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Technical Memorandum
Perchlorate Contamination of Ground Water in the Raymond Basin
NASA / JPL March 6, 2009 Conference Call Action Items 1, 2 and 3

Prepared for: City of Pasadena Water and Power

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TECHNICAL MEMORANDUM

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN

NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3

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TECHNICAL MEMORANDUM

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN

NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3

1.0 INTRODUCTION

As the result of the March 6, 2009 teleconference regarding ground water modeling for areas below and near the Jet Propulsion Laboratory (JPL). Six action items were identified requiring evaluation and/or comment by GEOSCIENCE, NASA, and Battelle. The six action items are as follows:

1. Review of existing borehole lithologic logs in the JPL and Arroyo Seco areas to assess the potential for subsurface preferential flow pathways.
2. Review and evaluation of results from the JPL aquifer pumping test - Appendix A of the JPL Groundwater Modeling Report, dated December 2003.
3. Evaluation of field conditions representative of the northern model boundaries in the vicinity of JPL.
4. Assumptions and justification for ground water model particle release locations.
5. Evaluation of development of a transient JPL ground water flow model.
6. Further evaluation of infiltration rates and timeframes for chemical migration within the vadose zone.

This technical memorandum addresses Action Items 1, 2, and 3. Action Item 4 will also be addressed by GEOSCIENCE in an existing scope of work but not in this technical memorandum. Action Item 5 will be evaluated by NASA and Action Item 6 is to be addressed by Battelle.

ACTION ITEM 1: REVIEW OF EXISTING BOREHOLE LITHOLOGIC LOGS IN THE JPL AND ARROYO SECO AREAS TO ASSESS THE POTENTIAL FOR SUBSURFACE PREFERENTIAL FLOW PATHWAYS

Action Item No. 1 included evaluation of available borehole lithologic logs from the Monk Hill Subarea and construction of geohydrologic cross-sections in the JPL and Arroyo Seco areas. The purpose of this was to assess the existence and character of subsurface preferential ground water flow pathways.

The scope of work included:

- A review of borehole lithologic logs and geologic data in the area extending from JPL to the City of Pasadena's Sunset Well,
- Preparation of a contour map showing the configuration of the bedrock surface,
- Preparation of a geohydrologic cross-section from JPL on the northeast to the San Rafael Hills on the southwest,
- Preparation of ground water elevation contours for Summer 1997 (earliest period with comprehensive ground water elevation records),
- Preparation of ground water elevation contours for Summer 2008 (most current available ground water elevation data), and
- Comparison of the configuration of the bedrock surface to historical ground water flow paths.

1.1 Subsurface Geologic Conditions

Borehole lithologic logs for a number of JPL monitoring wells (Battelle, 2009) and ground water production wells in the Monk Hill subarea were evaluated to define the distribution of the subsurface sedimentary units. The lithologic logs were used in combination with bedrock elevation contours published by the California Department of Water Resources (DWR) in *Technical Information Record 1335-7-A-2* (DWR, 1969a) to prepare the bedrock elevation contours shown on Figure 1a. Also shown on Figure 1a is the more recent surficial geology as published by the United States Geological Survey in the 2005 *Preliminary Geologic Map of the Los Angeles Quadrangle* (USGS, 2005). The configuration of the bedrock elevation contours indicate the existence of a buried bedrock valley trending west to east through the JPL site and then south along the west side of Monk Hill.

A comparison of ground water levels in JPL monitoring wells MW-1, MW-9, and MW-15 (see Figure 1a) to those in other JPL monitoring wells reveals what appears to be a very steep hydraulic gradient (i.e., a relatively large change in ground water elevations across a relatively small horizontal distance), in the northeastern portion of the JPL site (see ground water elevations in Figure 3). The JPL Groundwater Modeling report shows an east-west trending partial ground water flow barrier immediately south of MW-9 as a possible explanation for this steep hydraulic gradient (see Figure 4-2 of NASA, 2003). However, geologic exploration in the JPL site area (USGS, 1987) show the fault to be mapped as a concealed fault which implies that it would not act as a ground water barrier in recent alluvial deposits (see Figure 3). As the presence of this postulated barrier would alter ground water flow from the north into the JPL site, its existence and/or properties should be fully evaluated.

A generalized geohydrologic cross-section was constructed across the eastern end of the La Crescenta-La Canada Valley from the northeastern boundary of the JPL site, southwest to the San Rafael Hills (see Figure 2). The cross-section was constructed using data from the USGS 2005 geologic map, USGS Professional Paper 1339 (USGS, 1987), and lithologic data from boreholes drilled in the area (Battelle). The subsurface lithologic contacts between alluvial units were based on those provided in Figure 2-6 of the JPL Ground Water Modeling report (NASA, 2003).

The generalized geohydrologic cross-section shown in Figure 2 indicates the presence of an east-west trending asymmetrical buried valley beneath the JPL site with a steep northern flank. The axis of this buried valley crosses the cross-section near monitoring well MW-13 and is normal to the section. Spring 1997 and Summer 2008 ground water elevations as shown on the cross-section (Figure 2) exhibit relatively flat gradients suggesting that the ground water flow direction is perpendicular to the cross section line and parallel to the axis of the buried bedrock valley shown in Figure 1a (i.e., NW to SE see Figure 4).

1.2 Ground Water Flow Directions

Figures 3 and 4 show ground water elevations as measured in the Spring of 1997 and Summer of 2008, respectively. Ground water elevations for Spring 1997 (see Figure 3) show pumping depressions in the vicinity of the Ventura and Windsor wells. A northeast-southwest trending ground water divide is shown between Monk Hill and JPL, apparently the result of pumping from the Ventura and Windsor wells during that time. The ground water elevations for Summer 2008 (see Figure 4) indicate that ground water flow generally follows the buried bedrock valley southeast through the La Crescenta-La Canada Valley and then south through the area west of Monk Hill following the Arroyo Seco channel towards monitoring well M-25, and the Coplin, Bangham, and Sunset production wells (see Figure 4). The ground water elevation contours and directions for Summer 2008 are consistent with previously published historical ground water elevation contours shown on Plate 1.

1.3 Preferential Ground Water Flow Pathway

Aside from periods when ground water flow patterns were heavily influenced by pumping of the Ventura and Windsor production wells (see Figure 3), ground water elevations in the area west of Monk Hill indicate that ground water generally follows the course of the buried bedrock valley as shown in Figure 1a. As such, ground water flowing to the south and southeast from the La Crescenta-La Canada Valley is separated by Monk Hill with preferential southerly flow parallel to Arroyo Seco, bounded by shallow bedrock beneath the Arroyo Seco to the west, and Monk Hill to the east. Recent and historical ground water elevation contours shown on Figure 4 and Plate 1 support the fact that the buried bedrock valley acts as a preferential ground water flow pathway west of Monk Hill.

2.0 ACTION ITEM 2 - REVIEW AND EVALUATION OF RESULTS FROM THE JPL AQUIFER PUMPING TEST - APPENDIX A OF THE JPL GROUNDWATER MODELING REPORT, DATED DECEMBER 2003

Action Item 2 included review and evaluation of the results of the JPL aquifer pumping test conducted in the vicinity of the JPL site (see Appendix A of NASA, 2003). The JPL aquifer pumping test involved continuous pumping of City of Pasadena Wells 52, Ventura, and Windsor, and monitoring of drawdown in nine (9) JPL monitoring wells for a period of 148.5 hours between May 18 and 24, 2001 (see Figure 5). The following table provides a summary of monitoring wells monitored during the test and their distances to the three pumping wells.

Summary of Wells Used in the JPL Regional Aquifer Pumping Test (May 18 - 24, 2001)

Monitoring Well	Distance to Pumping Wells		
	Well 52 [ft]	Ventura [ft]	Windsor [ft]
MW-3	1,446	2,051	2,831
MW-4	1,313	1,785	2,626
MW-5	1,149	1,497	2,297
MW-8	2,133	2,667	3,497
MW-9	2,256	2,862	3,179
MW-10	1,672	1,908	2,656
MW-12	1,928	2,503	3,292
MW-13	2,462	2,913	3,733
MW-17	1,005	1,231	1,580

NASA's analysis of the aquifer pumping test data using the Multi Layer Program Unsteady state (MLPU) analytical ground water model resulted in an aquifer transmissivity of the entire aquifer system (JPL Model Layers 1 through 4) of approximately 95,000 gallons per foot per day (gpd/ft). The storativity ranged from 0.00013 to 0.000017 for JPL Model Layers 1 through 4.

In order to provide an independent check of aquifer parameters (i.e., transmissivity and storativity) resulting from NASA's analysis of the aquifer pumping test, a weighted logarithmic mean analysis was conducted (Cooper and Jacob, 1946). This method is based upon the principle of superposition which, when applied to multiple pumping wells, states that the total drawdown produced at a given time is the sum of the drawdown that would be produced independently by each well pumping alone. The transmissivity (T) and storativity (S) of an aquifer can be calculated by plotting the specific drawdown ($s_n/\Sigma Q_k$) versus the weighted logarithmic mean $(r_k^2/t)^n$. The resulting plot is known as a Generalized Composite Drawdown Graph. The terms are defined as follows:

n	=	number of pumping wells.
k	=	increment of discharge (i.e., pumping).
s_n	=	the drawdown(s) observed in well n in the k^{th} pumping period. A pumping period is initiated at any time during the test that the discharge rate in any of the pumping wells changes, ft.
$\sum_{i=1}^{n} Q_k$	=	The sum of the discharge rates from all pumping wells at the time of measurement of drawdown s_n, cfs.
t_k	=	The time which has elapsed since the beginning of the k^{th} pumping period, sec.
r_k^2	=	The square of the radial distance between the observed well and the pumping well at the k^{th} increment of discharge, ft^2.

The change in specific drawdown over one log cycle of $(r_k^2/t)^n[\Delta(s_n/\Sigma Q_k)]$ on the generalized composite drawdown graph is used to calculate regional aquifer transmissivity (T) from the following equation (Cooper and Jacob, 1946):

$$T = \frac{2.303}{4\pi\Delta(s_n / \sum Q_k)}$$

where:

T = transmissivity, cfs/ft.

$\Delta\left(\frac{s_n}{\sum Q_k}\right)$ = change in specific drawdown over one log cycle of the weighted logarithmic mean $(r_k^2/t)^n$, ft/cfs.

Storativity (S) is calculated from:

$$S = 2.25T(r_k^{\,2} / t)_0$$

where:

$(r_k^{\,2} / t)_0 = (r_k^{\,2} / t)$ at $s_n / \sum Q_k = 0$

$s_n / \sum Q_k$ = specific drawdown, ft/cfs.

S = storativity, fraction.

T = transmissivity, cfs/ft.

t = time, sec.

Monitoring well drawdown data (from MW-3, -4, -5, -8, -10, -12, -13, and -17), pumping well discharge rates (from City of Pasadena Wells 52, Ventura, and Windsor), and pumping periods provided in Appendix A of the JPL Groundwater Modeling Report (NASA, 2003) were used to calculate the weighted logarithmic mean and specific drawdown for each of the monitoring wells for which data were provided. The resulting charts showing specific drawdown versus weighted logarithmic mean as applied to the monitoring well data are provided in Appendix A of this report.

The results of the analysis show that the transmissivity of the well field area ranged from approximately 14,000 to 237,000 gpd/ft with an average of approximately 93,000 gpd/ft. The storativity ranged from approximately 0.0001 to 0.02 with an average of 0.004. The following table presents a summary of aquifer parameters for each of the monitoring wells as calculated by the weighted logarithmic mean method:

Summary of Aquifer Parameters for JPL Monitoring Wells as Calculated by the Weighted Logarithmic Mean Method

Monitoring Well Designation	Monitoring Well Port	JPL Model Layer	Transmissivity [gpd/ft}	Storativity [fraction]
MW-3	2	2	91,154	0.0016
MW-3	3	3	74,063	0.0010
MW-3	4	4	13,779	0.0001
MW-4	3	2	79,000	0.0012
MW-4	5	4	13,941	0.0001
MW-5	NA	1	197,501	0.0163
MW-8	NA	1	237,001	0.0066
MW-10	NA	1	197,501	0.0100
MW-12	2	2	118,500	0.0011
MW-12	3	3	91,154	0.0009
MW-12	5	4	15,000	0.0001
MW-13	NA	1	74,063	0.0065
MW-17	2	2	107,728	0.0035
MW-17	3	3	65,834	0.0025
MW-17	4	4	17,687	0.0004
		MINIMUM:	13,779	0.00010
		MAXIMUM:	237,001	0.01626
		AVERAGE:	92,927	0.00346

As can be seen, the resulting average transmissivity from the weighted logarithmic mean analysis (i.e., 93,000 gpd/ft) matches closely the transmissivity of the whole aquifer system calculated from the results of NASA's MLPU model (i.e., 95,000 gpd/ft). The storativity ranged from 0.0001 to 0.02 and averages 0.003. As such, it appears that the method used by NASA to evaluate data from the JPL aquifer pumping test is reasonable.

The east-west trending partial ground water flow barrier as shown in the JPL Groundwater Modeling report (see Figure 4-2 of NASA, 2003) is situated between the pumping wells used during the aquifer pumping test and JPL monitoring well MW-9. Although MW-9 was reportedly monitored during the regional aquifer pumping test, there were no drawdown data provided for this well in Appendix A of the JPL Groundwater Modeling report. As such, aquifer parameters between MW-9 and the pumping wells could not be evaluated using the weighted logarithmic mean method. If made available, these data may provide insight into the existence and/or character of the postulated ground water flow barrier.

3.0 ACTION ITEM 3 - EVALUATION OF FIELD CONDITIONS REPRESENTATIVE OF THE NORTHERN MODEL BOUNDARIES IN THE VICINITY OF JPL

Action Item No. 3 addresses the ground water model boundary conditions in the Northern Portion of the Raymond Basin in the vicinity of the JPL site as presented in the ground water model developed by GEOSCIENCE in 2005. A detailed description of the ground water model is provided in the Raymond Basin Ground Water Flow Model Predictive Simulation report (GEOSCIENCE, 2005).

3.1 Delineation of Active and Inactive Model Cells

The active/inactive model cell boundary near the JPL site is based on geologic boundaries from a 1969 geologic map from California Division of Mines and Geology (CDMG; see Figure 6). The active model cells include the Alluvium, Quaternary Nonmarine Terrace Deposits and Pleistocene Nonmarine Deposits as shown in Figure 6.

3.2 Underflow Recharge near the JPL Site

Ground water recharge from mountain front runoff (underflow) is a component of recharge in the vicinity of the JPL site, flowing through weathered and fractured bedrock as a result of areal recharge occurring in the essentially non-water-bearing surrounding mountains. The underflow recharge from mountain front runoff to the Raymond Basin was estimated using the watershed modeling code Hydrological Simulation Program – Fortran (HSPF; EPA, 1997). This program uses daily precipitation and evaporation to estimate surface water runoff, evapotranspiration, and ground water recharge.

The area of the Arroyo Seco watershed (see Figure 7) that contributes underflow recharge to the JPL site is approximately 13,965 acres. The Arroyo Seco watershed area was delineated using

ESRI's hydrologic modeling extension for ArcView[1], which calculates the flow direction of the steepest descent for each 30 x 30 meter cell from the USGS DEM[2]. The hydrological modeling extension then uses the DEM based flow directions to delineate surface water divides separating tributary watershed areas.

The Arroyo Seco watershed The Arroyo Seco watershed area experiences a long-term average annual precipitation of 27.75 inches per year (see Figure 7). The HSPF-modeled monthly underflow recharge in the vicinity of the JPL site ranged from 0 (July 1984) to 3,976 acre-ft (March 1983), with an average annual recharge of approximately 2,200 acre-ft per year during the period from 1981 through 2002.

The approximate total area of the surrounding mountains contributing to the total underflow into Raymond Basin is 36,508 acre-ft. DWR estimated the average annual underflow for the entire Raymond Basin to be 6,520 acre-ft per year (DWR, 1969). In order to compare DWR's total estimated underflow (i.e., 6,520 acre-ft per year) to the HSPF-modeled underflow for the Arroyo Seco watershed (i.e., 2,200 acre-ft per year), the DWR estimated underflow was adjusted by multiplying by the ratio of the watershed areas (approximately 38 percent). This resulted in an estimated underflow for the Arroyo Seco watershed of 2,494 acre-ft per year, a value similar to that obtained from the HSPF model (2,200 acre-ft per year).

The north to south recharge to the Arroyo Well area can be explained by the fact that the underflow from the Arroyo Seco watershed enters the recent alluvium north of the Arroyo well (see Figure 3 – Arroyo Seco -Millard Canyon Cr. area). The Bridge Fault (which is part of the Sierra Madre Fault Zone), crosses the Arroyo Seco north of the Arroyo well juxtaposing granitic basement rock over Pleistocene alluvium. However, the fault does not act as a ground water barrier to southward moving ground water flow from the Arroyo Seco watershed as recent alluvium overlies the fault at the JPL Bridge site, and provides a pathway for ground water flow

[1] ArcView Version 3.2a developed by Environmental Systems Research Institute, Inc. (ESRI).

[2] Digital Elevation Model.

from the Arroyo Seco watershed to the Raymond Basin. (see Plate 2.6 of USGS Professional paper 1339).

FINDINGS and SUMMARY of action items 1, 2 and 3

Findings identified for each of the three action items under evaluation are summarized as follows:

1. ***Review of existing borehole lithologic logs in the JPL and Arroyo Seco areas to assess the potential for subsurface preferential flow pathways.***

    - The configuration of the bedrock elevation contours shown in Figure 1 indicate the existence of a buried bedrock valley trending east-west through the JPL site and then southerly, west of Monk Hill and parallel to the Arroyo Seco channel.
    - The geohydrologic cross-section constructed across the eastern end of La Crescenta-La Canada Valley supports the presence of an asymmetrical buried valley beneath the JPL site.
    - The JPL Groundwater Modeling report attributes the steep hydraulic gradient in the northeastern portion of the JPL site to a east-west trending partial ground water flow barrier. The existence and/or properties of this postulated barrier should be fully evaluated as it could affect the amount of ground water flow from the north into the JPL site.
    - Ground water elevation contours west of Monk Hill suggest that ground water flow generally follows the course of the buried bedrock valley. Ground water flows southeast and south from the La Crescenta-La Canada Valley and is separated by Monk Hill. Ground water to the west of Monk Hill flows southerly, generally parallel to Arroyo Seco and following the axis of the buried bedrock valley.

2. ***Review and evaluation of results from the JPL aquifer pumping test - Appendix A of the JPL Groundwater Modeling Report, dated December 2003.***

    - The JPL aquifer pumping test resulted in an aquifer transmissivity for the entire aquifer system (Model Layers 1 through 4) of approximately 95,000 gpd/ft with a storativity ranging from 0.00013 to 0.000017.
    - Independent analysis of the JPL aquifer pumping test data using the weighted logarithmic mean method resulted in an aquifer transmissivity for the wellfield area ranging from 14,000 to 237,000 gpd/ft with an average of approximately

93,000 gpd/ft. The storativity ranged from 0.0001 to 0.02 with an average of 0.004.

- The aquifer average wellfield transmissivity from the weighted logarithmic mean analysis (i.e., 93,000 gpd/ft) closely matches the transmissivity of the entire aquifer system as calculated from the results of the NASA model (i.e., 95,000 gpd/ft). As such, the method used by NASA to evaluate the JPL aquifer pumping test data can be considered reasonable.
- Drawdown data measured at monitoring well MW-9 during the JPL aquifer pumping test was not included in the JPL Groundwater Modeling report. If made available, this data should be evaluated by independent methods to evaluate the existence and/or character of the postulated ground water flow barrier in the northeastern portion of the JPL site.

