Monterey Peninsula
Water
Management
District

Fractured Rock Aquifer Sustainability

Progress Report to the Water Demand Committee

June 2010

Monterey Peninsula Water Management District

Presentation Outline

1. Direction of Board
2. Definition of Fractured Rock Aquifers
3. Aquifer Sustainability vs. Aquifer Quality
4. Scientific Approach to Evaluating Fractured Rock Aquifers
5. Progress report - Pilot study of Carmel Woods and Aguajito Areas
6. Conclusions and Recommendations

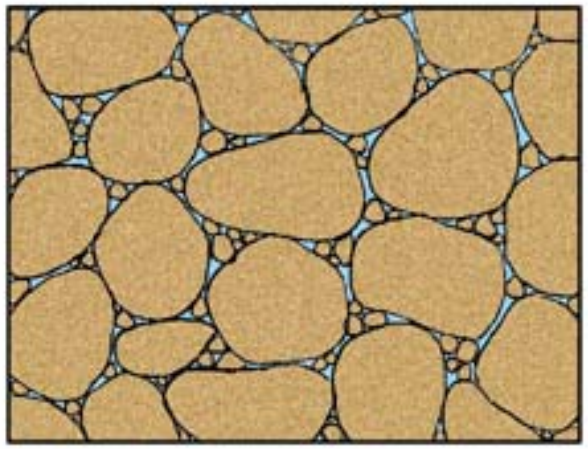
Monterey Peninsula Water Management District

Direction from Board

- The Water Demand Committee at its December 7, 2009 meeting recommended preparation of an ordinance to suspend WDS processing.
- The Technical Advisory Committee reviewed the concept of such an ordinance at its January 5, 2010 meeting. The TAC posed questions and made suggestions, but did not have a specific recommendation because an ordinance was not available for review at that time.
- At the January 28, 2010 regular board meeting the board considered adopting **URGENCY ORDINANCE NO. 143 TEMPORARILY SUSPENDING PROCESSING AND RECEIPT OF APPLICATIONS FOR WATER DISTRIBUTION SYSTEMS IN FRACTURED ROCK FORMATIONS**
- With a 7-0 vote, the board denied the adoption of the ordinance and directed staff to investigate the sustainability of fractured rock aquifer systems and bring a progress report back to the Water Demand Committee within 90 days.

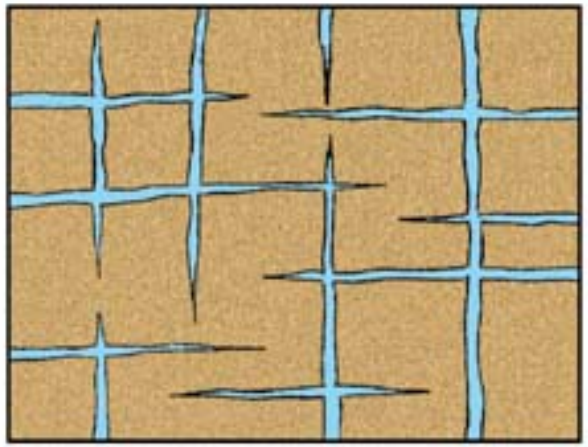
Monterey Peninsula Water Management District

2. Definition of Fractured Rock Aquifer



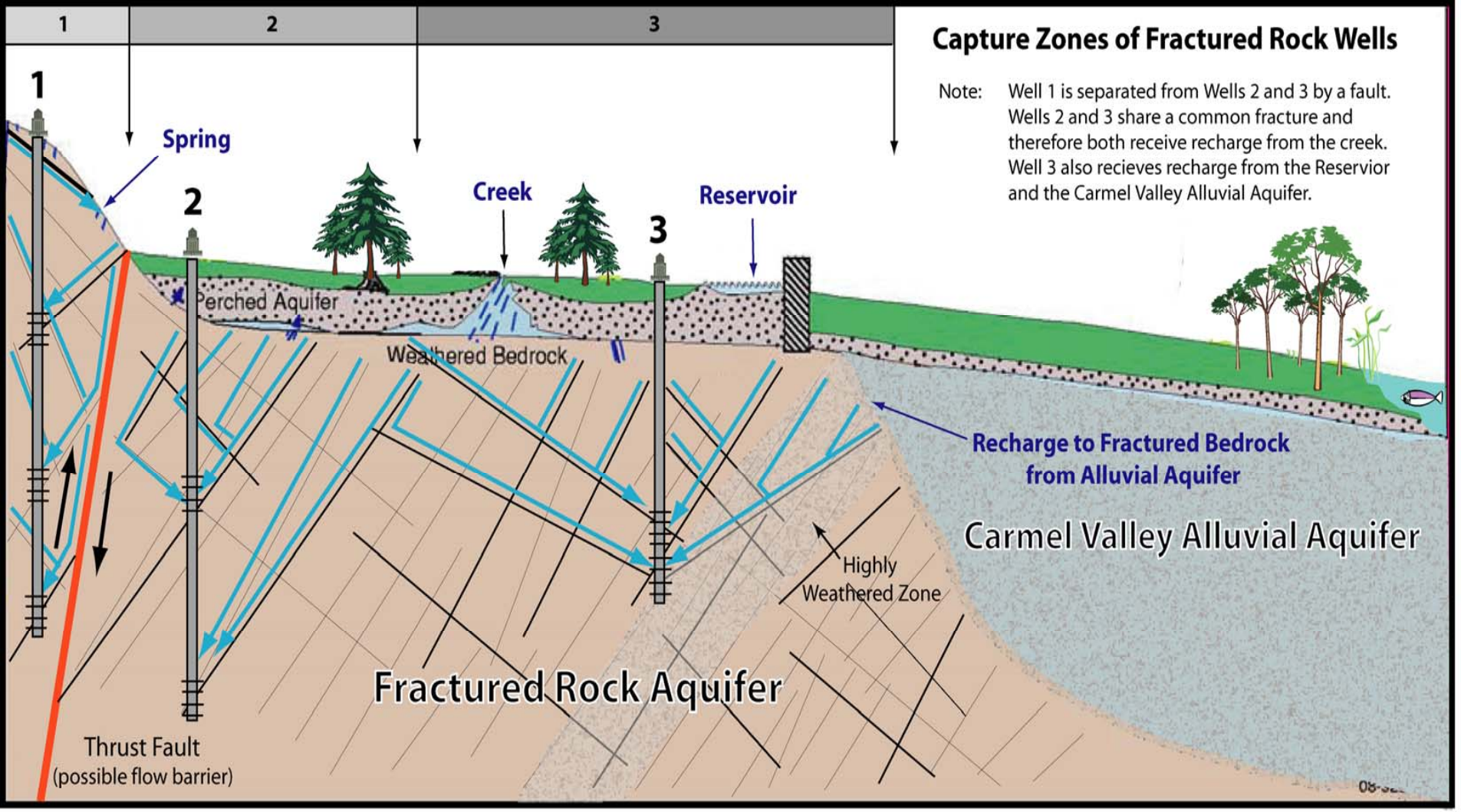
Fluvial Aquifer

Water exists in spaces between grains (primary porosity). Carmel Valley Alluvial Aquifer



Fractured Rock Aquifer

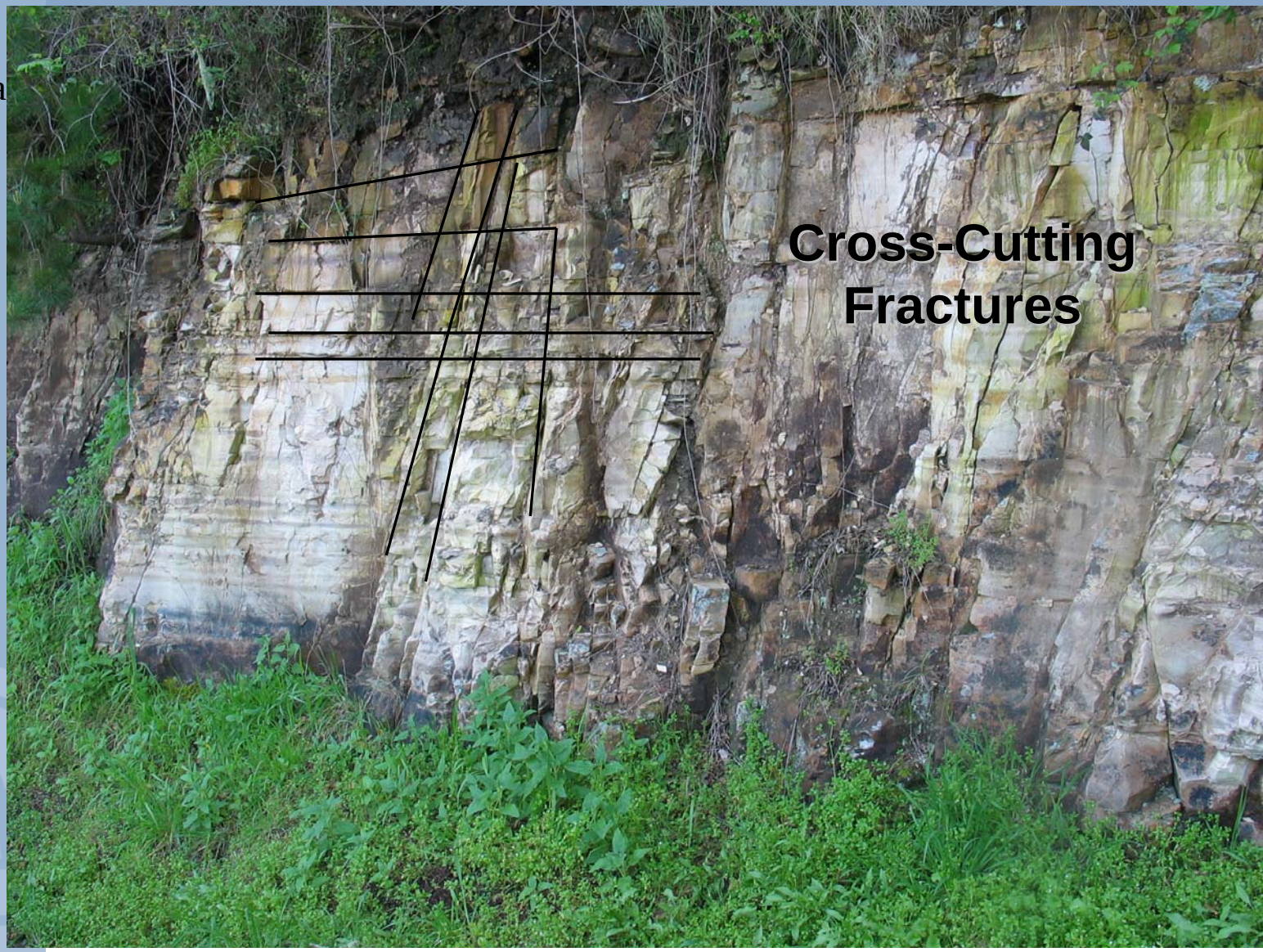
Water exists in fractures in non water bearing rocks (secondary porosity).



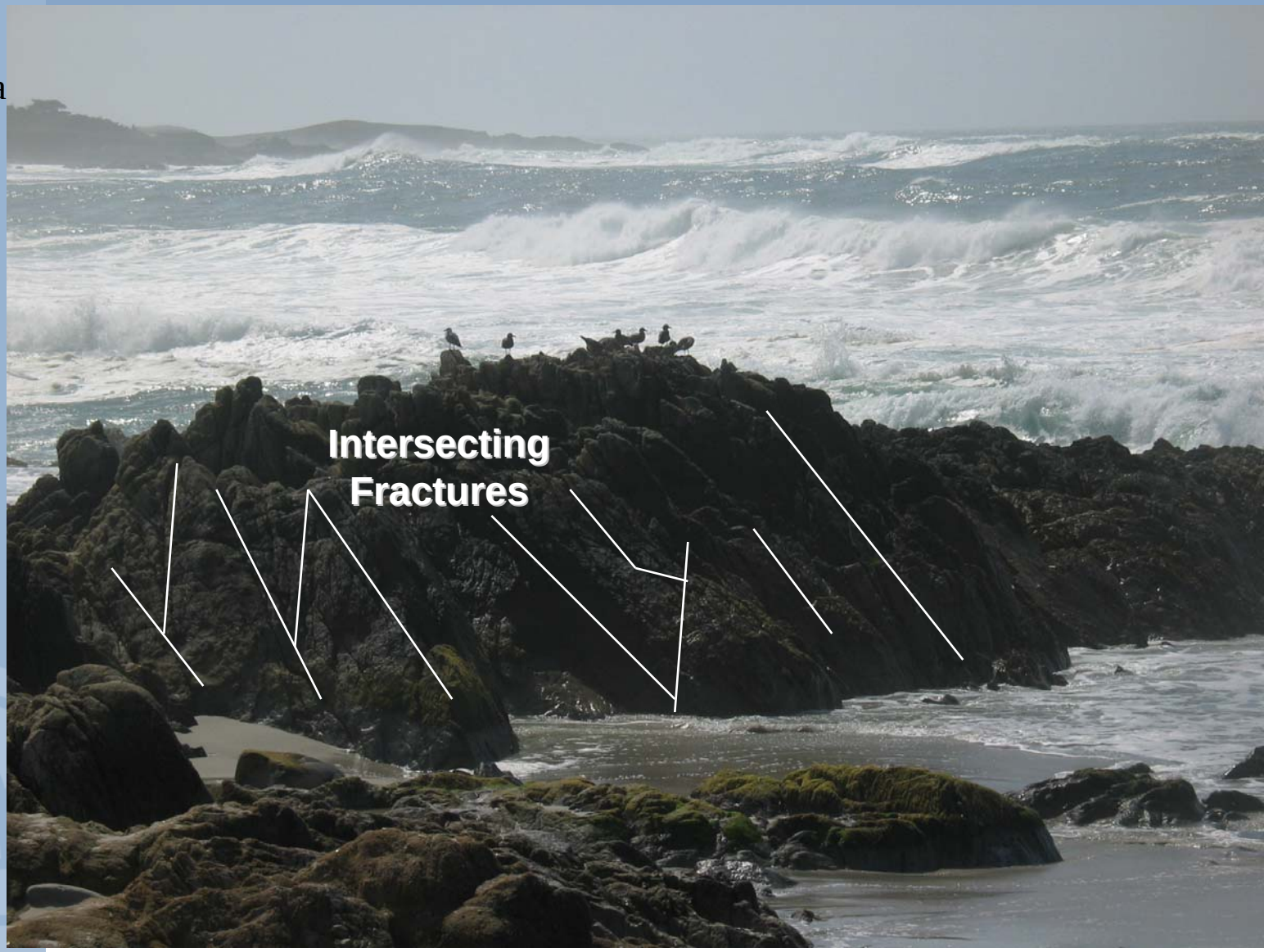
Monterey Peninsula Water Management District

Conceptual Illustration of Recharge and Capture Zone Mechanisms in Fractured Rock Settings

