Area 3 is the contact between the Pismo Formation and the Monterey Formation. Area 4 consists of the developed oil field southwest of the North Flank fault and north of the Martin fault. Area 5 lies south of the Martin fault (as correlated to an unnamed surface fault trace mapped by Hall, 1973).

Three target aquifer zones have been identified in the Edna sandstone beneath PXP property. Figure 9 shows the plan view extent of these zones. Figure 10 shows a geologic cross-section that includes two of the zones.

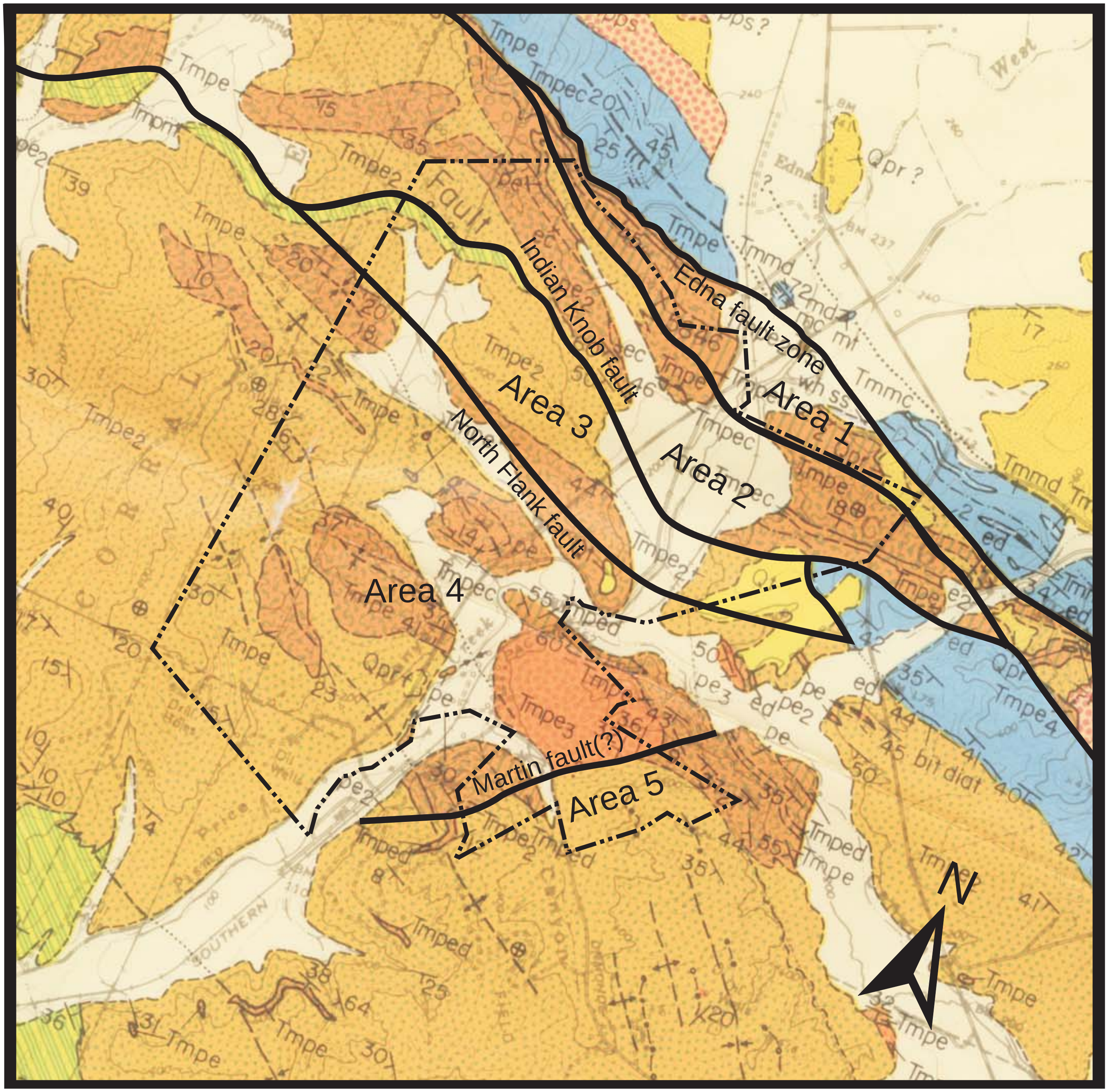
Area 1

A massive, cemented, dolomitic sandstone in Area 1 forms a resistant ridge with steep southwest-facing slopes that coincide with the down-dropped footwall of the Edna fault zone splay. Beneath the dolomitic sandstone are bituminous sands. Subsurface information from abandoned oil well “Mello No. 2" shows potential aquifer zones through 280 feet depth, but no lithologic information above 400 feet to evaluate tar and oil presence, which can interfere with ground water production. Spotty to fair oil saturation is reported below 412 feet depth. Given the limited areal extent of the saturated bituminous sands, and the indication of oil in the underlying materials, no target aquifers with ground water development potential have been identified in Area 1.

