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From:
Patrick Curry - ARCADIS

Date:
January 30, 2015

ARCADIS Project No.:
B0064479,80,81

Subject:
Revised - Passive Flux Meter and Transducer Study Summary
Racer Trust Plants 2, 3, and 6, Lansing, Michigan

Prior to the June 2014 submittal of the updated *Draft Corrective Measures Study* (CMS, ARCADIS 2014a) for the RACER Trust Lansing Site (Site), additional work was completed to further characterize and evaluate the lower 1,4-dioxane plume located beneath Plants 2 and 3. As described in the *Resource Conservation and Recovery Act Facility Investigation (RFI) Phase 2 Supplemental Activities Summary Report* (ARCADIS 2014), the lower 1,4-dioxane plume extends from the Plant 3 “coliseum” area to the south-central portion of Plant 2. The lower 1,4-dioxane plume is present within the saturated deep overburden and weathered bedrock units at depths generally greater than 65 feet below grade. The orientation of the plume as of November 2014 is included on Figure 1.

The additional work consisted of the following:

1. Deployment of Passive Flux Meters (PFMs, <http://enviroflux.com/technology/passive-flux-meter>) to directly measure groundwater flux, or Darcy velocity, within the lower 1,4-dioxane plume and confirm groundwater flow direction. Additionally, an evaluation of mass flux is presented, as is a pore flushing model based on the PFM results.
2. Completion of a groundwater transducer study to evaluate the potential effect of municipal pumping on groundwater elevation observed at the Site within the weathered bedrock / bedrock aquifer.

The deployment of transducers and PFMs and the Site is summarized on Figure 1.

Passive Flux Meter Deployment and Results

As proposed in the work plan dated February 7, 2014, groundwater flux was measured at Plants 2, 3 and 6 by deploying PFMs in six weathered bedrock monitoring wells and two deep overburden monitoring wells. The PFMs consist of a nylon mesh tube filled with a sorbent resin / alcohol tracer mixture. The PFMs are inserted into groundwater monitoring wells where they passively intercept groundwater flow. After a period of time the PFM is removed from the well and the residual tracer mass is evaluated to calculate Darcy velocity. Darcy velocity (q) is defined as the product of hydraulic conductivity (K) and horizontal gradient (i) (i.e. $q = Ki$). Additional information on PFM technology can be found at the Enviroflux website (<http://enviroflux.com/technology/passive-flux-meter>). The locations of the wells included in the study are included on Figure 1.

Based on conditions encountered in the field, there were several changes to the PFM deployment from what was proposed in the February 2014 work plan. These changes included the following:

- MW-13-42 – There was insufficient water for PFM deployment. This PFM was moved to MW-13-29.
- MW-13-34 – A blockage within the screen would not allow placement of PFM. The resulting damage to the PFM did not allow for reuse.
- MW-13-53 – There was only 7 feet of water in the 10 foot well screen at the time of deployment. The 5 foot directional PFM was installed at this location and the remaining 5 foot non-directional PFM was installed at MW-12-21.

The PFMs were constructed in lengths of five feet that included a number of vertical segments that provided measurement of the average groundwater flux through each segment. In all of the monitoring wells except MW-12-21, a middle segment of the PFMs was designed to also measure the direction of the groundwater flow. In this segment, the PFM is divided into three sections; each covering 120 degrees around the circumference of the PFM segment (i.e. three pie pieces). In theory, the section that faces up-gradient will measure the highest groundwater flow of the three sections within the segment. The orientation of the PFM segments was controlled during deployment.

The PFMs were deployed March 4 and 5, 2014, by placing the PFM at the bottom of each monitoring well. The PFMs were deployed for approximately two weeks. On March 20, 2014, each PFM was removed and sampled at designed intervals into glass sample jars provided by Enviroflux. The samples from the PFMs were shipped to Enviroflux for laboratory analysis and interpretation. Survey data was used to estimate the midpoint elevations of the segments in each PFM and evaluate the vertical variability of the measured groundwater flow in each well.

Groundwater Flux Results

Groundwater flux was estimated through the specified intervals within the PFMs. The mean value of groundwater flux along the lower 1,4-dioxane plume is 4.0 centimeters per day (cm/d) or approximately 50 feet per year (ft/yr). The distribution of the groundwater flux measurements around the mean appears to be normal with a slight positive skewness (Figure 2). Overall, the variation in measured groundwater flux was moderate (coefficient of variation of 0.47) as shown in the graphs of groundwater flux variability with depth at each monitoring well (Figures 3, 4, and 5). The measured groundwater flux in the deep overburden wells ranged from 3.1 to 7.9 cm/d (Figure 3). In the weathered bedrock wells the groundwater flux ranged from 0.4 to 8.4 cm/d (Figures 4 and 5). The average groundwater flux at each well is summarized on Table 1.