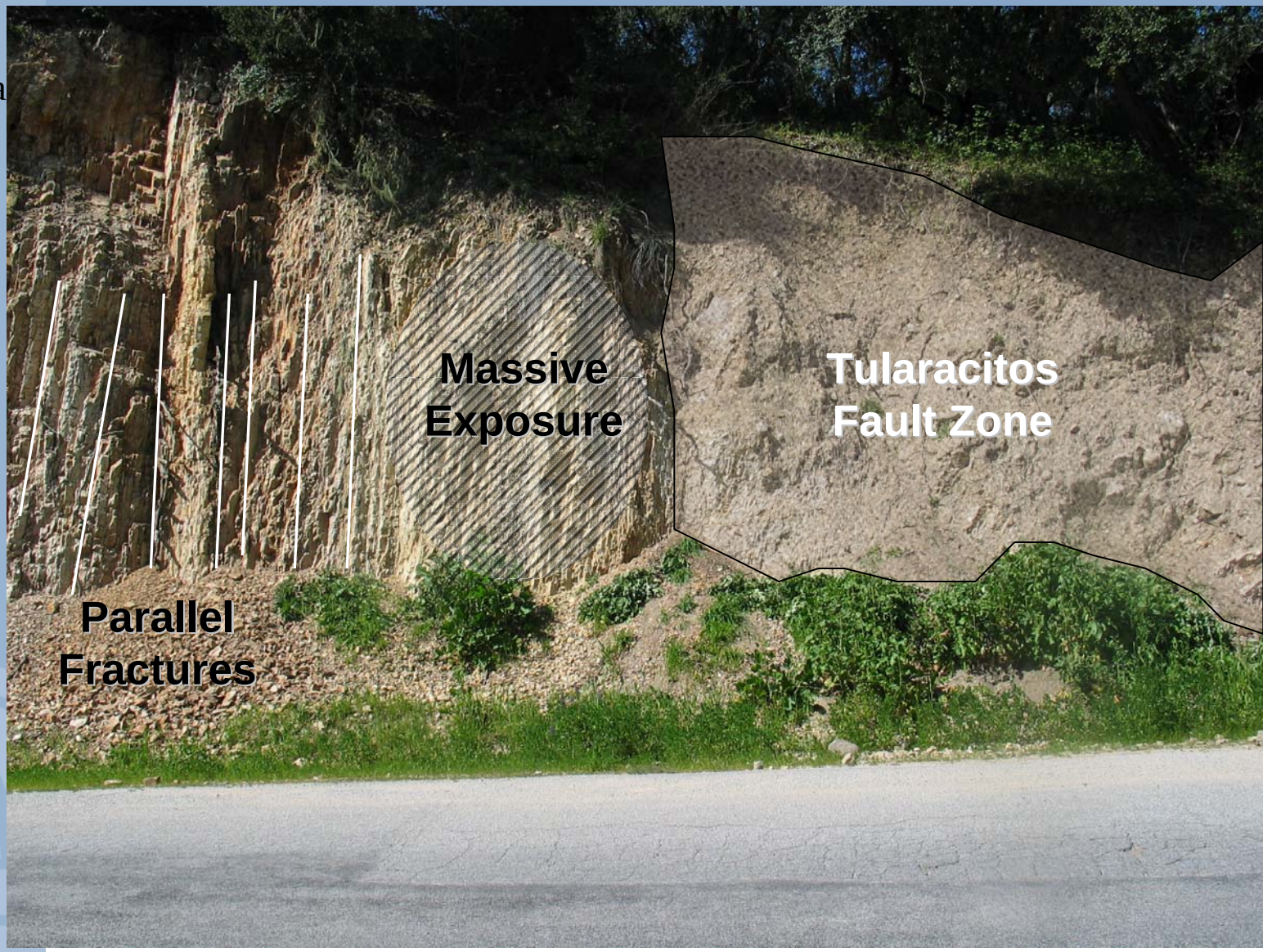
Monterey Peninsula
Water
Management
District



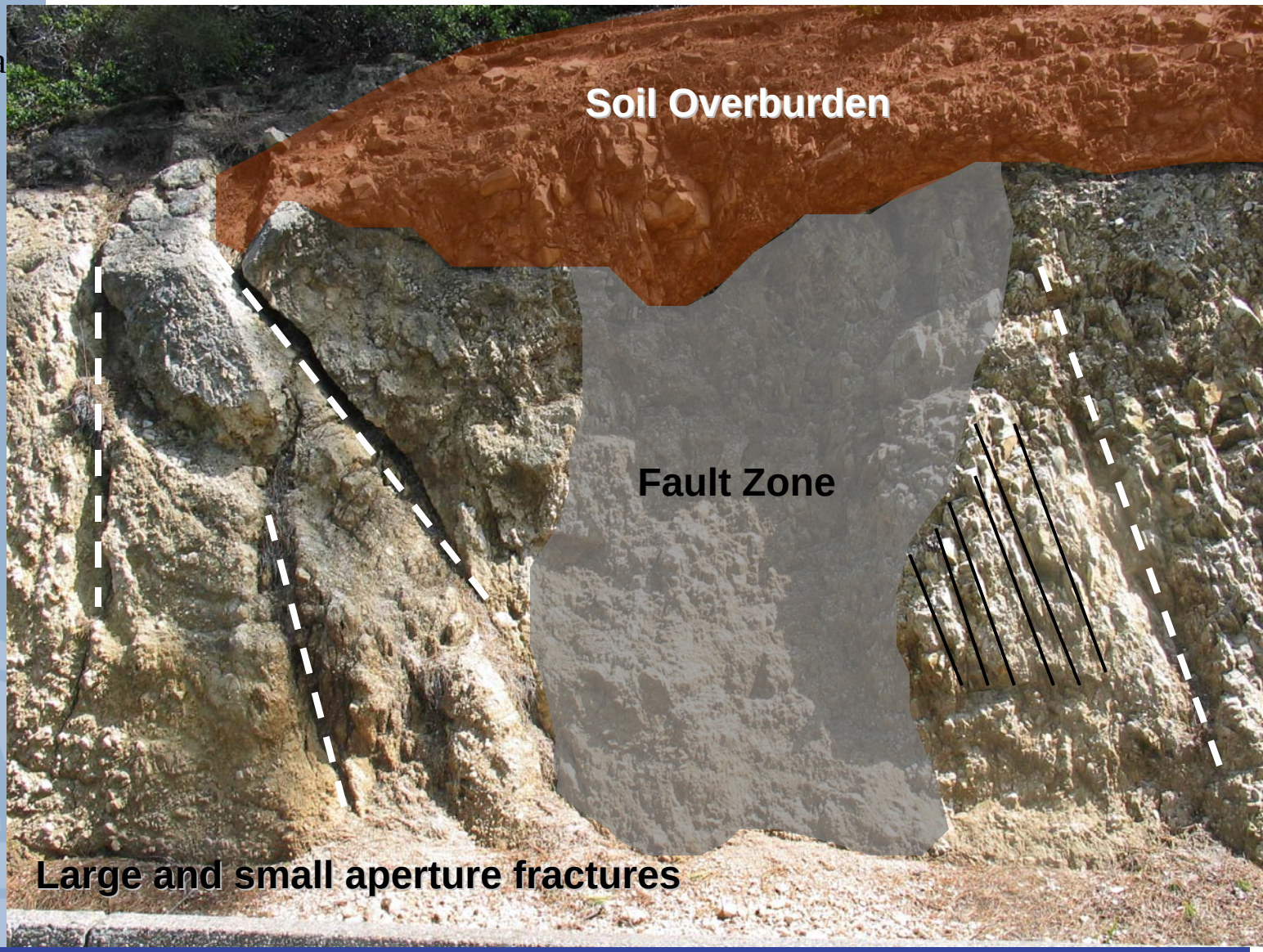
Monterey Peninsula
Water
Management
District



Monterey Peninsula
Water
Management
District

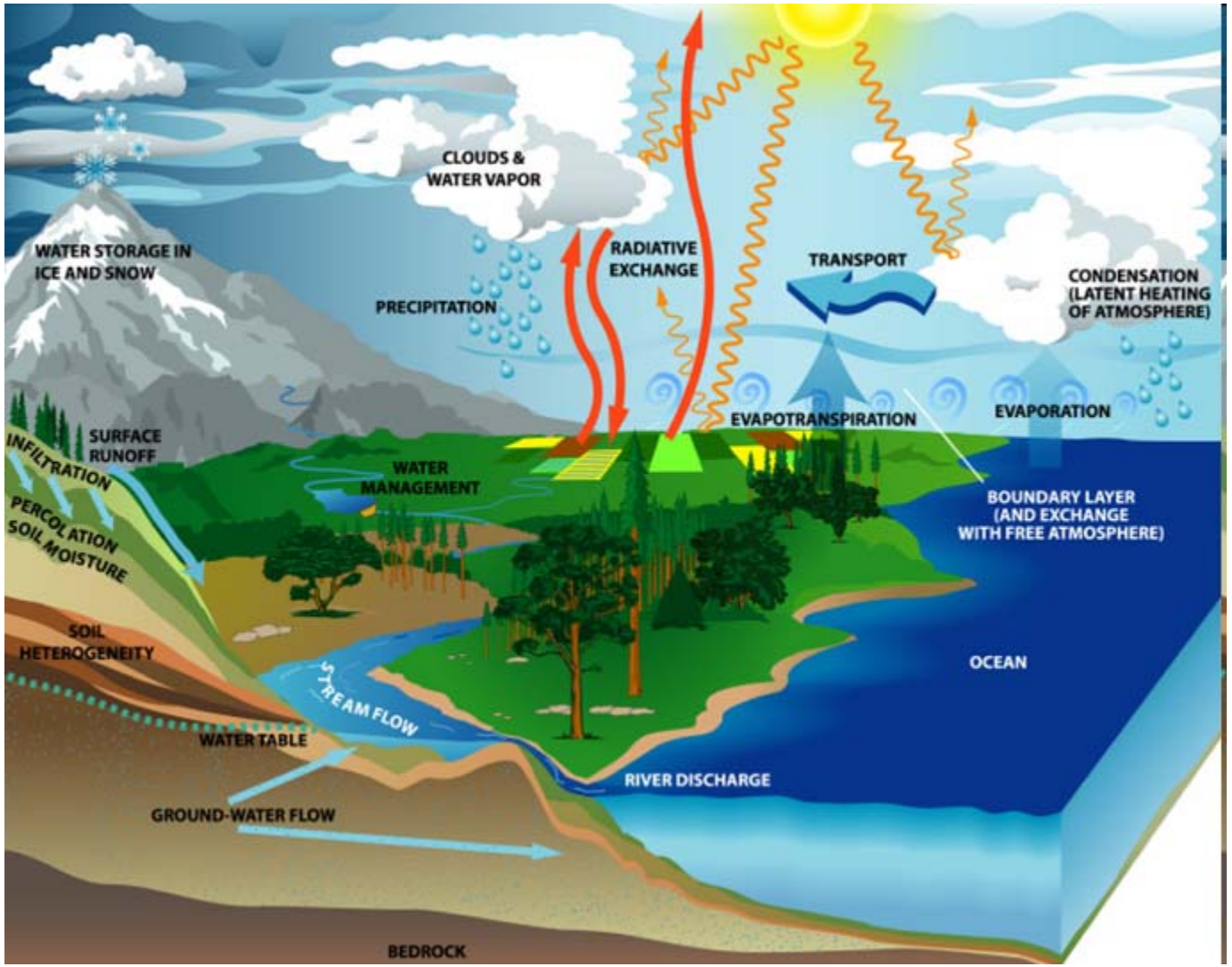


Monterey Peninsula
Water
Management
District



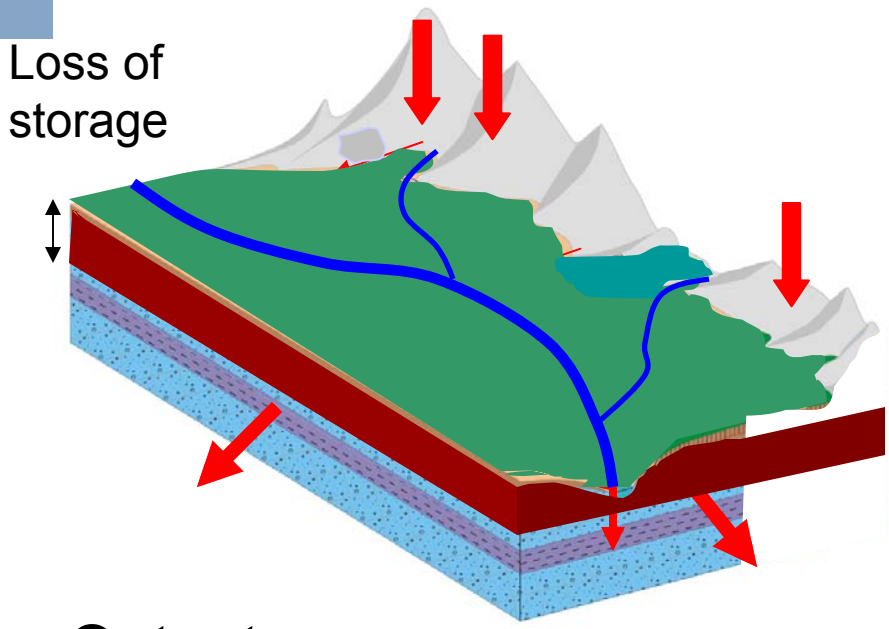
Monterey Peninsula Water Management District

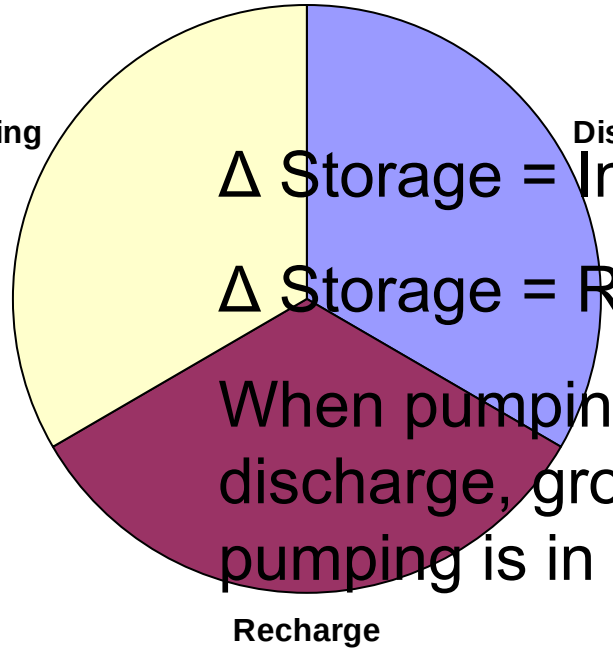
3. Aquifer Sustainability vs. Aquifer Quality



Monterey Peninsula Water Management District

- **Safe Yield:** Maintain the balance between meeting water demands while avoiding environmental impacts to the aquifer system.





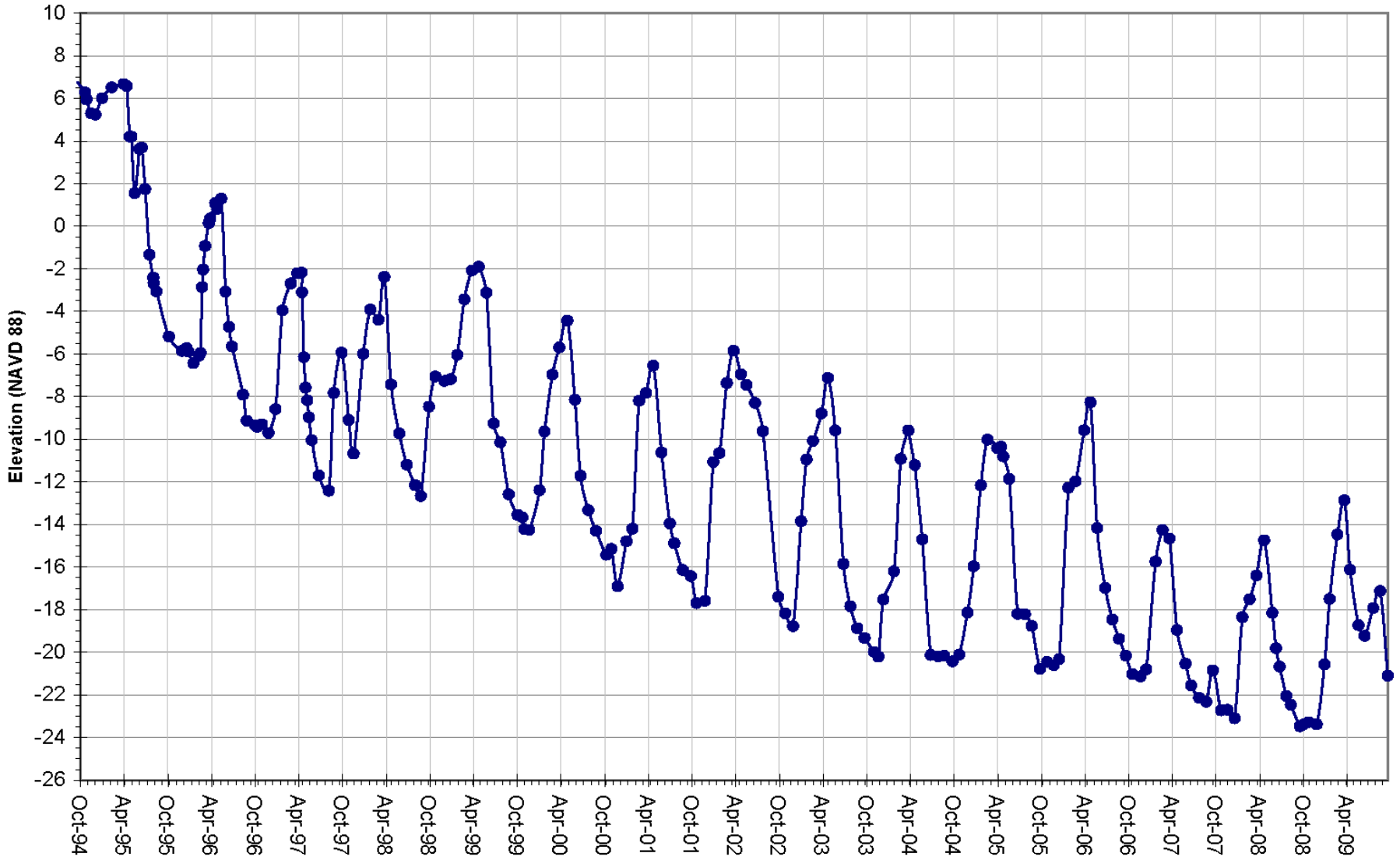
Δ Storage = Inputs – Outputs

Δ Storage = Recharge – Discharge – Pumping

When pumping is greater than recharge and discharge, groundwater storage is depleted and pumping is in excess of safe yield

Pumping captures water from recharge and discharge

- Less flow in Rivers and Streams
- Less Groundwater flow out of bod



Monterey Peninsula
Water Management District

Watermaster Well No. 112 - MPWMD FO-09 (Deep) (15S/1E-15Pb)

Screened from 790-830 in the Santa Margarita Formation (Tsm)
Wellhead Elevation 188.85 MSL
DWR Driller Log No. N/A
Datasource: MPWMD

Monterey Peninsula Water Management District

Quality of Fractured Rock Aquifer

"Quality" in this context is defined as ability of aquifer to yield significant quantities of water to a well within economic constraints. Quality of the aquifer is *not* the same as sustainability of an aquifer. Sustainability is obtained by pumping within the safe yield of the aquifer.