Area 2

The largest aquifer zone (Zone A2) identified on PXP is in Area 2. It includes a conglomerate and mostly non-bituminous, soft and friable sands which are penetrated by the existing PXP water wells and by abandoned oil test hole Signal “Rock” No. 75, which also contains information on lithology above and below the aquifer zone. Above Zone A2, which is correlated as between the top of the conglomerate at approximately 500 feet depth and the approximate base of fresh water sands at 1,200 feet.

The existing wells in Zone A2 operate at 150 gpm, but have been tested at rates in excess of 200 gpm. Well 1 is the active well and Well 2 is a backup. Well 3 is currently out-of-service. A summary of PXP water well information is included in Table 2.



Base Map: Hall, 1973, Geology of the Arroyo Grande Quadrangle
Base Map Scale: 1 inch = 2,000 feet

Figure 8
Resource Characterization Areas
PXP Ground Water Resources Study

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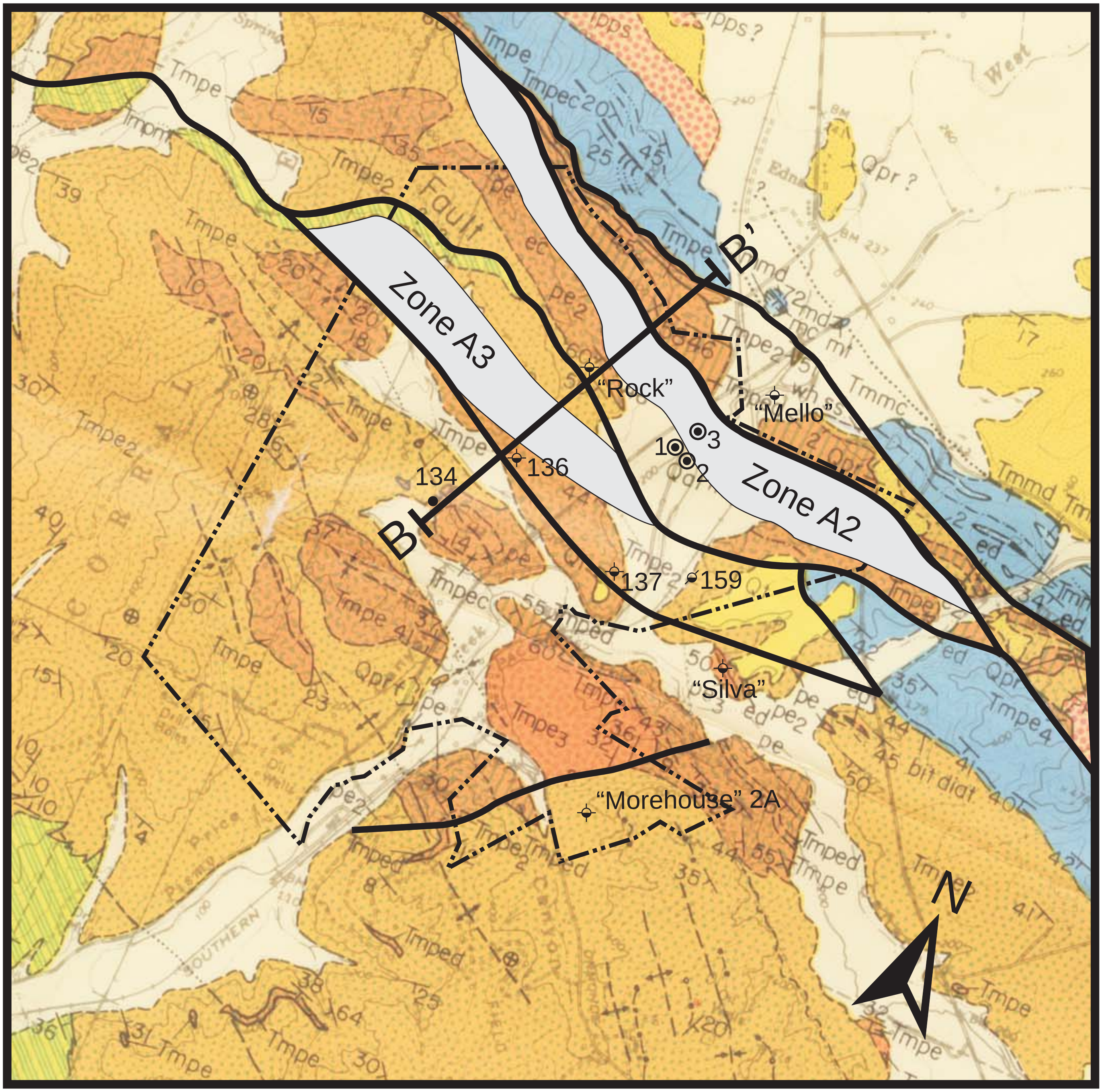