3. ***Evaluation of field conditions representative of the northern model boundaries in the vicinity of JPL.***

- The area of the Arroyo Seco watershed that contributes underflow recharge to the JPL site is approximately 13,965 acres. The long-term average annual precipitation in this area is 27.75 inches per year.
- The HSPF-modeled monthly underflow in the vicinity of the JPL site during the period from 1981 to 2002 ranged from 0 to 3,976 acre-ft with an average annual recharge of approximately 2,200 acre-ft per year.
- For comparison with the HSPF-modeled underflow from the Arroyo Seco watershed, the total average annual underflow to Raymond Basin estimated by DWR in 1969 (6,520 acre-ft per year) was adjusted by the ratio of watershed areas (approximately 38 percent). This resulted in an estimated underflow from the Arroyo Seco watershed of 2,494 acre-ft per year, a value similar to that obtained from the HSPF model (2,200 acre-ft per year).

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FIGURES

GEOSCIENCE Support Services, Inc.

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
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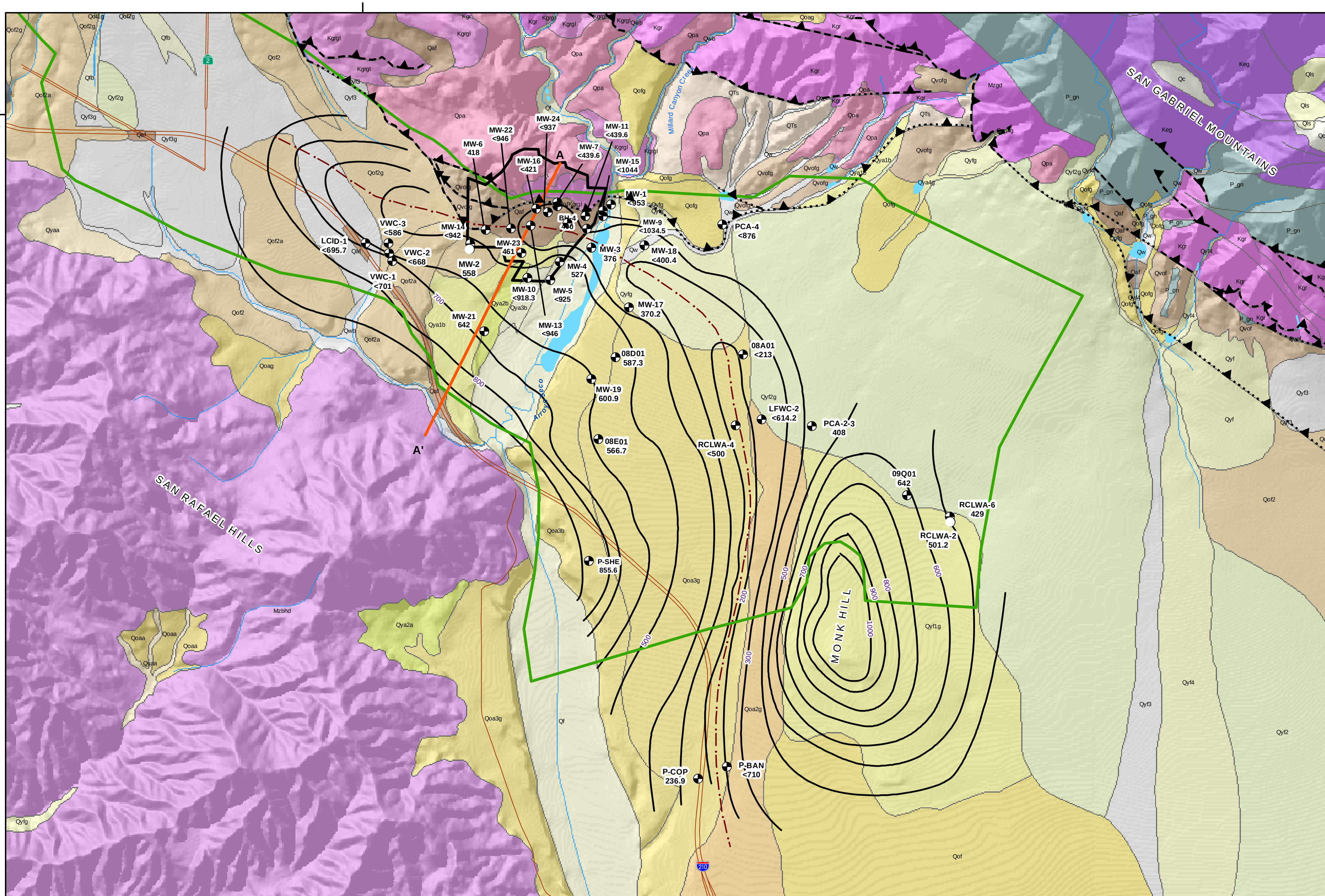
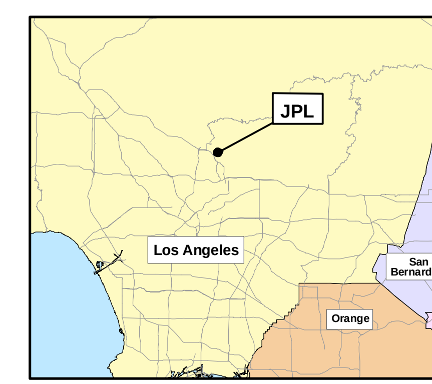


BEDROCK ELEVATIONS

EXPLANATION

- MW-21 / 642 — Wells With Drillers Logs; Bedrock Elevation, ft amsl
- 600 — Bedrock Elevation (ft amsl)
- Axis of Buried Bedrock Valley
- Thrust Fault (dashed where inferred)
- Thrust Fault (dotted where concealed)
- NASA JPL Property Boundary
- NASA JPL Model Boundary (Wheeler, 2000)
- A — A' Geologic Cross - Section (See Figure 2)
- Highway or Interstate
- River or Drainage Channel
- Spreading Basins

*See Figure 1a for legend of geologic units for USGS 2005 surficial geology.



24-Jun-09

Prepared by: LH

Map Projection: UTM 1927, Zone 11

NORTH

0 2,000 4,000 Feet

Source: Bedrock Elevations modified From DWR, 1969a)
Faults and geology taken from Preliminary Geologic Map of Los Angeles 30' x 60' Quadrangle, Southern California. USGS, 2005.

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Figure 1a

CITY OF PASADENA WATER AND POWER

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GEOLOGIC LEGEND (USGS, 2005)

Qaf, Artificial fill	Qoag, Old alluvium
Qwb, Wash deposits	Qoaa, Old alluvium
Qw, Wash deposits	Qoa, Old alluvium
Qf, Alluvial-fan deposits	Qoa3b, Old alluvium
Qc, Colluvium	Qoa3g, Old alluvium
Qc?, Colluvium	Qoa2g, Old alluvium
Qls, Landslide deposits	Qofg, Old alluvial-fan deposits
Qya4g, Young alluvium	Qof, Old alluvial-fan deposits
Qya3b, Young alluvium	Qof2a, Old alluvial-fan deposits
Qya2b, Young alluvium	Qof2g, Old alluvial-fan deposits
Qya2a, Young alluvium	Qof2, Old alluvial-fan deposits
Qya1b, Young alluvium	Qvof, Very old alluvial-fan deposits
Qyf, Young alluvial-fan deposits	Qvofg, Very old alluvial-fan deposits
Qyfg, Young alluvial-fan deposits	Qpa, Pacoima Formation
Qyf4, Young alluvial-fan deposits	QTs, Saugus Formation
Qyf3, Young alluvial-fan deposits	Kgr, Granitic rocks
Qyf3g, Young alluvial-fan deposits	Kgrgl, Granitic rocks
Qyf2g, Young alluvial-fan deposits	Keg, Echo granite
Qyf2, Young alluvial-fan deposits	Mzbhd, Biotite-hornblende diorite
Qyf1g, Young alluvial-fan deposits	Mzgd, Granodiorite
Qyf1, Young alluvial-fan deposits	P_gn, Gneiss

Source: Faults and geology taken from
Preliminary Geologic Map of Los Angeles
30' x 60' Quadrangle, Southern California. USGS, 2005.

24-Jun-09

Prepared by: LH

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_1b_geology_lgnd_6-09.mxd

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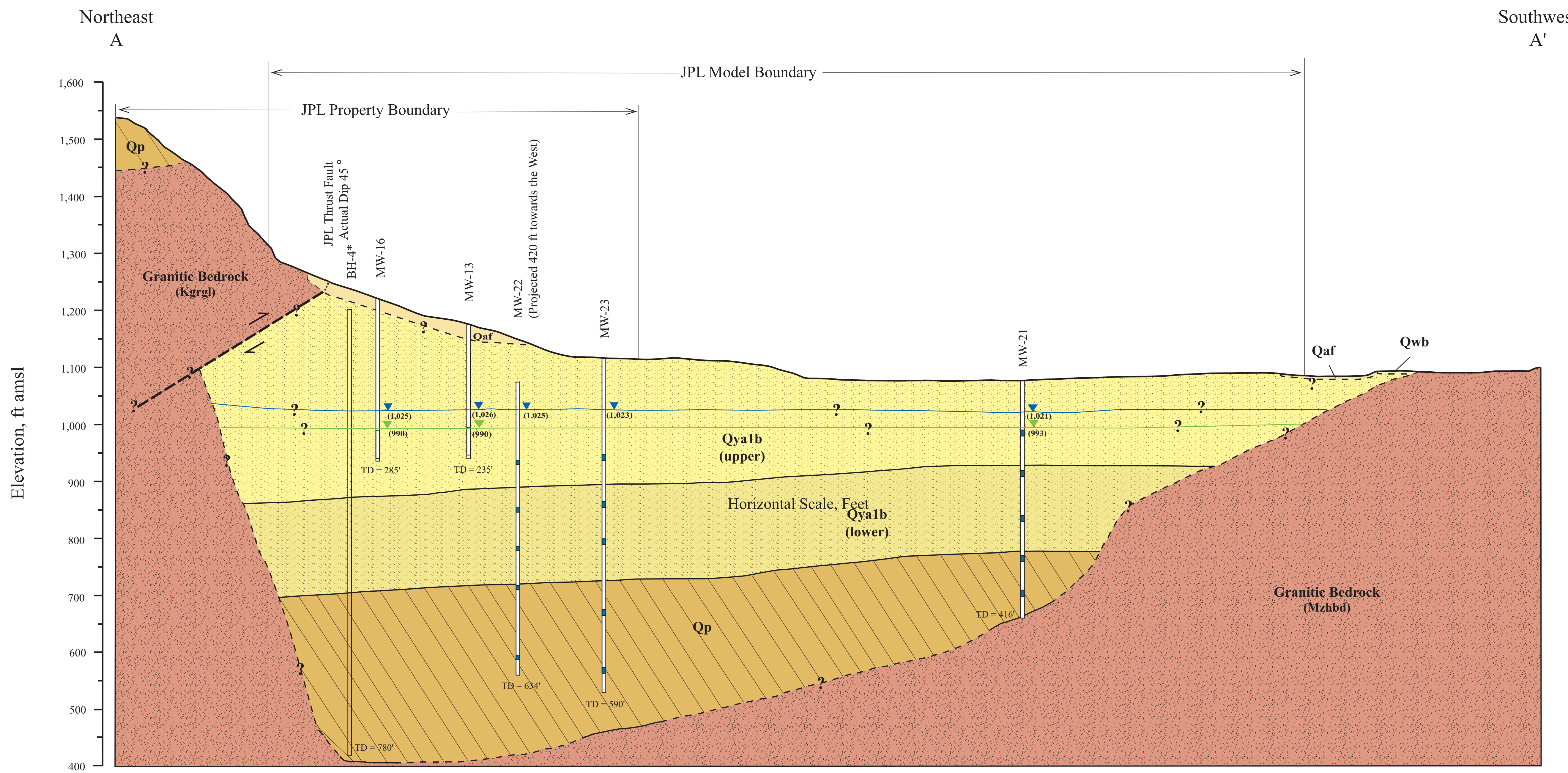
Figure 1b



JPL Monitoring Well

Well Screen

Spring 2008 Ground Water Elevation (1,021)

Spring 1997 Ground Water Elevation (993)

Geologic Contact, Dashed Where Approximately Located

Thrust Fault, Dashed Where Inferred Dotted Where Concealed

TD = 590' **Total Depth of Well, Feet Below Ground Surface**

Qaf **Artificial Fill**

Qwb **Wash Deposits, Boulders**

Qya1b (upper) **Older Fanglomerate Series (upper), Pleistocene**

Qya1b (lower) **Older Fanglomerate Series (lower), Pleistocene**

Qp **Pacoima Formation, Early Pleistocene**

Granitic Bedrock, includes Kgrgl and Mzhbd, Paleozoic

Horizontal Scale, Feet

0 600 1,200

Vertical Scale Exaggerated 3:1

Note:
See Figure 1a for location of Section A-A'.

*Fault relationship and BH-4 lithology based on USGS Professional Paper 1339, Plate 2-6.

JPL model boundary prepared by Foster Wheeler Environmental Corp. Draft Feasibility Study for Operable Units 1 and 3, Jan 2000.

Source: Subsurface geologic contacts based on Figure 2-6 Geologic Cross Section D-D', Foster Wheeler Environmental Corp. Draft Feasibility Study for Operable Units 1 and 3 for NASA JPL, January 2000.

Surface geologic contacts based on Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, Southern California USGS, 2005

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CITY OF PASADENA WATER AND POWER

GEOHYDROLOGIC CROSS SECTION A - A'

Drawn: LH
Checked:
Approved:
Date: 24-Jun-09

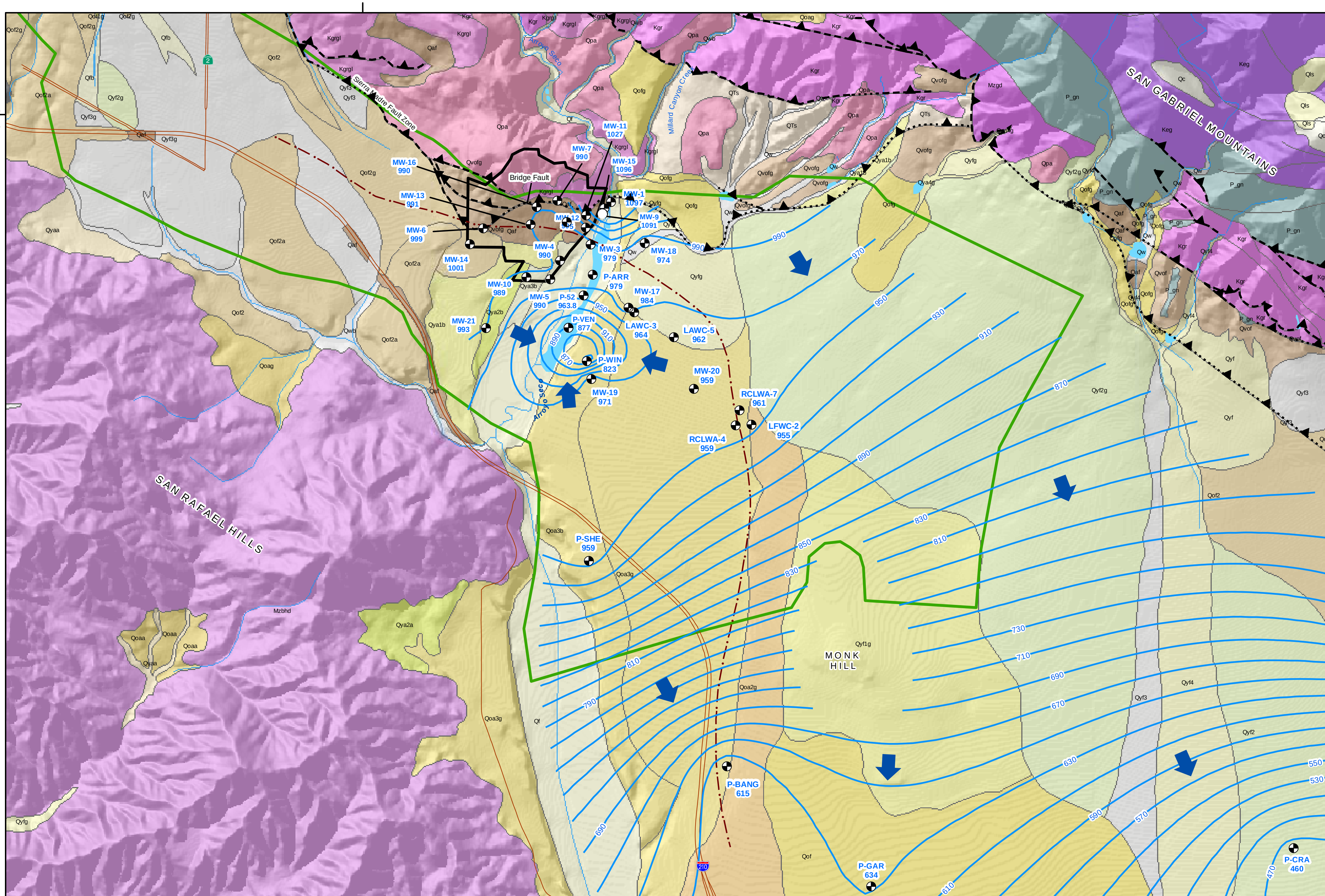
Figure 2

Projects\City_of_Pasadena\JPL_NASA Action Items 1-3\Technical Memorandum\Figures\Fig_2_A-A_cross_section_6-09_11X17.ai

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3

T.2 N.
T.1 N.



R.13 W. R.12 W.

GROUND WATER ELEVATIONS SPRING 1997

EXPLANATION

Wells Sampled During May 1997

- MW-6 977 — Wells with Water Level Measurements; Ground Water Elevation, ft amsl
- 600 — Spring 1997 Water Level Elevations, ft amsl (Sources: Foster, Wheeler Environmental Corp. 1998 and RBMB, 2008)
- 1997 Ground Water Flow Direction
- Axis of Buried Bedrock Valley
- Thrust Fault (dashed where inferred)
- Thrust Fault (dotted where concealed)
- NASA JPL Property Boundary
- NASA JPL Model Boundary (Wheeler, 2000)
- Highway or Interstate
- River or Drainage Channel
- Spreading Basins

*See Figure 1a for legend of geologic units from USGS 2005 surficial geology.

24-Jun-09

Prepared by: LH

Map Projection: UTM 1927, Zone 11

NORTH
0 2,000 4,000 Feet

Source: Faults and geology taken from Preliminary Geologic Map of Los Angeles 30' x 60' Quadrangle, Southern California USGS, 2005.