Poor Quality (low yield) Fractured Rock Aquifer

High Quality (high yield) Fractured Rock Aquifer

Little to no fractures

Non-connected small fractures fractures

Connected small fractures

Connected small and large fractures

Monterey Peninsula Water Management District

4. Scientific Approach to Evaluating Fractured Rock Aquifers

Types of Data:

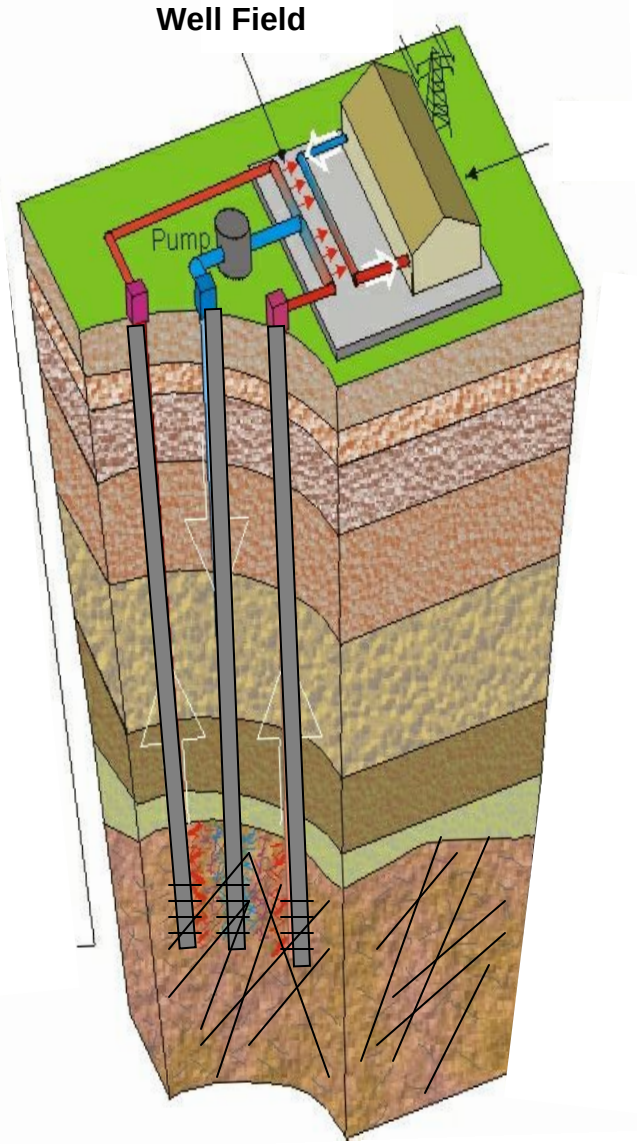
•Non-changing: Geology, fracture patterns, and location, depth, and construction of wells.

•Transient (time dependant): water table elevation, pumping (rates, volumes, and pump tests), water chemistry.

Value of Data:

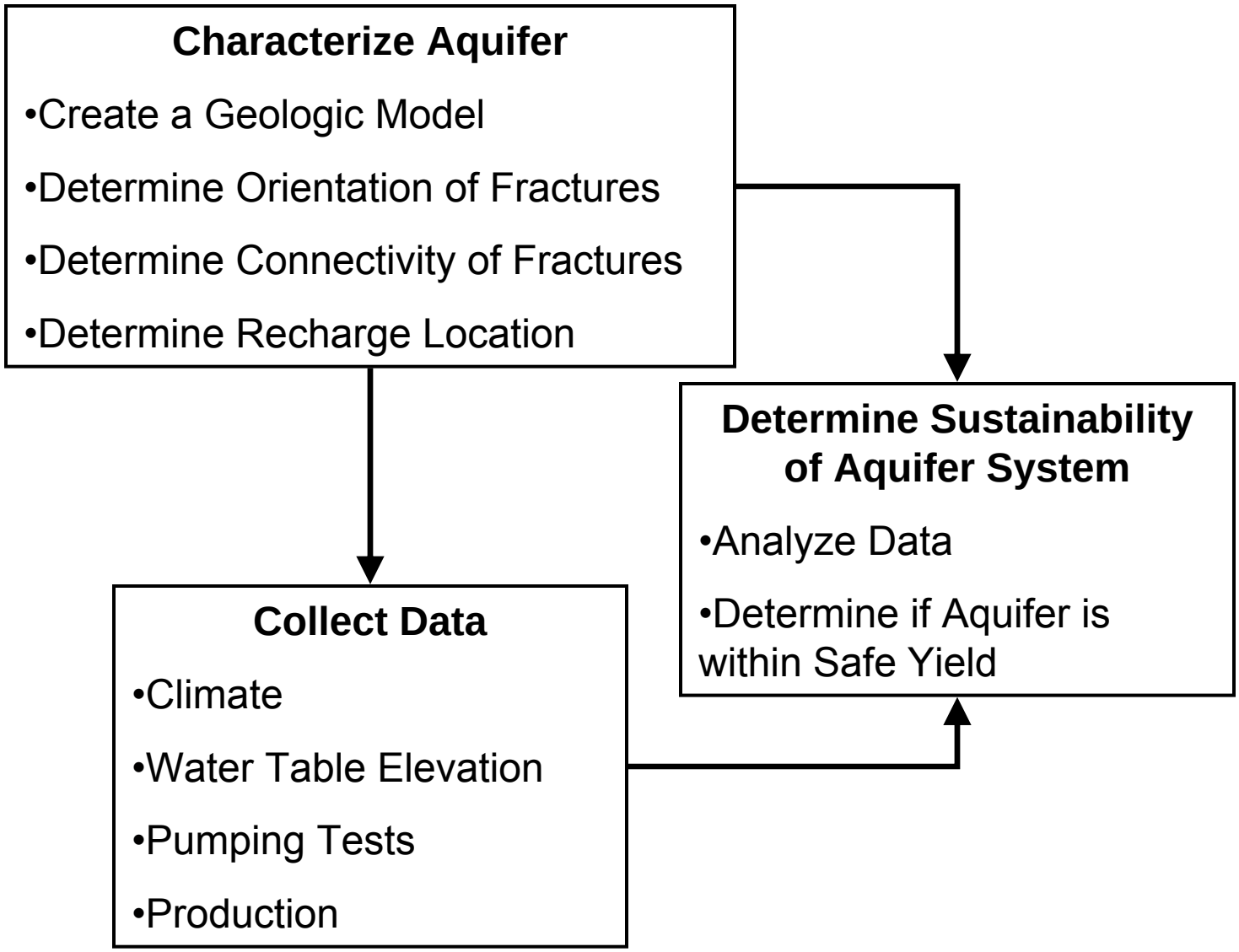
•Non-changing: Geologic structure, size and orientation of fractures. (pathways for water to move)

•Transient: Change in groundwater storage, timing of recharge, aquifer parameters, connectivity of fractures.



Monterey Peninsula Water Management District

Work Flow for Determining the Sustainability of a Fractured Rock Aquifer



Fractured Rock Aquifer Matrix for Characterizing Fracture Size and Connectivity

Characteristics of Aquifer and Wells	Connectivity of Fractures		Size of Fractures	
	Non Connected Fractures	Connected Fractures	Large Fractures	Small Fractures
High well yield(s) [1,2,6]		X	X	
Clustering of high well yields [5]			X	
Similar water chemistry [2,3,5]		X		
Pumping effects from neighboring wells [2,3]		X		
Similar water levels [1,2,3]		X		
Similar well construction (Screen Elevation) [1,5]		X		
Long Screened intervals [1]				
Large fractures and multiple fracture patterns in outcrops [4,5]		X	X	
Mappable Linements [4,5]		X		
Similar properties alligned with Regional Structures [4,5]		X	X	
Fast and complete recovery following pump test		X	X	
Low well yield(s) [1,2,6]	X			X
Clustering of low well yields [5]	X			
Varied water chemistry [2,3,5]	X			
Pumping effects from neighboring wells not observed [2,3]	X			
Dissimilar water levels [1,2,3]	X			
Dissimilar well construction (Screen Elevation) [1,5]	X	X		
Multiple Screened intervals [1]	X			
Small fractures and singular pattern in outcrops [4,5]	X			X
No Linements [4,5]	X			
No allignment with Regional Structures [4,5]	X			
Slow and incomplete recovery following pump test	X			X

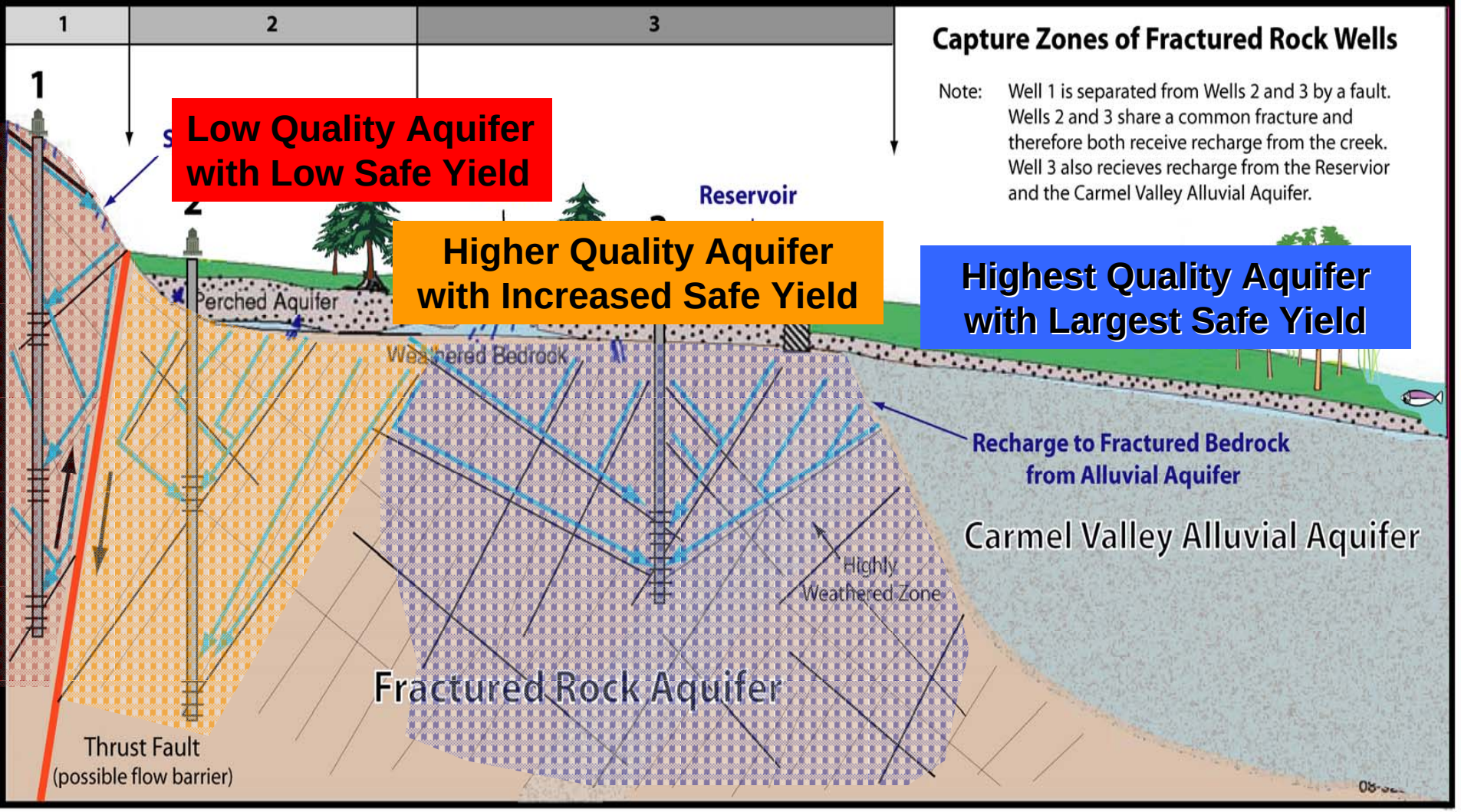
Well Connected High Quality Fractured Rock Aquifer

Low Quality Disconnected Fractured Rock Aquifer

*High Quality and Low Quality Fractured Rock Aquifers Can be sustainable if Pumping is Less than Safe Yield of Aquifer System

5) Spatial Analysis (GIS)

6) Well Yields calculated during the Water system permit

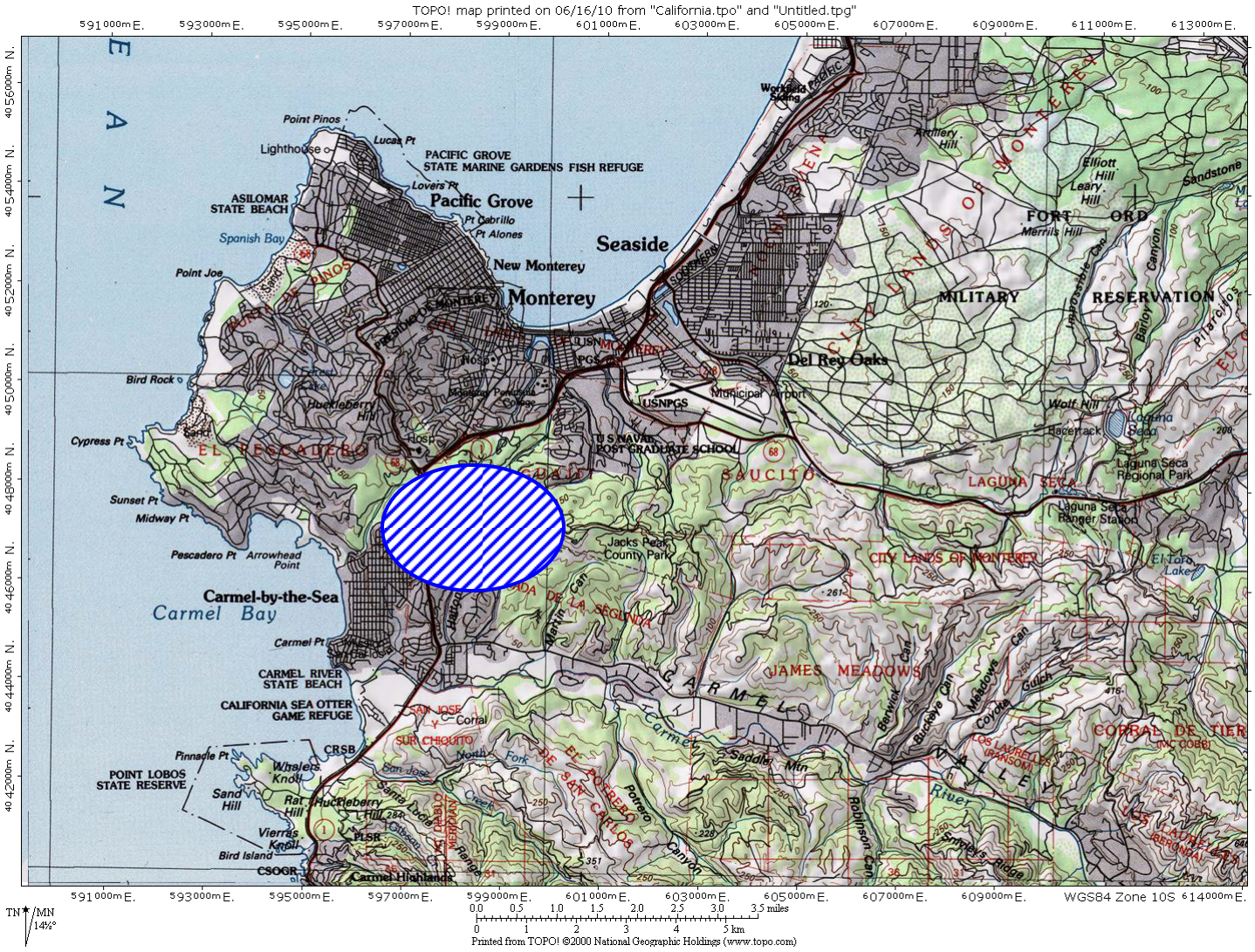


Monterey Peninsula Water Management District

Conceptual Illustration of Recharge and Capture Zone Mechanisms in Fractured Rock Settings

