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June 23, 2005

Mr. Norman Shopay
Project Manager
California Department of Toxic Substances Control
Geology and Corrective Action Branch
700 Heinz Avenue
Berkeley, California 94710

Subject: *Groundwater Elevation and Hydraulic Gradient Error Analysis, Interim Measures No. 2*
Pacific Gas and Electric Company, Topock Project

Dear Mr. Shopay:

This letter transmits the revised *Groundwater Elevation and Hydraulic Gradient Error Analysis for the Interim Measures No. 2*, Pacific Gas and Electric Company (PG&E) Topock project. This technical memorandum has been prepared in response to the Department of Toxic Substances Control (DTSC) request that PG&E provide an expanded analysis of the potential errors associated with gradient measurements between designated well pairs at the Topock site.

PG&E submitted an Interim Measures (IM) Performance Monitoring Plan to DTSC on April 15, 2005 to directly address the metrics, performance standards and reporting requirements for the IM (DTSC letter of February 14, 2005). The Performance Monitoring Plan contains an analysis of potential errors associated with gradient measurements. The enclosed document expands on that discussion and reports on new methodologies (including revised methods to used compensate for variations in temperature and salinity) to reduce the potential for errors in groundwater elevation and gradient calculations.

If you have any questions, please do not hesitate to contact me at (805) 546-5243.

Sincerely,

Paul Bertr
for Yvonne Meeks

Enclosed

Cc: Kate Burger/DTSC

Groundwater Elevation and Hydraulic Gradient Error Analysis, Interim Measures No. 2 PG&E Topock Compressor Station

PREPARED FOR: Pacific Gas & Electric Company

DATE: June 23, 2005

Introduction

Pacific Gas and Electric Company (PG&E) is implementing Interim Measure (IM) No. 2 at the Topock Compressor Station near Needles, California, as described in the *Final Interim Measures Work Plan No. 2* prepared by CH2M HILL on March 2, 2004 and *Addenda to Interim Measures Work Plan No. 2,* prepared by CH2M HILL on March 1, 2004. The objective of the IM is hydraulic control of the plume boundaries near the Colorado River to maintain a net landward groundwater gradient from the Colorado River.

To achieve the IM objectives, groundwater is extracted from a well (TW-2D) approximately 600 feet from the Colorado River. Water levels are monitored at key wells near the extraction well and at gaging stations along the Colorado River to determine groundwater gradients and flow directions. These data are evaluated monthly to confirm that the IM objectives continue to be met.

In a letter dated February 14, 2005, the Department of Toxic Substances Control (DTSC) established the performance standards, performance criteria, and reporting and response action requirements for IM activity in the floodplain area. As mandated by DTSC (DTSC 2005), three well pairs have been selected to monitor hydraulic gradients: MW-33-150/MW-31-135, MW-34-80/MW-20-130, and MW-42-65/MW-20-130. These well pairs are highlighted on Figure 1. The objective behind selecting these well pairs is to provide a clear, quantitative metric for assessing the hydraulic gradients induced by groundwater extraction and achievement of the IM performance standard. DTSC has specified that "success" is achieved when the average monthly gradients are at least 0.001 feet per foot (ft/ft) in the direction of the MW-20 bench (i.e., towards wells MW-31-135 and MW-20-130).

The process of measuring groundwater levels at the Topock site is complicated by the frequent fluctuations of groundwater levels in response to changes in river stage and by variations in salinity of the groundwater, particularly between wells completed at different depths.

By recording groundwater levels and river stage every half hour using sensitive pressure transducers and data loggers in all floodplain wells and at two river gages, accurate measurements of groundwater levels and river stage are obtained despite the frequent changes in river stage. The precision of the transducers is 1.1 millimeters (0.0036 foot). Once calibrated to manually-measured water levels, the transducers provide a very accurate record of water level fluctuations.

A draft *Performance Monitoring Plan for Interim Measures in the Floodplain Area* (CH2M HILL 2005a) was submitted to DTSC on April 15, 2005, referred to hereafter as the Performance Monitoring Plan. The Performance Monitoring Plan contains an analysis of potential errors associated with gradient measurements between the designated well pairs. This document summarizes and expands on that discussion and reports on the methodology now used to reduce the potential for error. It provides an evaluation of potential measurement errors for water levels associated with previous and newly-revised methodologies used on the Topock project (including revised methods used to compensate for variations in temperature and salinity) and an error analysis for the groundwater gradients calculated between well pairs that are used to evaluate the IM objective.

Water Level Measurements

Groundwater levels are monitored manually using water level sounding tapes and automatically with pressure transducers at all wells in the Performance Monitoring Plan.

Potential sources of error associated with the measurement of groundwater levels include:

- Measurement inaccuracies associated with water level sounding tapes (i.e., tape/cable stretch).
- Operator measurement (i.e., reading the water level sounding tape and transcribing the measured value).
- Pressure transducer accuracy and precision.

Manual water levels are taken at least biweekly during transducer downloads. To minimize the potential for manual measurement inaccuracies, the water level sounding tapes are all from the same manufacturer, are dedicated to the Topock site, and are periodically calibrated. The calibration involves taking all the sounding tapes to a single well and measuring the depth to water with each sounding tape. This exercise is repeated at several wells including shallow, deep, and high salinity wells. Experience has shown that the sounding tapes consistently provide accuracy to ±0.01 foot.

Field staff training is a regular part of the field program. Measurement of water levels with the proper techniques, and to the proper reference points, are very important. All reference points have been marked to ensure water level soundings are always taken to the same reference point (e.g., well casing, bridge, etc.).

The pressure transducers at Topock are set to measure and store a water level every 30 minutes. Data may be stored at more frequent intervals during hydraulic testing activities. Transducers are vented to the atmosphere (via vent tubes within the cables) to prevent changes in barometric pressure from introducing errors in transducer measurements. Calibration of each transducer is verified biweekly against the manual level measurements and adjusted, as necessary. Adjustments typically are required following transducer reinstallations, transducer replacements, or modifications of the wellhead.

The certified transducer accuracy is ±0.07 foot for most of the transducers used at the Topock site (rated at 30 pounds per square inch [psi]). Some 0- to 100-psi-range transducers are also installed that exhibit a certified accuracy of ±0.185 foot. The accuracy error can be evaluated by measuring the "zero reading" when a pressure transducer is under atmospheric pressure (e.g., a 30-psi transducer should read 0 psi ±0.07 at land surface). The potential error in water level measurement due to transducer accuracy is a constant and would be seen as an offset upon installation. This offset is corrected during the first calibration to a manual water level measurement. Errors due to instrument precision are 0.0036 foot for the 30-psi transducers and 0.012 foot in the 100-psi transducers. In the floodplain area, all transducers are 30 psi or less, with the exception of one 100-psi transducer in well MW-33-150. The biweekly verification of the calibrations and annual factory maintenance ensure any other transducer errors, such as electronic drift, are minimized or eliminated.

Standard Operating Procedures for the transducers (e.g., installation, programming, downloads, maintenance, etc.) and for manually measuring water levels have been previously submitted as Appendices A and C in the *Sampling, Analysis, and Field Procedures Manual* for the Topock program (CH2M HILL 2005b).

Salinity and Temperature Measurements

Salinity and temperature vary both horizontally and vertically in the aquifer. In order to evaluate hydraulic gradients, it is necessary to adjust the groundwater elevations from the different wells to "equivalent fresh water heads." Water density increases linearly with salinity and decreases non-linearly with temperature. The amount of the adjustment applied depends on the salinity, the temperature, and the height of the water column in the well.

Hydraulic head in a well is the sum of two parameters: the *elevation head*, which is assumed for the Topock site to be the elevation of the bottom of the screened interval, and the *pressure head*, which is the height of the water column in the well above the elevation head. Elevation head is solely dependent on elevation, whereas the pressure head is the component that is converted to equivalent freshwater head.

For example, consider two 100-foot-deep wells completed with 10-foot screens at precisely the same elevation above sea level. These wells would both be measuring the hydraulic head at the screen interval depth of 90 to 100 feet. The unadjusted groundwater elevation or hydraulic head (in feet above mean sea level [amsl]) at the wells can be calculated using the following equation:

$$HydHead = TOC - DTW \quad (1)$$

where TOC is the surveyed top of casing or measurement point in feet amsl, and DTW is the depth to water in feet below the top of casing. This equation assumes that the water in the well is freshwater with a density of 1 g/cm^3 so that 1 foot of water in the well is equal to 2.309 psi at the well screen.