Base Map: Hall, 1973, Geology of the Arroyo Grande Quadrangle
Base Map Scale: 1 inch = 2,000 feet

Explanation

◉ Ground water well

⌖ Oil well (abandoned)

● Oil well

ZONE A2 Target aquifer zones

Figure 9
Target Aquifers Zones
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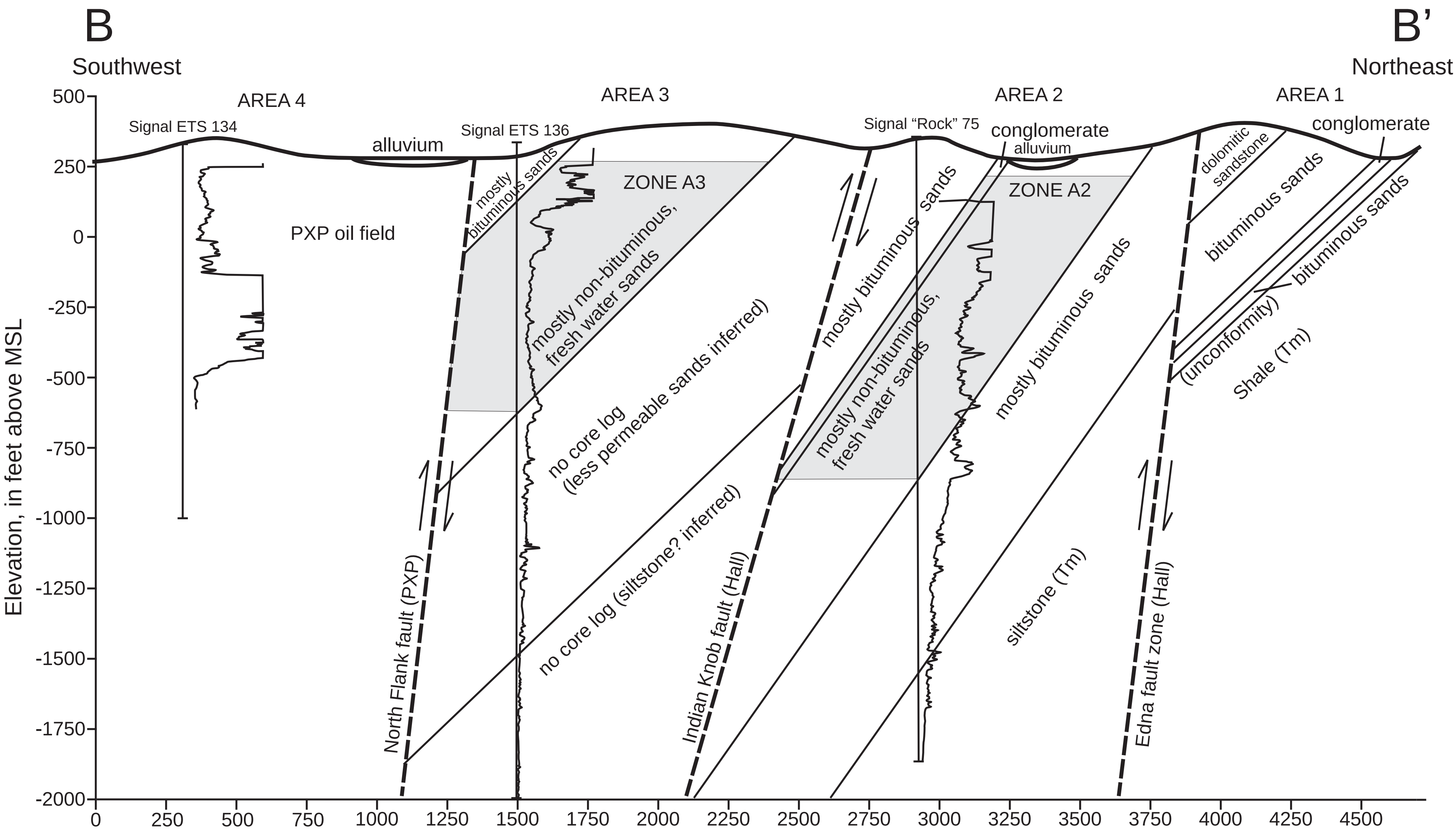