Monterey Peninsula Water Management District

5. Carmel Woods Aguajito Pilot Study Area



Monterey Peninsula
Water
Management
District

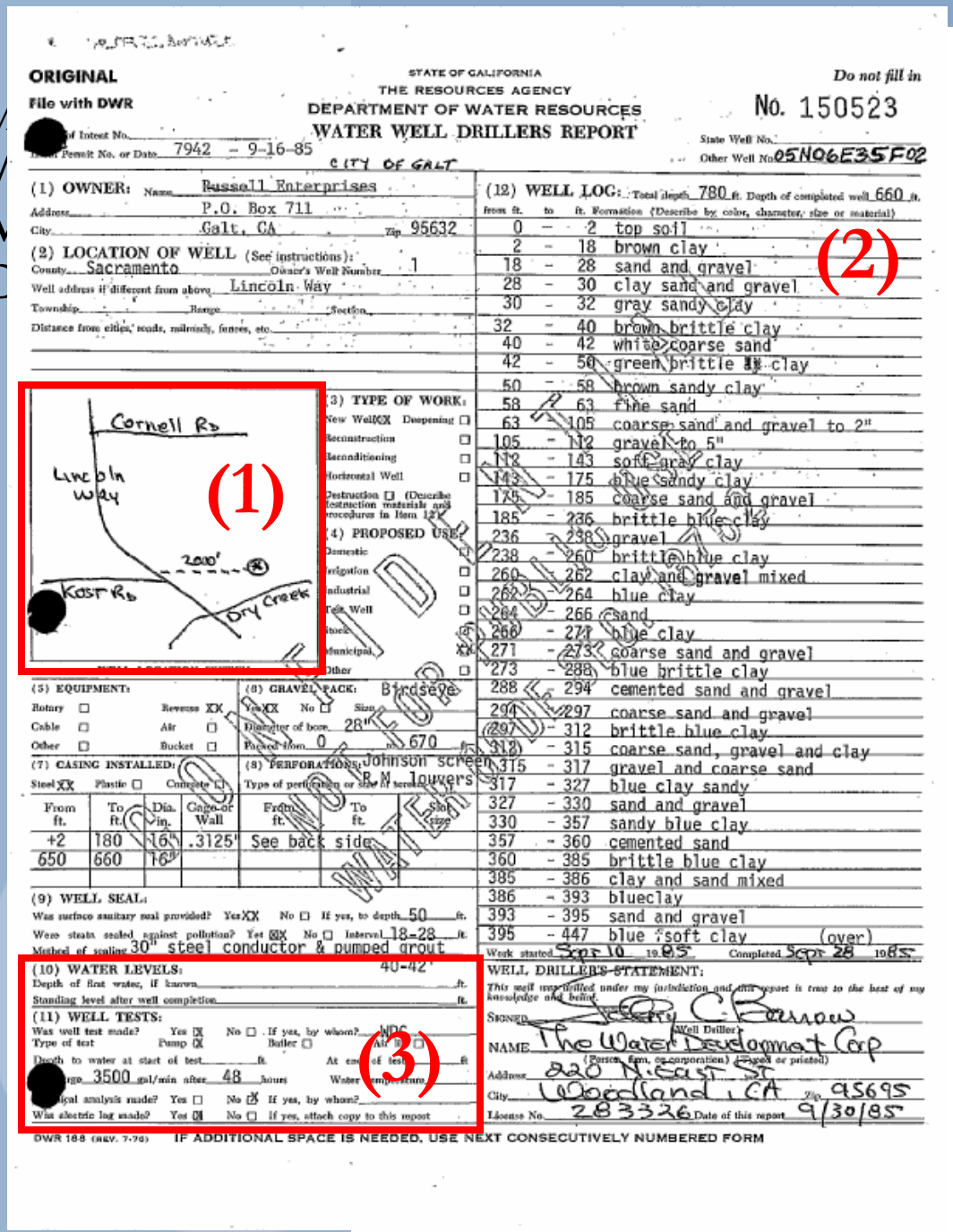
Steps to Evaluate Fractured Rock Aquifer in Pilot Study Area

1. Review existing data for study area
2. Review geologic and hydrogeologic reports
3. Review topographic maps to understand hydrologic basins and identify recharge and discharge boundaries
4. Create a geologic model
5. Evaluate water elevation, chemistry, and pump test to understand the quality and sustainability of the aquifer

Monterey Peninsula Water Management District

Data Available for Pilot Study Area

- DWR Driller Logs
- Geologic Map
- Pumping Tests
- Water Chemistry
- Non-Continuous Water Table Elevations
- Annual Production Volumes
- Instantaneous Pumping Rates



ORIGINAL
File with DWR

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
WATER WELL DRILLERS REPORT

Do not fill in
No. 150523

Notice of Intent No.
Permit No. or Date 7942 - 9-16-85
CITY OF GALT
State Well No.
Other Well No 05N06E35F02

(1) OWNER: Name Russell Enterprises
Address P.O. Box 711
City Galt, CA Zip 95632

(2) LOCATION OF WELL (See instructions):
County Sacramento Owner's Well Number 1
Well address if different from above Lincoln Way
Township Range Section
Distance from cities, roads, railroads, fences, etc.

Cornell Rd
Lincoln Way
2000'
Kost Rd
Dry Creek
(1)

(3) TYPE OF WORK:
New Well XX Deepening
Reconstruction
Reconditioning
Horizontal Well
Destruction (Describe destruction materials and procedures in Item 12)

(4) PROPOSED USE:
Domestic
Irrigation
Industrial
Test Well
Stock
Municipal XX
Other

(5) EQUIPMENT:
Rotary Reverse XX
Cable Air
Other Bucket

(6) GRAVEL PACK: Birdseye
Yes XX No Size
Diameter of bore 28"
Packed from 0 ft. to 670 ft.

(7) CASING INSTALLED:
Steel XX Plastic Concrete

From ft.	To ft.	Dia. in.	Gage or Wall
+2	180	16"	.3125"
650	660	16"	

(8) PERFORATIONS: Johnson screen R.M. louvers
Type of perforator or size of screen
See back side

(9) WELL SEAL:
Was surface sanitary seal provided? Yes XX No If yes, to depth 50 ft.
Were strata sealed against pollution? Yes XX No Interval 18-28 ft.
Method of sealing 30" steel conductor & pumped grout 40-42'

(10) WATER LEVELS:
Depth of first water, if known ft.
Standing level after well completion ft.

(11) WELL TESTS:
Was well test made? Yes XX No If yes, by whom? NDC
Type of test Pump XX Bailer Air
Depth to water at start of test ft. At end of test ft.
Yield 3500 gal/min after 48 hours Water temperature
Chemical analysis made? Yes No XX If yes, by whom?
Was electric log made? Yes XX No If yes, attach copy to this report
(3)

(12) WELL LOG: Total depth 780 ft. Depth of completed well 660 ft.

from ft.	to ft.	Formation (Describe by color, character, size or material)
0	2	top soil
2	18	brown clay
18	28	sand and gravel
28	30	clay sand and gravel
30	32	gray sandy clay
32	40	brown brittle clay
40	42	white coarse sand
42	50	green brittle clay
50	58	brown sandy clay
58	63	fine sand
63	105	coarse sand and gravel to 2"
105	112	gravel to 5"
112	143	soft gray clay
143	175	blue sandy clay
175	185	coarse sand and gravel
185	236	brittle blue clay
236	238	gravel
238	260	brittle blue clay
260	262	clay and gravel mixed
262	264	blue clay
264	266	sand
266	271	blue clay
271	273	coarse sand and gravel
273	288	blue brittle clay
288	294	cemented sand and gravel
294	297	coarse sand and gravel
297	312	brittle blue clay
312	315	coarse sand, gravel and clay
315	317	gravel and coarse sand
317	327	blue clay sandy
327	330	sand and gravel
330	357	sandy blue clay
357	360	cemented sand
360	385	brittle blue clay
385	386	clay and sand mixed
386	393	blueclay
393	395	sand and gravel
395	447	blue soft clay (over)

(2)

Work started Sept 10 19 85 Completed Sept 28 1985

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
Signed Jerry C. Barrow (Well Driller)
NAME The Water Development Corp (Person, firm, or corporation) (Type or print)
Address 820 N. East St.
City Woodland, CA Zip 95695
License No. 283326 Date of this report 9/30/85

DWR 188 (REV. 7-76) IF ADDITIONAL SPACE IS NEEDED, USE NEXT CONSECUTIVELY NUMBERED FORM

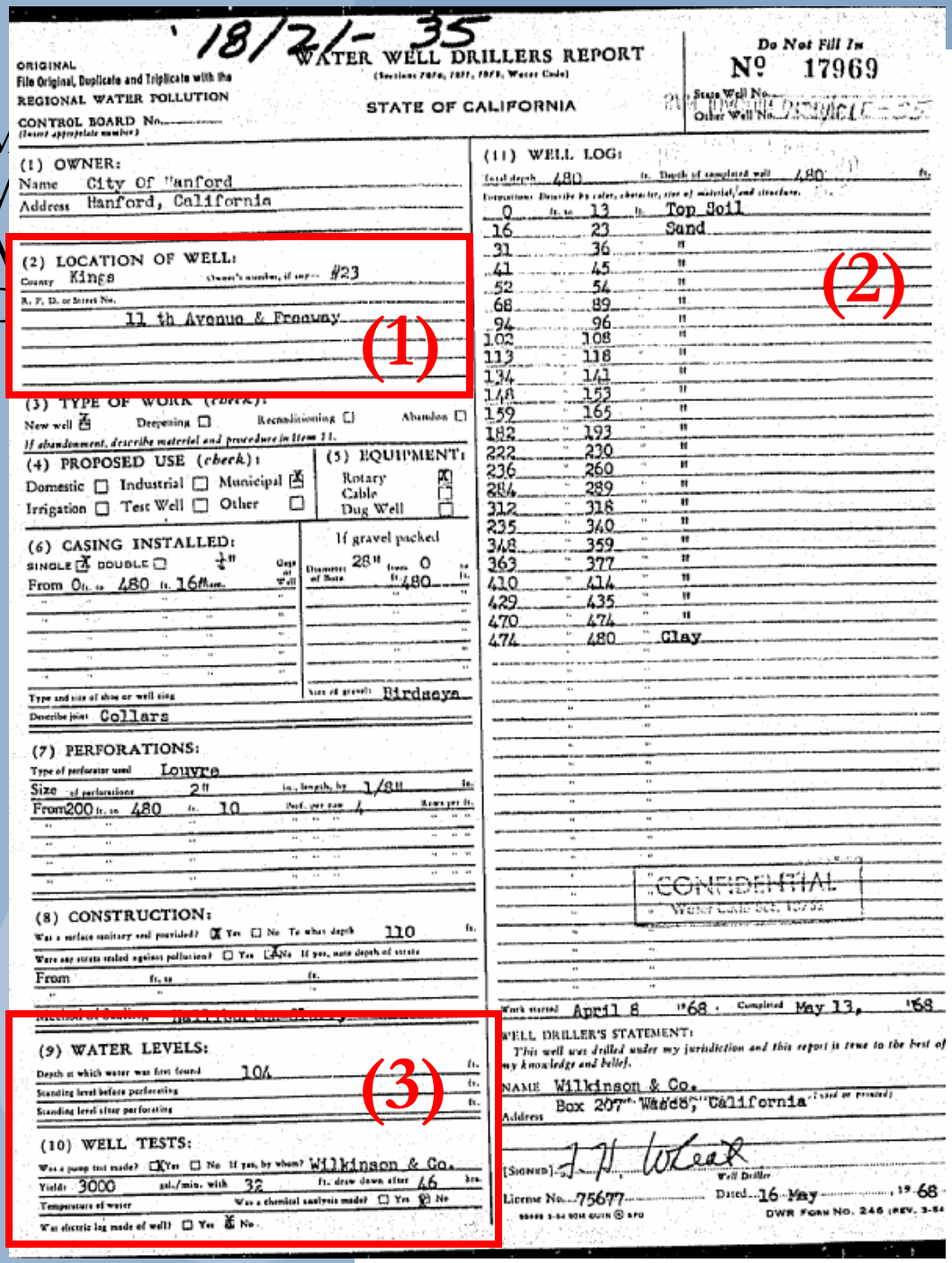
High Quality Well Log

Well log screening attempts to identify logs which contain:

1) Adequate location information

2) Fair to excellent lithologic descriptions, preferably with modifiers such and gravelly/silty/sandy and qualifiers such as hard/soft/cemented.

3) Good pump test and water level data.



18/21-35

ORIGINAL
File Original, Duplicate and Triplicate with the
REGIONAL WATER POLLUTION
CONTROL BOARD No.

WATER WELL DRILLERS REPORT
(Sections 7850, 7851, 7852, Water Code)
STATE OF CALIFORNIA

Do Not Fill In
No. 17969
State Well No.
Other Well No. DISTRICT 35

(1) OWNER:
Name City Of Hanford
Address Hanford, California

(2) LOCATION OF WELL:
County Kings Owner's number, if any #23
R. F. D. or Street No.
11 th Avenue & Freeway
(1)

(3) TYPE OF WORK (check):
New well ☒ Deepening ☐ Reconditioning ☐ Abandon ☐
If abandonment, describe material and procedure in Item 11.

(4) PROPOSED USE (check):
Domestic ☐ Industrial ☐ Municipal ☒
Irrigation ☐ Test Well ☐ Other ☐

(5) EQUIPMENT:
Rotary ☒
Cable ☐
Dug Well ☐

(6) CASING INSTALLED:
SINGLE ☒ DOUBLE ☐ 4" Gage of Well
From 0 ft. to 480 ft. 16 lbs.
Type and size of shoe or well ring
Describe joint Collars

If gravel packed
Diameter of Bore 28" from 0 ft. to 480 ft.
Size of gravel: Birdseye

(7) PERFORATIONS:
Type of perforator used Louvre
Size of perforations 2" in., length, by 1/8" in.
From 200 ft. to 480 ft. 10 Perf. per row 4 Rows per ft.

(8) CONSTRUCTION:
Was a surface sanitary seal provided? ☒ Yes ☐ No To what depth 110 ft.
Were any strata sealed against pollution? ☐ Yes ☒ No If yes, note depth of strata
From ft. to ft.

(9) WATER LEVELS:
Depth at which water was first found 104 ft.
Standing level before perforating ft.
Standing level after perforating ft.
(3)

(10) WELL TESTS:
Was a pump test made? ☒ Yes ☐ No If yes, by whom? Wilkinson & Co.
Yield: 3000 gal./min. with 32 ft. draw down after 46 hrs.
Temperature of water Was a chemical analysis made? ☐ Yes ☒ No
Was electric log made of well? ☐ Yes ☒ No

(11) WELL LOG:
Total depth 480 ft. Depth of completed well 480 ft.
Formation: Describe by color, character, size of material, and structure.

0	13	Top Soil
16	23	Sand
31	36	"
41	45	"
52	54	"
68	89	"
94	96	"
102	108	"
113	118	"
134	141	"
148	153	"
159	165	"
182	193	"
222	230	"
236	260	"
284	289	"
312	318	"
235	340	"
348	359	"
363	377	"
410	414	"
429	435	"
470	474	"
474	480	Clay

(2)

CONFIDENTIAL
Water Code Sec. 13752

Work started April 8 1968. Completed May 13, 1968

WELL DRILLER'S STATEMENT:
This well was drilled under my jurisdiction and this report is true to the best of my knowledge and belief.
NAME Wilkinson & Co.
Address Box 207 Wasco, California
[SIGNED] J. H. Wilcox Well Driller
License No. 75677 Dated 16 May 1968

DWR FORM NO. 246 (REV. 3-54)

Low Quality Well Log

☹

1) Location information is sparse

2) Lithologic description is very poor.

3) Poor pump test and water level data.