If the depth to water is the same at both wells, then the calculated groundwater elevations or hydraulic heads for both wells would be the same (assuming the same TOC for both wells). Therefore, there would be a flat hydraulic gradient and no groundwater flow between the wells.

However, if in the above example, the salinity is higher in one well, then the density is greater than 1 g/cm^3 and 1 foot of water in the well equals more than 2.309 psi. Therefore the pressure at the well screen in the well with higher salinity is greater than the other well. If the well had contained freshwater within the water column, the water column would have risen higher, and a different (smaller) DTW measurement would have been obtained. Even though the measured water levels in the two wells are the same, the pressure in the aquifer at the well with the higher salinity must be greater. Groundwater flows from points with higher head to points with lower head.

The adjustment to an equivalent freshwater head accounts for the differences in density and provides a common frame of reference in which to compare groundwater levels between wells of differing salinity. The salinity adjustment is the largest source of potential uncertainty in the head measurements at Topock. Another possible source of uncertainty is variation in temperature, although temperature has a minor effect on water density compared to salinity at the Topock site.

The salinity adjustment used to convert measured head to equivalent freshwater head is calculated as follows:

$$SalCorr\ (ft) = Column \times SAL \times 0.0071 \qquad (2)$$

where *SAL* is the salinity of the water column in percent, *Column* is the height of the water column to be adjusted in feet, and 0.0071 is the conversion factor between salinity and specific gravity. The *SalCorr* term is added to the measured head to produce the equivalent freshwater head, as shown below.

The temperature-dependent density of water (data from In-Situ, 2000) within the well is determined using the following empirical equation (Figure 2):

$$Density\ (g/cm^3) = 4.78\text{x}10^{-8}\, T^3 - 8.15\text{x}10^{-6}\, T^2 + 6.16\text{x}10^{-5}\, T + 1.00 \qquad (3)$$

where T is temperature in degrees Celsius (°C).

The temperature adjustment (*TempCorr*) for each water elevation is calculated as follows:

$$TempCorr\ (ft) = Column \times [1/Density] - Column \qquad (4)$$

For manual water level data, the water column from the water table to the bottom of the screen (the pressure head, defined above) requires an adjustment for salinity and temperature. Transducers measure direct hydraulic pressure above their positions in the wells (i.e., density changes above the transducer are already accounted for in the pressure transducer measurement). The portion of the water column from the transducer to the bottom of the screen requires an adjustment for salinity and temperature since density variation in that portion of the pressure head is not accounted for by the transducer.

For manual water level data, the temperature- and salinity-adjusted groundwater elevation is calculated as follows:

$$CorrectElev\ (ft\ AMSL) = RawElev + SalCorr + TempCorr \qquad (5)$$

where *RawElev* (feet amsl) is the groundwater elevation with no adjustment for temperature or salinity.

For transducer data, the temperature and salinity adjusted groundwater elevation is calculated as follows:

$$HydHead\ (ft\ AMSL) = PressHead + Offset + SalCorr + TempCorr \quad (6)$$

where *PressHead* (feet) is the height of the water column above the transducer and offset (ft amsl) is the elevation of the transducer above the datum. Note that, for transducer data, the salinity and temperature correction are applied to the column of water between the bottom of the well screen and the transducer.

Until early 2005, the salinity value that was used to make the adjustments to equivalent freshwater head was a running average of laboratory- and field-measured salinities obtained from each well. The averages were updated periodically, when significant changes in salinity were measured at a well. This remains the procedure for many wells. At the key gradient evaluation wells, however, downhole specific conductance sensors have recently been installed in the well screens. The downhole sensors measure specific conductance (which can be converted to salinity) at the same frequency as water level (i.e., typically every 30 minutes) and these data are used to adjust the groundwater elevation data to freshwater equivalent head. When all of the five key gradient wells have been sampled and their columns have been mixed (as discussed below), salinity corrections will be made using transducer specific-conductance data. This is anticipated to be mid-June onward.

Groundwater elevations are also adjusted for temperature differences, using temperature measurements recorded at the downhole transducers. At most wells, these transducers are installed relatively shallow in the water column (i.e., typically less than 25 feet below the water table). At the key wells used in gradient calculations, the transducers are installed within the well screens in an attempt to more accurately reflect temporal changes. Wells without downhole transducers are adjusted for temperature using manual measurements obtained during sampling. A summary of the methods used to measure salinity and temperature is provided in Table 1.

Recent Well Profiling and Trend Monitoring

Groundwater elevations derived using manual water level measurements must be adjusted with salinity and temperature corrections that are representative of the entire water column (groundwater elevations derived using transducer data need no correction for the water column above the transducer). To ensure water columns are mixed and the salinity is homogeneous throughout the water column, all wells are now (as of June 2005) purged and sampled with the pump in the upper 15 feet of the water column, and additional recirculation or mixing is also conducted during or following the sampling event. By pumping from the uppermost portion of the well, most of the otherwise stagnant water in the well can be purged during every sampling event.

As an example of the improvements in salinity homogenization that were obtained from this mixing technique, Figure 3 shows several salinity profiles at well MW-34-80 measured between August 2004 and May 2005. In August 2004, sampling procedures had the purge pump installed at the well screen, so the water in the upper (unscreened) part of the well column was not circulated during purging and sampling. Measured salinity from purging was representative of the aquifer and the lower portion of the water column in the well but not representative of the entire water column in the well. In August 2004, the salinity below the pump and in the screened interval (i.e., the purged zone) was measured to be significantly different from the salinity in the water column above the pump. In May 2005, after raising the pump and implementing a mixing protocol, the water column is homogeneous with respect to salinity.

The salinity and temperature profiles in key gradient wells (and MW-34-100) were monitored on May 6, 2005, and are shown on Figures 4 and 5, respectively. The pumps in the MW-34 wells had been raised so that the water in the well casing was homogenous with respect to salinity and temperature. In contrast, the pumps in wells MW-31-135, MW-33-150, and MW-42-65 had not yet been raised, and the water columns had not been mixed; therefore, temperature and salinity gradients still existed. After evaluating the gradients in May 2005, pumps were raised in all wells, and the mixing protocol was made standard.

A comparison of salinities and temperatures measured during profiling with those measured during routine sampling are summarized in Table 2.

Between sampling events, the salinity and temperature within the screened interval may change, reflecting changes in salinity within the surrounding aquifer. To accurately reflect these changes in salinity at the key gradient wells, downhole salinity and temperature probes were installed within the screen interval of each key gradient well. Figures 6 and 7 show the salinity and temperature trends measured at these key wells pairs (except salinity at MW-20-130, due to a sensor malfunction) over several days in May 2005. Temperature was generally constant, with small fluctuations observed only in MW-34-80. The salinity was constant at MW-34-100 and MW-42-65. At MW-33-150, an increase in salinity was seen for several days, followed by a period of stability. At MW-31-135, daily variations in salinity were observed.

Groundwater Elevation Calculations and Adjustments

Groundwater elevations are adjusted for salinity and temperature as described in the *Sampling, Analysis, and Field Procedures Manual* (CH2M HILL 2005b) and in Appendix B of the Performance Monitoring Plan (CH2M Hill 2005a). The calculations to adjust groundwater elevations for salinity and temperature differences (i.e., to equivalent freshwater heads) are performed automatically in the database and applied to each manual water level and transducer measurement.

Table 3 tabulates the salinity and temperature profile data for MW-33-150 and shows how groundwater elevations are calculated and adjusted for salinity and temperature. Groundwater elevations, calculated using the minimum, maximum and average salinity from the May 2005 profiling, are provided in Table 4. Similarly, groundwater elevations calculated with the range in temperature values measured during the profiling are presented in Table 5. The wells are separated into categories of “mixed” and “unmixed” to distinguish which wells have already had the pumps raised to ensure complete mixing of the water column. The groundwater elevation calculated using average profile salinity values is considered the most accurate. Comparison of the last column of each table demonstrates that mixing reduces error significantly with respect to salinity but appears to make little difference with respect to temperature. For mixed wells (no salinity gradient), the deviation from the average salinity-adjusted groundwater elevation is 0.05 foot or less when the minimum or maximum salinity value is used to adjust the groundwater elevation. For wells that were not mixed, the deviation from the average groundwater elevation is up to 0.52 foot (MW-33-150).