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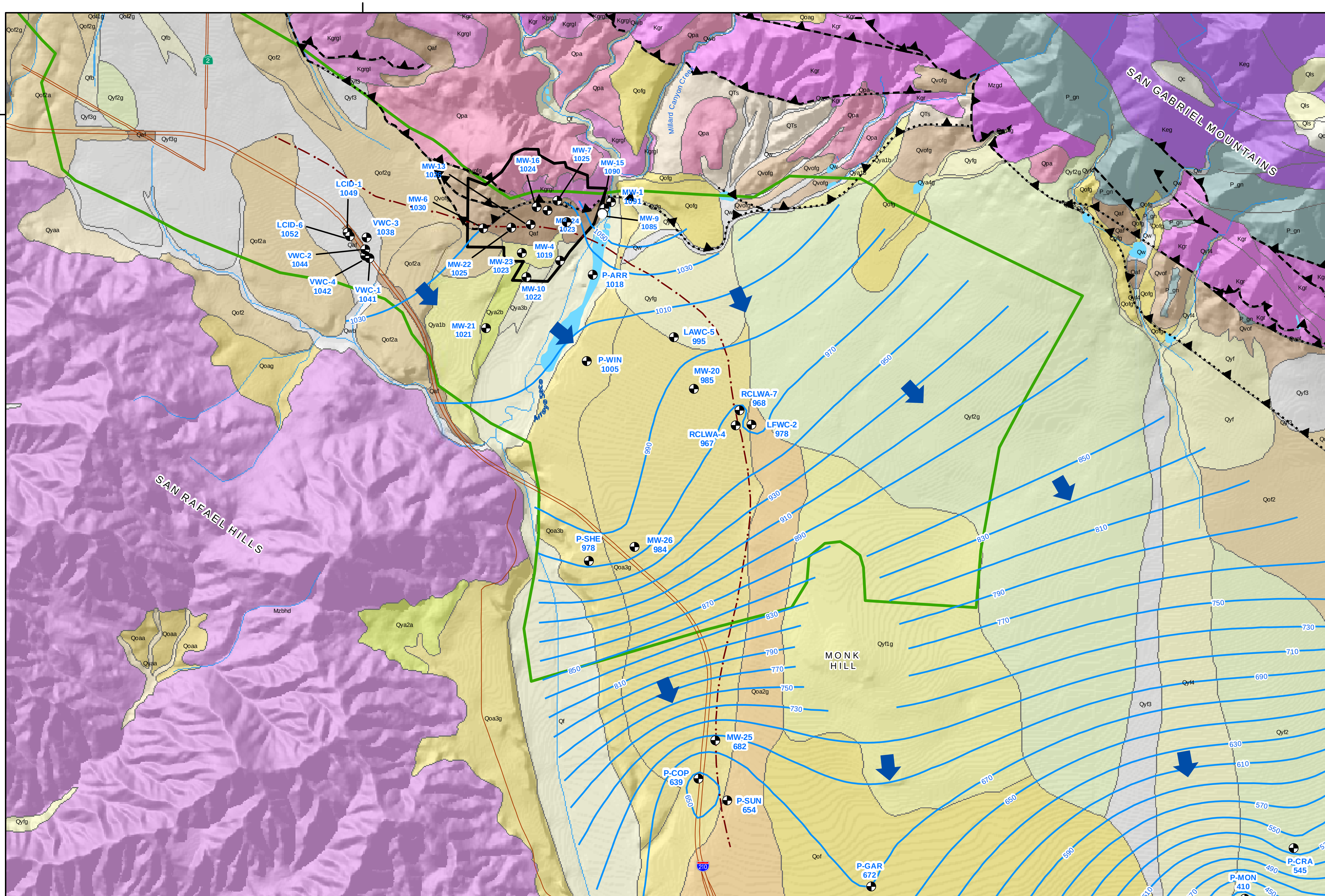
Figure 3

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_3_april_1990_july_1997_wl_elev_6-09.mxd

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3



GROUND WATER ELEVATIONS SUMMER 2008

EXPLANATION

Wells Sampled During Summer 2008

MW-26 984 — Wells with Water Level Measurements; Ground Water Elevation, ft amsl

600 — Spring 2008 Water Level Elevations, ft amsl (Sources: NASA, 2008 and RBMB, 2008.)

2008 Ground Water Flow Direction

Axis of Buried Bedrock Valley

Thrust Fault (dashed where inferred)

Thrust Fault (dotted where concealed)

NASA JPL Property Boundary

NASA JPL Model Boundary (Wheeler, 2000)

Highway or Interstate

River or Drainage Channel

Spreading Basins

*See Figure 1a for legend of geologic units from USGS 2005 surficial geology.

24-Jun-09

Prepared by: LH

Map Projection: UTM 1927, Zone 11

NORTH

0 2,000 4,000 Feet

Source: Faults and geology taken from Preliminary Geologic Map of Los Angeles 30' x 60' Quadrangle, Southern California USGS, 2005.

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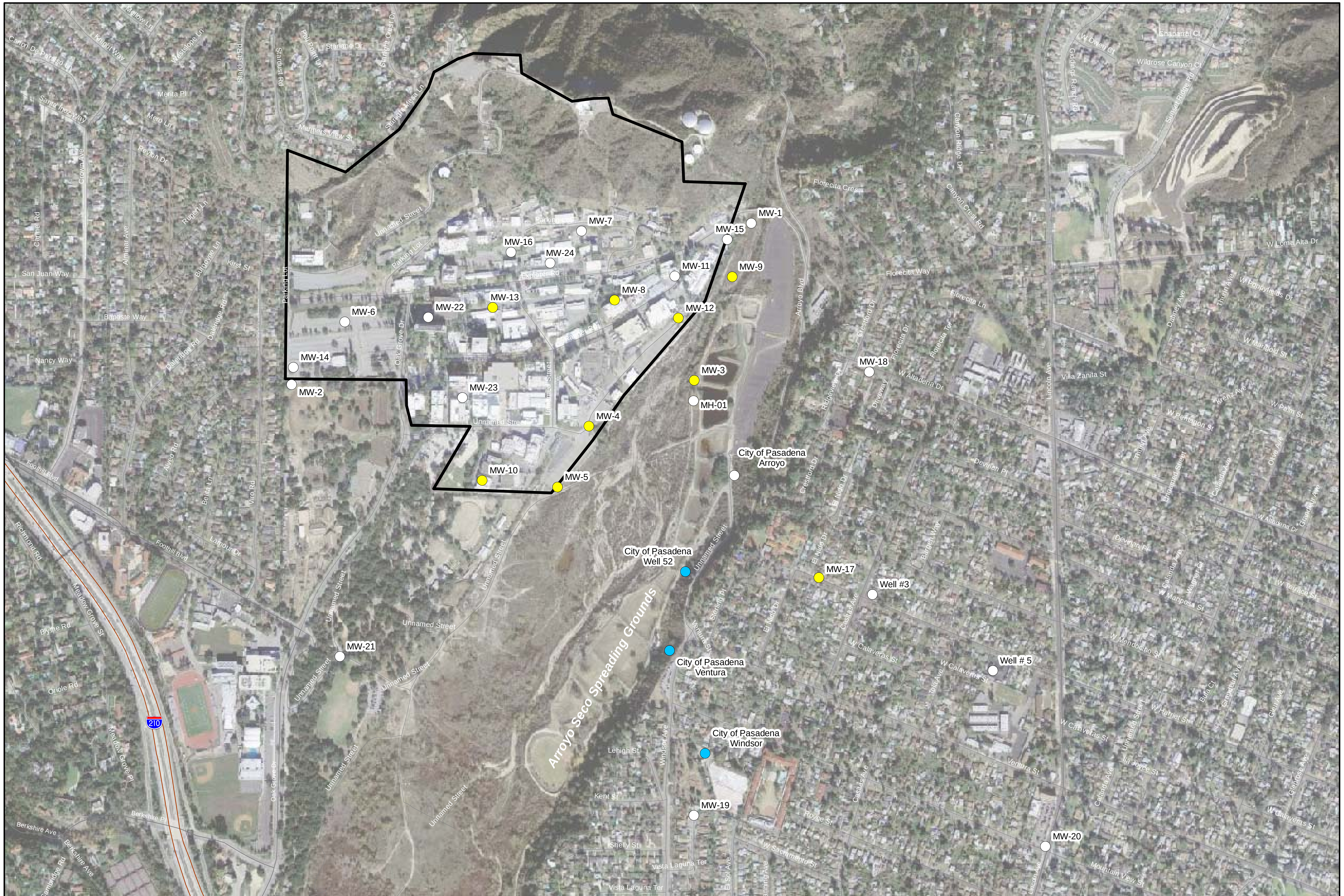
Figure 4

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_4_april-may_2008_wl_elev_6-09.mxd

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3

WELLS USED DURING AQUIFER PUMPING TEST JAN-MAY 2001



EXPLANATION

- Production Wells Used During JPL Aquifer Pumping Test
- Monitoring Wells Used During JPL Aquifer Pumping Test
- Other Wells in Area
- NASA JPL Property Boundary

T.1 N.

R.12 W.

24-Jun-09

Prepared by: LH

Map Projection: UTM 1983, Zone 11

NORTH

0 500 1,000 Feet

Airphoto from Terraserver (dated 3-29-04)

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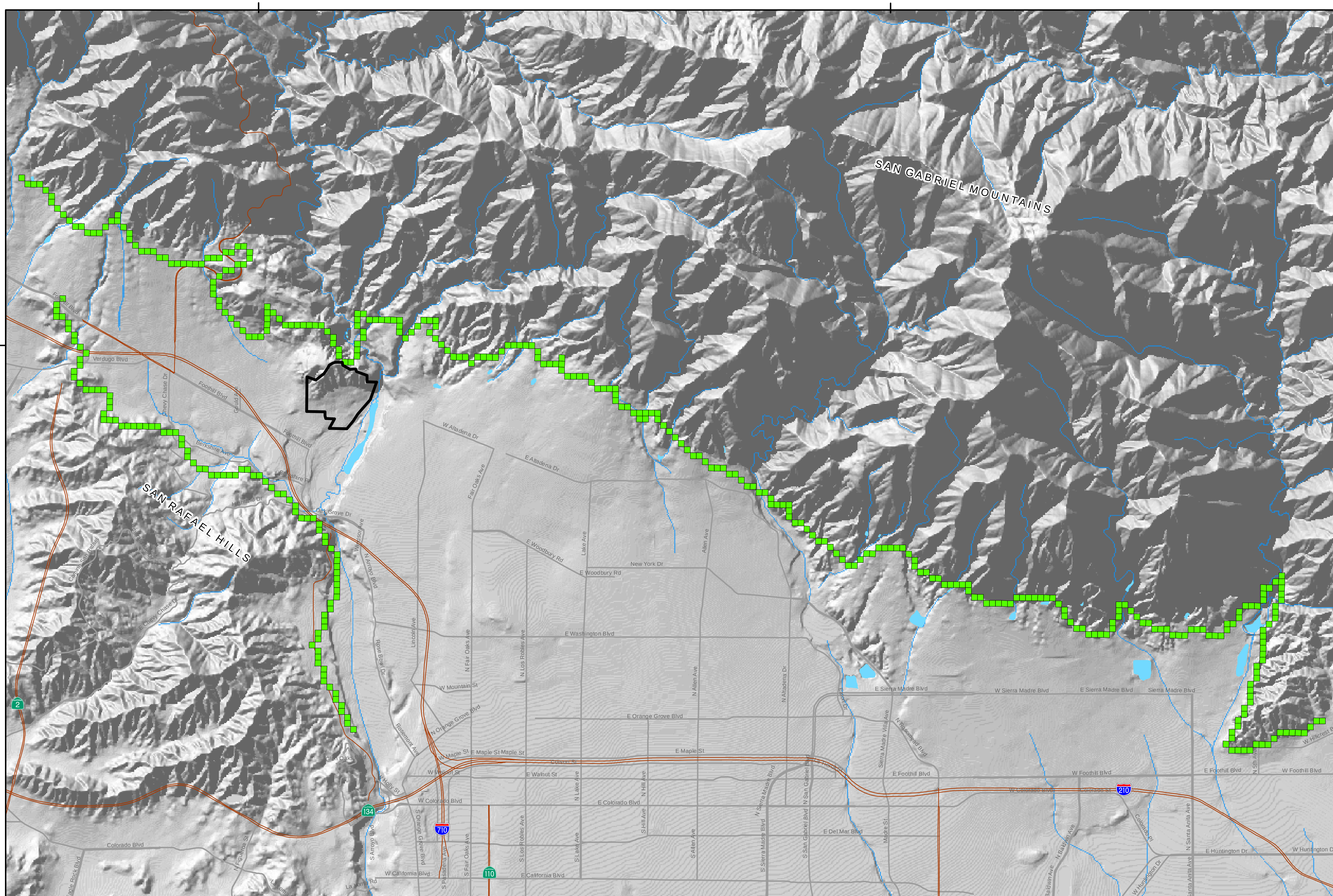
Figure 5

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_5_pump_test_locs_6-09.mxd

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3



MODEL RECHARGE CELLS ASSOCIATED WITH MOUNTAIN FRONT RUNOFF

EXPLANATION

- Model Cells Representing Recharge Associated with Mountain Front Runoff
- NASA JPL Property Boundary
- Highway or Interstate
- Highway or Interstate
- River or Drainage Channel
- Spreading Basins

NOTE:
2005 GEOSCIENCE Ground Water Flow Model was based on geology from California Division of Mines and Geology "Geologic Map of California - Los Angeles Sheet" Scale 1:250,000 (1969).

*See Figure 6b for legend of geologic units from DWR 1969 surficial geology.

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Map Projection: UTM 1927, Zone 11

NORTH

0 1 2 Miles

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Figure 6a

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_5_pump_test_locs_6-09.mxd

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS

GEOLOGIC LEGEND (CDMG, 1969)

- Qal, Alluvium
- Qt, Quaternary Nonmarine Trerrace Deposits
- Qc, Pleistocene Nonmarine Deposits
- Pml, Middle or Lower Pliocene Marine Deposits
- Mu, Upper Miocene Marine Deposits
- Mm, Middle Miocene Marine Deposits
- gr, Mesozoic Granitic Rocks
- gr-m, Pre-Cretaceous Granitic and Metamorphic rock
- pCg, Undivided Precambrian Metamorphic Rocks, Gneiss
- pCgr, Undivided Precambrian Granitic Rocks

NOTE:
Previous GEOSCIENCE Model was based on geology available at the time.
Geology from California Division of Mines and Geology
"Geologic Map of California - Los Angeles Sheet" Scale 1:250,000 (1969)

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GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_6b_geology_lgnd_6-09.mxd

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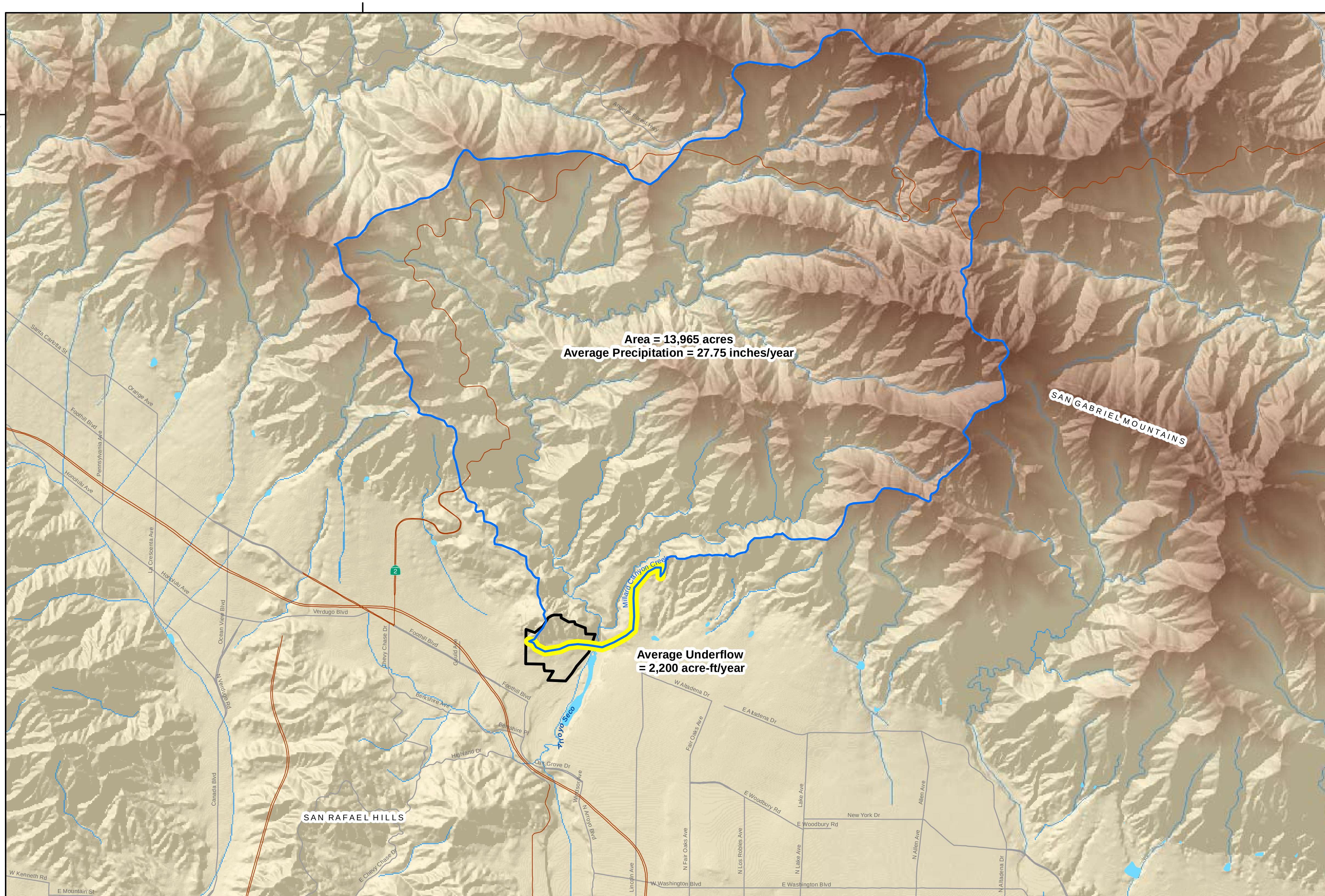
Figure 6b

CITY OF PASADENA WATER AND POWER

PERCHLORATE CONTAMINATION OF GROUND WATER IN THE RAYMOND BASIN
NASA / JPL MARCH 6, 2009 CONFERENCE CALL ACTION ITEMS 1, 2 AND 3



ARROYO SECO WATERSHED BOUNDARY

EXPLANATION

- Arroyo Seco Watershed Boundary
- Underflow Outflow from the Arroyo Seco Watershed
- NASA JPL Property Boundary
- Highway or Interstate
- Street
- River or Drainage Channel
- Spreading Basins

24-Jun-09

Prepared by: LH

Map Projection: UTM 1927, Zone 11

NORTH

0 1 2 Miles

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Figure 7

GIS_proj/city_of_pasadena_jpl_perch_6-09/0_Fig_1a_bedrock_elev_6-09.mxd

PLATE

GEOSCIENCE Support Services, Inc.