Location of Wells Within the Pilot Fractured Rock Aquifer Sustainability Study Area

Monterey Peninsula Water Management District

Annual Average Rainfall within the Fractured Rock Aquifer Well Sustainability Study Area

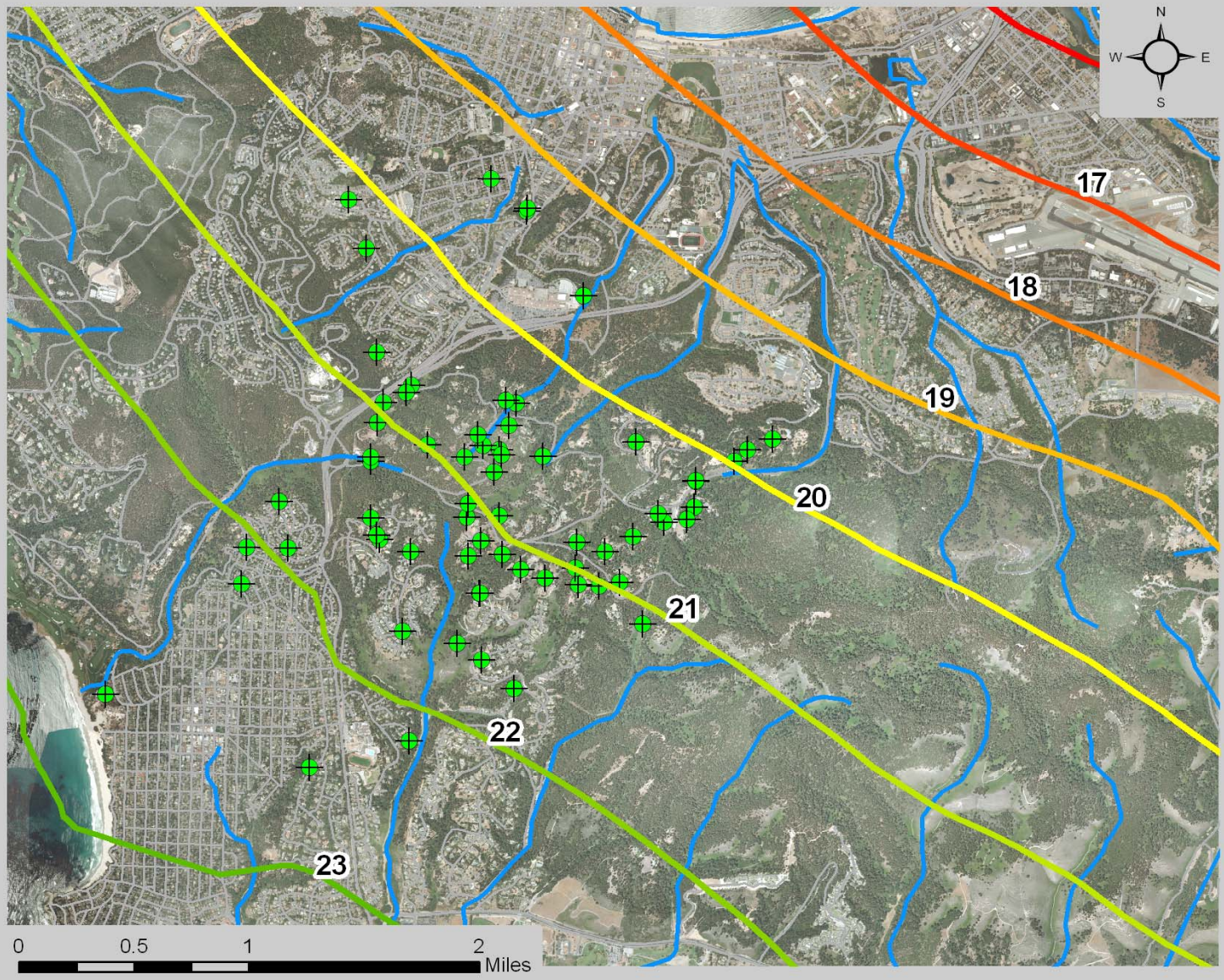
Monterey Peninsula Water Management District

Legend

Annual Rainfall

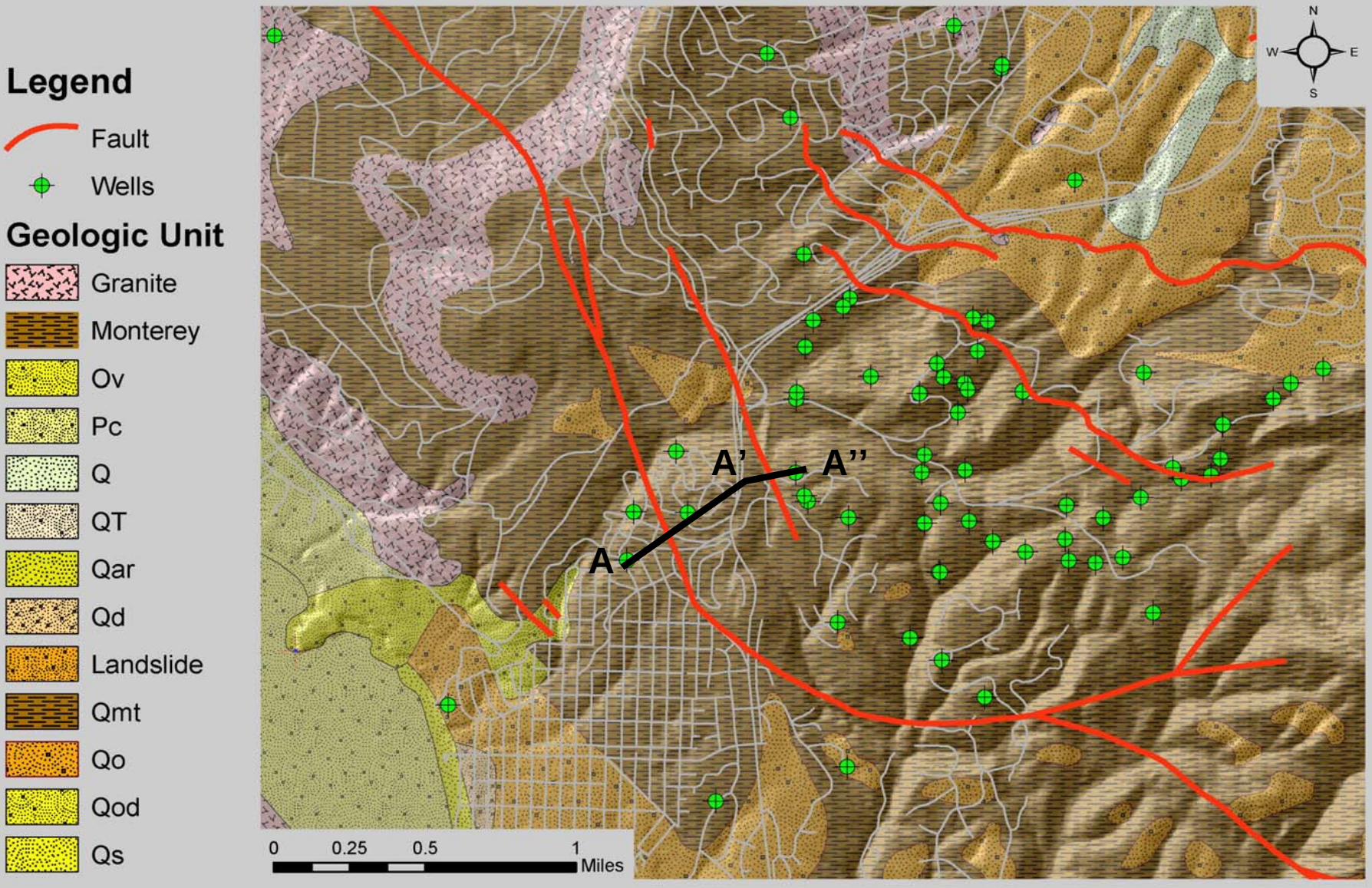
inches

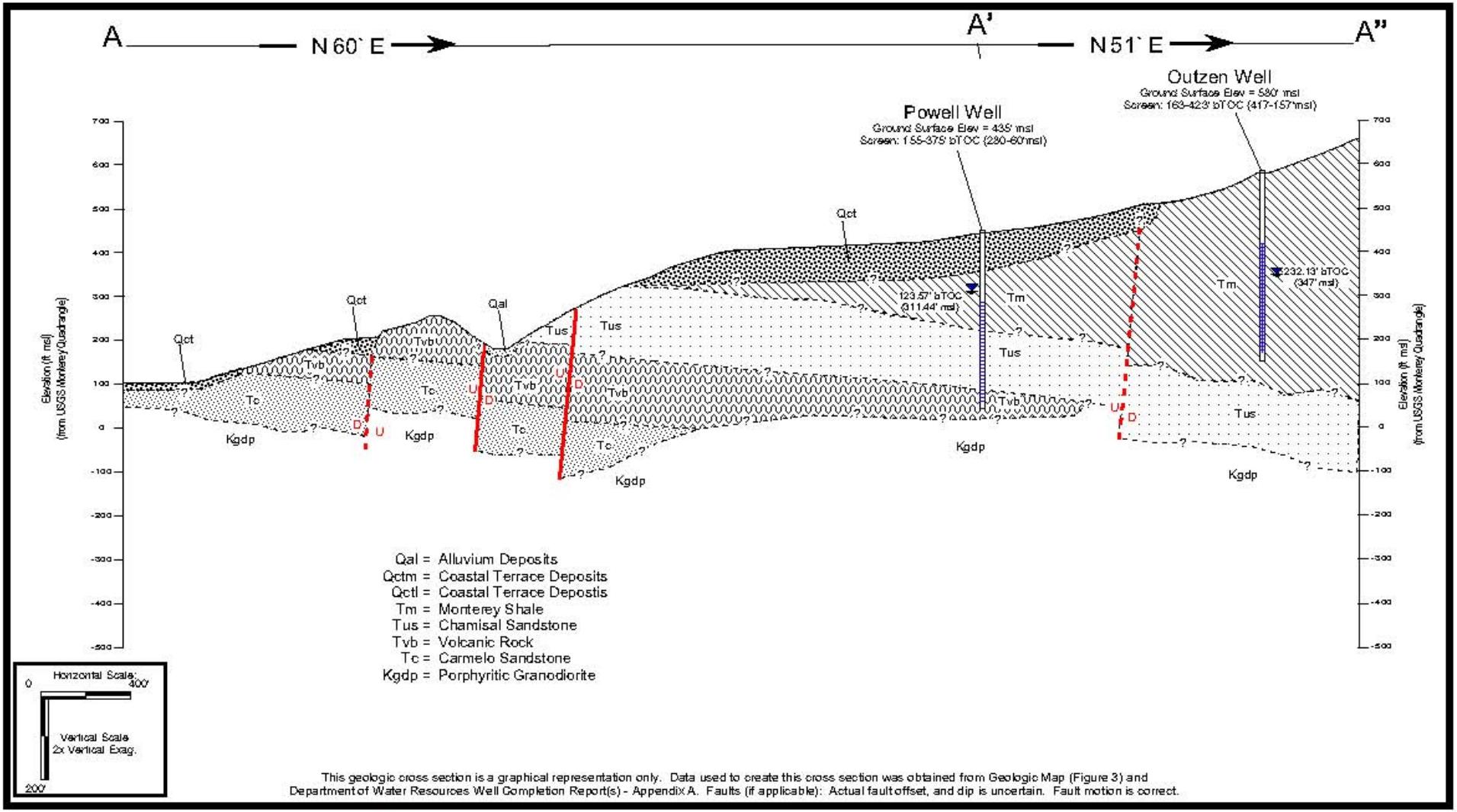
- 16
- 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24



Geologic Map of the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District





This geologic cross section is a graphical representation only. Data used to create this cross section was obtained from Geologic Map (Figure 3) and Department of Water Resources Well Completion Report(s) - Appendix A. Faults (if applicable): Actual fault offset, and dip is uncertain. Fault motion is correct.

BIERMAN Hydrogeologic
A Professional Company
Hydrogeologic Consulting & Water Resource Management

CONCEPTUAL GEOLOGIC CROSS SECTION A-A'-A"

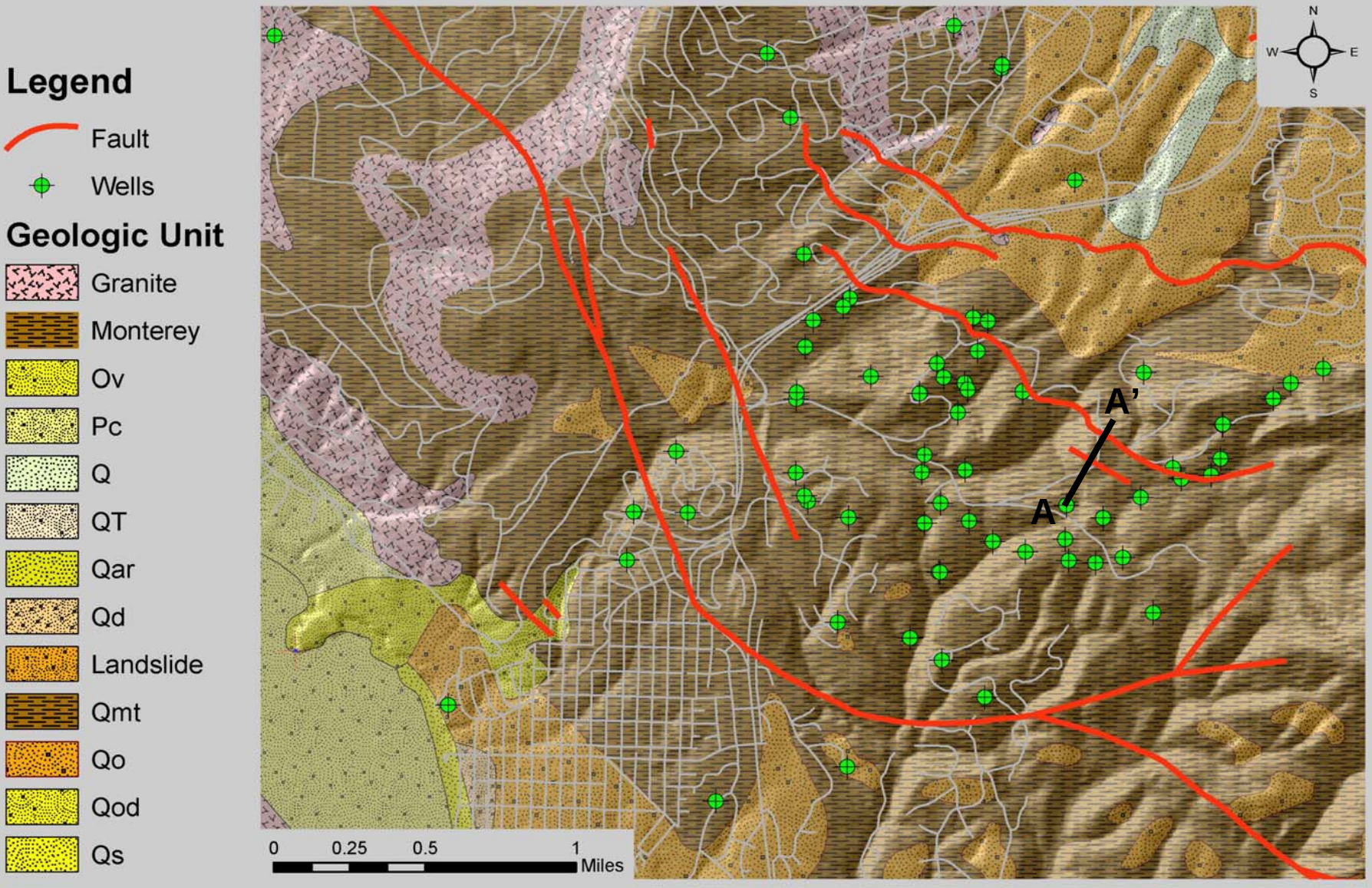
APN: 009-081-027
Carmel, Monterey County, California

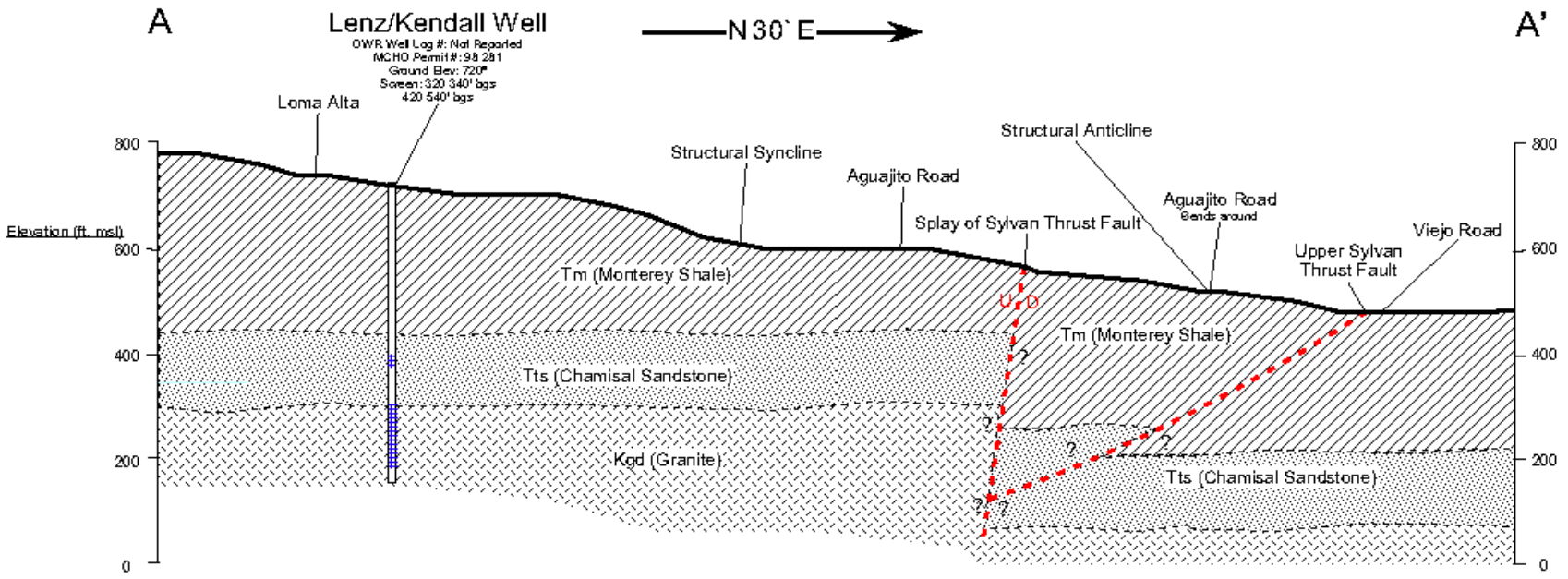
FIGURE 4

By: MS, 12/2/10
File: Powell/Figures/A-A".cvx

Geologic Map of the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District

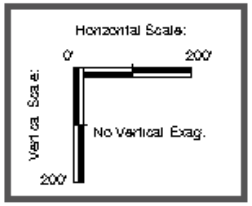




EXPLANATION

Tm = Monterey Formation (porcelanite) - (Miocene) - Light brown to white, hard, brittle, platy.
Tts = Chamisal Sandstone (Miocene) - Marine deposition; buff to light-gray, poorly to well sorted arkosic sandstone, locally friable, locally conglomeratic.
Kgd = Granodiorite to Quartz Monzonite Basement Complex (Cretaceous)

NOTES:
This geologic cross section is a graphical representation only. Data used to create this cross section was obtained from Geologic Map (Figure 3) and Department of Water Resources Well Completion Report(s) - Appendix A. Faults (if applicable): Actual fault offset, and dip is uncertain. Fault motion is correct.