Explanation

Oil corehole location with resistivity log

ZONE A2	Target aquifer zones

Scale:
1 inch = 500 feet horizontal
1 inch = 500 feet vertical

Figure 10
Geologic Cross-Section B-B’
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Table 2
PXP Water Well Information

Information	Well 1	Well 2	Well 3
Drilled	November 26, 1979[1]	March 17, 1980	March 26, 1980
Casing[2]	10-inch PVC	8-inch PVC	8-inch PVC
Depth	226 feet (measured)	295 feet (measured)	300 feet (reported)
Perforations	not available	200-300 feet	220-300 feet
1980 Depth to Water	not available	March 1980: 12 feet	March 1980: 8 feet
2008 Depth to Water	June 17, 2008: 27 feet	June 17, 2008: 23 feet	Sept. 25, 2008: 19 feet
Pump	15 HP submersible	25 HP submersible	30 HP submersible
Status	active	stand-by	out-of-service
Open Discharge Flow	230 gpm	245 gpm	unknown

NOTES:

[1] Based on depth correlation with e-log for Test Hole 2.

[2] Driller reported PVC construction for Well 2 and Well 3, although wellhead is steel at surface. Well 1 is also assumed to be PVC (with steel wellhead).

Water demand at PXP includes domestic use for the office trailer and service to emergency wash stations, irrigation for landscaped areas near the main entrances to the oil field facilities, dust control for occasional grading activities, make-up water for the stream generators (primary supply for stream generators is oil field produced water), and maintaining fresh water reservoirs (less than 2 acres in surface area). The cumulative demand for these water uses is estimated to be less than 10 acre-feet per year.

Zone A2 Ground Water in Storage

Zone A2 encompasses approximately 145 acres in plan view. In cross-section, the zone is inferred as a parallelogram whose stratigraphic thickness remains constant at approximately 400 feet but whose horizontal width and vertical depth varies laterally as the dips change. A maximum zone depth of 1,200 feet at Signal “Rock” No. 75 (surface dips of 50-60 degrees) is interpreted to diminish to the stratigraphic thickness of approximately 400 feet the southeast, where flat-lying beds are present.

For ground water storage calculations, Zone A2 is divided into three sections. The first section, from the northwest limits to Signal “Rock” No. 75, encompasses approximately 55 acres, with an estimated average saturated thickness of 1,050 feet. The second section, from Signal "Rock" No. 75 to the horizontal bedding symbol on the geologic map, encompasses approximately 60 acres, with an estimated saturated thickness of 725 feet. The third section, from the horizontal bedding symbol to the southeast limit, encompasses approximately 30 acres, with an estimated saturated thickness of 350 feet. The volume of these three sections, when combined with a nominal specific yield of 0.10 for the Edna sands (median value for water-bearing zones of Pismo Formation as reported by DWR, 2002), results in an estimated 11,000 acre-feet of water in storage.

The amount of water available to existing wells is significantly less, however. For example, if the existing PXP wells were limited to drawing water from storage in the middle section (where they are located) and limited to drawing from the upper 125 feet of Pismo Formation (above the perforated intervals of Wells 2 and 3), they would have access to approximately 750 acre-feet of water in storage in the Pismo Formation. When adding the approximate 300 acre-feet of alluvial water in storage, these wells appear to be able to tap close to 1,000 acre-feet in the event of severe drought.

If necessary, access to additional storage can be achieved with deeper wells, such that there would be no constraint on aquifer yield from depletion of storage reserves during drought. The e-log for Test Hole 3 (Appendix C) shows the sand aquifer zone being penetrated beginning at 300 feet depth, which is close to 200 feet deeper than at the other PXP wells. A 500 or 600-foot deep well completed at Test Hole 3 could effectively double the available ground water in storage.

Zone A2 Sustainable Yield

Given no constraint from available ground water in storage in Zone A2 during severe drought, the sustainable yield of the aquifer zone is estimated to be the perennial recharge. Sources of recharge include percolation of precipitation, subsurface inflow, and seepage from the overlying alluvial deposits.