Table 1. Average groundwater flux through each monitoring well

Well	Hydrostratigraphic Unit	Average Groundwater Flux (cm/d)	Average Groundwater Flux (ft/yr)
MW-12-21	Deep Overburden	3.2	38
MW-13-22	Weathered Bedrock	6.7	80
MW-13-29	Deep Overburden	5.8	69
MW-13-43	Weathered Bedrock	3.5	42
MW-13-45	Weathered Bedrock	5.2	62
MW-13-51	Weathered Bedrock	3.0	36
MW-13-52	Weathered Bedrock	2.1	25
MW-13-53	Weathered Bedrock	4.1	49
Average:		4.0	50

Additional pre-design work, including an aquifer tracer study, is proposed for 2015 to determine the porosity (n) of the weathered bedrock zone and better quantify the groundwater seepage velocity (v). Groundwater seepage velocity is the Darcy velocity divided by the aquifer porosity ($v = Ki/n = q/n$). The groundwater flux within the weathered bedrock generally decreases from north to south consistent with a plume slowing as it moves from the higher conductivity Grand River Formation beneath Plant 3 to the lower conductivity Saginaw Formation beneath Plant 2. If an average porosity of 15% is assumed for the weathered bedrock (similar to porous media) the seepage velocity may range from 160 to 530 ft/yr. Based on groundwater monitoring data, the groundwater velocity at the toe of the plume is at least less than 400 ft/yr as it has not been detected in the sentinel wells installed in November 2013.

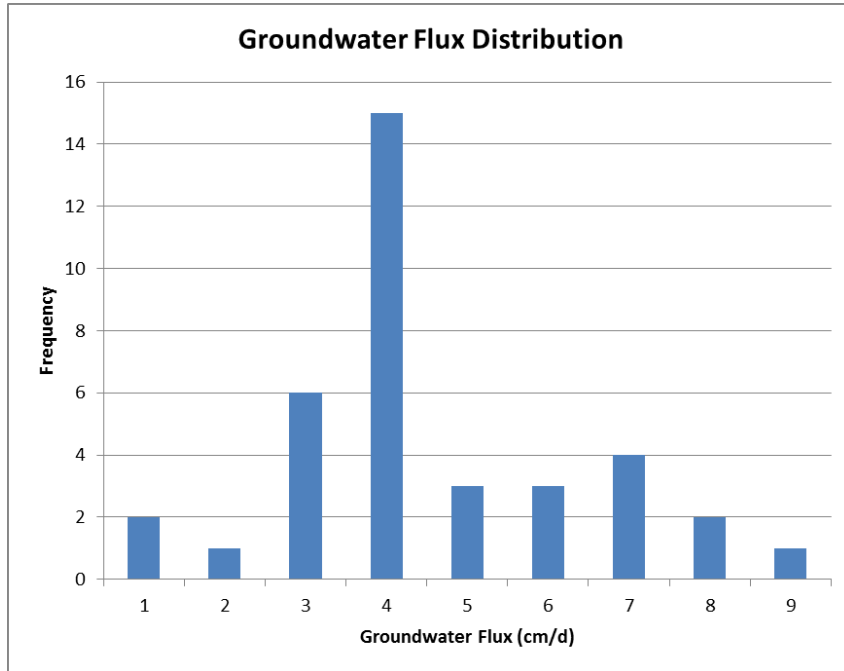


Figure 2. Groundwater flux distribution from PFM results.

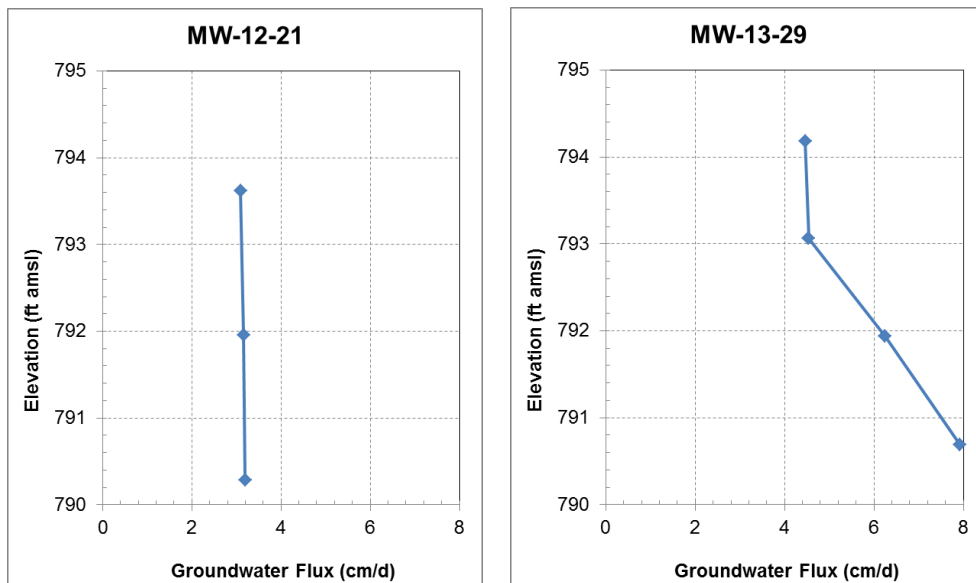


Figure 3. Groundwater flux in deep overburden wells.