Plate 1. Source: Dept. of Public Works, 1943

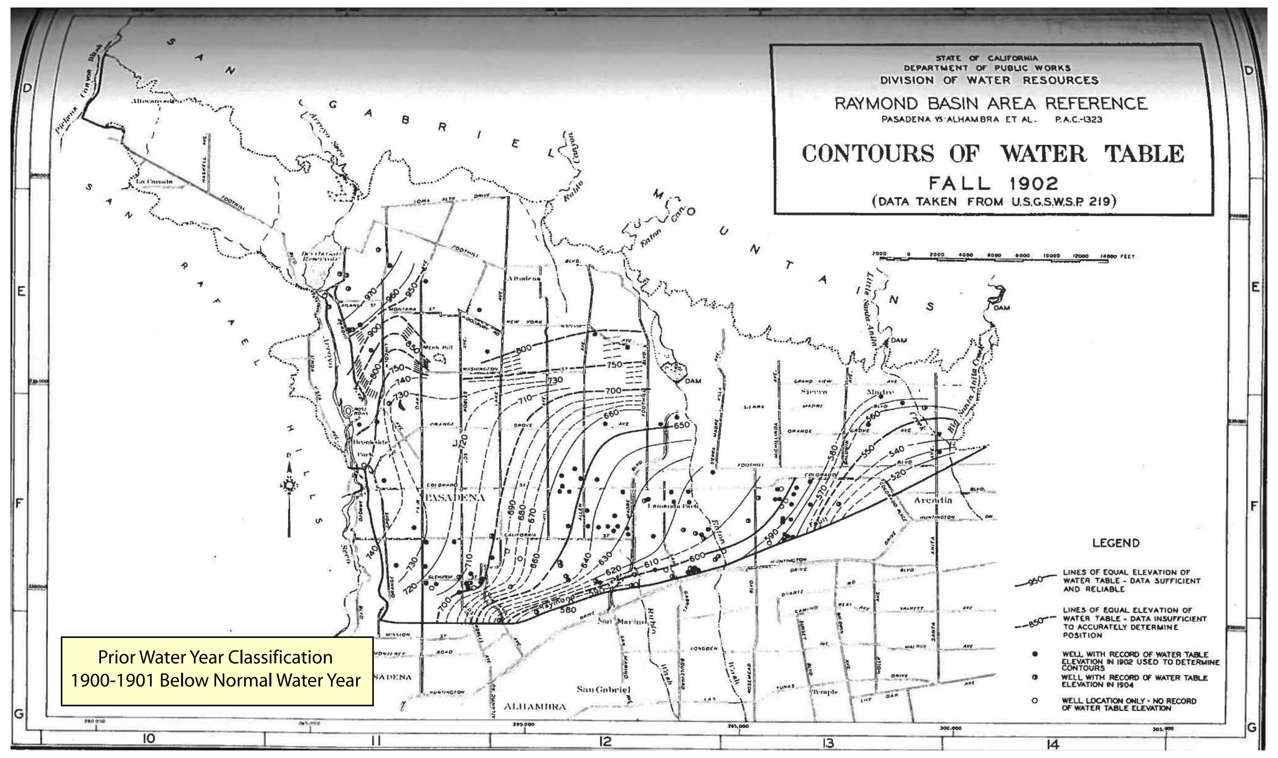


Plate 2. Source: Dept. of Public Works, 1943

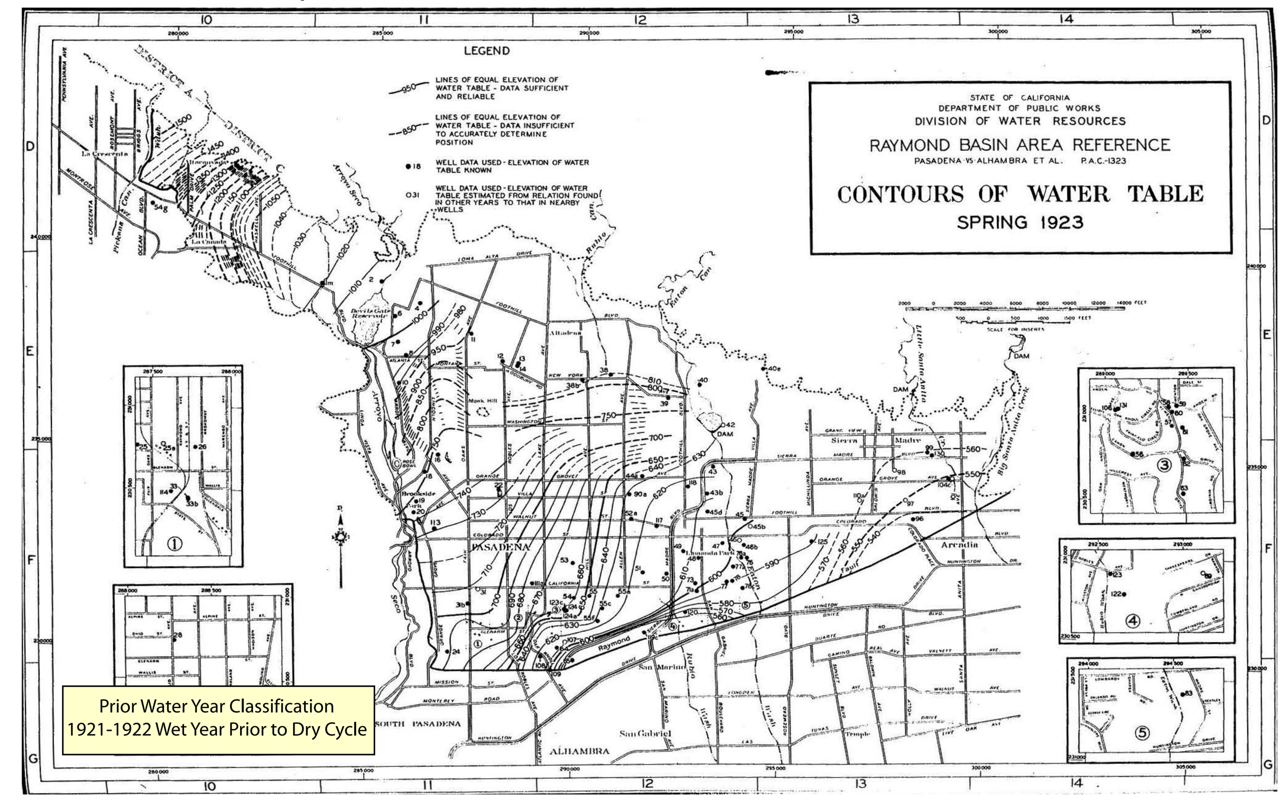


Plate 3. Source: Dept. of Public Works, 1943

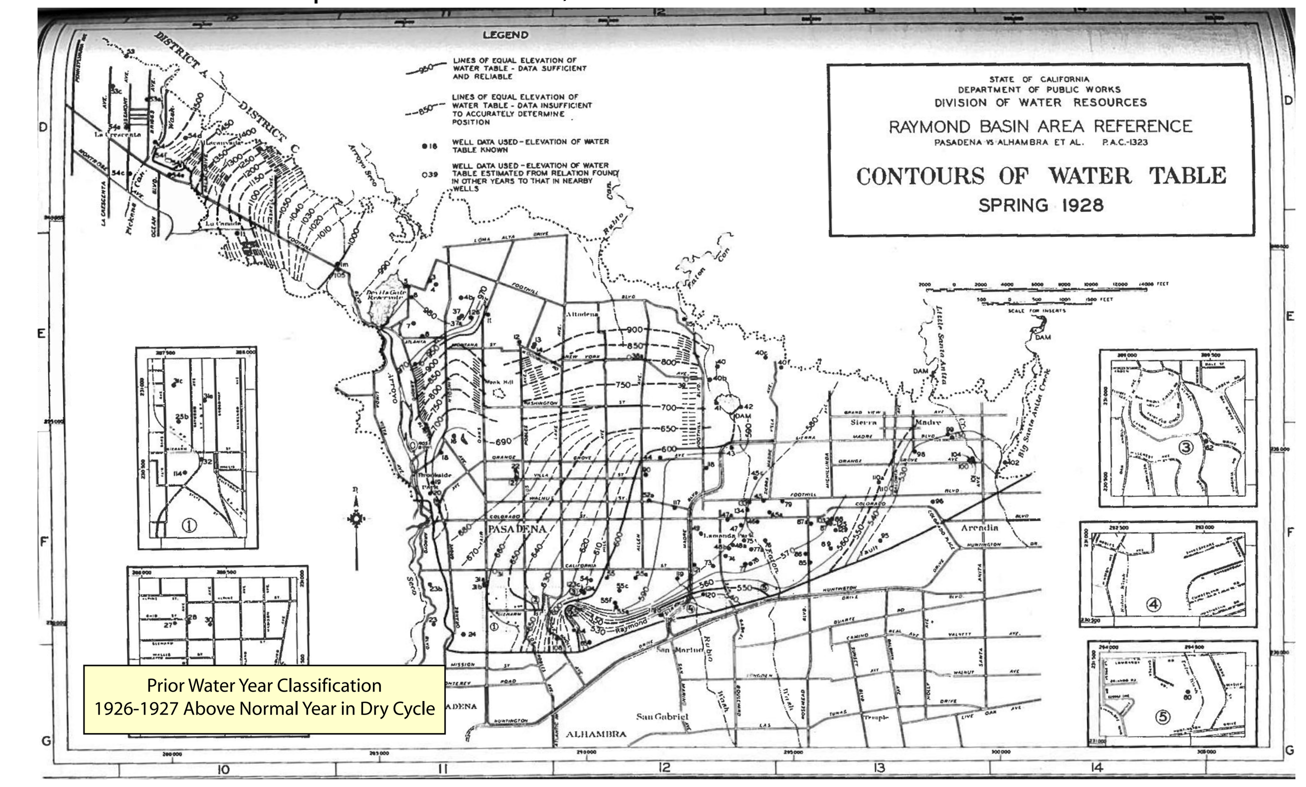


Plate 4. Source: Dept. of Public Works, 1943

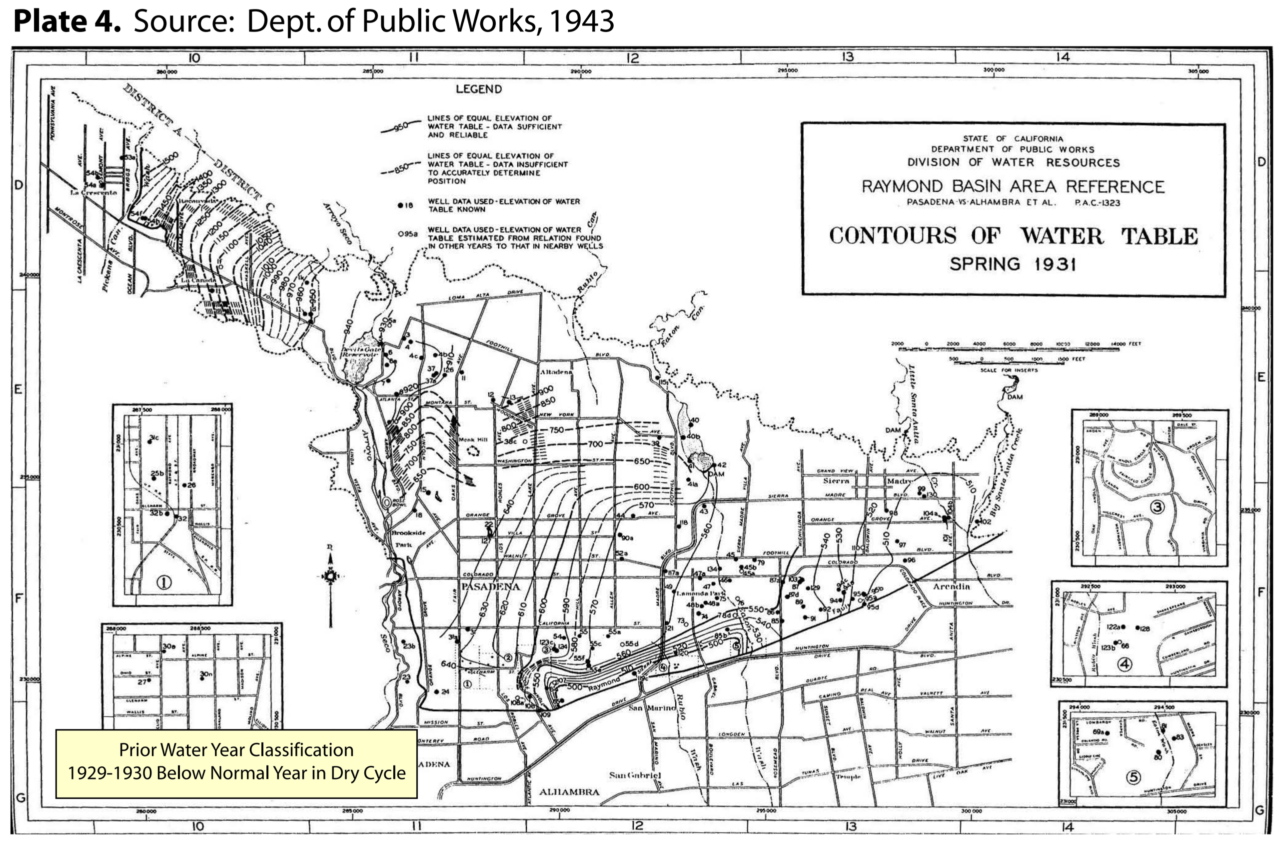


Plate 5. Source: CA Dept. of Water Resources, 1969

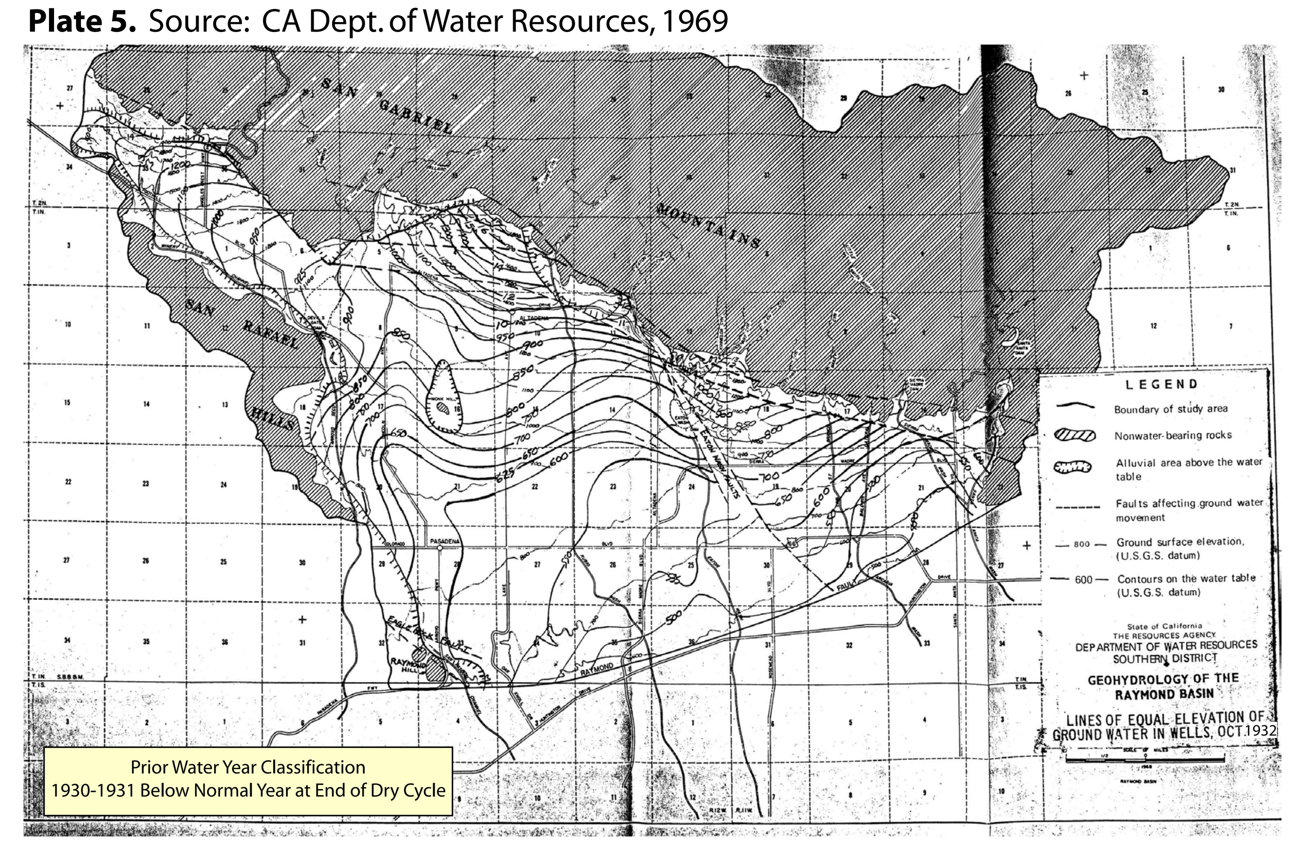


Plate 6. Source: Dept. of Public Works, 1943

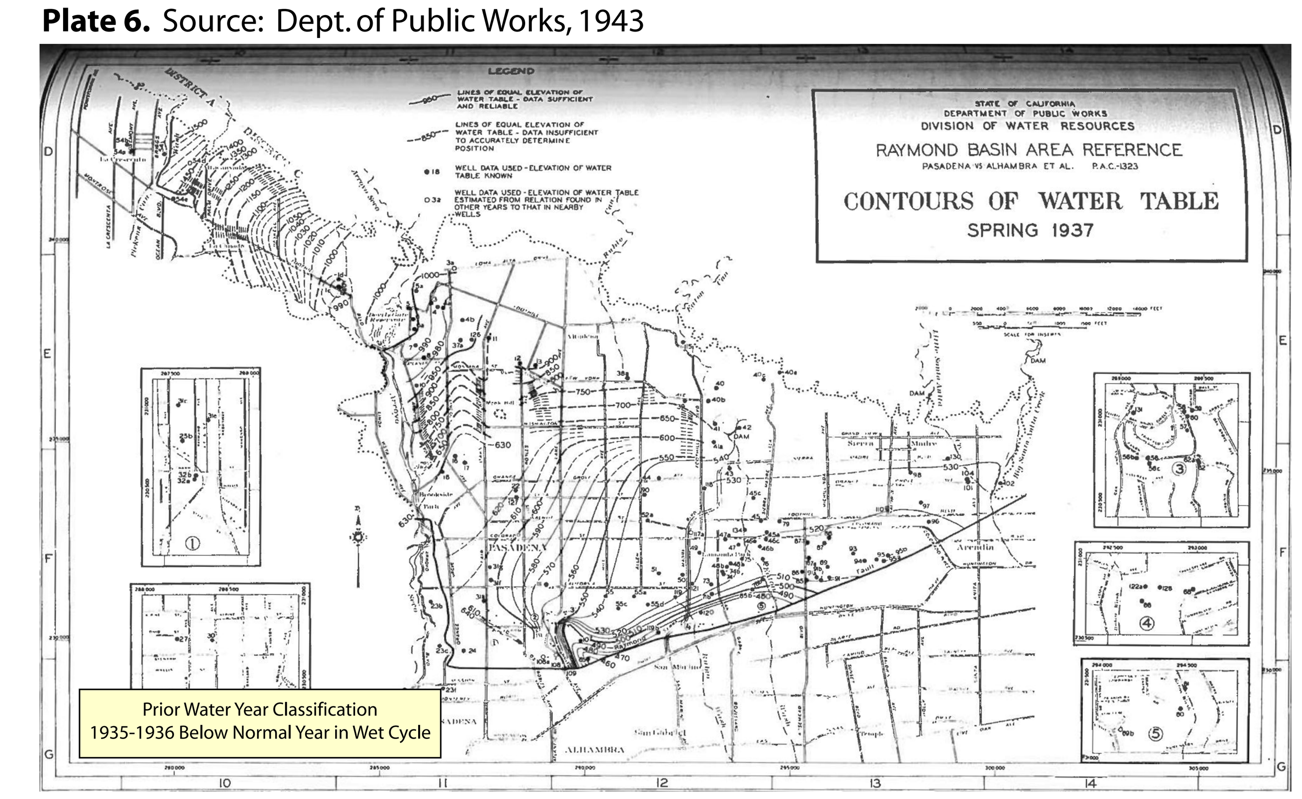