Under existing conditions, the perennial recharge is at least 70 afy, based on the minimum average base flow from these zones during severe drought. As Zone A2 is developed, additional recharge potential would come from increased leakage through the overlying alluvial deposits, which in turn would capture a greater portion of stream flow.

The two-hour aquifer tests conducted at PXP Wells 1 and Well 2 do not provide a clear indication of the aquifer characteristics of Zone A2. The early drawdown and recovery data may be affected by well efficiency considerations and/or casing storage effects. Data from the pumping test also appears to be affected by leakage from the overlying Pismo Creek alluvial deposits and/or delayed drainage (Pumping test data in Appendix B).

The local intrinsic permeability of the Edna sands have been measured in cores from oil test holes. At Signal ETS No. 136, values for the non-bituminous sandstone in Zone A3 between 195 and 940 feet depth (14 samples) ranged from 180 to 691 millidarcys, averaging 400 millidarcys (equivalent to a hydraulic conductivity of 8 gallons per day per foot squared; 1.1 feet per day). This value is greater than the estimated hydraulic conductivity of the deep Pismo Formation aquifer in the Oak Park structural basin (3 gallons per day per foot squared) but conservative for Zone A2, where the lithology includes coarser sands than either the Oak Park deep aquifer or Zone A3.

Alluvial leakage would be estimated using Darcy's law, with an area of 40 acres of saturated deposits and a vertical hydraulic conductivity of 1.1 feet per day (no correction for anisotropy as the beds are dipping at close to 45 degrees beneath most of the alluvial deposits). The vertical hydraulic gradient controls the leakage rate. Currently, the vertical hydraulic gradient is reversed, with more pressure in Zone A2 than the overlying alluvial deposits. As Zone A2 is pumped, the pressure in the aquifer would be reduced, until water begins flowing from the alluvium into the Pismo Formation. If the pressure head in the Pismo Formation goes below the interface with the alluvial deposits, the vertical gradient could reach a maximum of one, which would allow up to 1.1 acre feet per day of alluvial water to leak beneath each acre of saturated alluvial deposits. There appears to be enough hydraulic communication between the alluvium and the underlying Zone A2 to transmit all of the alluvial water in storage, including recharge to the alluvial deposits from stream seepage.

Stream seepage into the alluvium may be approximated by multiplying the seepage capacity of the channel by the average number of days when the stream is flowing. The stream channel through the upper PXP parcels is approximately 10 feet across, although surface flows do not cover the entire channel year-round. A conservative vertical hydraulic conductivity of 2.5 feet per day is assigned to the creek bed and underlying alluvial deposits, based on pumping tests conducted at off-site alluvial wells downstream, where the horizontal hydraulic conductivity is estimated at 25 feet per day.

Using the above assumptions, with 1,500 feet of channel through Area 2, the potential seepage capacity of the stream at full width would be 0.86 acre-feet per day (314 afy assuming year-round flow). A certain amount of bank storage and seepage would also develop during periods of higher flow, which would offset the narrower seepage areas during the low flow periods. Surface inflow from the Edna Valley is not year-round. For the purposes of yield assessment, it is assumed to flow, on average, at least nine months per year). The corresponding stream seepage capacity of the alluvial deposits through Area 2 is estimated at 240 afy. Note that this value is much lower than average annual flows on Pismo Creek.

The final component of recharge to Zone A2 is subsurface inflow from adjacent beds, in particular inflow from zones in Area 2 stratigraphically above Zone A2, which open up in width to the northeast as the Indian Knob fault moves away from the Edna fault zone (Figure 8). This component, along with direct percolation of precipitation, is part of what contributes to the base flow measured at creek survey Station 8. During drought, this is at least 70 afy, as discussed above for the alluvial deposits sustainable yield.

In summary, the sustainable yield of PXP aquifer Zone A2 is estimated to be equal to the perennial recharge of the zone, estimated at **310 afy**. This recharge includes 70 afy of existing percolation of precipitation and subsurface inflow, and 240 afy potential capture of stream flow through leakage from the alluvial deposits.

Area 3

Area 3 includes some alluvial deposits along Pismo Creek, and Pismo Formation aquifer Zone A3. This zone includes mostly non-bituminous, fine sands and silty sands which are penetrated by the abandoned oil test hole Signal ETS No. 136. The electric log signature for Signal ETS No. 136 indicates deteriorating water quality below approximately 980 feet depth. There are spring seeps at the base of this zone along the inferred alignment of the North Flank fault which drain to creek survey Tributary 3 (EC 450 µmhos/cm).

Zone A3 is bounded on the south by a bituminous zone, both in outcrop and in the subsurface, based on oil test holes for Signal ETS No. 137 and No. 159. The bituminous zone limits Zone A3 hydraulic communication with Pismo Creek alluvial deposits.