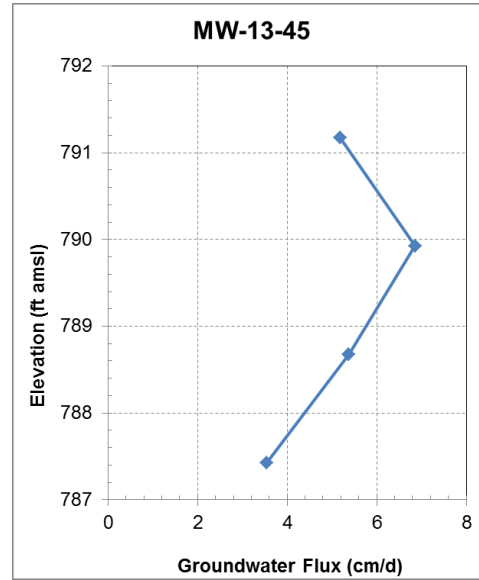
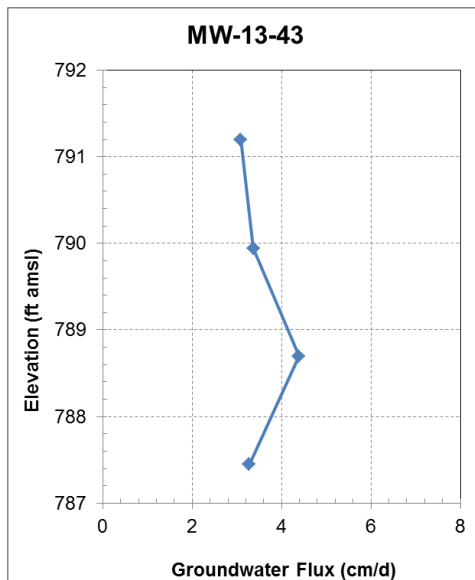
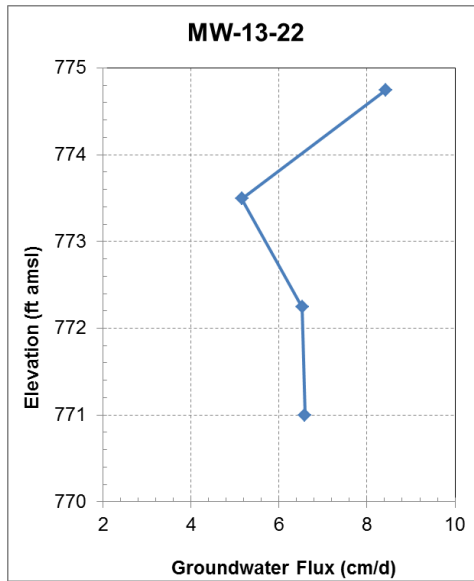


Figure 4. Groundwater flux in weathered bedrock wells located within the 1,4-dioxane plume.