The temperature of water in a well typically varies by less than a few degrees Fahrenheit throughout the water column. As a result, temperature differences within a water column of a well are not a source of significant error in groundwater elevation calculations. Temperature remains an important adjustment because it can be significantly different at wells located at different parts of the site (e.g., greater than 12°F difference has been observed between MW-20-130 and MW-34-80).

Hydraulic Gradient Calculation and Evaluation

As discussed in the Performance Monitoring Plan (CH2M HILL 2005a), uncertainty in gradients resulting from the use of a running average salinity for each well is on the order of 0.0002 or about one-fifth of the DTSC criterion of 0.001 (DTSC 2005). To reduce the level of uncertainty in average salinity and, therefore, in calculated water levels and gradient, more frequent and more accurate measurements of salinity are now being collected in the key well pairs. This has been accomplished by two actions. One has been to install downhole sensors that measure salinity, temperature, and water levels simultaneously at regular intervals, currently set for every half hour, in each of the three key well pairs. The second action is to maintain vertical homogeneity in salinity within wells by moving the sample pumps to the upper part of the water column. As shown on Figure 3, a mixing protocol and installation of the pump near the top of the water column at the MW-34 wells has pulled water from the screened interval to near the top of the water column and eliminated the stagnation and any significant salinity gradient.

Table 6 summarizes the average groundwater elevations and the standard deviations based on May 2005 salinity profiling. The standard deviation for each well is calculated using the salinity profile data from that well. That is, rather than calculating the adjusted groundwater elevation using a single salinity value, the adjusted groundwater elevation is calculated using a number of salinity values representing the range of salinity observed during profiling. The resultant standard deviation reflects the fact that adjusted groundwater elevations will vary if different salinities are used to adjust the data. An example of the calculations is provided in Table 2.

The standard deviation is highest for wells that were not mixed at the time of the profiling, and these wells have the highest variability in salinity. Wells that were mixed have nearly homogeneous salinity concentrations throughout the water column, and the resulting standard deviation for groundwater elevations is small. Based on the average standard deviations in Table 6, mixing the water column produces a ten-fold reduction of error.

A standard deviation for groundwater elevation due to the variability of temperature in the water columns can also be calculated for each well. For the key gradient wells (and MW-34-100), the average standard deviation due to temperature is 0.006 foot, and the range is 0.004 to 0.014 foot. This standard deviation is appropriate for mixed and non-mixed wells, since a natural temperature gradient within the well is likely to be established between sampling events due to heat conduction with the aquifer (i.e., distinguishing between mixed and unmixed is irrelevant).

Currently, the pumps in all key wells have been raised to near the top of the water column and the water columns are mixed during sampling events. Therefore, the standard deviation for groundwater elevations due to the variability of salinity at mixed wells (0.010 foot) is most appropriate when considering future groundwater elevations and gradient calculations. A cumulative standard deviation for groundwater elevations due to salinity and temperature at mixed wells is 0.010 (salinity) + 0.006 (temperature) = 0.016 foot. Transducer precision error also must be documented: 0.004 foot for the 30-psi transducers in well pairs MW-34-80/MW-20-130 and MW-42-65/MW-20-130 and 0.012 foot for the 100-psi transducer in the MW-33-150/MW-31-135 well pair.

Table 7 summarizes the potential gradient error when one standard deviation in groundwater elevation error is accounted for and compared to the current required net landward gradient of 0.001 ft/ft. Table 7 also shows the calculations when the same gradient error is evaluated against a net landward gradient of 0.0005 ft/ft.

The gradient error at one standard deviation is 0.00004 to 0.00005 ft/ft ($4\text{-}5 \times 10^{-5}$) or less than 5 percent of the currently-required 0.001 ft/ft (1×10^{-3}) net landward gradient. This is nearly an order of magnitude better than the 0.0002 ft/ft (2×10^{-4}) error that had been calculated previously using running average salinities. If the required net landward gradient is reduced in half to 0.0005 ft/ft (5×10^{-4}), the potential error is still only 7 to 11 percent.

Conclusions and Recommendations

Purging protocols have been improved to ensure the entire water column is purged and mixed during sampling. This ensures that salinity concentrations are constant through the water column, and the water in the well has a consistent density. In addition, salinity and temperature are monitored with downhole sensors installed within the well screen at the key gradient wells. These steps have reduced the error associated with calculating equivalent freshwater heads from water level measurements. Errors in hydraulic gradients calculated with groundwater elevations adjusted using running average salinity values were on the order of 20 percent. Gradient errors calculated from mixed profiles (accounting for both temperature and salinity variability) are now 5 percent or less.

With the reduced errors in calculating gradients, the IM objective of a net landward groundwater gradient from the Colorado River can now be evaluated to a greater precision. It is now likely that the objective can be accurately evaluated even if a landward hydraulic gradient of 5×10^{-4} ft/ft is used as a goal.

Salinity and temperature profiles will be measured monthly at the key gradient pair wells for the next 4 months. Trends in salinity and temperature at these wells will also be monitored.

References

California Department of Toxic Substances Control (DTSC). 2005. Letter. "Criteria for Evaluating Interim Measures Performance Requirements to Hydraulically Contain Chromium Plume in Floodplain Area." February 14.

CH2M HILL. 2005a. *Performance Monitoring Plan for Interim Measures in the Floodplain Area. PG&E Topock Compressor Station*.

. 2005b. *Sampling, Analysis, and Field Procedures Manual, Revision 1, PG&E Topock Compressor Station, Needles, California*. March 31.

In-Situ, Inc. 2000. *Water Level Accuracy and Correcting for Errors due to Gravitational Acceleration and Liquid Density*. Technical Note 001.

Tables

TABLE 1
SUMMARY OF TEMPERATURE AND SALINITY MONITORING
PG&E TOPOCK

Wells	Salinity Monitoring	Temperature Monitoring
Key Gradient Wells	Specific conductance is measured every 30 minutes with downhole sensors. The downhole sensors are installed within the well screens.	Temperature is measured every 30 minutes with downhole sensors. The downhole sensors are installed within the well screens.
PMP Wells	Salinity and/or specific conductance is measured during purging of wells during routine GMP sampling. Measurements are conducted in the field and/or at the laboratory.	Temperature is measured every 30 minutes. The temperature is measured at the depth of the transducer installation, which is different from well to well.
Other Wells	Salinity and/or specific conductance is measured during purging of wells during routine GMP sampling. Measurements are conducted in the field.	Temperature is measured during purging of wells during routine GMP sampling. Measurements are conducted in the field.

Notes:
GMP -- Groundwater Monitoring Program; PMP -- Performance Monitoring Program
PMP wells are instrumented with transducers that measure water level and temperature unless otherwise noted.
Specific conductance values are converted to salinity as described in CH2M HILL (2005a).

TABLE 2
TEMPERATURE AND SPECIFIC CONDUCTANCE FROM PROFILING AND SAMPLING
PG&E TOPOCK

	SC from Sampling (µS/cm)						SC from Profiling (µS/cm)			
	Most Recent		2004-2005				May 2005			
LocID	Date	SC	Range			Median	Range			Average
MW-31-135	03/10/2005	12,500	9,500	to	13,700	13,100	8,411	to	11,690	8,420
MW-33-150	03/16/2005	21,600	15,900	to	21,600	NA	5,061	to	16,651	10,530
MW-34-080	05/18/2005	16,000	10,400	to	26,900	14,600	13,587	to	14,215	13,920
MW-34-100	05/18/2005	19,000	14,600	to	25,000	18,700	15,052	to	16,830	15,830
MW-42-065	03/16/2005	21,400	20,500	to	22,200	21,400	9,719	to	18,259	15,220

	Temperature from Sampling (°F)						Temperature from Profiling (°F)			
	Most Recent		2004-2005				May 2005			
LocID	Date	Temperature	Range			Median	Range			Average
MW-20-130	03/09/2005	84.2	82.0	to	86.2	84.6	83.2	to	84.1	83.9
MW-31-135	03/10/2005	86.0	83.5	to	86.8	85.2	83.2	to	83.6	83.3
MW-33-150	03/16/2005	78.8	78.8	to	79.7	NA	79.6	to	80.3	80.0
MW-34-080	05/18/2005	75.9	70.5	to	81.1	74.2	70.4	to	72.1	71.1
MW-34-100	05/18/2005	75.9	71.8	to	78.1	75.6	69.6	to	72.9	70.9
MW-42-065	03/16/2005	77.9	76.4	to	77.9	81.9	72.5	to	76.2	75.4