Plate 7. Source: Dept. of Public Works, 1954

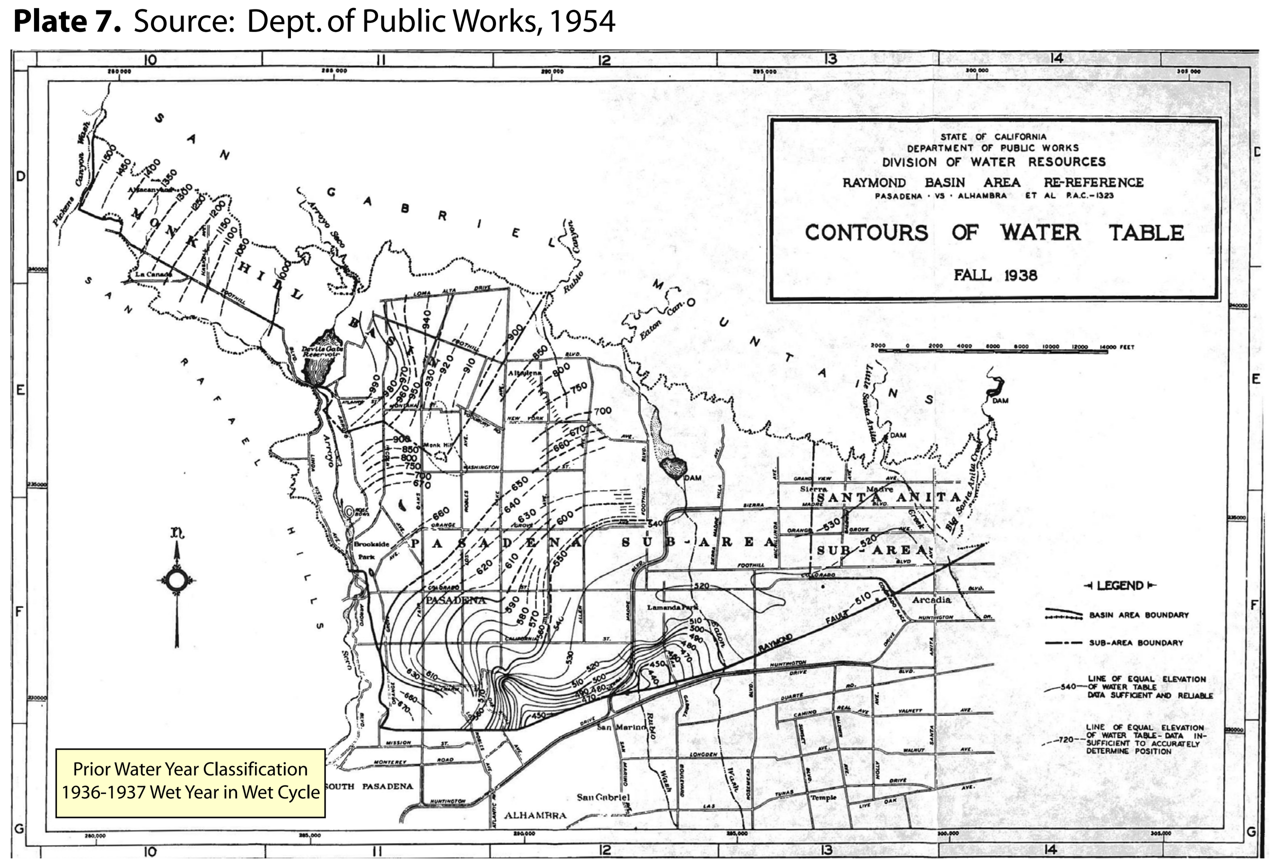


Plate 8. Source: Dept. of Public Works, 1954

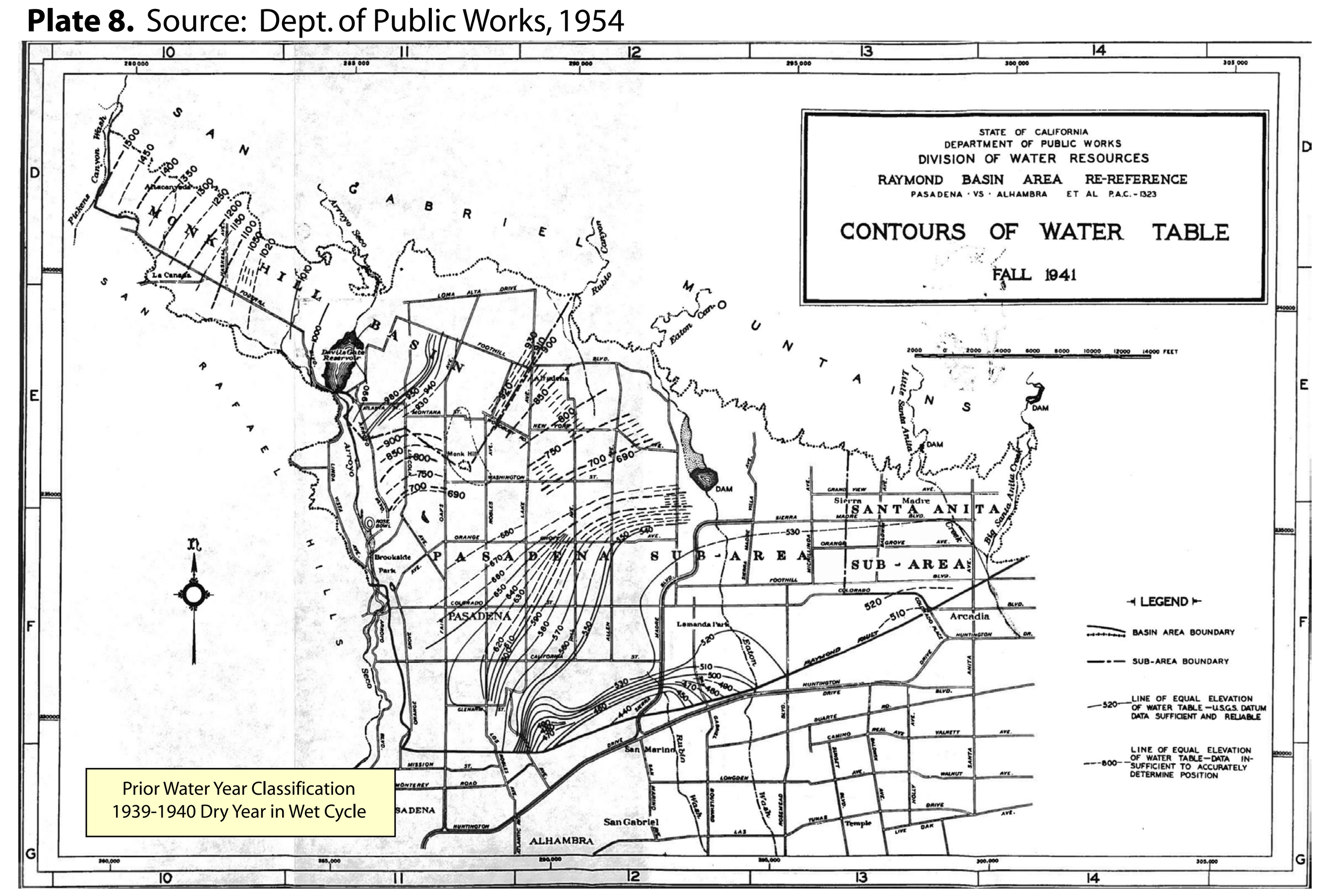


Plate 9. Source: Dept. of Public Works, 1954

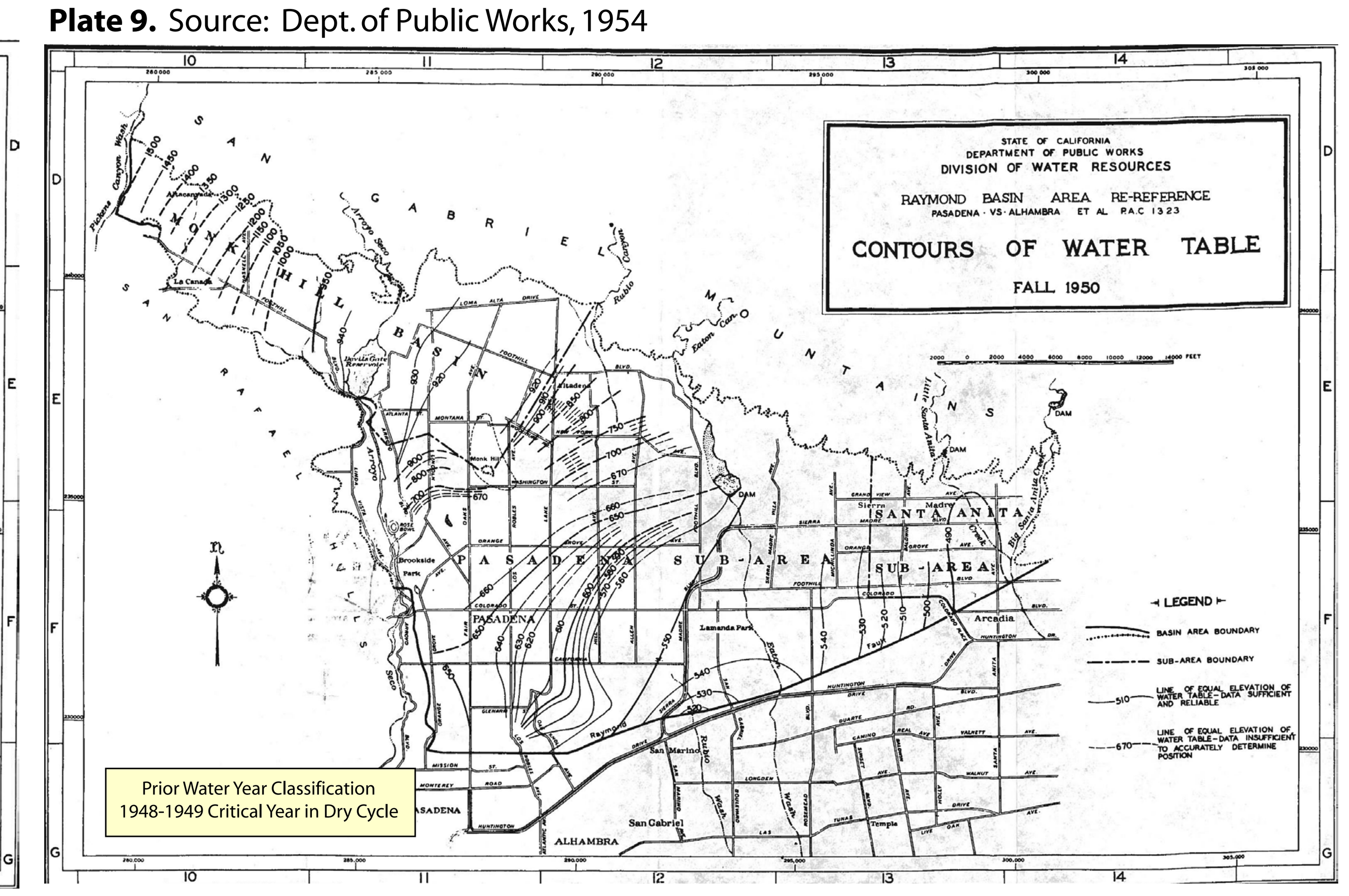


Plate 10. Source: CA Dept. of Water Resources, 1969

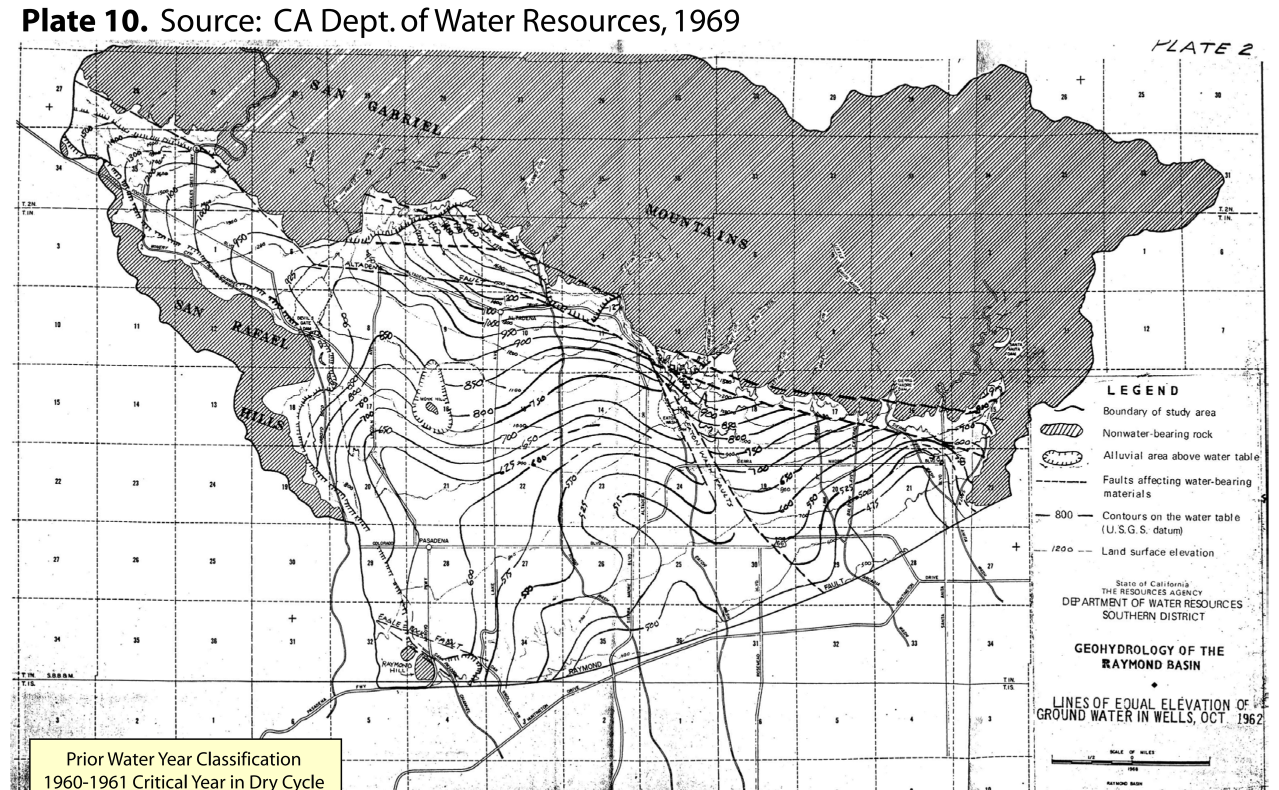


Plate 11. Source: CA Dept. of Water Resources, 1971

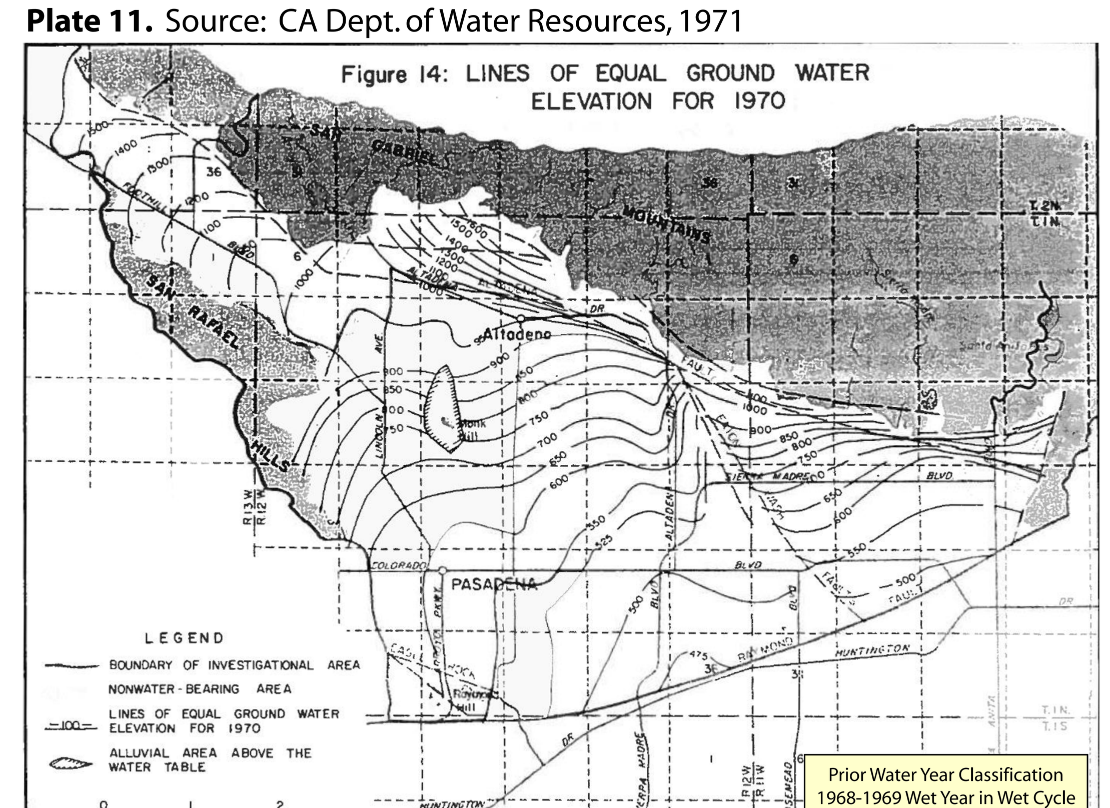
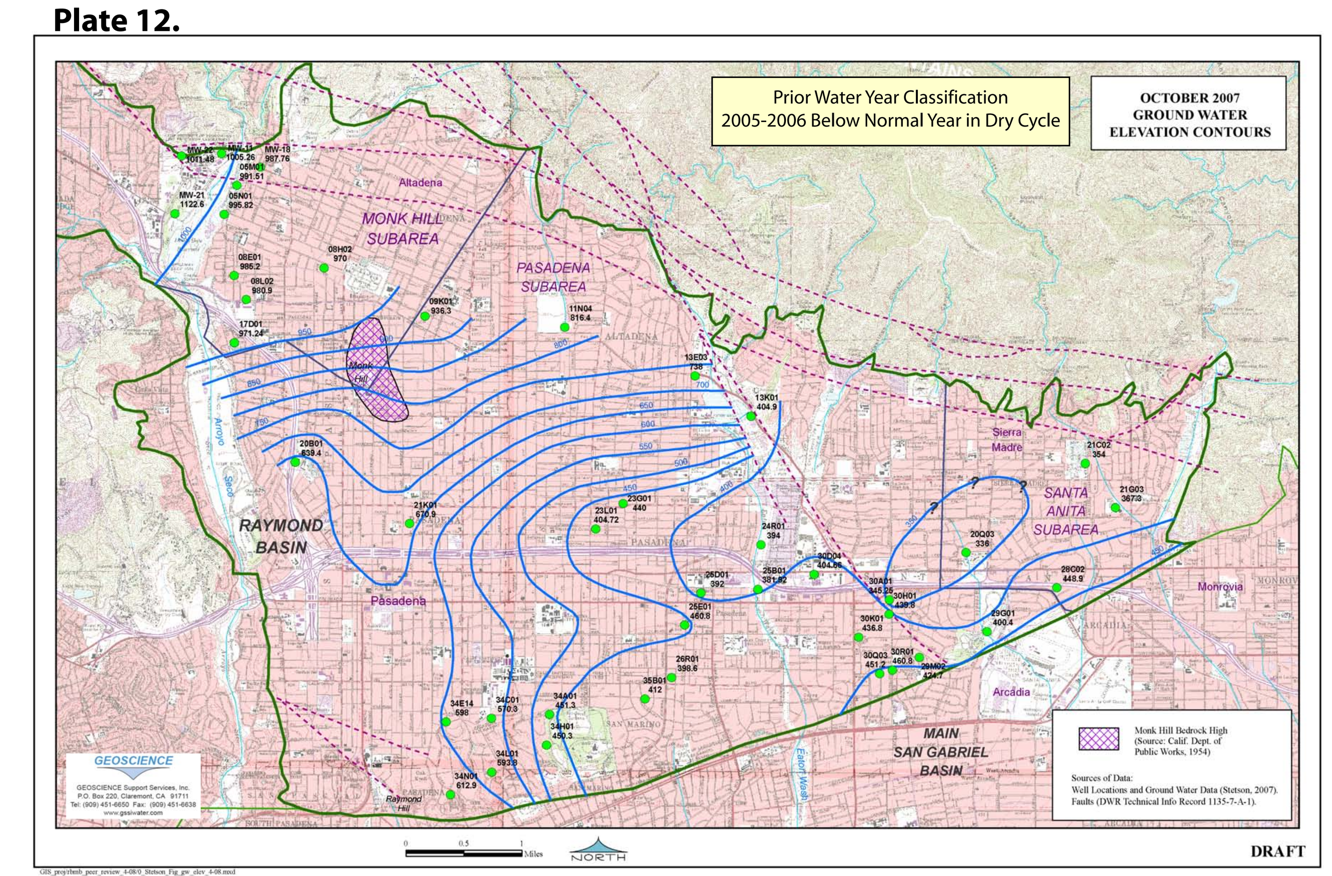


Plate 12.