BIERMAN Hydrogeologic
A Professional Company
Hydrogeologic Consulting & Water Resource Management

CONCEPTUAL GEOLOGIC CROSS SECTION A-A'

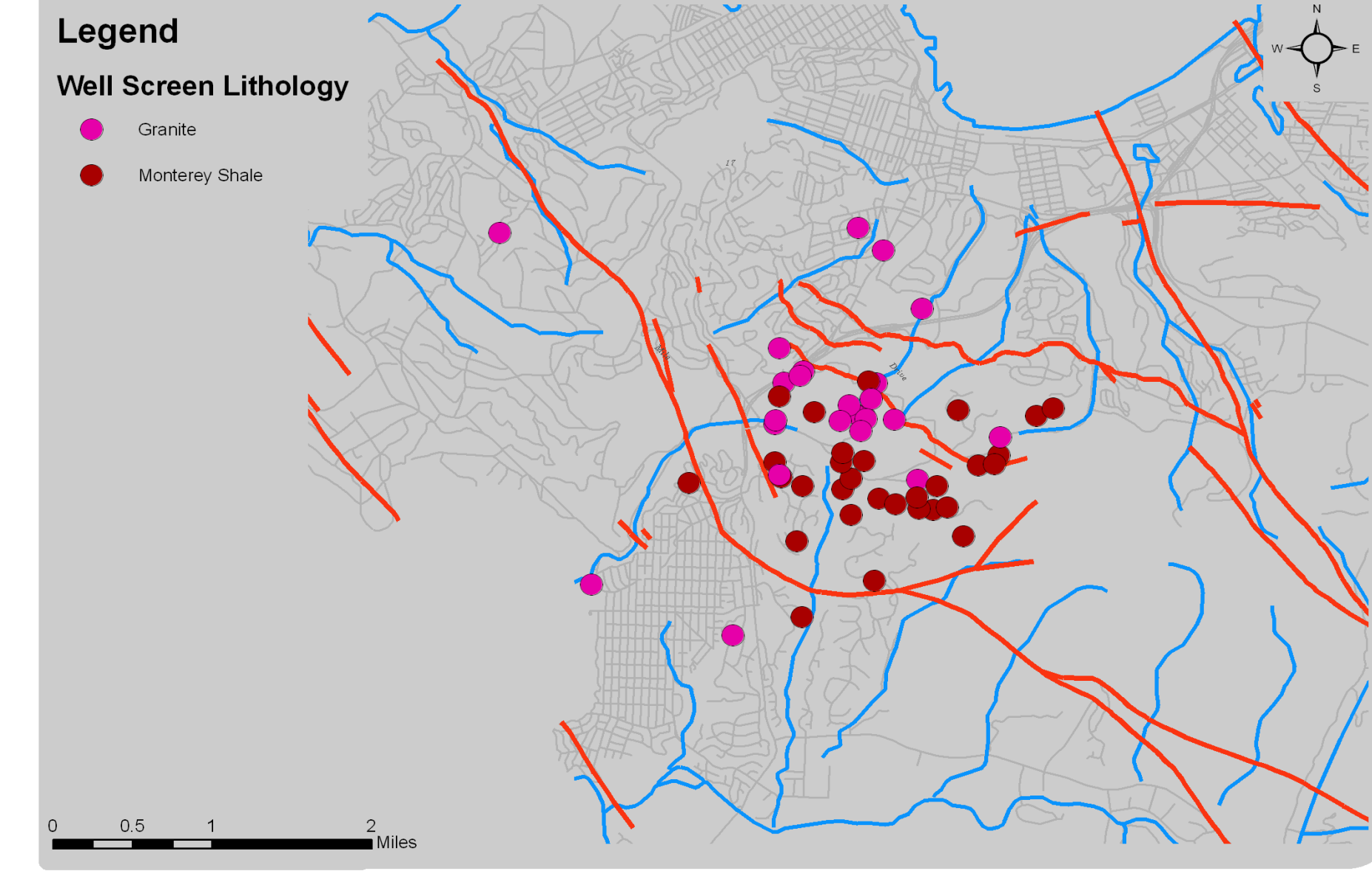
APN: 103-102-016 & 017
Monterey County, California

FIGURE 4

Drawn By: AB, 4/01/09
File: Jenn/Figure 4/A-A'.cdr

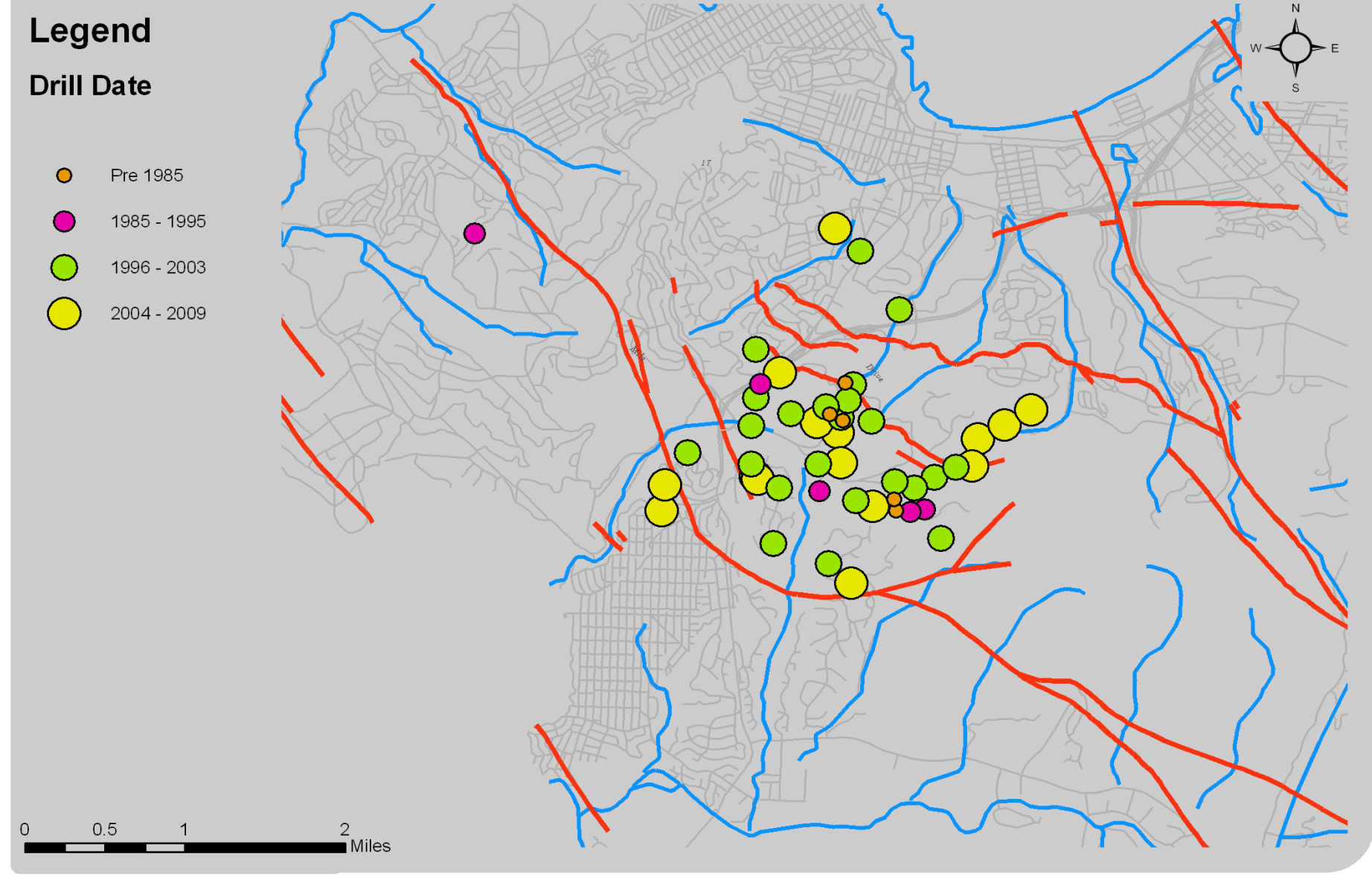
Screened Interval Geology of wells within the Fractured Rock Aquifer Well Sustainability Study

Monterey Peninsula Water Management District



Drill dates for well within the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District



Monterey Peninsula Water Management District

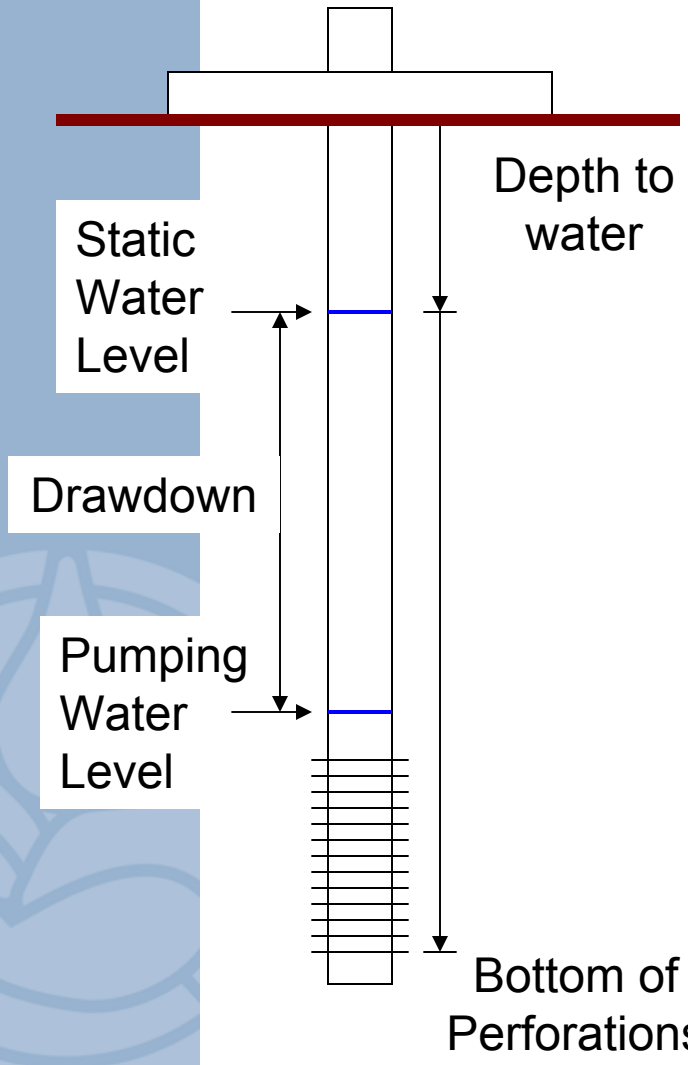
Well Performance – Aquifer Quality

Pumping tests are performed upon well completion to calculate the ability of well to produce water.

- MPWMD water distribution system permits require 72 hour pumping tests during permitting process
  - Good quality data
  - Accurate aquifer parameters
  - Consistent methodology
  - Poor geographic coverage
- DWR pumping test
  - Data often incomplete
  - Can not be used to calculate aquifer parameters
  - Inconsistent methods
  - Good geographical coverage

Monterey Peninsula Water Management District

MPWMD Well Yield Calculation for Water Distribution System Permit

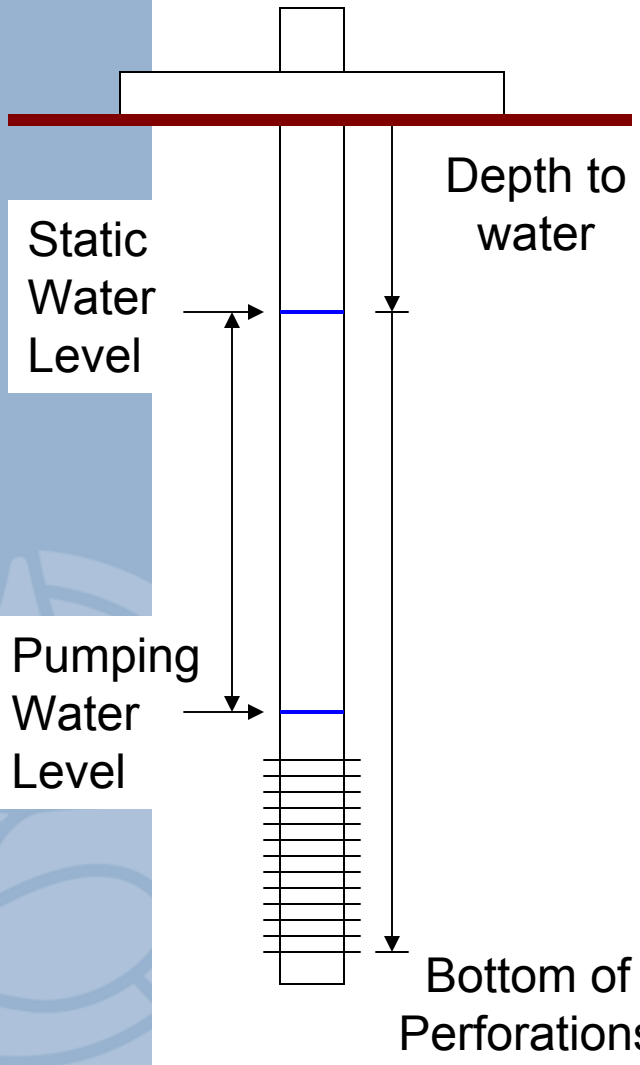


- **Available Drawdown** = 1/3 (depth to bottom of perforations – Static Water Level)
- **Specific Capacity**[1] = GPM / Drawdown
- **Calculated well yield** = Specific Capacity[1] * Available Drawdown
- Poor Geographical Coverage