Notes:
Profiling conducted on May 6, 2005.
°F - degrees Fahrenheit
NA - not applicable (only 2 data points)
SC - specific conductance
µS/cm - microSiemens per centimeter

TABLE 3
EXAMPLE OF ADJUSTED GROUNDWATER ELEVATION CALCULATIONS
PG&E TOPOCK

WELL: MW-33-150

[A]	Top of Casing =	487.77	ft AMSL
[B]	Depth to Water =	34.10	ft BTOC
[C]	Well Depth =	155.0	ft BTOC
[D]	Water Column =	120.9	ft

[E]	[F]	[H]	[I]	[J]	[K]	[L]	[M]	[N]	[O]
Depth	Temperature (°F)	Specific Conductance (uS/cm)	Salinity (%)	Uncorrected Groundwater Elevation (ft AMSL)	Salinity Adjustment (ft)	Salinity Adjusted Groundwater Elevation (ft AMSL)	Temperature Adjustment (ft)	Temperature Adjusted Groundwater Elevation (ft AMSL)	Salinity and Temperature Adjusted Groundwater Elevation (ft AMSL)
--	--	--	[H]x0.00006467	[A]-[B]	[I}x[D}x0.0071	[J]+[K]	EQN1	[J]+[M]	[J]+[K]+[M]
0.7	80.0	5,556	0.36	453.67	0.31	453.98	-0.41	453.26	453.57
5	80.0	5,587	0.36	453.67	0.31	453.98	-0.41	453.26	453.57
10	80.1	5,590	0.36	453.67	0.31	453.98	-0.41	453.26	453.57
15	80.1	5,593	0.36	453.67	0.31	453.98	-0.41	453.26	453.57
20	80.0	5,612	0.36	453.67	0.31	453.98	-0.41	453.26	453.57
25	80.0	5,658	0.37	453.67	0.31	453.98	-0.41	453.26	453.57
30	79.9	5,836	0.38	453.67	0.32	453.99	-0.41	453.26	453.58
35	79.9	5,929	0.38	453.67	0.33	454.00	-0.41	453.26	453.59
40	79.9	6,056	0.39	453.67	0.34	454.01	-0.41	453.26	453.60
45	79.9	6,225	0.40	453.67	0.35	454.02	-0.41	453.26	453.60
50	79.9	6,401	0.41	453.67	0.36	454.03	-0.41	453.26	453.61
55	79.9	6,978	0.45	453.67	0.39	454.06	-0.41	453.26	453.65
60	79.9	8,687	0.56	453.67	0.48	454.15	-0.41	453.26	453.74
65	79.9	12,838	0.83	453.67	0.71	454.38	-0.41	453.26	453.97
70	80.0	14,707	0.95	453.67	0.82	454.49	-0.41	453.26	454.08
75	80.0	14,889	0.96	453.67	0.83	454.50	-0.41	453.26	454.08
80	80.0	14,910	0.96	453.67	0.83	454.50	-0.41	453.26	454.09
85	80.0	14,919	0.96	453.67	0.83	454.50	-0.41	453.26	454.09
90	80.1	14,931	0.97	453.67	0.83	454.50	-0.41	453.26	454.09
95	80.1	14,952	0.97	453.67	0.83	454.50	-0.41	453.26	454.09
100	80.1	15,144	0.98	453.67	0.84	454.51	-0.41	453.26	454.10
105	80.2	16,387	1.06	453.67	0.91	454.58	-0.42	453.25	454.16
110	80.2	16,588	1.07	453.67	0.92	454.59	-0.42	453.25	454.17
115	80.3	16,603	1.07	453.67	0.92	454.59	-0.42	453.25	454.17
120	80.3	16,632	1.08	453.67	0.92	454.59	-0.42	453.25	454.18
Minimum	**79.9**	**5,556**	**0.36**	**--**	**0.31**	**453.98**	**-0.42**	**453.25**	**453.57**
Maximum	**80.3**	**16,632**	**1.08**	**--**	**0.92**	**454.59**	**-0.41**	**453.26**	**454.18**
Median	**80.0**	**8,687**	**0.56**	**--**	**0.48**	**454.15**	**-0.41**	**453.26**	**453.74**
Average	**80.0**	**10,528**	**0.68**	**--**	**0.58**	**454.25**	**-0.41**	**453.26**	**453.84**
Std. Dev.	**0.1**	**4,674**	**0.30**	**--**	**0.26**	**0.259**	**0.00**	**0.002**	**0.258**

Notes:
EQN1 = - ([D] x (1 / (4.7799E9 x $[F]^3$ - 8.155E7 x $[F]^2$ + 6.158 x [F] + 0.9999)) - [D]) where temperature [F] is in °C.
Temperature and specific conductance measured at MW-33-150 with a Troll 9000 on May 6, 2005.
ft -- feet; AMSL -- above mean sea level; BTOC -- below top of casing; uS/cm -- microSiemens per centimeter

TABLE 4
POSSIBLE ERRORS IN GROUNDWATER ELEVATIONS DUE TO SALINITY GRADIENTS
PG&E TOPOCK

Well	Top of Casing (ft AMSL)	Depth to Water (ft BTOC)	Well Depth (ft BTOC)	Specific Conductance Data Source [1]	Specific Conductance (uS/cm)	Salinity (%)	Salinity Adjustment (ft) [2]	Uncorrected Elevation (ft AMSL)	Salinity Corrected Elevation (ft AMSL)	Deviation from Use of Average Column Salinity (ft)
UNMIXED WELLS (AS 05/06/05)										
MW-20-130	500.66	48.79	133	Min Profile (est.)	7,000	0.5	0.27	451.87	452.14	-0.28
				Max Profile (est.)	12,000	0.8	0.46	451.87	452.33	-0.08
				Recent Sampling	11,000	0.7	0.43	451.87	452.30	-0.12
				Average	11,000	0.7	0.55	451.87	452.42	--
MW-31-135	498.11	43.34	134	Min Profile	8,410	0.5	0.35	454.77	455.12	-0.01
				Max Profile	11,690	0.8	0.49	454.77	455.26	0.12
				Recent Sampling	10,900	0.7	0.45	454.77	455.22	0.09
				Average Profile	8,740	0.6	0.36	454.77	455.13	--
MW-33-150	487.77	34.10	155	Min Profile	5,060	0.3	0.28	453.67	453.95	-0.30
				Max Profile	16,650	1.1	0.92	453.67	454.59	0.34
				Recent Sampling	16,900	1.1	0.94	453.67	454.61	0.35
				Average Profile	10,528	0.7	0.58	453.67	454.25	--
MW-42-65	463.37	10.18	80	Min Profile	9,720	0.6	0.31	453.19	453.50	-0.20
				Max Profile	18,260	1.2	0.59	453.19	453.78	0.08
				Recent Sampling	12,500	0.8	0.40	453.19	453.59	-0.11
				Average Profile	15,920	1.0	0.51	453.19	453.70	--
MIXED WELLS (AS 05/06/05)										
MW-34-80	461.20	6.46	84	Min Profile	13,590	0.9	0.48	454.74	455.22	-0.01
				Max Profile	14,215	0.9	0.51	454.74	455.24	0.01
				Recent Sampling	14,400	0.9	0.51	454.74	455.25	0.02
				Average Profile	13,920	0.9	0.50	454.74	455.23	--
MW-34-100	460.97	7.08	102	Min Profile	15,050	1.0	0.66	453.89	454.54	-0.03
				Max Profile	16,830	1.1	0.73	453.89	454.62	0.04
				Recent Sampling	16,100	1.0	0.70	453.89	454.59	0.01
				Average Profile	15,830	1.0	0.69	453.89	454.57	--

Notes:

1 - Profile minimum, maximum and average are determined from water column profiling conducted on 05/06/05, except MW-20-130, which is estimated (salinity probe failed during profiling). Recent sampling is the closest available laboratory measured specific conductance data. Average specific conductance for MW-20-130 is average specific conductance from from sampling in 2005.

2 - Salinity Adjustment = H x S x 0.00071 where H is the height of the water column (ft), S is the salinity (%) and 0.0071 is the conversion between salinity and density.