There are no existing water wells in Zone A3. The anticipated capacity of wells in Zone A3 would be less than equivalent-depth wells in Zone A2, based on finer-grained lithology and a limited hydraulic connection with the Pismo Creek alluvial deposits. Capacities in the 25-75 gpm range should be achievable.

Zone A3 Ground Water in Storage

Zone A3 encompasses approximately 90 acres in plan view and extends approximately 5,000 feet between the west property line and Pismo Creek. In cross-section, the zone is inferred as having a stratigraphic thickness of approximately 530 with a depth of 980 feet at Signal ETS No. 136.

The volume of Zone A3, when combined with a nominal specific yield of 0.10 for the Edna sands, results in an estimated 6,000 acre-feet of water in storage. Even if only 10 percent of this is available to wells, ground water in storage will not be the limiting factor for the sustainable yield estimate.

Zone A3 Sustainable Yield

As with Zone A2, there is no constraint from available ground water in storage in Zone A3 during severe drought, consequently, the sustainable yield of the aquifer zone is estimated to be the perennial recharge. Sources of recharge include primarily percolation of precipitation and seepage from overlying alluvial deposits. Subsurface inflow from other Edna sandstone zones may also contribute to perennial yield.

Approximately 35 acres overlying Zone A2 are covered by alluvial deposits, of which 10 acres are adjacent to Pismo Creek and 25 acres are in a tributary drainage (Figure 9). The remaining 55 acres of Zone 2 outcrops as non-bituminous Edna sands which are estimated to receive 10 percent deep percolation of direct precipitation, for an average of 10 afy.

The hydraulic connection between Zone A3 and the saturated Pismo Creek alluvial deposits, which extend 1,000 feet through Area 3, is uncertain. Pismo Creek stream channel sediments become more clayey in Area 3. The greatest increase in creek base flow, which would be coincident with greater alluvial/stream channel deposit permeability, was measured in Area 2.

There is less potential for recharge to Zone A3 from the alluvial deposits than for Zone A2. Pending further investigation, the effective leakage factor for the stream channel in Area 3 is reduced to 0.25 feet per day (one order of magnitude less than upstream). Using the same methodology as for Zone A2, the resulting perennial recharge to Zone A3 from stream seepage, would be 20 afy. Note that a significant portion of the estimated 300 afy of seepage potential into alluvial deposits in Area 2 could flow into Area 3 alluvial deposits for capture by Zone A3 wells. The 20 afy stream seepage potential into Area 3 alluvial deposits, however, is assumed to be too far downstream to be pulled into Zone A2 wells.

The alluvium/colluvium mantle overlying 25 acres of Zone A3 at higher elevations would transmit recharge it receives from percolation of precipitation into Zone A3. This loose material is mostly sand eroded from the exposed aquifer zone, with good permeability. An estimated 20 percent percolation of direct precipitation is assigned to these deposits, for an annual average recharge of 10 afy. The watershed surrounding these alluvial/colluvial deposits is 65 acres, and would provide additional runoff which could be retained for deep percolation. A nominal 5 percent of the precipitation over the surrounding watershed area is assumed to be available for deep percolation to Zone A3, or 6 afy.

Subsurface inflow from Pismo Formation zones between Zone A3 and the Indian Knob fault is likely. The area of this outcrop is approximately 45 acres. A nominal 5 percent of the precipitation on this area, equivalent to 4 acre-feet, is assumed to deep percolate and to be available for subsurface inflow to Zone A3.

In summary, a sustainable yield of **50 afy** is estimated for aquifer Zone A3. Of this, 20 afy is contingent on a limited hydraulic connection with Pismo Creek alluvial deposits. If the hydraulic connection with alluvial deposits is not severely limited, a large portion of the 300 afy seepage capacity of Pismo Creek in Area 2 could be tapped by wells in Zone A3.

Area 4

Area 4 on PXP consists of the active oil field and extends between the North Flank fault and the southern property boundary. Water resources within permeable zones in this area are mostly stored with heavy oil in the bituminous sands. There are permeable, non-bituminous sands beginning 1,000 feet west of PXP within the Indian Knob structural subbasin. Information from off-site drilling along this subbasin margin indicates Miguelito member siltstones and shales are present at shallow depth, precluding any significant hydraulic connection with Area 4 sandstone zones. There are no aquifer zones targeted for development within Area 4.