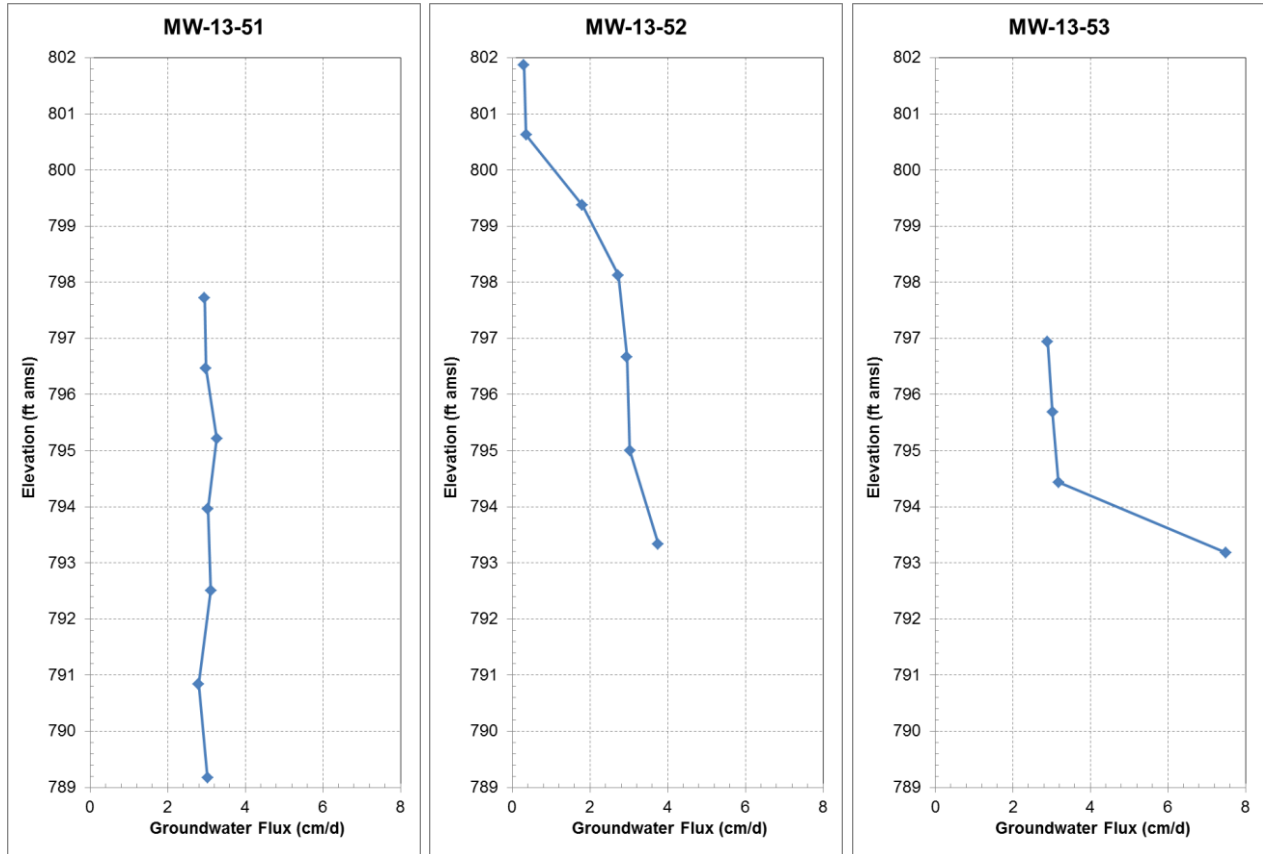


Figure 5. Groundwater flux in weathered bedrock wells located down gradient of the plume’s leading edge.

Groundwater Flow Direction Results

For monitoring wells that contained the PFM segment for estimating the direction of groundwater flow, the direction and magnitude of measured groundwater flow are summarized in a rosette diagram (Figure 6). The direction of groundwater flow varied between well locations and along the plume length, but is generally to the south as expected based on the plume orientation. In the well near the source area (MW-13-22) where groundwater recharge occurs, the direction of measured groundwater flow was to the northwest. Down gradient of the source, the estimated direction of groundwater flow ranged from east-southeast in MW-13-43 to west in MW-13-45. Down gradient of the plume, the direction of measured groundwater flow ranged from southwest at MW-13-53 to southeast at MW-13-52. The variability of measured groundwater flow can be attributed, in part, to the variability of groundwater flow at any given point in an aquifer (i.e. not a straight line), as well as the limited size of the data set. The results are consistent with recharge at the coliseum source area and then southerly flow from the coliseum to Plant 2.

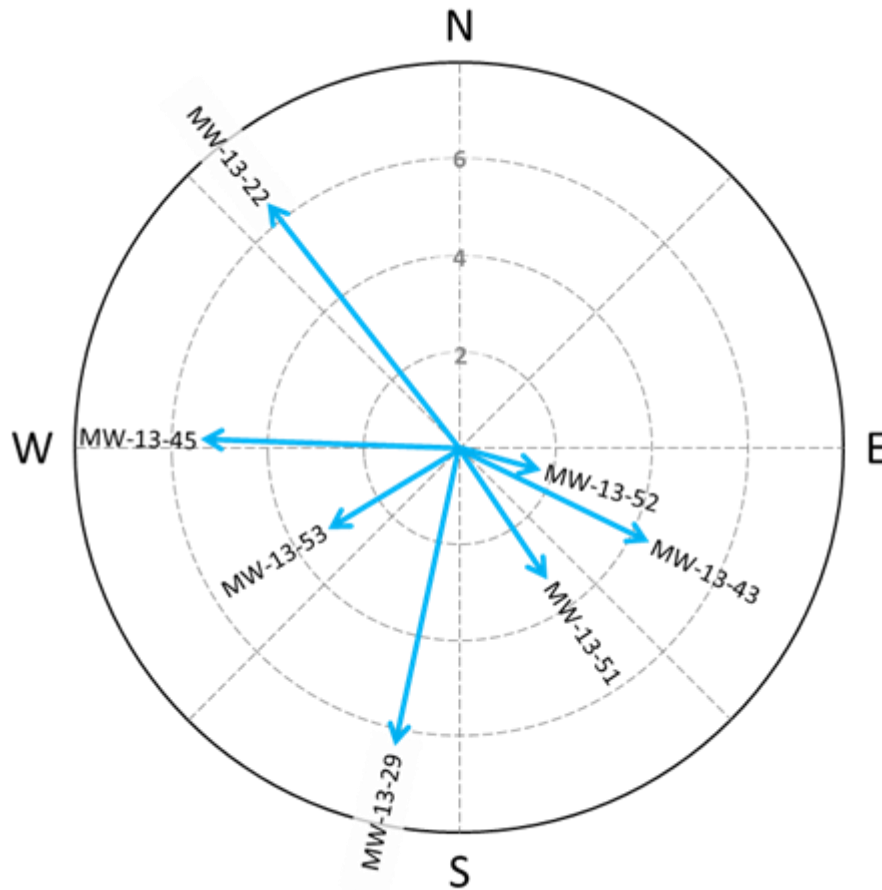


Figure 6. Estimated groundwater flow direction at each well.