TABLE 5
POSSIBLE ERRORS IN GROUNDWATER ELEVATIONS DUE TO TEMPERATURE GRADIENTS
PG&E TOPOCK

Well	Top of Casing (ft AMSL)	Depth to Water (ft BTOC)	Well Depth (ft BTOC)	Temperature Data Source[1]	Temp. (°F)	Temp. (°C)	Temp. [2] Adjustment (ft)	Uncorrected Elevation (ft AMSL)	Temperature Corrected Elevation (ft AMSL)	Deviation from Use of Average Column Temp. (ft)
UNMIXED WELLS (AS OF 05/06/05)										
MW-20-130	500.66	43.74	133	Min Profile	83.2	28.4	-0.35	456.92	456.57	0.01
				Max Profile	84.1	28.9	-0.36	456.92	456.56	0.00
				Recent Sampling	84.2	29.0	-0.36	456.92	456.56	0.00
				Average Profile	83.9	28.8	-0.36	456.92	456.56	--
MW-31-135	498.11	43.34	134	Min Profile	83.2	28.4	-0.35	454.77	454.42	0.00
				Max Profile	83.6	28.7	-0.36	454.77	454.41	0.00
				Recent Sampling	86.0	30.0	-0.40	454.77	454.37	-0.04
				Average Profile	83.3	28.5	-0.36	454.77	454.41	--
MW-33-150	487.77	34.10	155	Min Profile	79.6	26.4	-0.40	453.67	453.27	0.01
				Max Profile	80.3	26.8	-0.42	453.67	453.25	-0.01
				Recent Sampling	78.8	26.0	-0.39	453.67	453.28	0.02
				Average Profile	80.0	26.7	-0.41	453.67	453.26	--
MW-42-65	463.37	10.18	80	Min Profile	72.5	22.5	-0.16	453.19	453.03	0.03
				Max Profile	76.2	24.6	-0.20	453.19	452.99	-0.01
				Recent Sampling	77.9	25.5	-0.22	453.19	452.97	-0.02
				Average Profile	75.4	24.1	-0.19	453.19	453.00	--
MIXED WELLS (AS 05/06/05)										
MW-34-80	461.20	6.46	84	Min Profile	70.4	21.3	-0.16	454.74	454.58	0.01
				Max Profile	72.1	22.3	-0.18	454.74	454.56	-0.01
				Recent Sampling	75.9	22.1	-0.18	454.74	454.56	-0.01
				Average Profile	71.1	21.7	-0.17	454.74	454.57	--
MW-34-100	460.97	7.08	117	Min Profile	69.6	20.9	-0.22	453.89	453.67	0.02
				Max Profile	72.9	22.7	-0.26	453.89	453.62	-0.03
				Recent Sampling	75.9	24.1	-0.30	453.89	453.58	-0.06
				Average Profile	70.9	21.6	-0.24	453.89	453.65	--

Notes:
Temp -- Temperature
1 - Profile minimum, maximum and average determined from water column profiling conducted on 05/06/05. Recent sampling is the closest available field measured temperature data.
2 - Temperature Adjustment = $- (H \times (1 / (4.780E\text{-}8 \times T^3 - 8.155E\text{-}6 \times T^2 + 6.158E\text{-}5 \times T + 0.9999)) - H)$
where T is the temperature (°C) and H is the height of the water column (ft).

TABLE 6
AVERAGE GROUNDWATER ELEVATIONS FOR MAY 2005 AND STANDARD DEVIATIONS BASED UPON SALINITY PROFILING
PG&E TOPOCK

Wells Unmixed (as of 05/06/05)]		
Well	**GW Elevation (ft AMSL)**	**Std. Dev. (ft)**
MW-20-130	453.83	NA
MW-31-135	454.60	0.033
MW-33-150	455.77	0.259
MW-42-65	455.63	0.110
	Average	0.134

Wells Mixed (as of 05/06/05)		
Well	**GW Elevation (ft AMSL)**	**Std. Dev. (ft)**
MW-34-80	455.95	0.0071
MW-34-100	456.07	0.0136
	Average	0.0104

Notes:
ft -- feet; AMSL -- above mean sea level; Std. Dev. -- standard deviation

TABLE 7
POTENTIAL GRADIENT ERRORS
PG&E TOPOCK

	[A]	[B]	[C]	[D]	[E]
Well Pair	**Distance Between Well Pair (ft)**	**Cummulative Std. Dev. (ft)**	**Potential Gradient Error at 1 Std. Dev. (feet/ft)**	**Percent of Required Gradient**	**Percent of Proposed Gradient**
MW-31-135 MW-33-150	519	0.028	0.00005	5%	11%
MW-20-130 MW-34-80	565	0.020	0.00004	4%	7%
MW-20-130 MW-42-65	440	0.020	0.00005	5%	9%

Notes:
All pressure transucers have precision of 0.0037 feet or bettter (i.e., 30 psi or less) except MW-33-150, which has a 100 psi transducer with a precision of 0.012 feet. Therefore, gradient pair MW-31-135 - MW-33-150 uses the higher transducer precision of 0.012 in gradient error calcuations.
Formulas:
[B] - Cummulative standard deviation [Std. Dev.] includes average mixed salinity standard deviation of 0.010 feet/ft, average temperature standard deviation of 0.006 feet/ft, and precision of pressure transducers (0.0037 and 0.012 feet for 30 and 100 psi transducers, respectively).
[C] = [B] / [A]
[D] = [C] / Required 0.001 feet/ft Gradient
[E] = [C] / Proposed 0.0005 feet/ft Gradient