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CITY OF PASADENA WATER AND POWER

HISTORICAL GROUND WATER ELEVATIONS

Drawn:
Checked:
Approved:
Date: 24-JUN-09

Plate 1

APPENDIX A

Weighted Logarithmic Mean Analyses Charts

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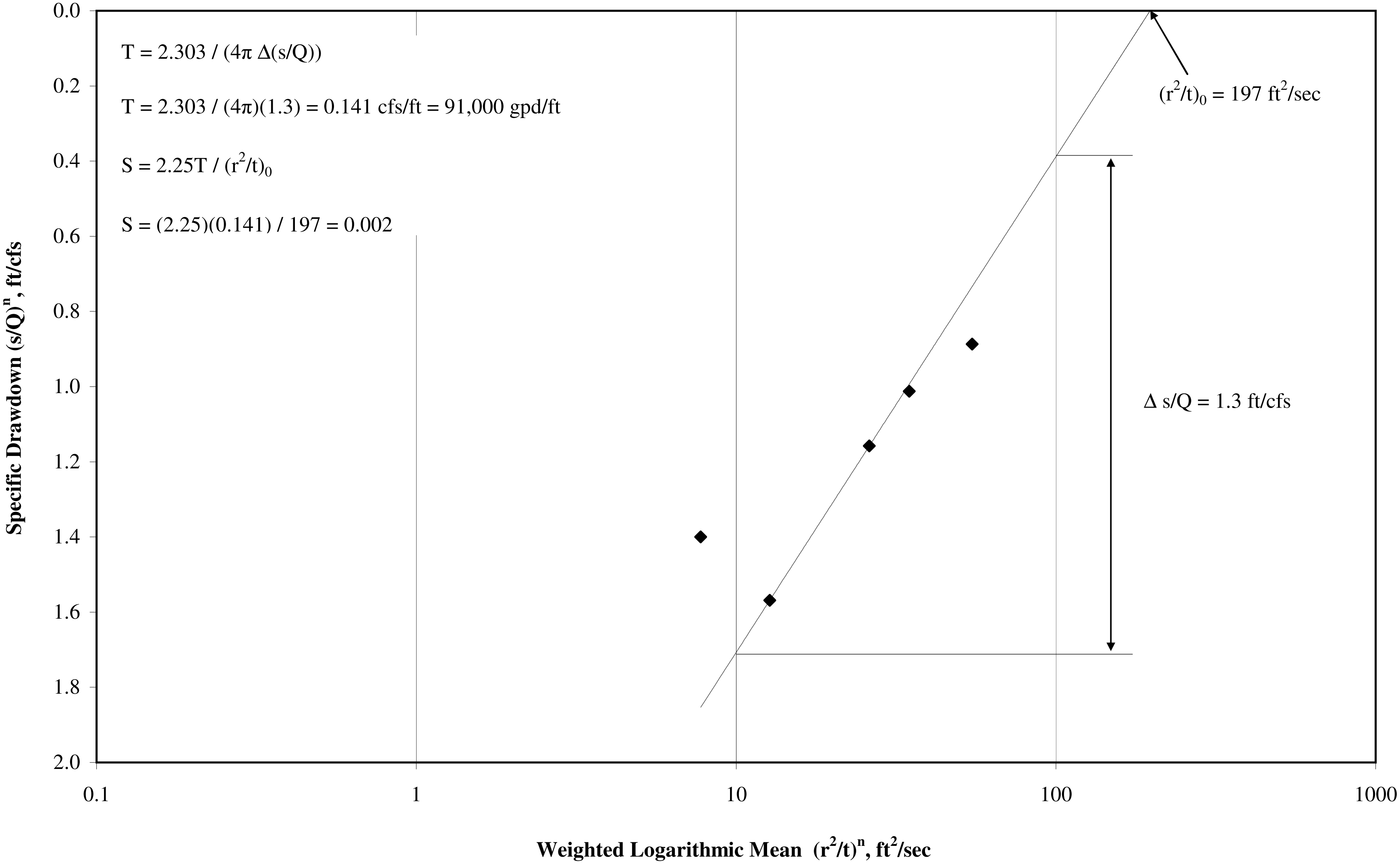
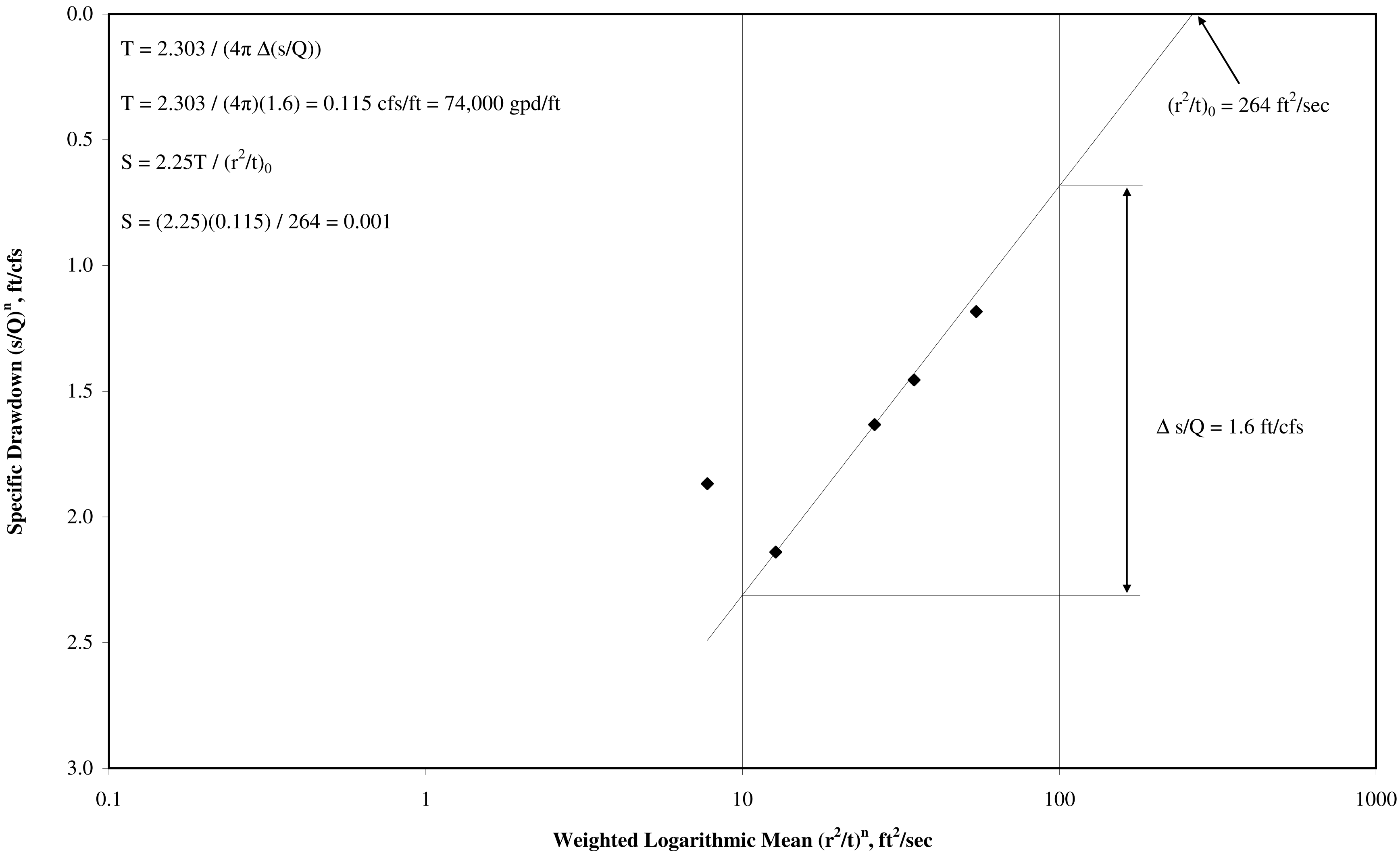
Weighted Logarithmic Mean Analysis - MW-3 Port 2