Mass Flux Calculations

Based on the average concentration of 1,4-dioxane detected at monitoring wells during the groundwater sampling events, the 1,4-dioxane mass flux was calculated as follows:

$$J = q \times C$$

Where:

J	=	advective contaminant mass flux, M/L ² /t
q	=	groundwater flux, L/t
C	=	concentration of 1,4-dioxane in groundwater M/L ³

The average 1,4-dioxane mass flux ranged from 0-13 mg/m²/day in the eight wells tested. In general, the mass flux was higher at the source area and decreased downgradient. This is due to the higher gradient and average concentrations observed near the coliseum source area. The results are presented in Table 2 and summarized on Figure 7.

Table 2. Average 1,4-dioxane mass flux at each monitoring well

Well	Hydrostratigraphic Unit	Average Groundwater Concentration* (µg/L)	Average Mass Flux (mg/m ² /day)
MW-12-21	Deep Overburden	410	13
MW-13-22	Weathered Bedrock	164	11
MW-13-29	Deep Overburden	29	1.7
MW-13-43	Weathered Bedrock	245	8.6
MW-13-45	Weathered Bedrock	27	1.4
MW-13-51	Weathered Bedrock	<5	0
MW-13-52	Weathered Bedrock	<5	0
MW-13-53	Weathered Bedrock	<5	0

* - as of March 2014

Groundwater Elevation Transducer Study

Absolute pressure transducers were deployed in twelve Site wells from March 21 through April 8, 2014. Pressure measurements were collected on a one-minute frequency, and atmospheric pressures were recorded by an on-site logger during this period. Initial processing of water levels included compensation of absolute pressures, and subsequent conversion of gage pressures to groundwater elevations through comparison to manual water-level data collected periodically during the period of transducer deployment. Attachment 1 presents plots of groundwater elevations (hydrographs) for each monitoring well.

Water levels measured in wells often exhibit significant fluctuations due to variations in atmospheric pressure. Water-level data for each well were examined to identify the effects of barometric influence on water levels, and water-level corrections (barometric efficiency) were mathematically applied to remove noise resulting from variations in atmospheric pressure. Barometric efficiencies ranging from 0.90 to 1.0 were applied to well water levels; these relatively high barometric efficiencies (approaching 1.0) are typical for confined, fractured-bedrock aquifers. Plots of corrected water levels are presented in Attachment 1.

Evaluation of Water Levels and Municipal Pumping

Barometrically-corrected water levels for each monitored well were plotted with municipal well pump on/off times to facilitate identification of hydraulic influence of pumping on well water levels (Attachment 1). The Lansing Township wells TWP #2, #3, #4, #5, and the Lansing Board of Water and Light (BWL) well BWL-15-08, are typically run continually; during the monitoring period, wells were pumped continuously, except for staggered individual shut-down periods of approximately 24 to 38 hours, as shown in the table below. Pumping well on/off times were recorded by data loggers attached to the municipal pump control switches.

Table 4. Municipal well shutdown summary

TWP WELL	PUMP OFF	PUMP ON
TWP #2	3/26/2014 7:54	3/27/2014 8:26
TWP #4	3/28/2014 6:03	3/31/2014 8:01
BWL-15-08	4/1/2014 6:33	4/2/2014 8:07
TWP #3	4/3/2014 8:10	4/4/2014 8:46
TWP #5	4/5/2014 18:23	4/7/2014 8:04

Water-level plots were visually examined to identify water-level drawdown and recovery responses to changes in system pumping. Observed responses were qualified as “response”, “potential” response or no response (“NR”) depending on the magnitude, shape, and timing of the responses, as well as uncertainty related to background trends. As shown in the table below and the water-level plots presented in Attachment 1, none of the monitored wells showed an apparent response to changes in pumping at well TWP #2 or TWP #3. Several of the monitoring wells exhibited water-level responses to changes in the pumping of well TWP #4, and several wells exhibited responses to pumping changes at well TWP #5. Municipal well BWL 10-10 showed a moderate recovery and drawdown related to changes in pumping at BWL 15-08.