Figures

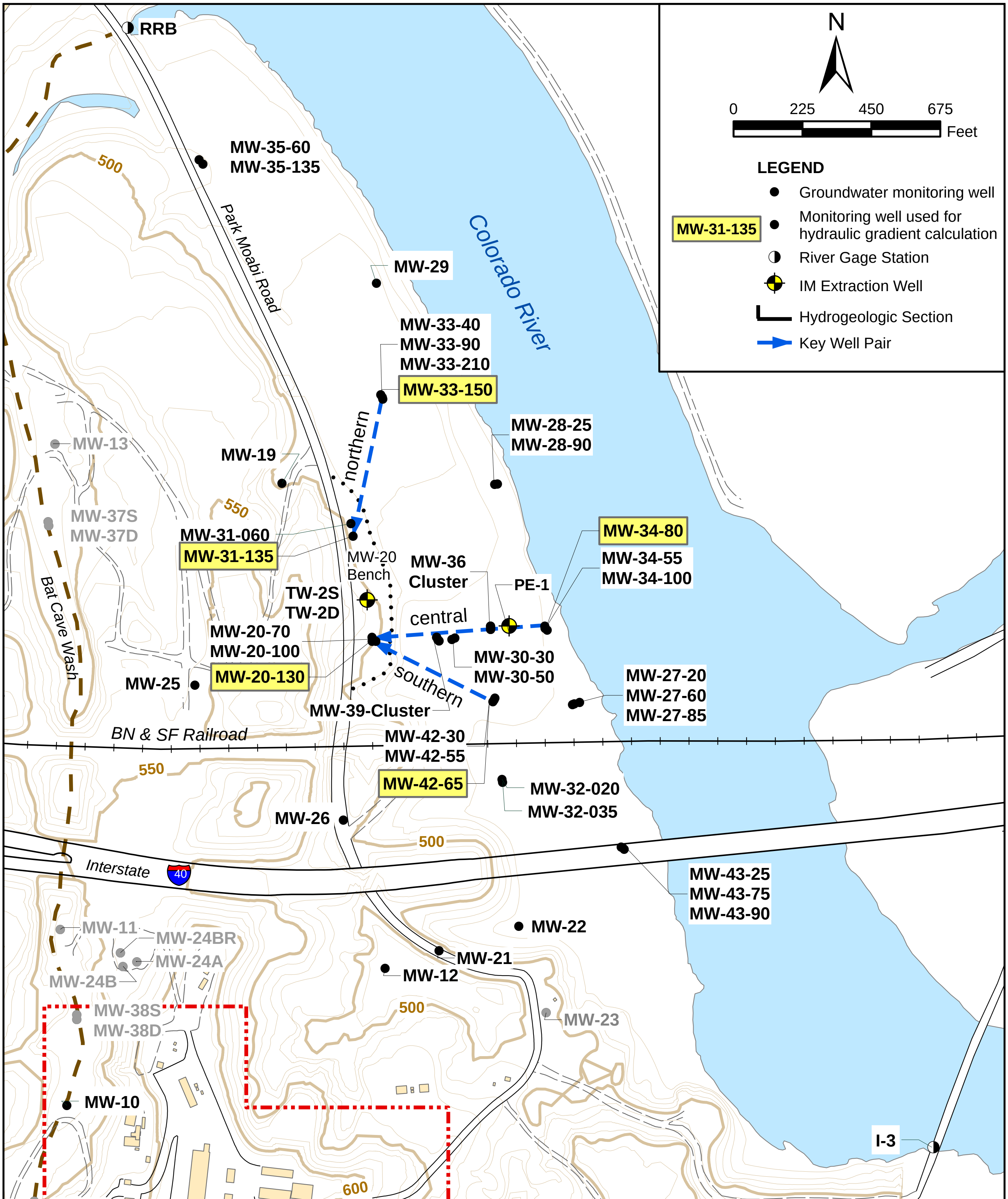

FIGURE 1
LOCATIONS OF WELLS AND KEYGRADIENT WELL PAIRS FOR IM PERFORMANCE MONITORING

ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2
PG&E TOPOCK

CH2MHILL

SFO \\ZINFANDEL\PROJ\PACIFICGASELECTRICCO\TOPOCKPROGRAM\GIS\MXD\2005\PMP_WELLS_SECTIONS_8X11.MXD
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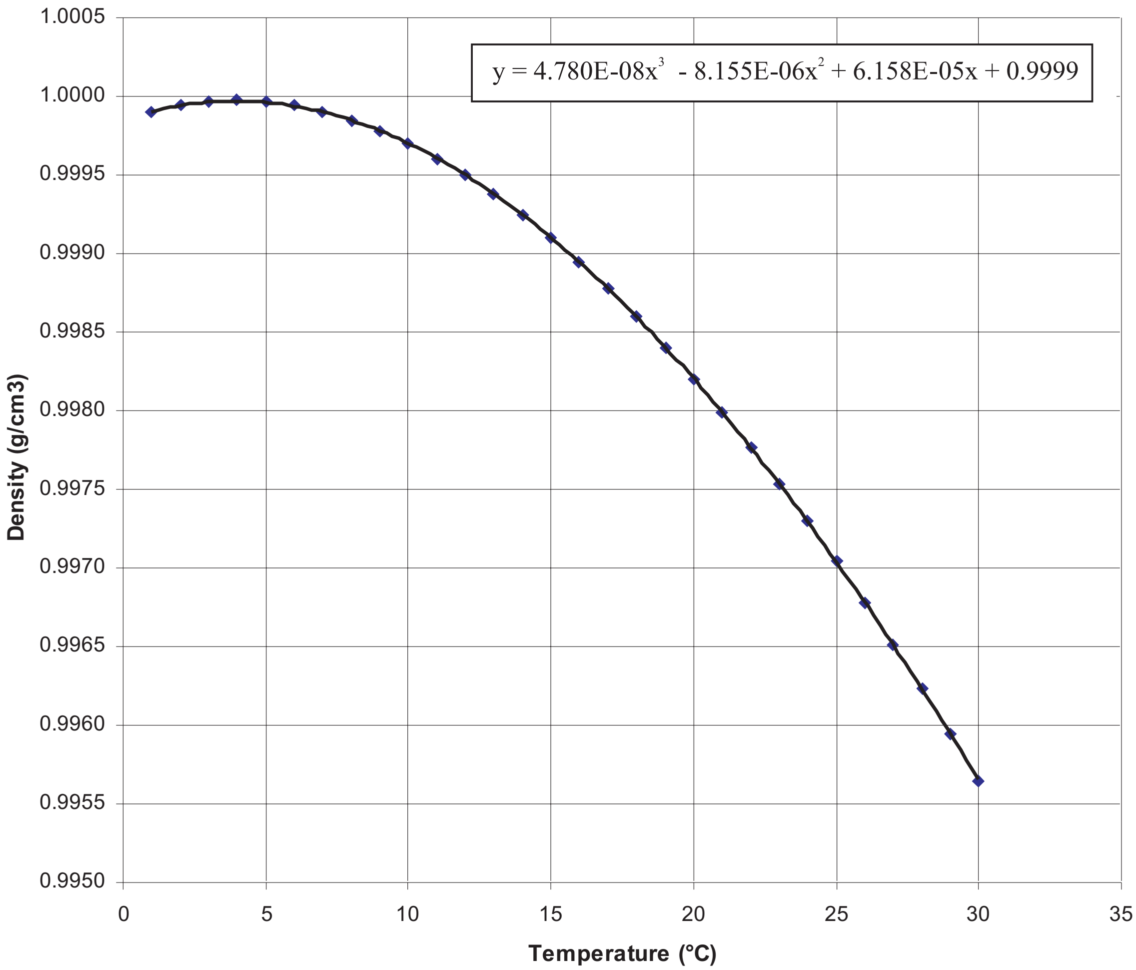

FIGURE 2
RELATIONSHIP BETWEEN TEMPERATURE AND FRESHWATER DENSITY

ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2, PG&E TOPOCK

CH2MHILL

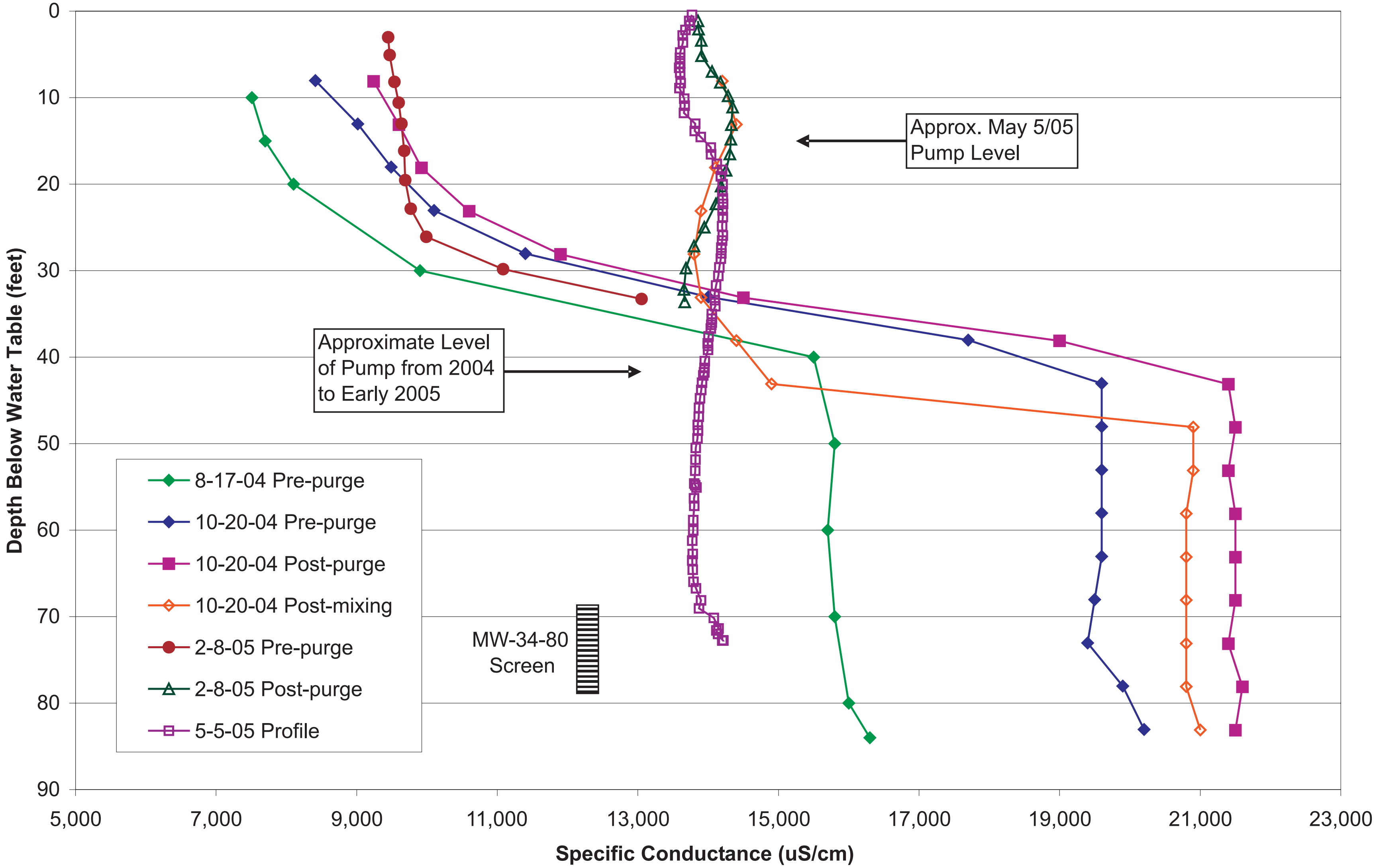

FIGURE 3
SPECIFIC CONDUCTANCE PROFILES AT WELL MW-34-80

ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2, PG&E TOPOCK

CH2MHILL

\\zinfandel\proj\G:\PacificGasElectricCo\TopockProgram\GW_Modeling\ErrorAnalysis_June2005\ErrorAnalysisFigures.cdr