1. Specific Capacity calculated from first 24 hours of 72 hour pumping test.

Monterey Peninsula Water Management District

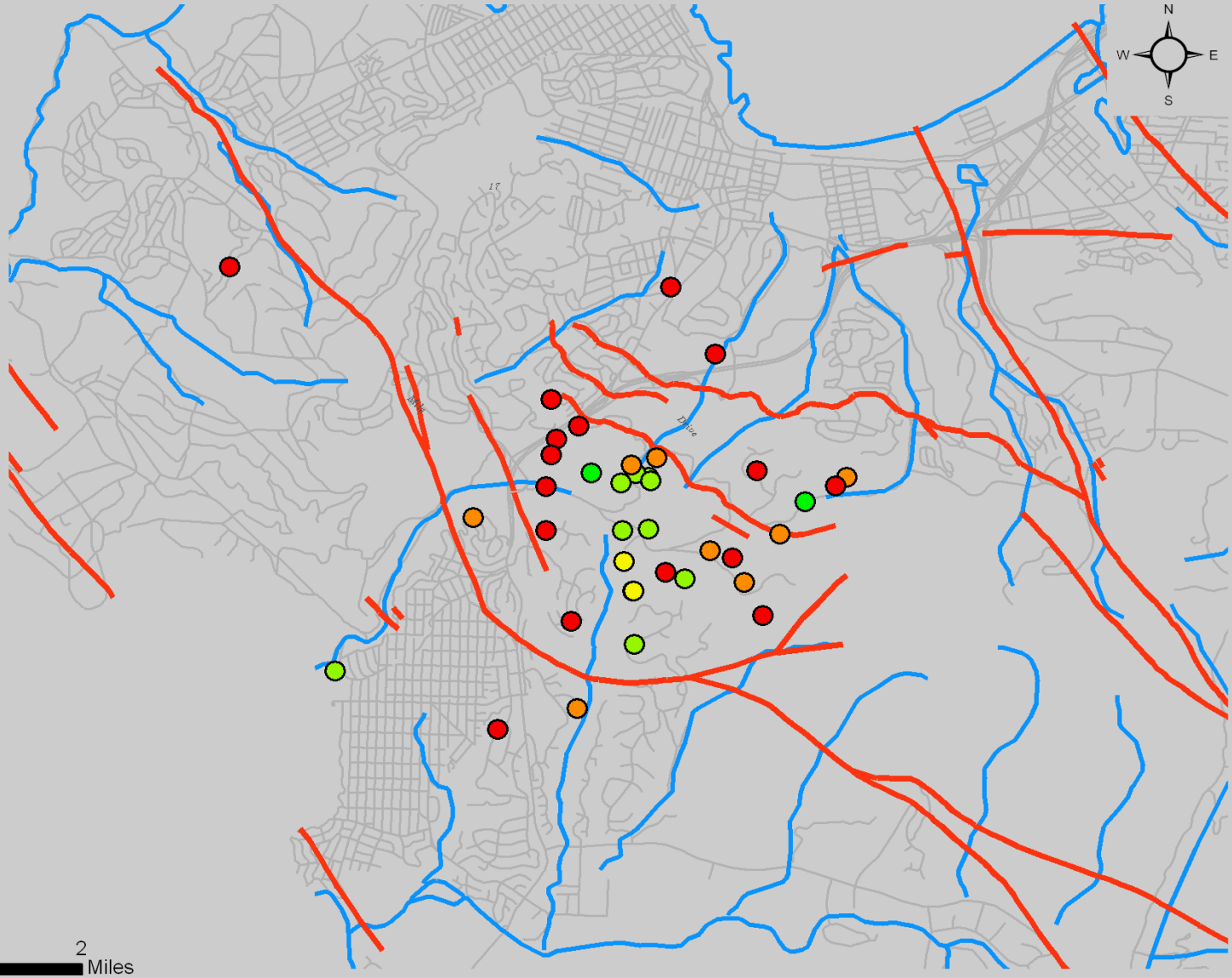
DWR Drawdown Ratio



- Driller reports often do not report drawdown associated with pumping tests.
- In an attempt to normalize flow rate data reported on Drillers logs with depth, we created a “Drawdown Ratio.”
- **Drawdown Ratio** = GPM / (Static Water Level – Depth to Bottom of Screens)
- Good Geographical Coverage

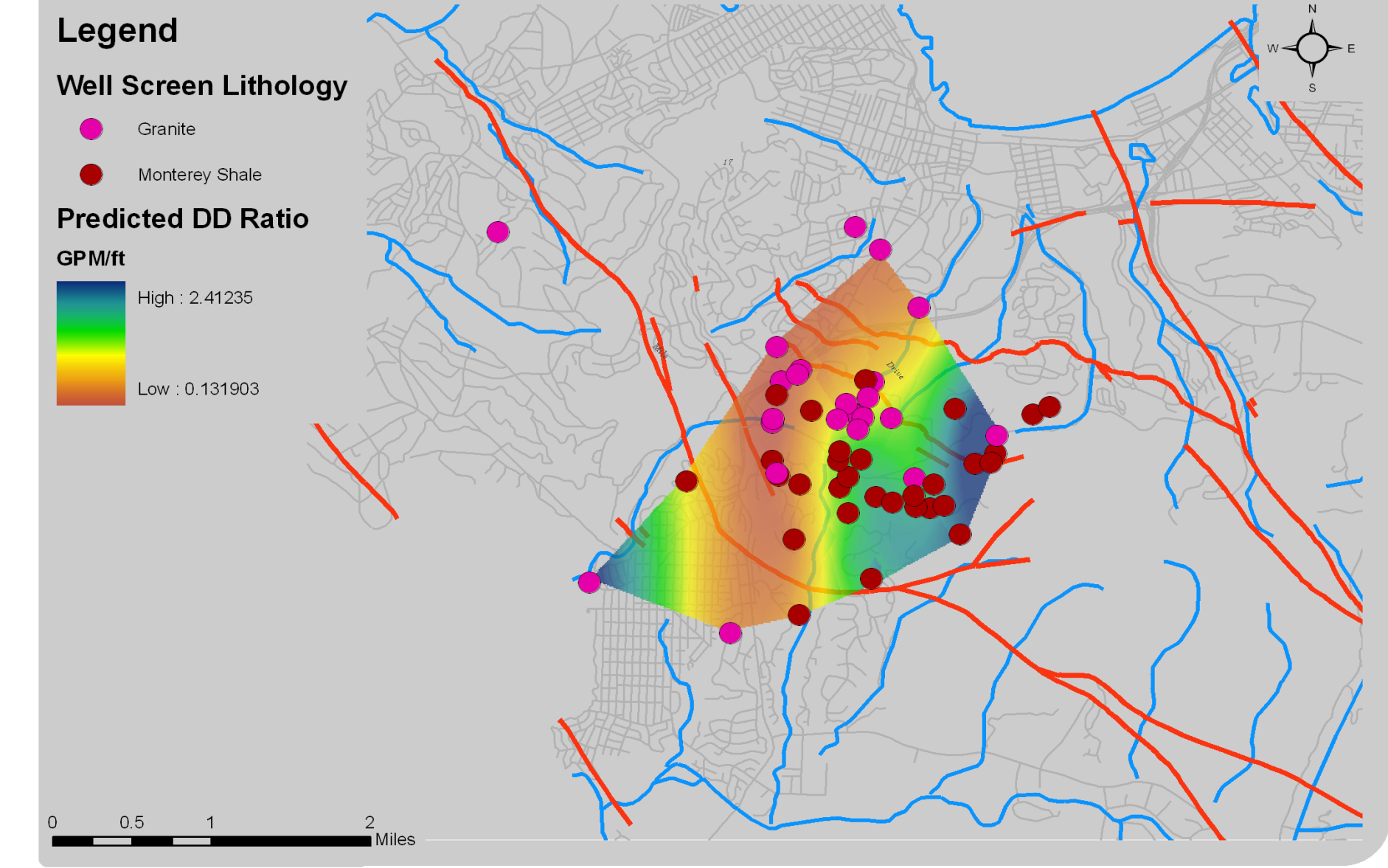
Drawdown Ratios within the Fractured Rock Aquifer Well Sustainability Study Area

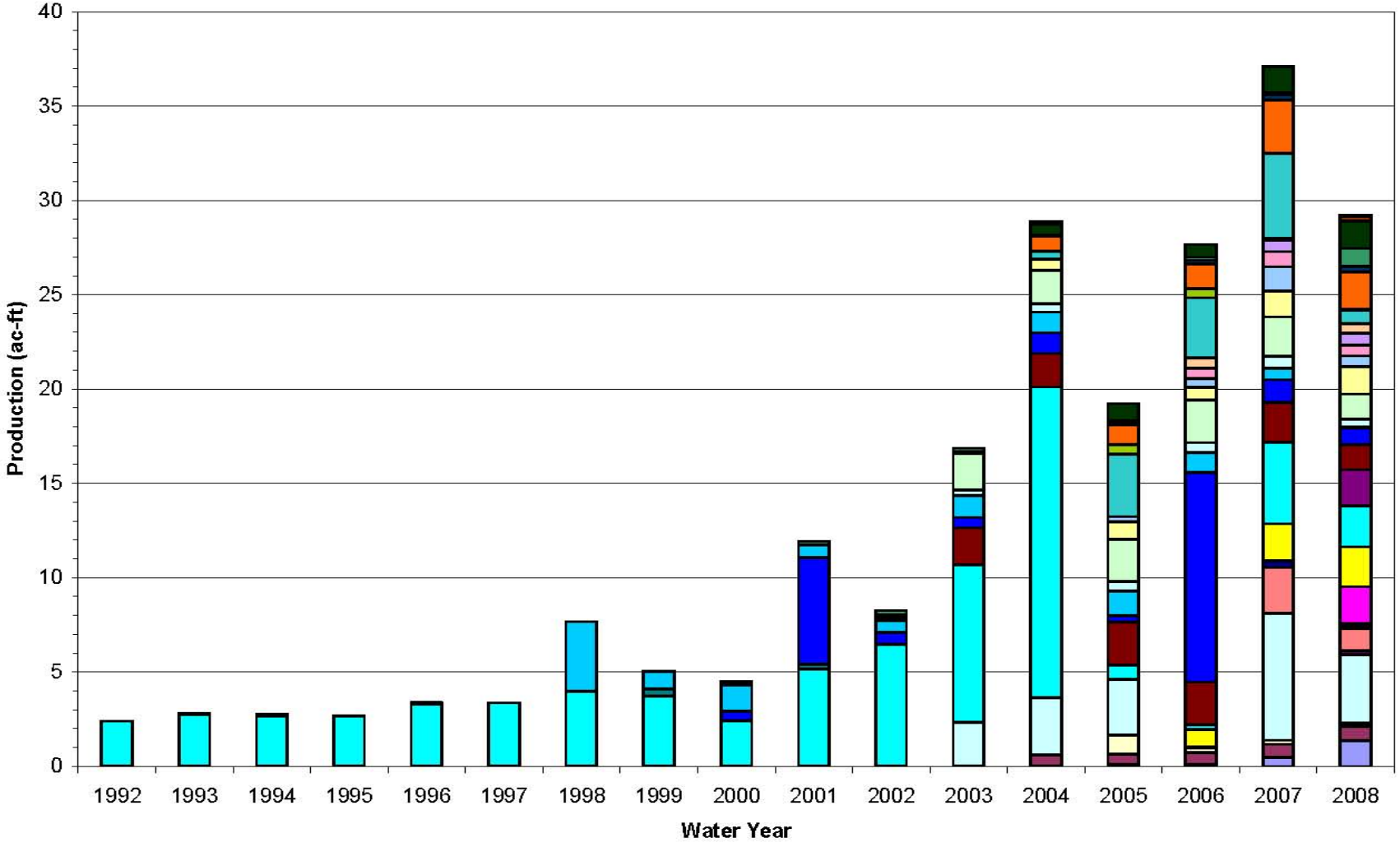
Monterey Peninsula Water Management District



Predicted Drawdown Ratios within the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District



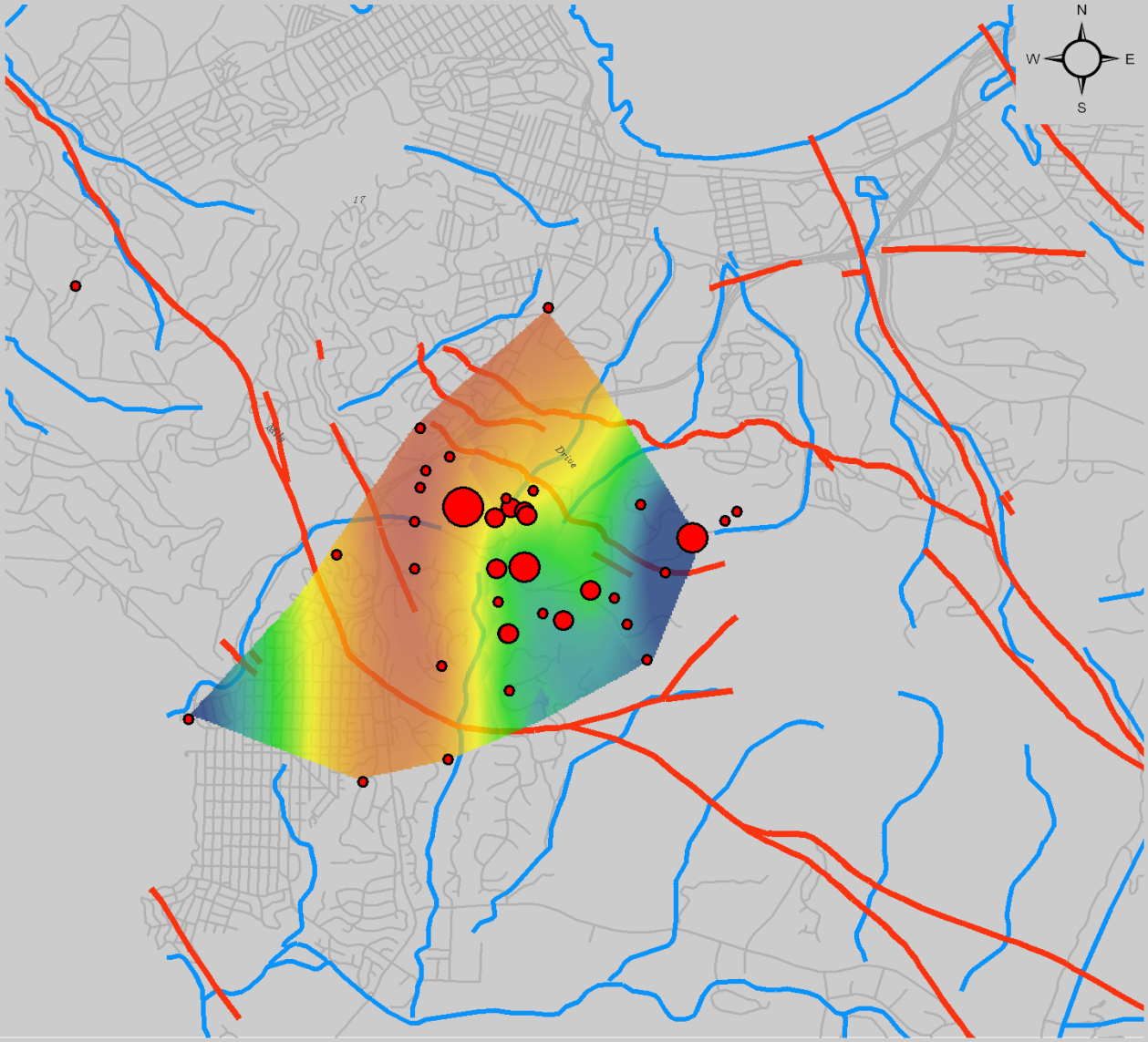


Monterey Peninsula
Water Management District

Production History by Water Year within the Pilot Fractured Rock Aquifer Sustainability Area

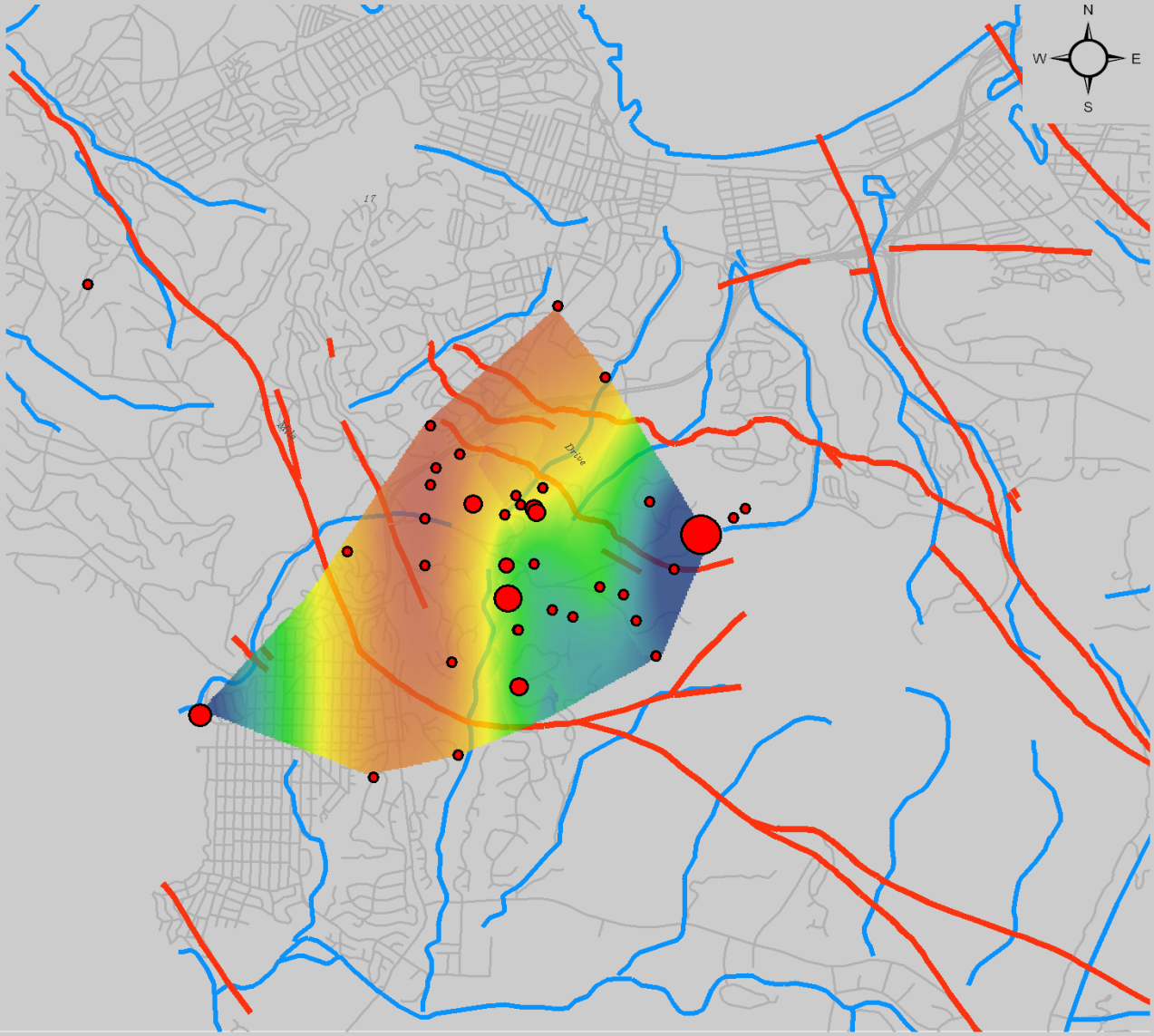
Average Annual Production within the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District