Area 5

Area 5 is underlain in part by non-bituminous sandstone southeast of the inferred surface expression of the Martin fault. The Tiber Canyon drainage trends through Area 5 subparallel to fold axes in the Pismo Formation, suggesting a potentially soft, friable sand zone is present in this area. As the possible extension of a minor synclinal fold, however, the friable zone that eroded out as Tiber Canyon may not extend laterally in the subsurface.

A lithologic log to 815 feet depth and related data for Area 5 oil test hole “Morehouse 2A” describes “blue sands” from 230-275 feet and 290-390 feet depth, which are differentiated from “hard sands”. The water level in “Morehouse” 2A was reported at 85 feet (above cement plug at 185 feet), and a “little water” was encountered at 84 feet in the original test hole 2 (ten feet away from 2A). “Morehouse 2A” was drilled in 1920 with a cable tool rig, therefore, if the blue sands had been important water zones, they should have been reported as such in the records. Since there was no mention of water production other than “a little” encountered at 84 feet, it is assumed that the blue sands were not productive water zones, and that there are no significant aquifer zones on PXP land in Area 5 near Tiber Canyon from a perspective of irrigation water use.

Stream Flow Impacts

Development of the northern alluvial aquifer or greater use of existing PXP wells tapping Edna sandstone Zone A2 would likely affect stream flow in Pismo Creek. Development of the Zone 3A sandstone aquifer could also affect flow in Pismo Creek, depending on the degree of hydraulic communication with the creek valley alluvium. This influence would need to be evaluated if water is developed from Zone A3.

Base flow that originates primarily in Area 2 on PXP property will decline in proportion to increased water use at the existing wells. This base flow currently provides water to maintain deep pools in the bituminous sandstone and flow in the riparian corridor during periods when there is no inflows from the Edna Valley. Utilization of base flow at PXP would also result in increased salinity of remaining surface waters during dry periods, as the base flows are shown lower the existing surface water EC by 300-500 µmhos/cm.

Ground water development in excess of base flows (40+ afy) will result in stream seepage during periods when Pismo Creek receives surface inflows from the Edna Valley. The majority of the seepage would occur following the onset of winter rains, and would replace the water drained from the alluvial deposits during the summer months. At maximum development for Zone 2A, the rate of stream seepage would average 0.33 cfs.

WATER QUALITY

The water quality in existing PXP Wells 1 and Well 2 (Pismo Formation Zone A2) is suitable for irrigation and appears suitable, based on the constituents tested, for domestic use with the exception of iron and manganese concentrations, which exceed secondary drinking water standards and would require treatment (Laboratory reports for grape irrigation suitability analysis in Appendix A). Secondary standards are consumer preference standards for taste and odor and do not pose health risks.

The PXP ground water has a sodium bicarbonate character with relatively low mineralization compared to local Edna Valley ground water, which is a magnesium bicarbonate water. The water quality of these two sources are compared in Stiff diagrams in Figure 11. The Edna Road well sample from May 1992 is from a well located near Twin Creeks Way and is considered representative of local aquifer zones. The West Corral de Piedra Creek sample is surface water from the creek at Edna Road as reported by Balance Hydrologics (2008).

There is enough of a difference between the Edna Valley waters and the PXP Pismo Formation waters to indicate that underflow from the Edna Valley to the Pismo Formation Zone 2A is not a significant source of recharge. If the PXP aquifer zone is fully developed, however, water quality may change over time in the direction of surface water quality from upstream creek flow represented by West Corral de Piedra Creek.

The water quality of the northern alluvial deposits is likely a mixture of creek water quality and Pismo Formation Zone A2 quality, based on the EC of base flow (730-745 µmhos/cm). Water quality in Zone A3 is unknown, but drains into a tributary to Pismo Creek where base flow EC was measured at 450 µmhos/cm, indicating good water quality in the shallower Edna member sands.

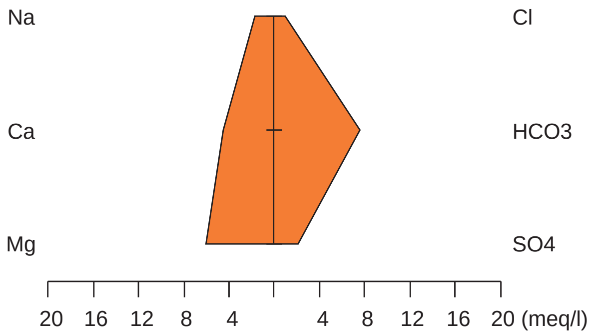
SUMMARY

The water resources of PXP include produced water from oil-related activities, surface water in Pismo Creek, and ground water in alluvial deposits and underlying Edna Formation sandstone. The oil field produced water, which is roughly eight times the volume of recovered oil, is currently returned to the subsurface beneath the oil field. Plans for treatment and alternate surface disposal of this water has been evaluated by others and is not the focus of this report.