Table 5. Summary of monitored well response to municipal pumping

Well ID	Hydrostratigraphic Unit	Barometric Efficiency (BE)	Response to TWP #4	Response to BWL-15-08	Response to TWP #5
BWL 10-10	Bedrock	0.90	response	response	response
MW 04-04R	Bedrock	1.0	NR	NR	NR
MW 12-04	Bedrock	1.0	response	NR	response
MW 13-22	Weathered Bedrock	1.0	potential	NR	NR
MW-13-28	Bedrock	1.0	potential	NR	NR
MW-13-34	Weathered Bedrock	1.0	potential	NR	NR
MW-13-39B	Bedrock	1.0	NR	NR	NR
MW-13-44	Bedrock	1.0	potential	NR	NR
MW-13-47	Bedrock	1.0	response	NR	response
MW-13-50	Bedrock	1.0	NR	NR	NR
MW-13-52	Weathered Bedrock	0.97	NR	NR	NR
MW-91-5	Bedrock	1.0	response	NR	response

Based on the sharp changes in slope corresponding directly to the timing of the shut-down and restart of TWP #4, the changes in groundwater elevation observed at wells MW-91-5, MW-13-47, MW-12-04, and BWL-10-10 are attributed to changes in pumping. The “potential” responses noted at several wells are associated with a confounding factor that occurred during the TWP #4 shut down. The weekend that TWP #4 shut down (beginning March 27, 2014) corresponded to a rise in temperatures and significant snow melt. It is possible that the rise in water levels observed at wells MW-13-44, MW-13-34, MW-13-28, and MW-13-22 at this time are due to infiltration of snowmelt (primarily through the floor of the coliseum).

When assessing water-level records with respect to nearby pumping, it is important to note that an observed response to pumping does not necessarily indicate hydraulic capture. Although the bedrock wells beneath the lower 1,4-dioxane plume indicate a hydraulic response to municipal pumping, they are not impacted. In addition, the distribution of the overlying 1,4-dioxane plume within the deep overburden and weathered bedrock does not appear to be affected by pumping wells. Based on lack of influence on pumping on the lower 1,4-dioxane plume, municipal wells are unlikely to be impacted by the lower 1,4-dioxane plume in the future.

Conclusions

Additional work was completed to further characterize and evaluate the lower 1,4-dioxane plume, prior to the submittal of the updated Corrective Measures Study. The additional work consisted of 1) deployment of PFMs to directly measure groundwater flux and confirm groundwater flow direction; and 2) a groundwater transducer study to evaluate the potential effect of municipal pumping on groundwater. The primary conclusions are as follows:

- Groundwater Flux – The measured groundwater flux along the plume ranges from 25 to 80 ft/yr with an average flux of approximately 50 ft/yr.
- Groundwater Flux Direction – The direction of groundwater flow varies at each point measurement, but is generally consistent with recharge at the coliseum source area and then flow to the south to Plant 2.
- 1,4-Dioxane Mass Flux – Based on measured concentrations of 1,4-dioxane at each well, the average 1,4-dioxane mass flux ranged from 0-13 mg/m²/day.
- Municipal Pumping Wells – Several bedrock wells near the lower 1,4-dioxane plume indicate a hydraulic response to municipal pumping. Based on the lack of influence of pumping on the lower 1,4-dioxane plume, municipal wells are unlikely to be impacted by the lower 1,4-dioxane plume in the future.

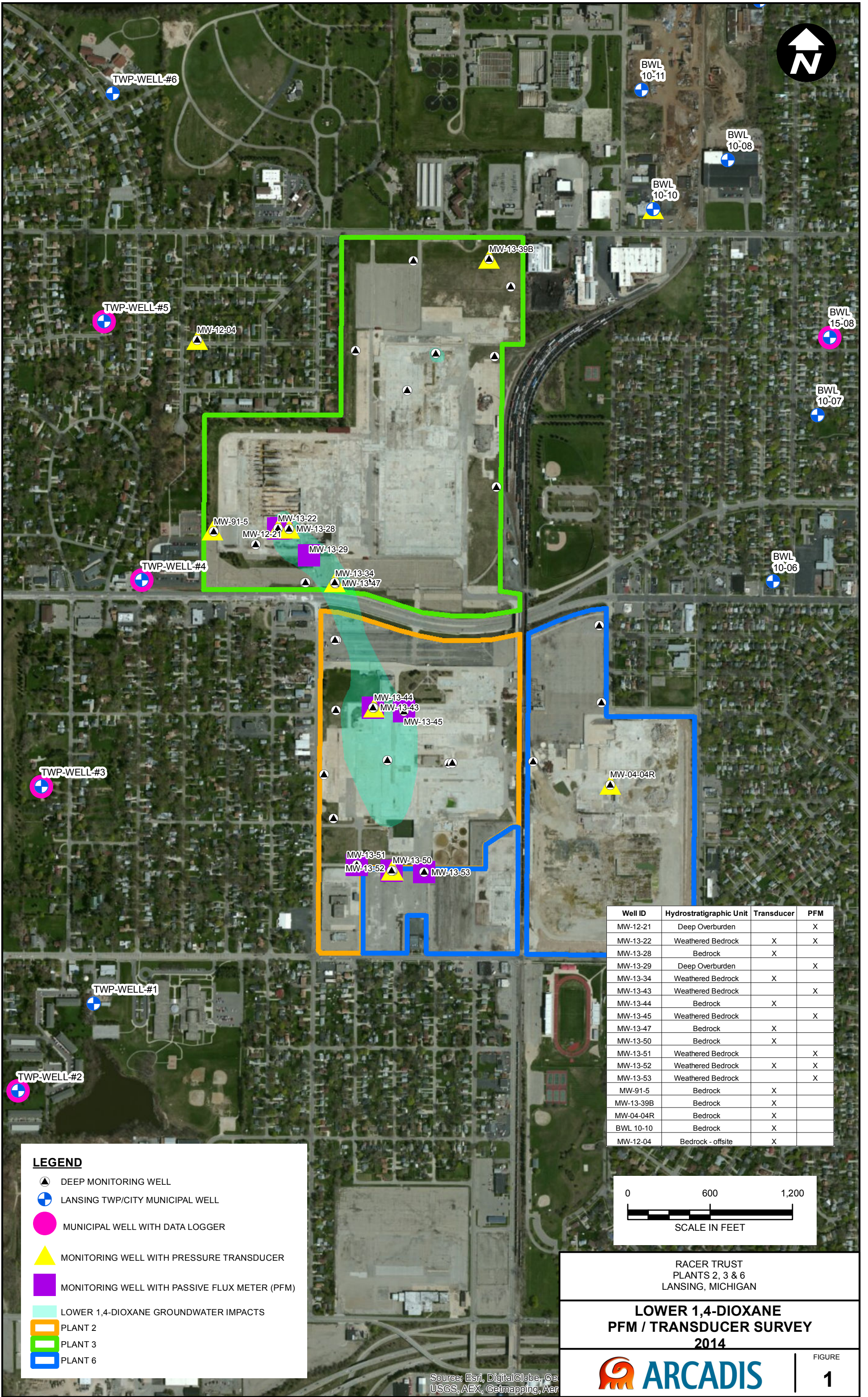
Additional pre-design work, including an aquifer tracer study, is proposed for 2015 to better quantify the porosity and seepage velocity of the weathered bedrock zone. Data from the tracer study, along with continued monitoring, will be used to refine the conceptual site model and design an appropriate remedy for the lower 1,4-dioxane plume.