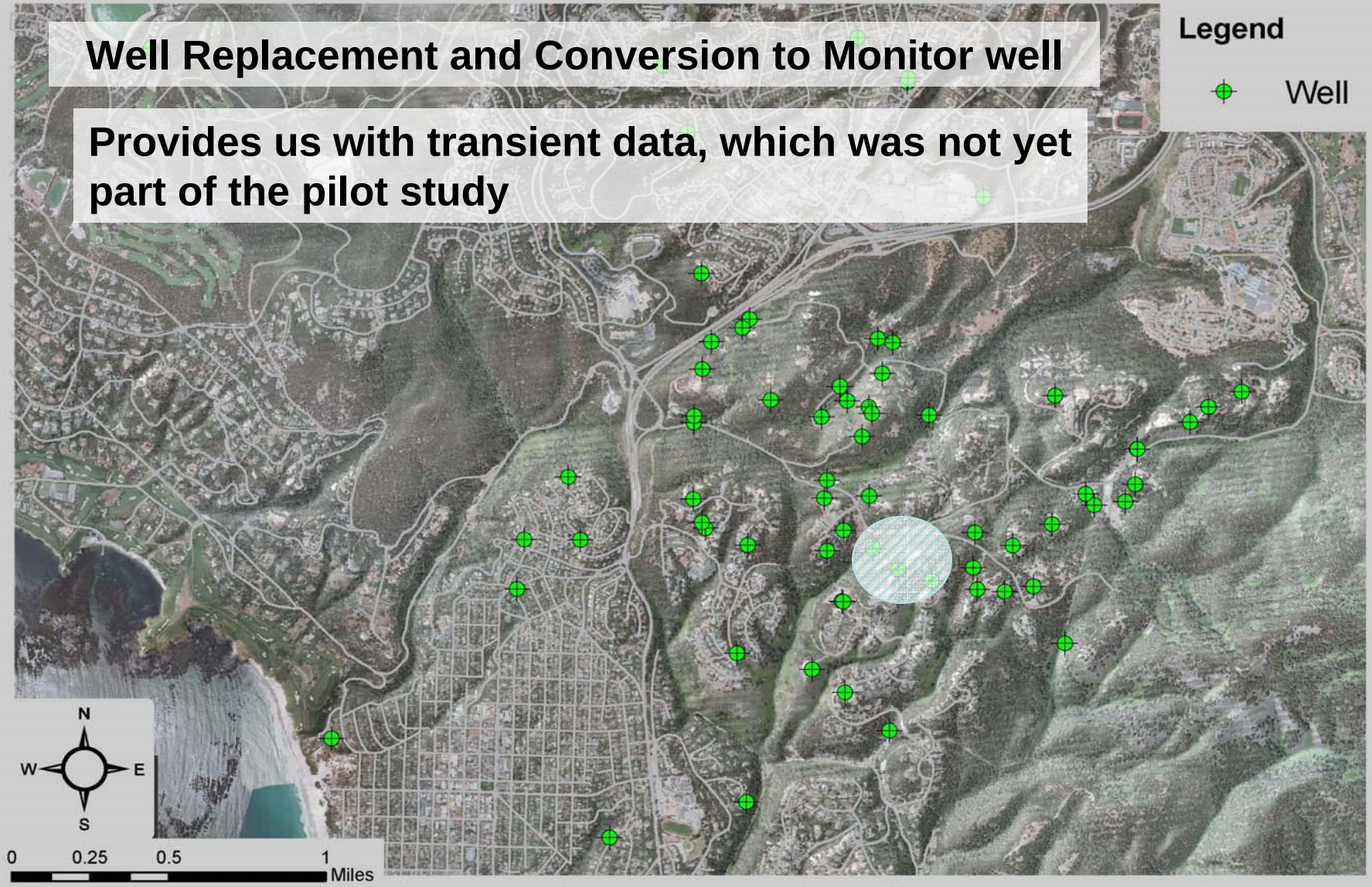
Total Recorded Production within the Fractured Rock Aquifer Well Sustainability Study Area

Monterey Peninsula Water Management District

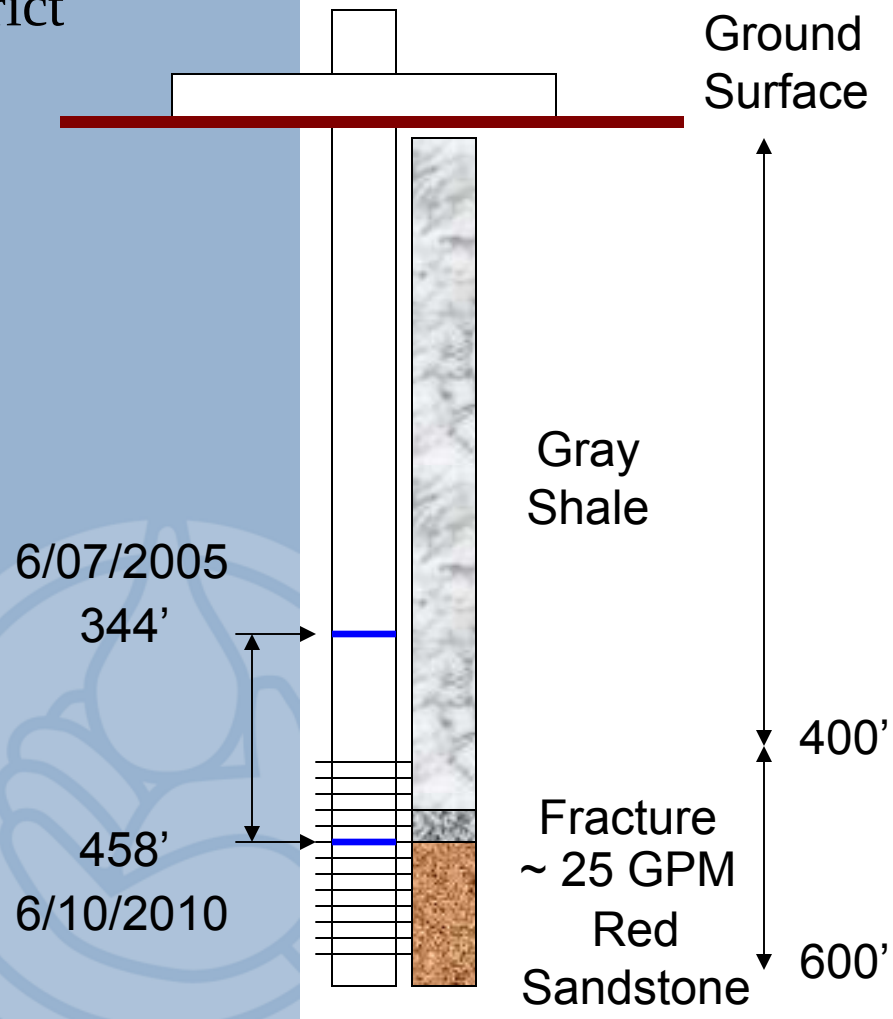


Location of Wells Within the Pilot Fractured Rock Aquifer Sustainibility Study Area

Monterey Peninsula Water Management District



Monterey Peninsula Water Management District



Data from Monitor well

- Drilled as Production well in 6/2005
- 72 hour pump test completed as requirement for WDS permit.
- Well produced 6.2 GPM over the test and pumping water level was 19 feet below static.
- An observation well 550 feet from the pumping well was monitored and considered to be hydrogeologically disconnected from the pumping well.
- In June 2005 static water level was 344 feet BGS compared to June 2010 when static water level was measured to be 459 feet BGS.
- A total of 4.5 acre-feet was produced from the well between 2005 and 2010.
- A replacement well has been drilled 500 feet from the monitoring well and is not hydrogeologically connected to the monitor well.

Conclusions drawn from monitor well data:

- Performance of well observed during pump test indicated good quality fractured rock aquifer.
- Wells spaced more than 500 feet from one another are not hydrogeologically connected.
- 4.5 acre feet was produced from the well and 114 feet of water level decline was observed.
- Well was not an adequate for the long term water supply demand outlined in the WDS permit process.
- Full water level recovery following pump test was not observed and could be a future consideration on evaluating wells during the WDS permit process.

Monterey Peninsula Water Management District

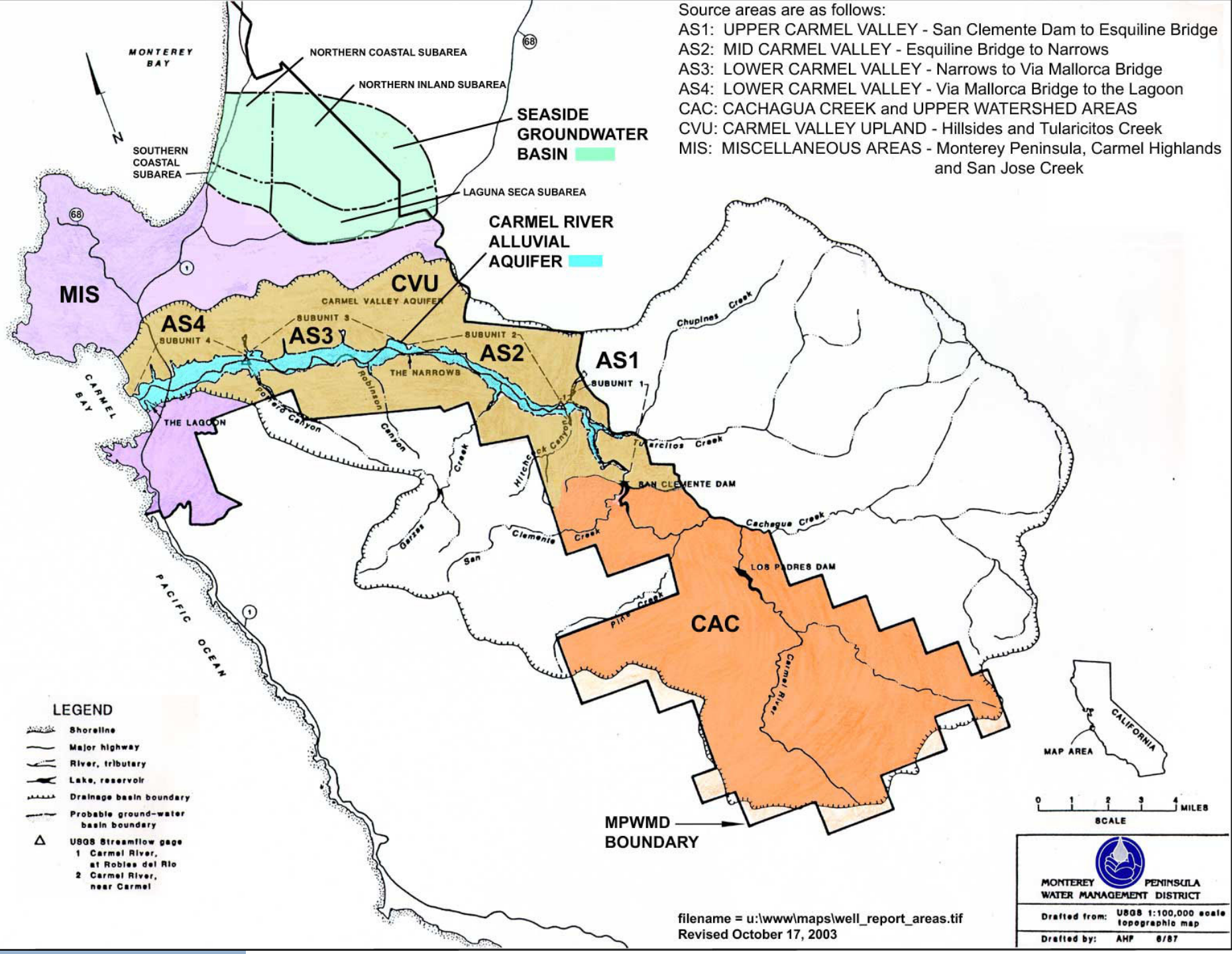
Pilot Study Conclusions

- Not enough data to determine sustainability in pilot study area;
  - More water table elevation data is necessary to measure changes in storage and timing of recharge,
  - Fracture pattern analysis is necessary to determine preferential groundwater flow paths.
- Cluster of wells with low DWR drawdown Ratio screened in Granitic Bedrock.
- Wells screened in Monterey formation have a higher DWR drawdown ratio than wells screened in Granitic Basement in the Pilot Study Area.
- Average annual production in study area has increased from 5 acre-feet in 2000 to 35 acre-feet in 2009.

Monterey Peninsula Water Management District

Recommendations

- Pilot Study Recommendations
  - Complete bedrock mapping and fracture analysis for fracture patterns in Pilot Study Area.
  - Instrument wells available for monitoring within the Pilot Study Area.
- District Wide Recommendations
  - Undertake tasks completed in Pilot Study Area in all fractured rock regions of the District to Identify areas of;
    - poor producing wells,
    - high or quickly increasing annual production
  - Add ongoing water level monitoring requirements to the Water Distribution System Process.
  - Instrument wells available for monitoring within fractured rock regions of the District.
  - Apply for grant opportunities.


Source areas are as follows:
AS1: UPPER CARMEL VALLEY - San Clemente Dam to Esquiline Bridge
AS2: MID CARMEL VALLEY - Esquiline Bridge to Narrows
AS3: LOWER CARMEL VALLEY - Narrows to Via Mallorca Bridge
AS4: LOWER CARMEL VALLEY - Via Mallorca Bridge to the Lagoon
CAC: CACHAGUA CREEK and UPPER WATERSHED AREAS
CVU: CARMEL VALLEY UPLAND - Hillsides and Tularicitos Creek
MIS: MISCELLANEOUS AREAS - Monterey Peninsula, Carmel Highlands and San Jose Creek
MONTEREY BAY
NORTHERN COASTAL SUBAREA
NORTHERN INLAND SUBAREA
SEASIDE GROUNDWATER BASIN
SOUTHERN COASTAL SUBAREA
LAGUNA SECA SUBAREA
CARMEL RIVER ALLUVIAL AQUIFER
MIS
CVU
CARMEL VALLEY AQUIFER
AS4
SUBUNIT 4
AS3
SUBUNIT 3
AS2
SUBUNIT 2
AS1
SUBUNIT 1
THE NARROWS
THE LAGOON
CARMEL BAY
PACIFIC OCEAN
Chupines Creek
Tularcitos Creek
SAN CLEMENTE DAM
Cachagua Creek
LOS PADRES DAM
CAC
Carmel River
MPWMD BOUNDARY
LEGEND
Shoreline
Major highway
River, tributary
Lake, reservoir
Drainage basin boundary
Probable ground-water basin boundary
USGS Streamflow gage
1 Carmel River, at Robles del Rio
2 Carmel River, near Carmel
MAP AREA
CALIFORNIA
0 1 2 3 4 MILES
SCALE
MONTEREY PENINSULA WATER MANAGEMENT DISTRICT
Drafted from: USGS 1:100,000 scale topographic map
Drafted by: AHP 6/87
filename = u:\www\maps\well_report_areas.tif
Revised October 17, 2003