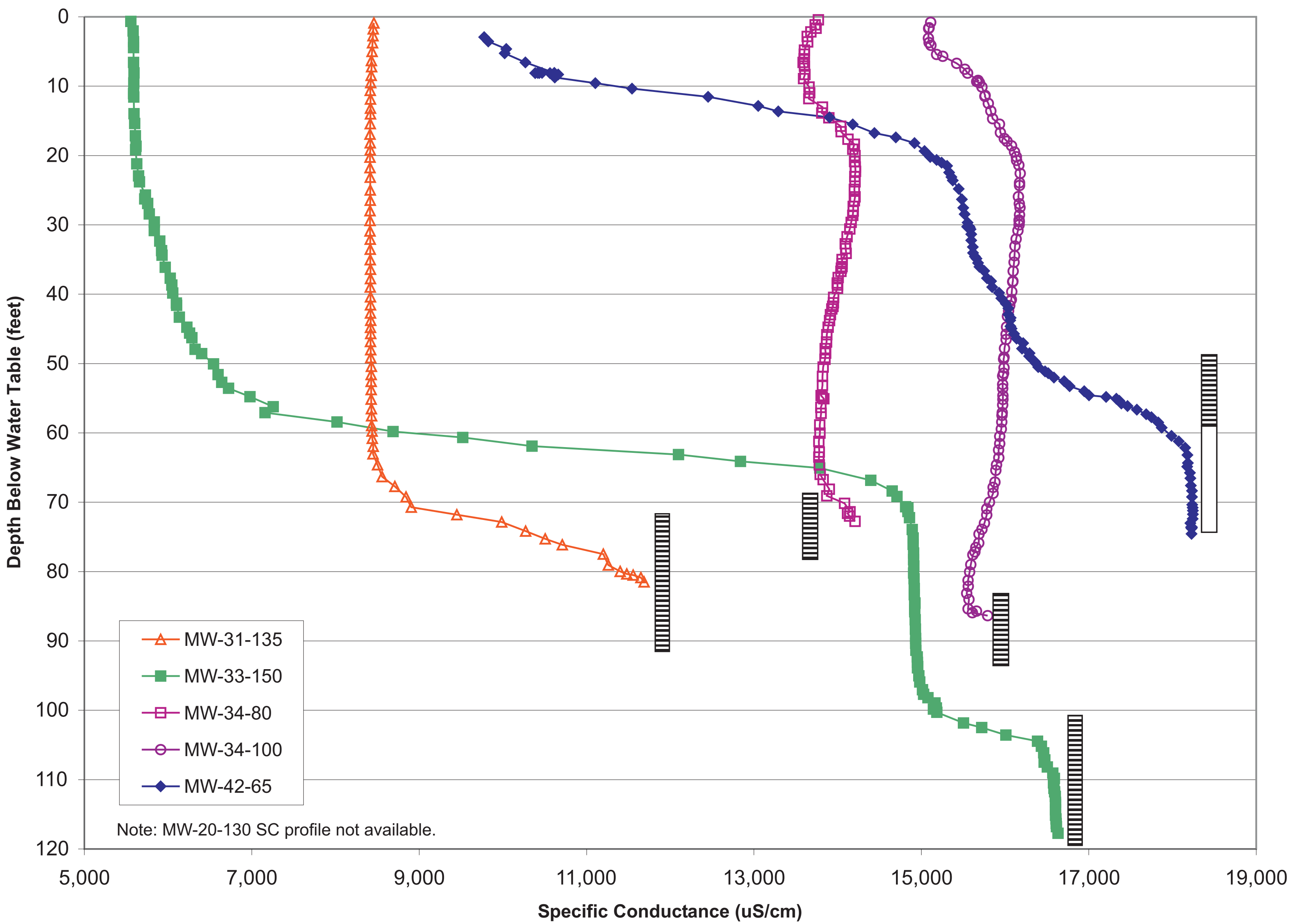

FIGURE 4
SPECIFIC CONDUCTANCE PROFILES AT KEY GRADIENT WELLS (MAY 2005)

ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2, PG&E TOPOCK

CH2MHILL

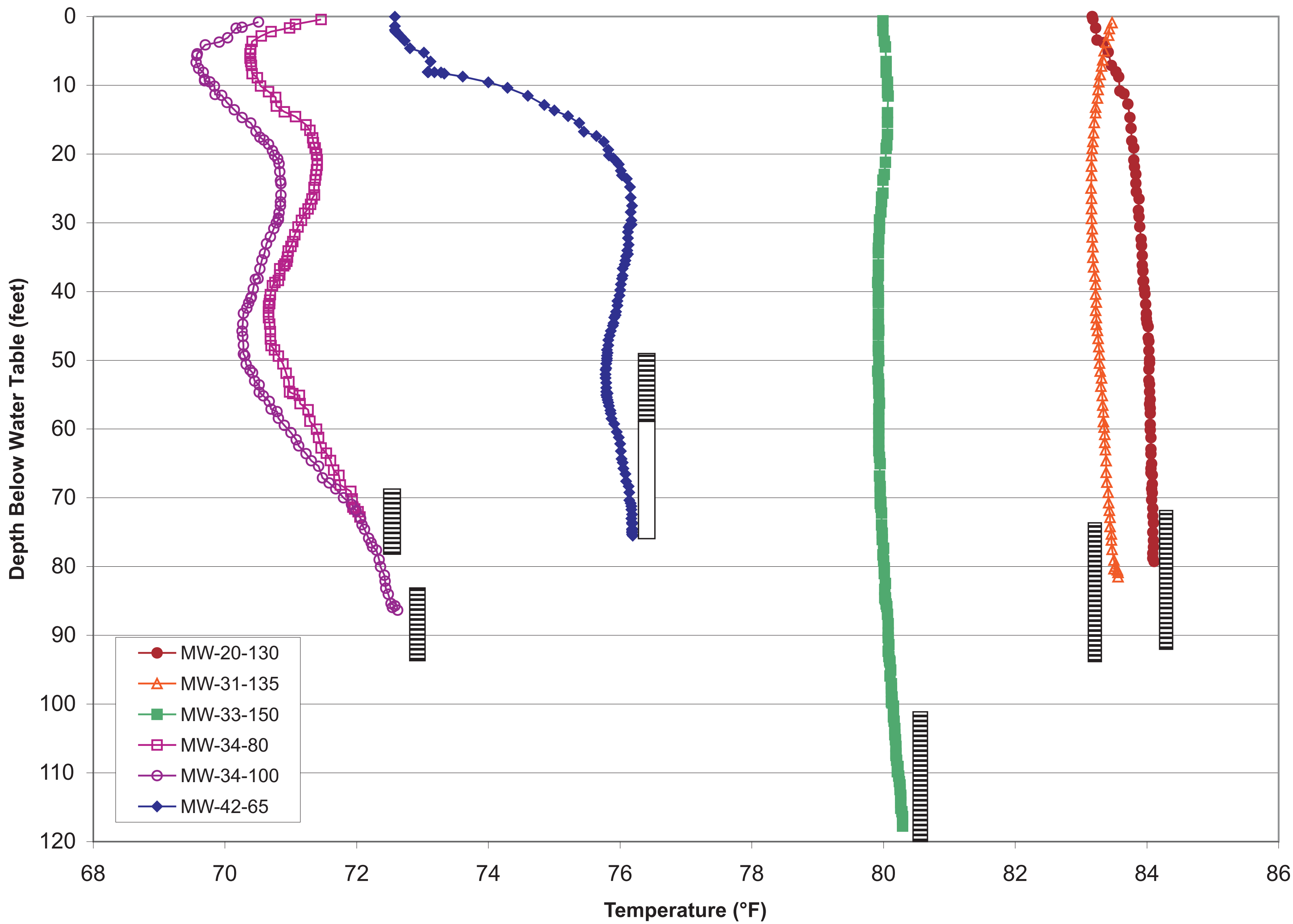

FIGURE 5
TEMPERATURE PROFILES AT KEY GRADIENT WELLS (MAY 2005)

ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2, PG&E TOPOCK

CH2MHILL

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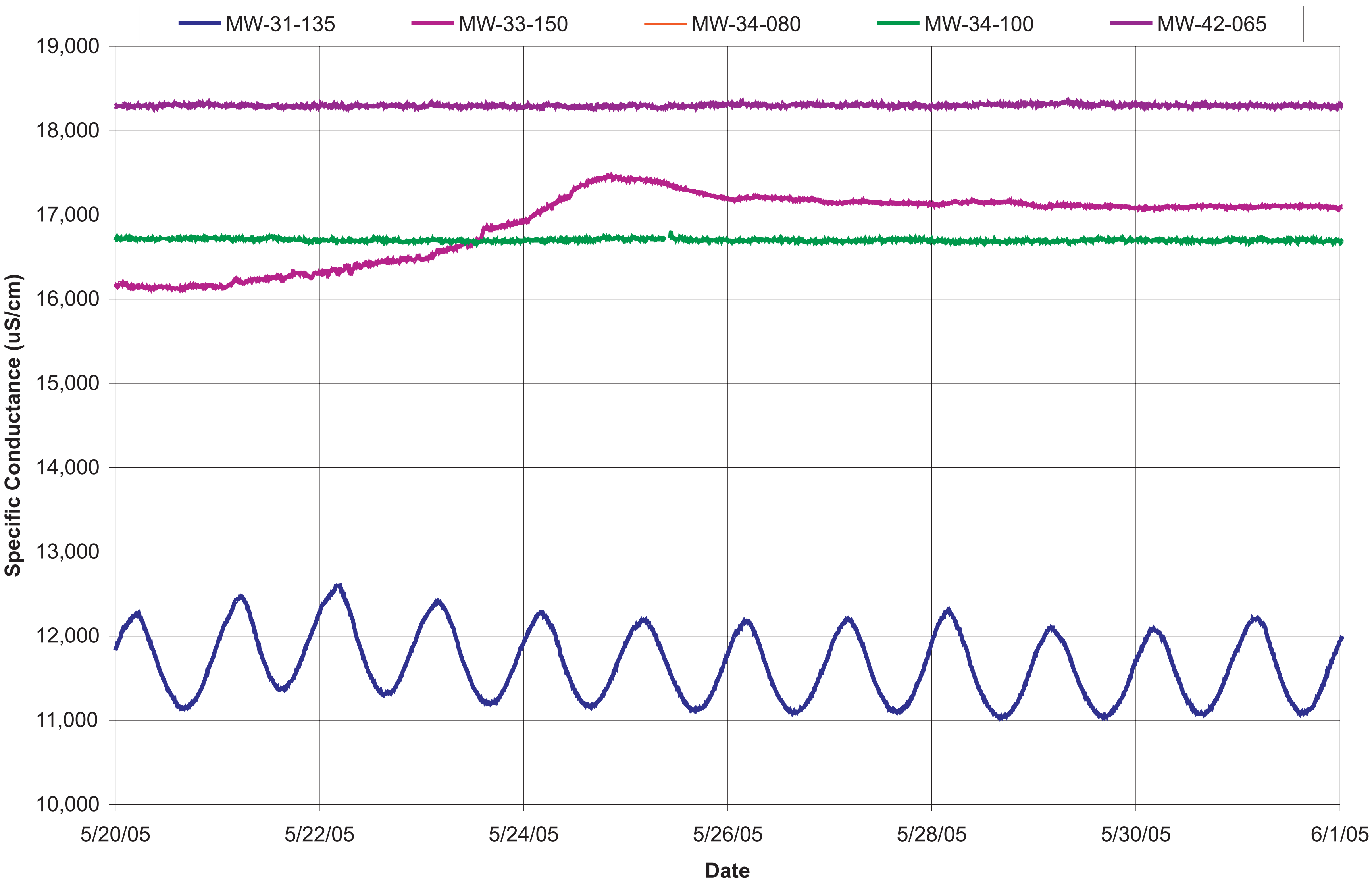

Notes:
Salinity sensor failed in late May at MW-34-80.
MW-34-100 shown on plot though not a key gradient pair well.

FIGURE 6
SPECIFIC CONDUCTANCE TRENDS AT KEY GRADIENT WELLS
ERROR ANALYSIS TECHNICAL MEMORANDUM
INTERIM MEASURES NO. 2, PG&E TOPOCK

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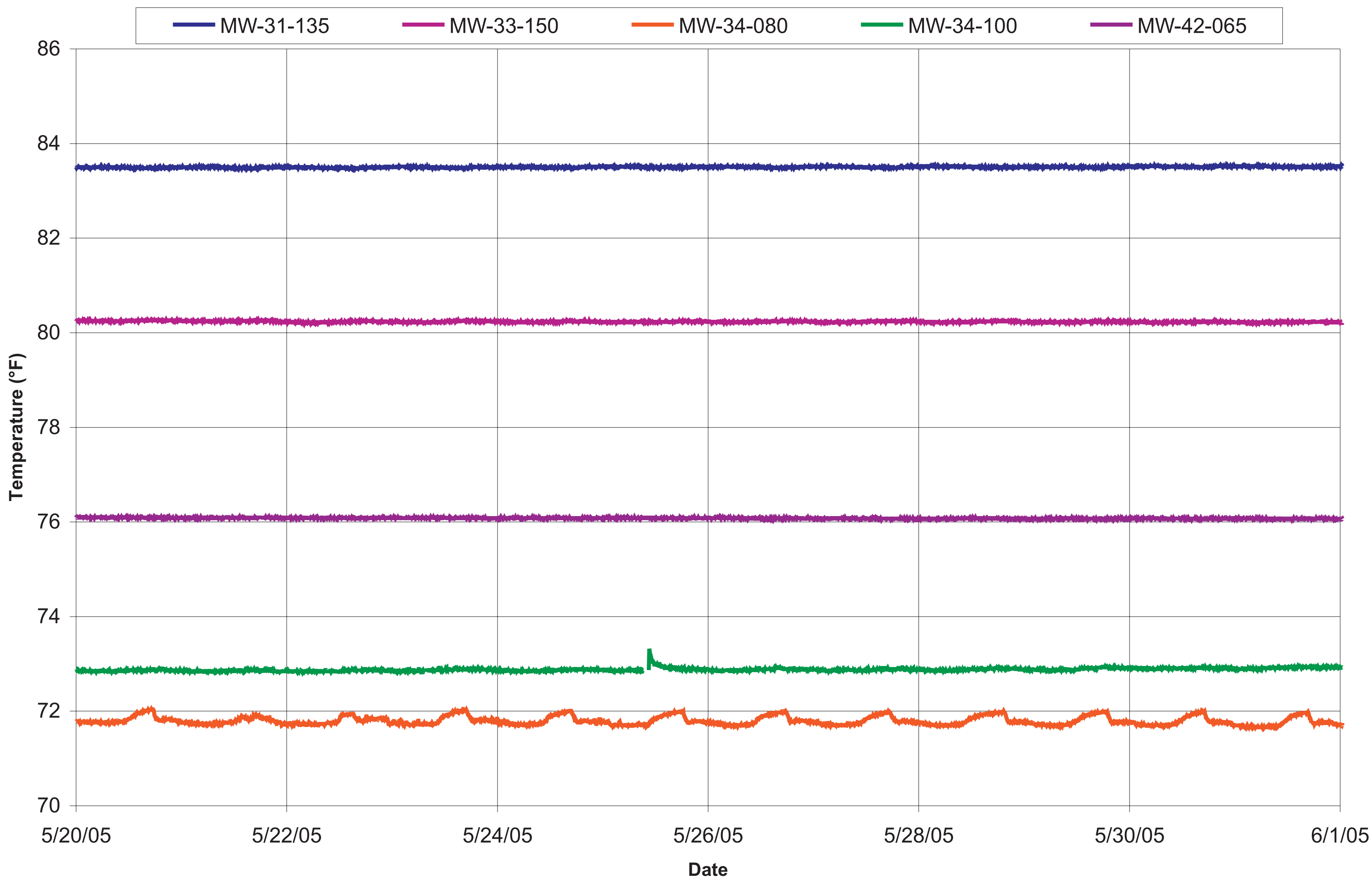

Notes:
MW-34-100 shown on plot though not a key gradient pair well.

FIGURE 7
TEMPERATURE TRENDS AT KEY GRADIENT WELLS

ERROR ANALYSIS REPORT
INTERIM MEASURES NO. 2, PG&E TOPOCK

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