References

- ARCADIS. 2014a. RCRA Corrective Action, Corrective Measures Study. Plants 2, 3 and 6 Industrial Land. June.
- ARCADIS. 2014b. RFI Supplemental Phase 2 Activities Summary Report. RACER Trust, Lansing, Michigan Plants 2, 3 & 6 Industrial Land. February 26.
- Zheng, C., and G. D. Bennett, 1995, Applied Contaminant Transport Modeling: Theory and Practice. Van Nostrand Reinhold (now Wiley), New York, 440 pp.

Figures

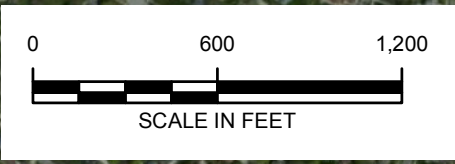
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LEGEND

- DEEP MONITORING WELL
- LANSING TWP/CITY MUNICIPAL WELL
- MUNICIPAL WELL WITH DATA LOGGER
- MONITORING WELL WITH PRESSURE TRANSDUCER
- MONITORING WELL WITH PASSIVE FLUX METER (PFM)
- LOWER 1,4-DIOXANE GROUNDWATER IMPACTS
- PLANT 2
- PLANT 3
- PLANT 6

Well ID	Hydrostratigraphic Unit	Transducer	PFM
MW-12-21	Deep Overburden		X
MW-13-22	Weathered Bedrock	X	X
MW-13-28	Bedrock	X	
MW-13-29	Deep Overburden		X
MW-13-34	Weathered Bedrock	X	
MW-13-43	Weathered Bedrock		X
MW-13-44	Bedrock	X	
MW-13-45	Weathered Bedrock		X
MW-13-47	Bedrock	X	
MW-13-50	Bedrock	X	
MW-13-51	Weathered Bedrock		X
MW-13-52	Weathered Bedrock	X	X
MW-13-53	Weathered Bedrock		X
MW-91-5	Bedrock	X	
MW-13-39B	Bedrock	X	
MW-04-04R	Bedrock	X	
BWL 10-10	Bedrock	X	
MW-12-04	Bedrock - offsite	X	