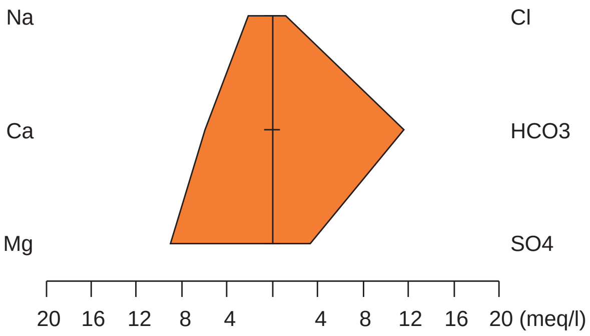
Surface flows enter PXP on Pismo Creek below the confluence of West Corral de Piedra and East Corral de Piedra, and on Canada Verde Creek. The inflows from Canada Verde Creek flow directly into the oil field area where no target fresh-water aquifer zones have been identified. The Pismo Creek Valley ground water subbasin, which has been mapped by the DWR beginning downstream of the Canada Verde Creek confluence with Pismo Creek, is not viable for development on PXP. The subbasin alluvial deposits are mostly unsaturated on PXP land.

Edna Subbasin

Edna Road Well, 5/18/1992
TDS = 700 mg/l; EC = 1,200 µmhos/cm

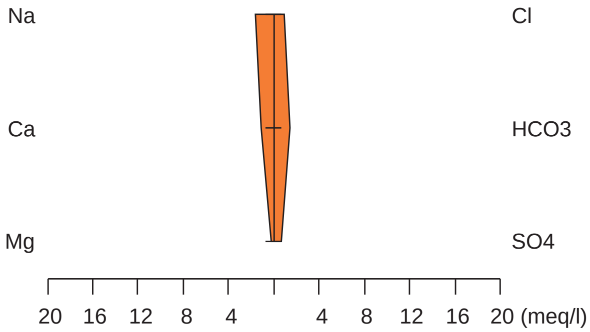


West Corral de Piedra, 7/3/2007
TDS = 800 mg/; EC = 1,200 µmhos/cm



Pismo Formation Zone A2

PXP Well 1, 6/11/2008
TDS = 220 mg/l; EC = 351 µmhos/cm



PXP Well 2, 6/11/2008
TDS = 427 mg/l; EC = 598 µmhos/cm

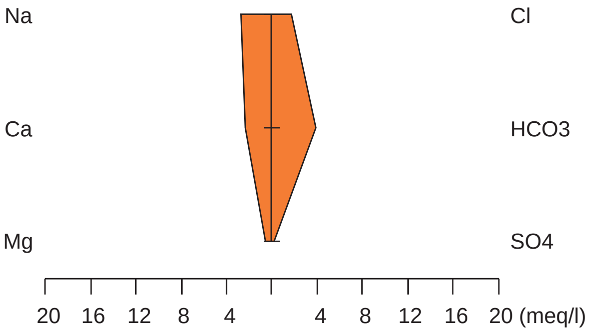


Figure 11
Stiff Diagrams
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Alluvial deposits in the northern PXP area, upstream of the oil field, are interpreted to extend 60-80 feet deep, and currently supply a base flow of at least 70 acre-feet per year to Pismo Creek (originating from the underlying Pismo Formation). The main constraint on potential sustainable yield from these deposits would be limited storage during severe drought. The total sustainable yield of these deposits is estimated at **130 afy**, although this yield would be reduced or eliminated by development of the underlying Edna sandstone.

The greatest potential ground water yield on PXP is from the Edna member of the Pismo Formation. Two aquifers have been identified. The northern Edna aquifer zone (Zone A2), which is tapped by the existing PXP water wells, has an estimated yield of **310 afy**, including an average of 240 afy of potential capture of stream flow. Water quality in Zone A2 is suitable for irrigation and appears suitable for domestic use, based on the constituents analyzed, except for iron and manganese concentrations. The southern Edna aquifer zone (Zone A3) south of the Indian Knob fault, as yet undeveloped, has an estimated yield of **50 afy**, of which 20 afy is potential capture of stream flow.

These estimates are reconnaissance level and suitable for planning purposes. An exploration and testing program would be helpful to confirm the yields and water quality of the northern alluvium and Edna Zone A3. Additional pumping tests would be helpful to confirm the yield of Edna Zone A2.

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