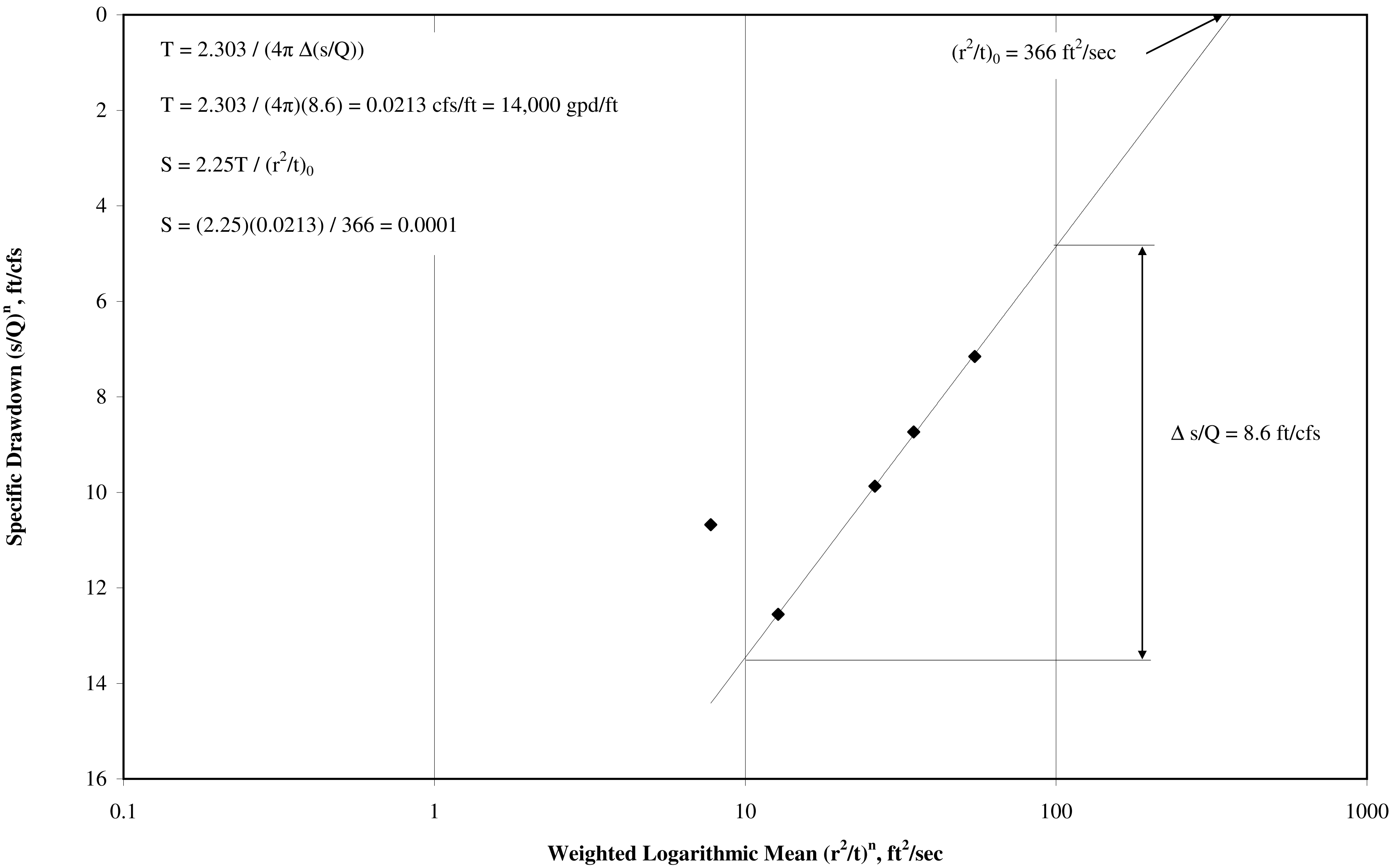
Appendix A

Weighted Logarithmic Mean Analysis - MW-3 Port 3



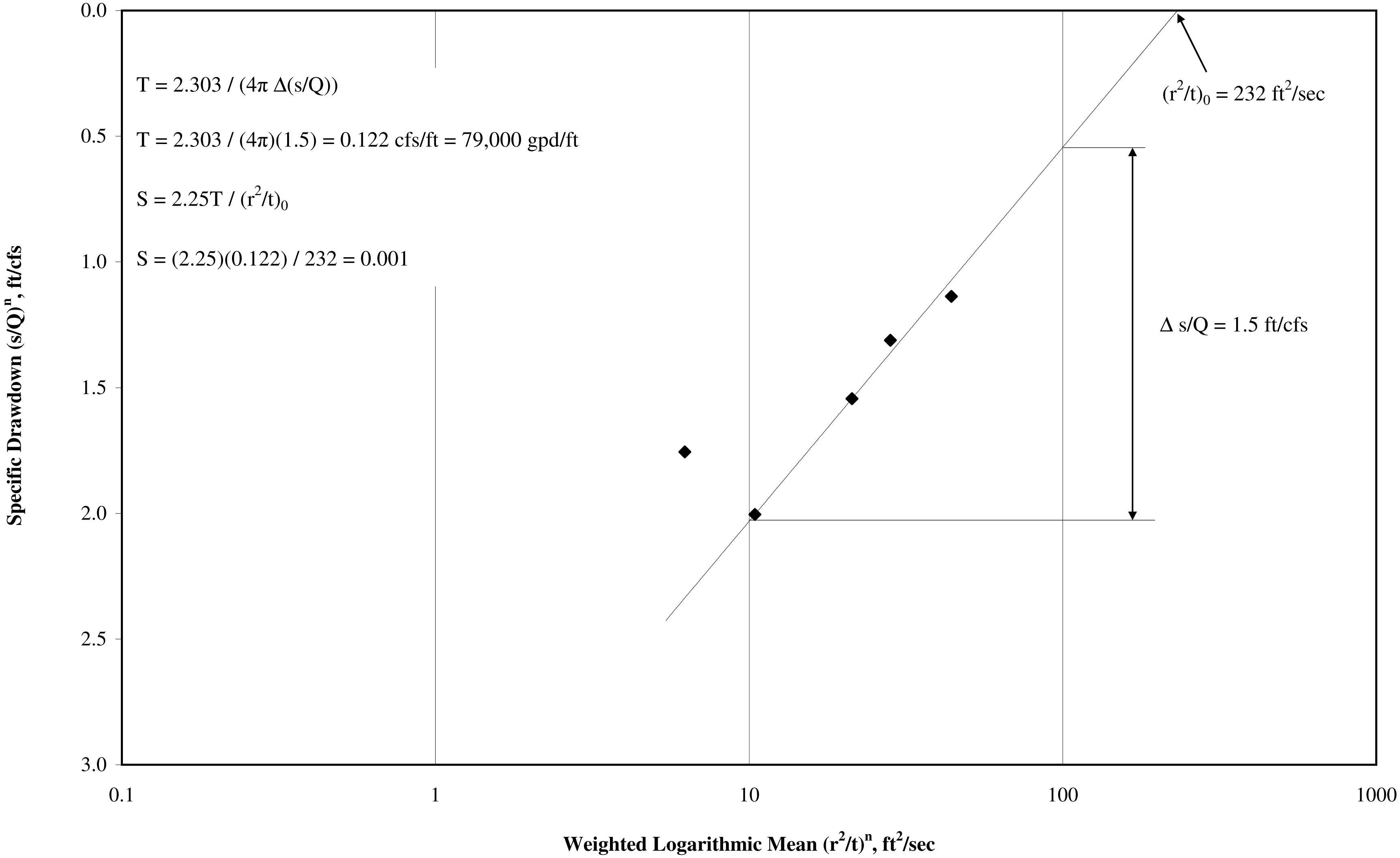
Appendix A

Weighted Logarithmic Mean Analysis - MW-3 Port 4



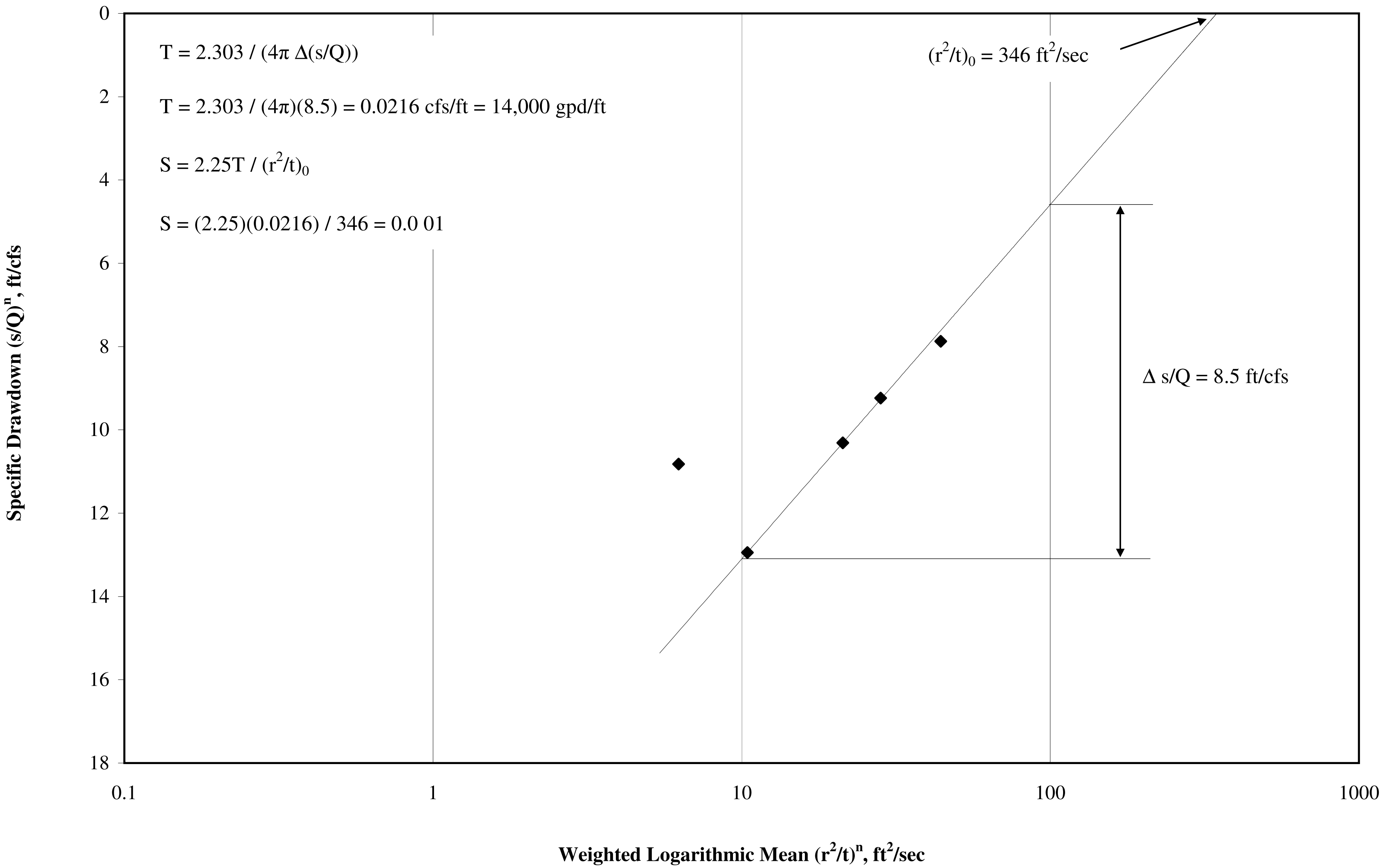
Appendix A

Weighted Logarithmic Mean Analysis - MW-4 Port 3



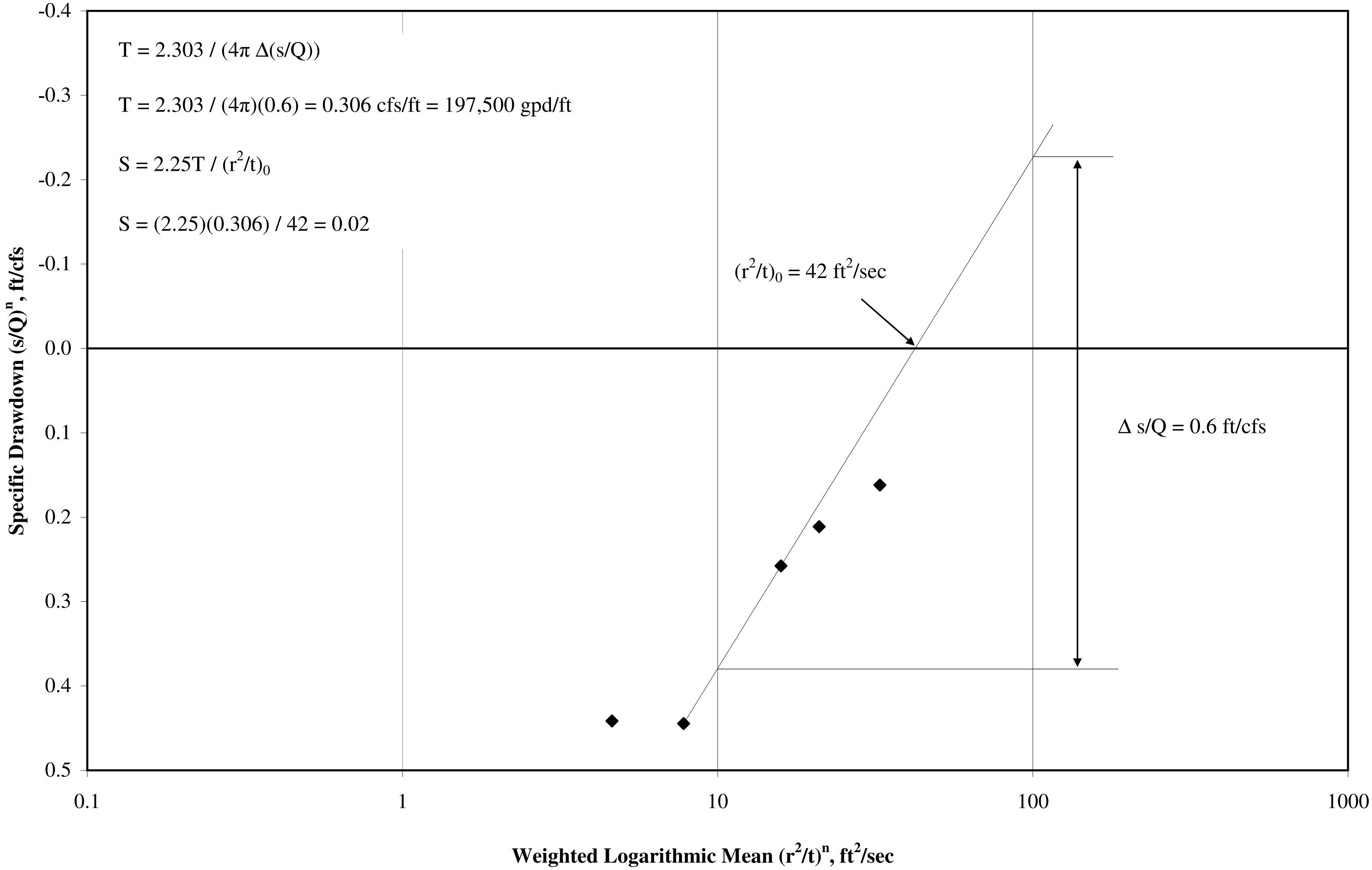
Appendix A

Weighted Logarithmic Mean Analysis - MW-4 Port 5



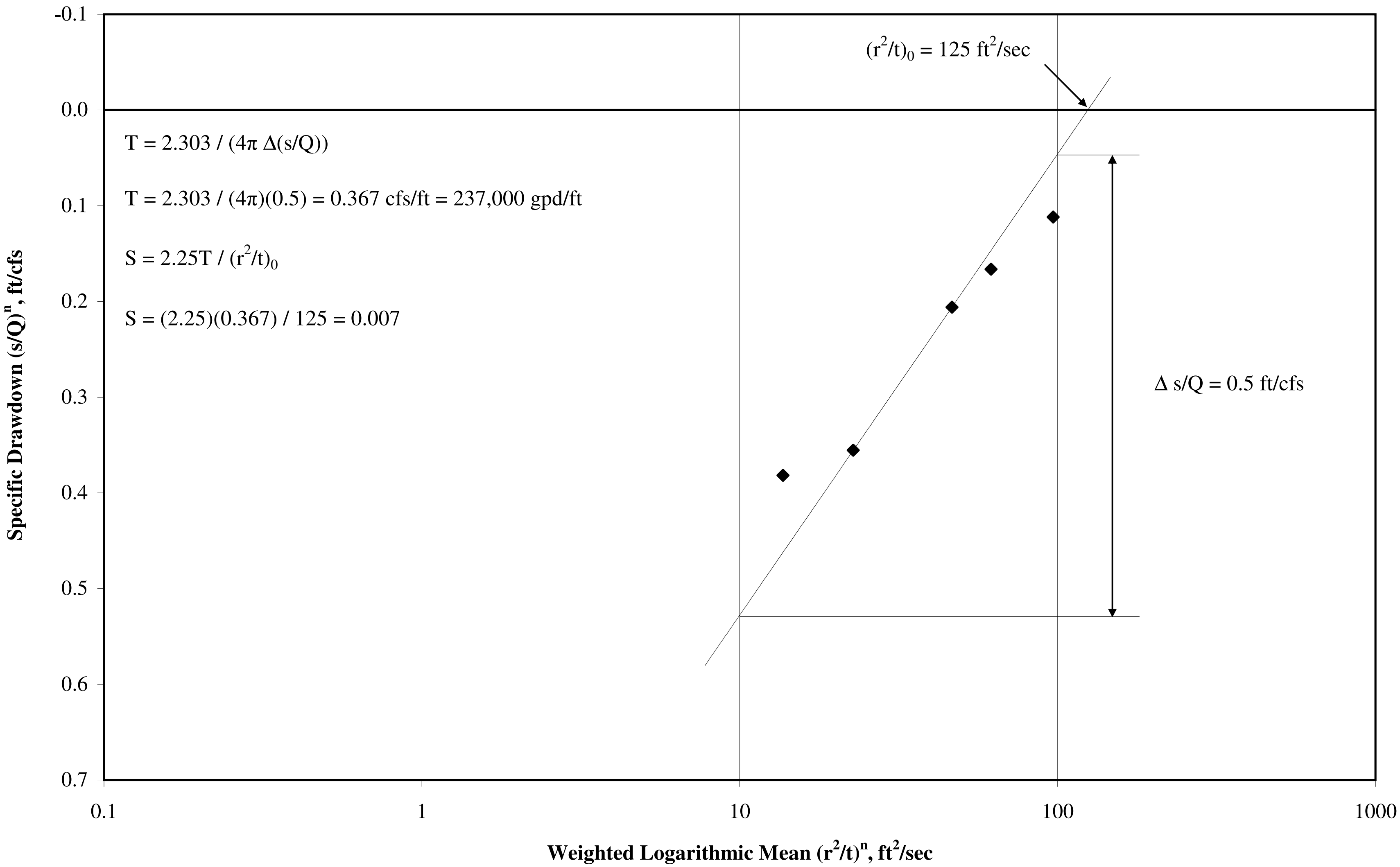
Appendix A

Weighted Logarithmic Mean Analysis - MW-5



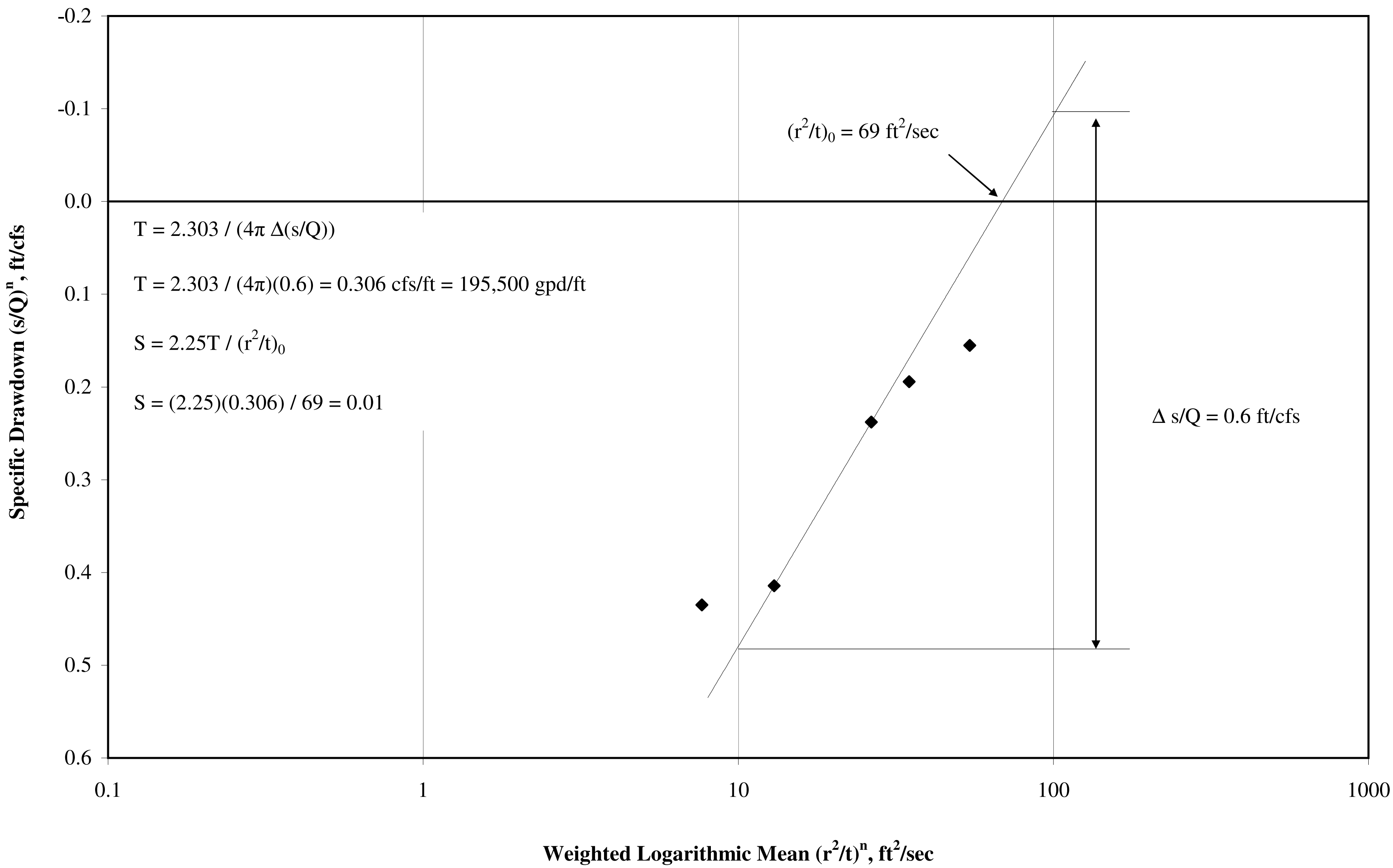
Appendix A

Weighted Logarithmic Mean Analysis - MW-8



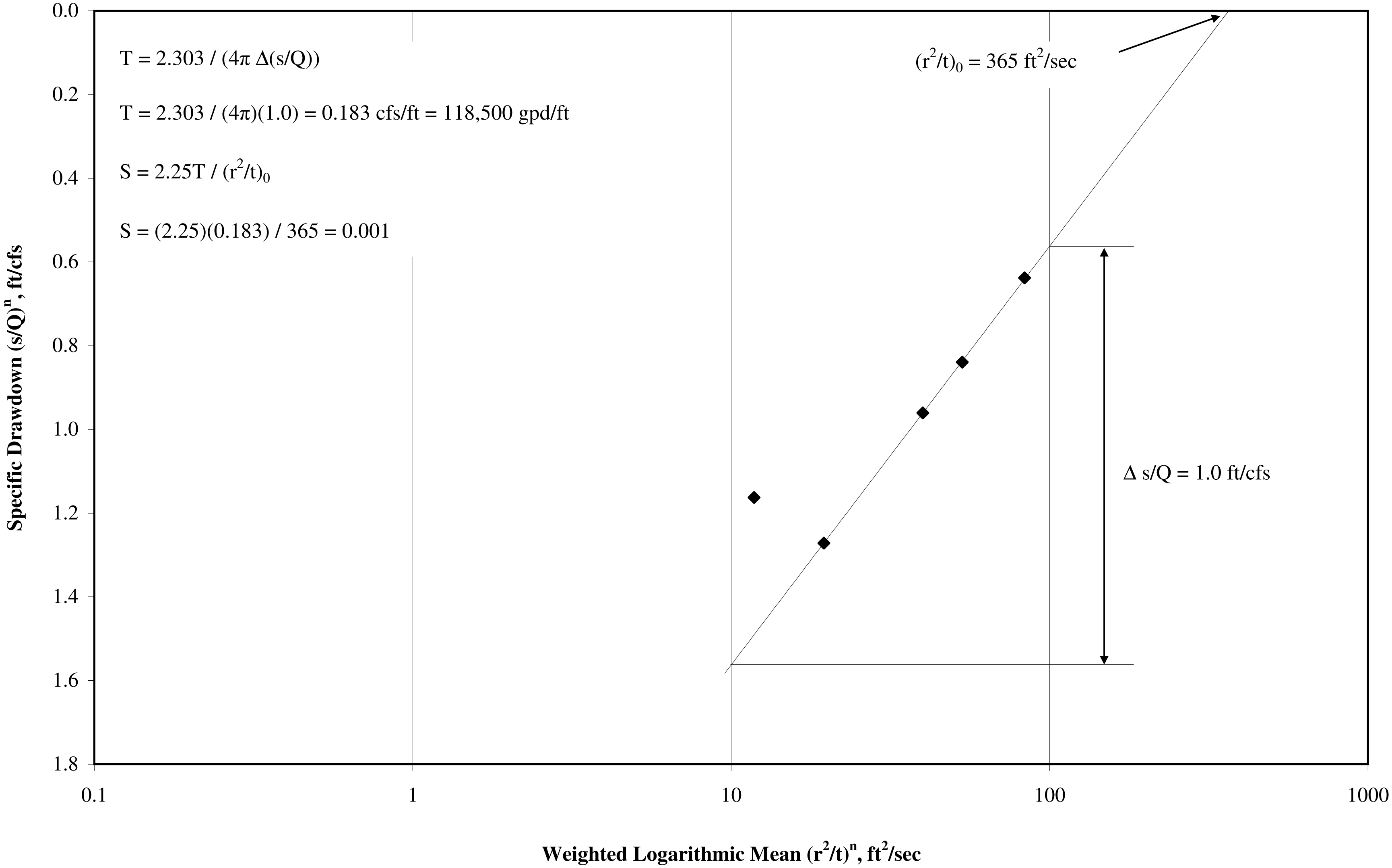
Appendix A

Weighted Logarithmic Mean Analysis - MW-10



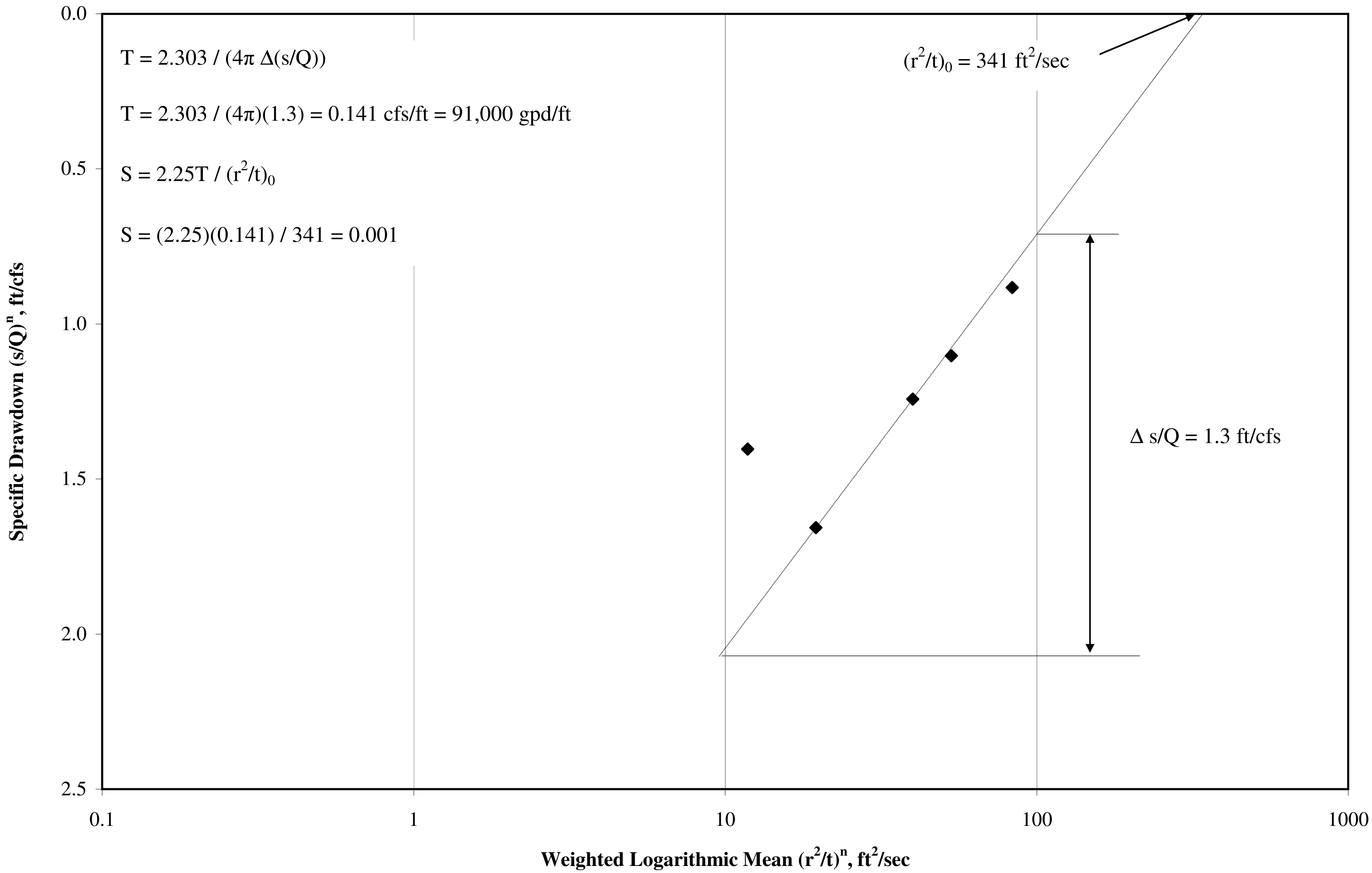
Appendix A

Weighted Logarithmic Mean Analysis - MW-12 Port 2



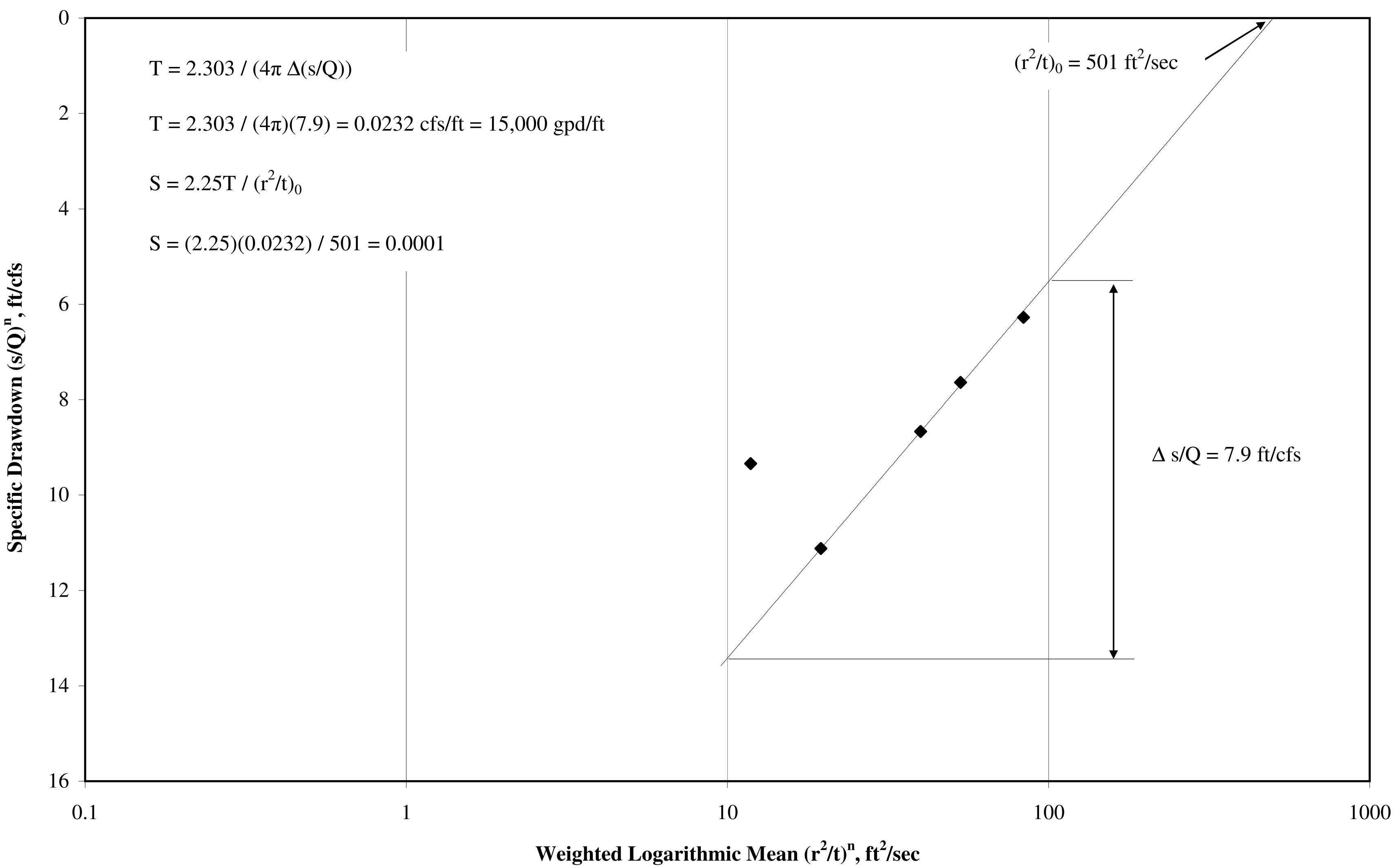
Appendix A

Weighted Logarithmic Mean Analysis - MW-12 Port 3



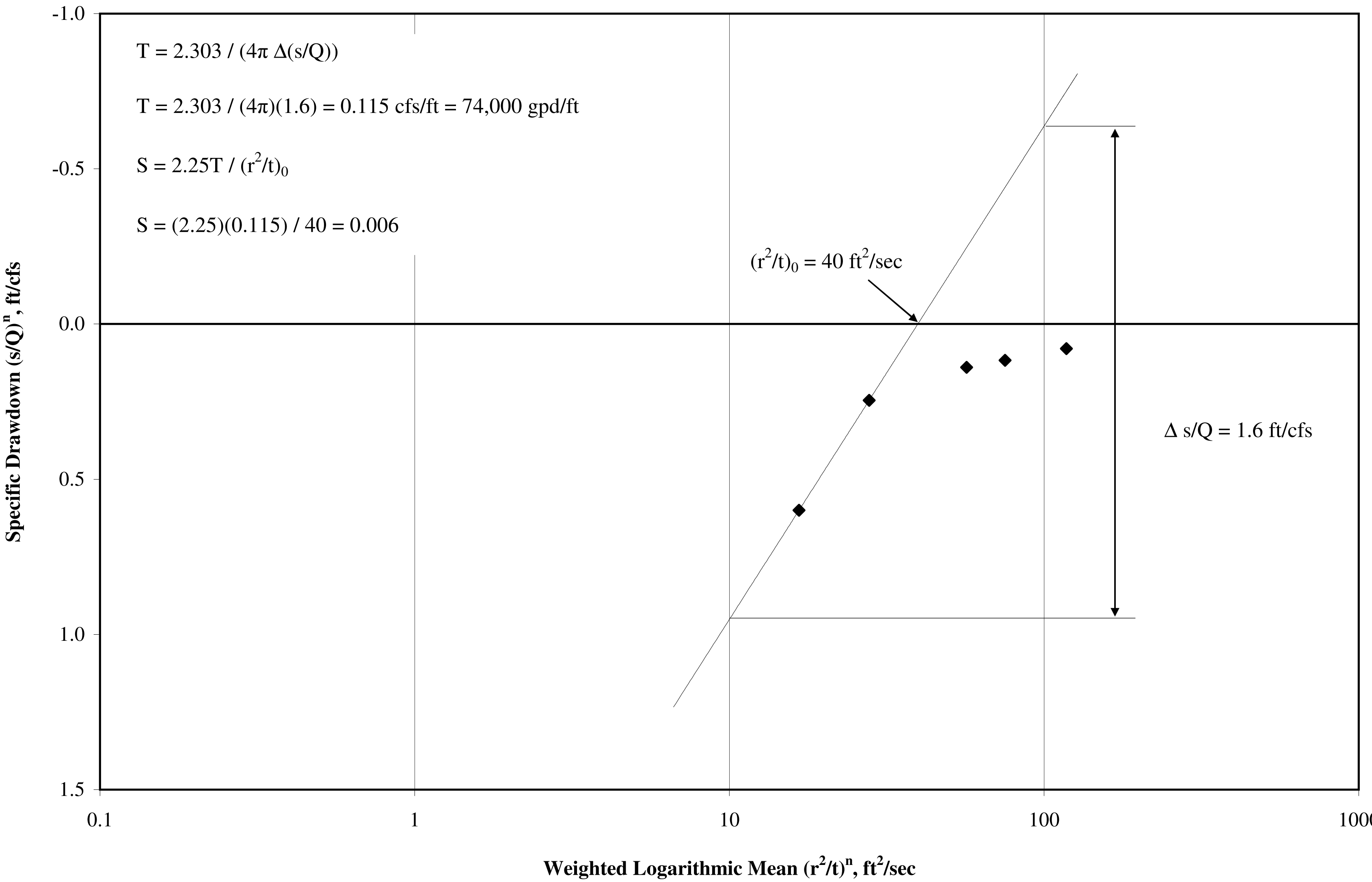
Appendix A

Weighted Logarithmic Mean Analysis - MW-12 Port 5



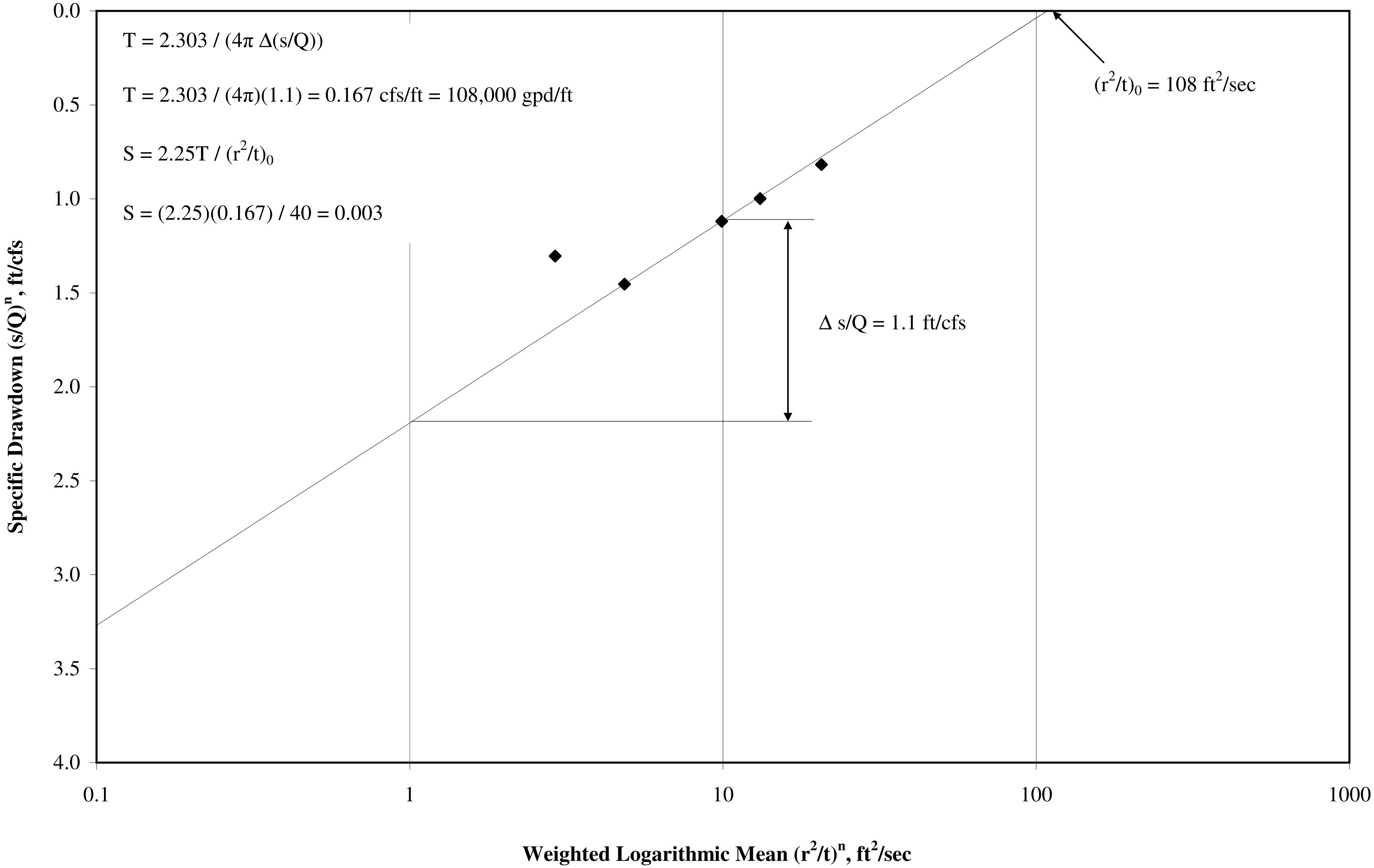
Appendix A

Weighted Logarithmic Mean Analysis - MW-13



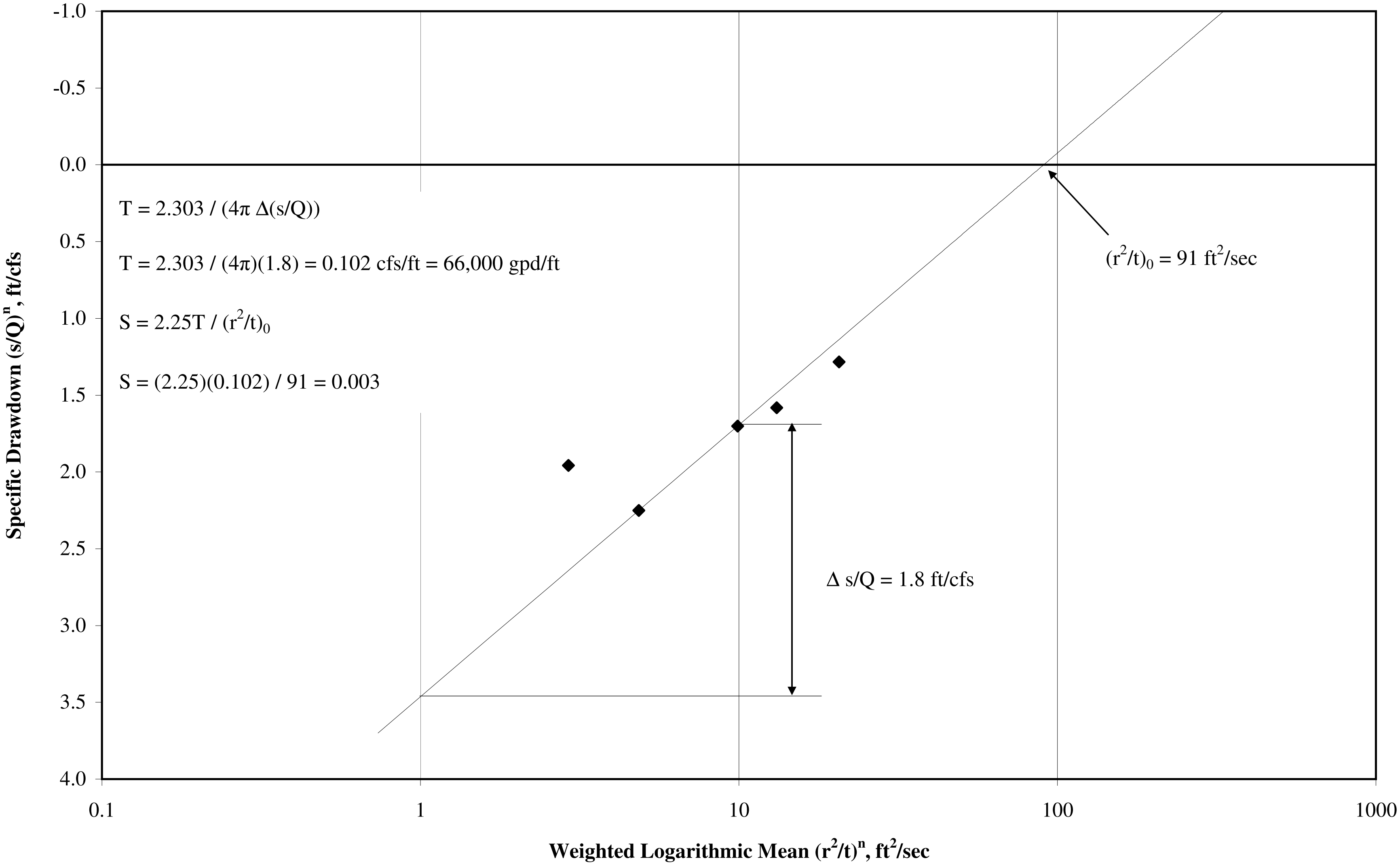
Appendix A

Weighted Logarithmic Mean Analysis - MW-17 Port 2



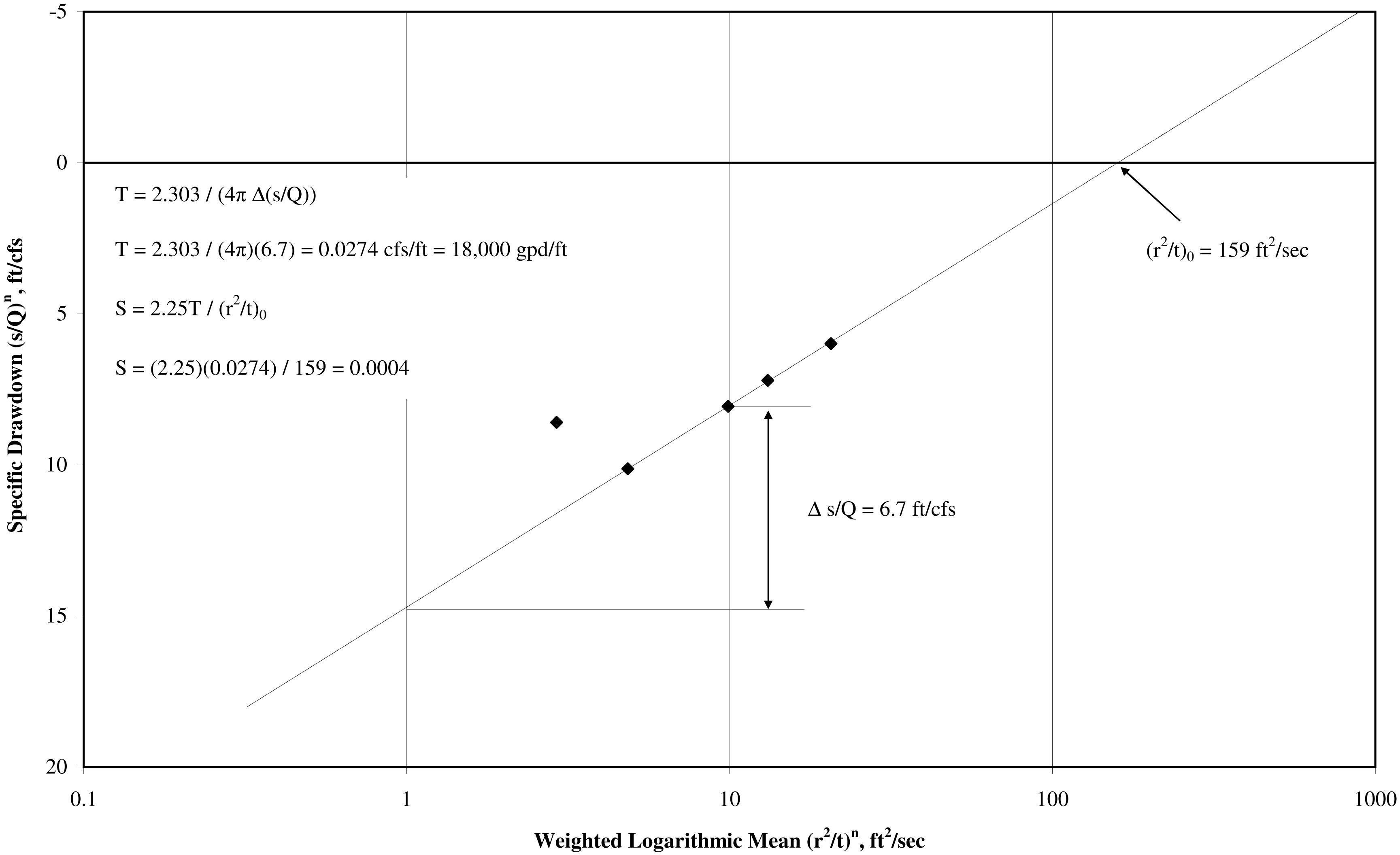
Appendix A

Weighted Logarithmic Mean Analysis - MW-17 Port 3



Appendix A

Weighted Logarithmic Mean Analysis - MW-17 Port 4



Appendix A