RACER TRUST
 PLANTS 2, 3 & 6
 LANSING, MICHIGAN

**LOWER 1,4-DIOXANE
 PFM / TRANSDUCER SURVEY
 2014**


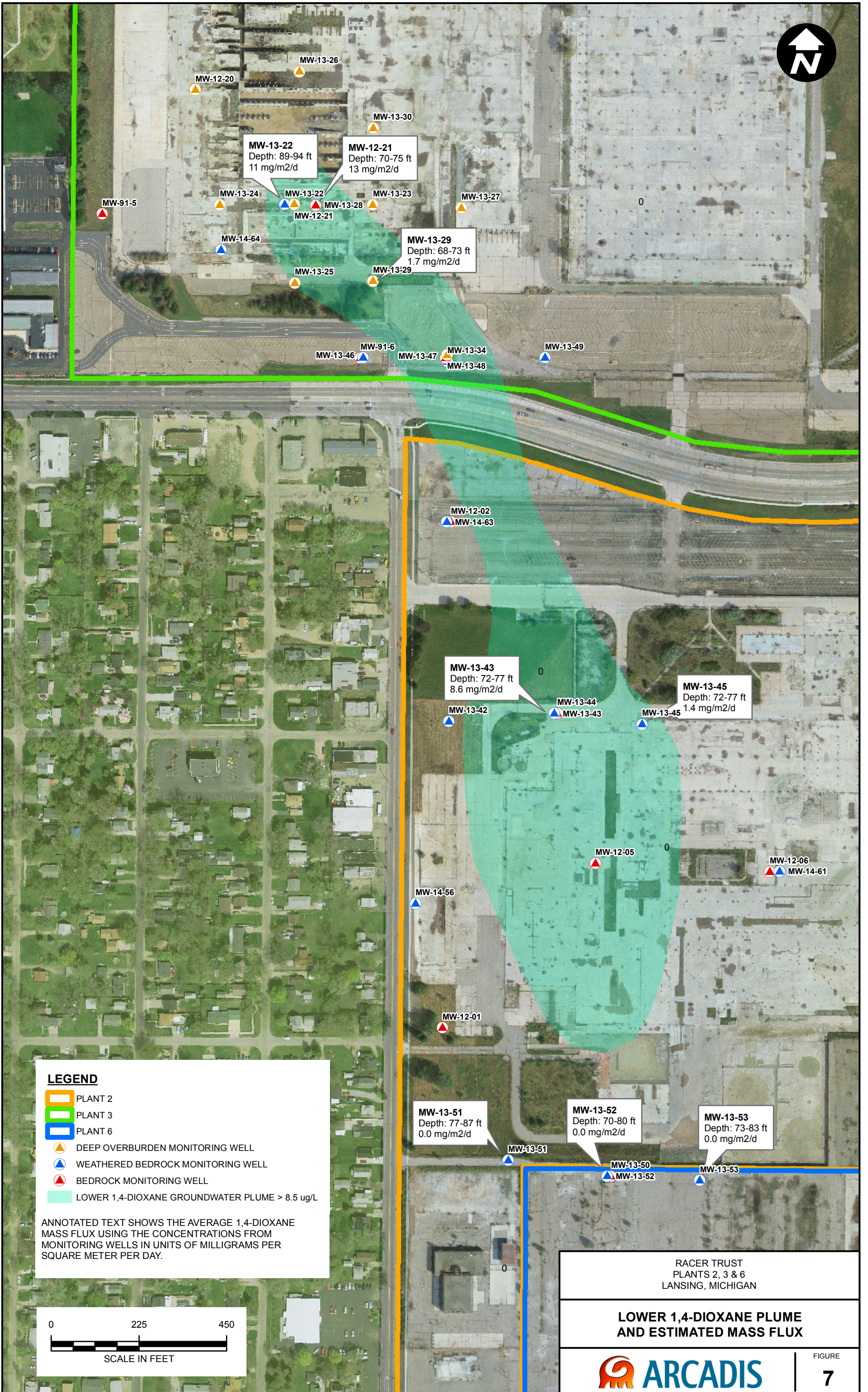


FIGURE
1

Source: Esri, DigitalGlobe, Geo
 USGS, AEX, Getmapping, Aer



MW-13-22
Depth: 89-94 ft
11 mg/m²/d

MW-12-21
Depth: 70-75 ft
13 mg/m²/d

MW-13-29
Depth: 68-73 ft
1.7 mg/m²/d

MW-13-43
Depth: 72-77 ft
8.6 mg/m²/d

MW-13-45
Depth: 72-77 ft
1.4 mg/m²/d

MW-13-51
Depth: 77-87 ft
0.0 mg/m²/d

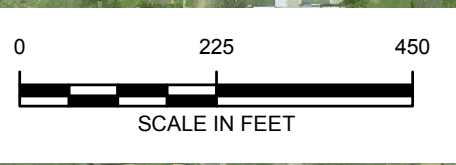
MW-13-52
Depth: 70-80 ft
0.0 mg/m²/d

MW-13-53
Depth: 73-83 ft
0.0 mg/m²/d

LEGEND

- PLANT 2
- PLANT 3
- PLANT 6
- DEEP OVERBURDEN MONITORING WELL
- WEATHERED BEDROCK MONITORING WELL
- BEDROCK MONITORING WELL
- LOWER 1,4-DIOXANE GROUNDWATER PLUME > 8.5 ug/L

ANNOTATED TEXT SHOWS THE AVERAGE 1,4-DIOXANE MASS FLUX USING THE CONCENTRATIONS FROM MONITORING WELLS IN UNITS OF MILLIGRAMS PER SQUARE METER PER DAY.



RACER TRUST
PLANTS 2, 3 & 6
LANSING, MICHIGAN

**LOWER 1,4-DIOXANE PLUME
AND ESTIMATED MASS FLUX**



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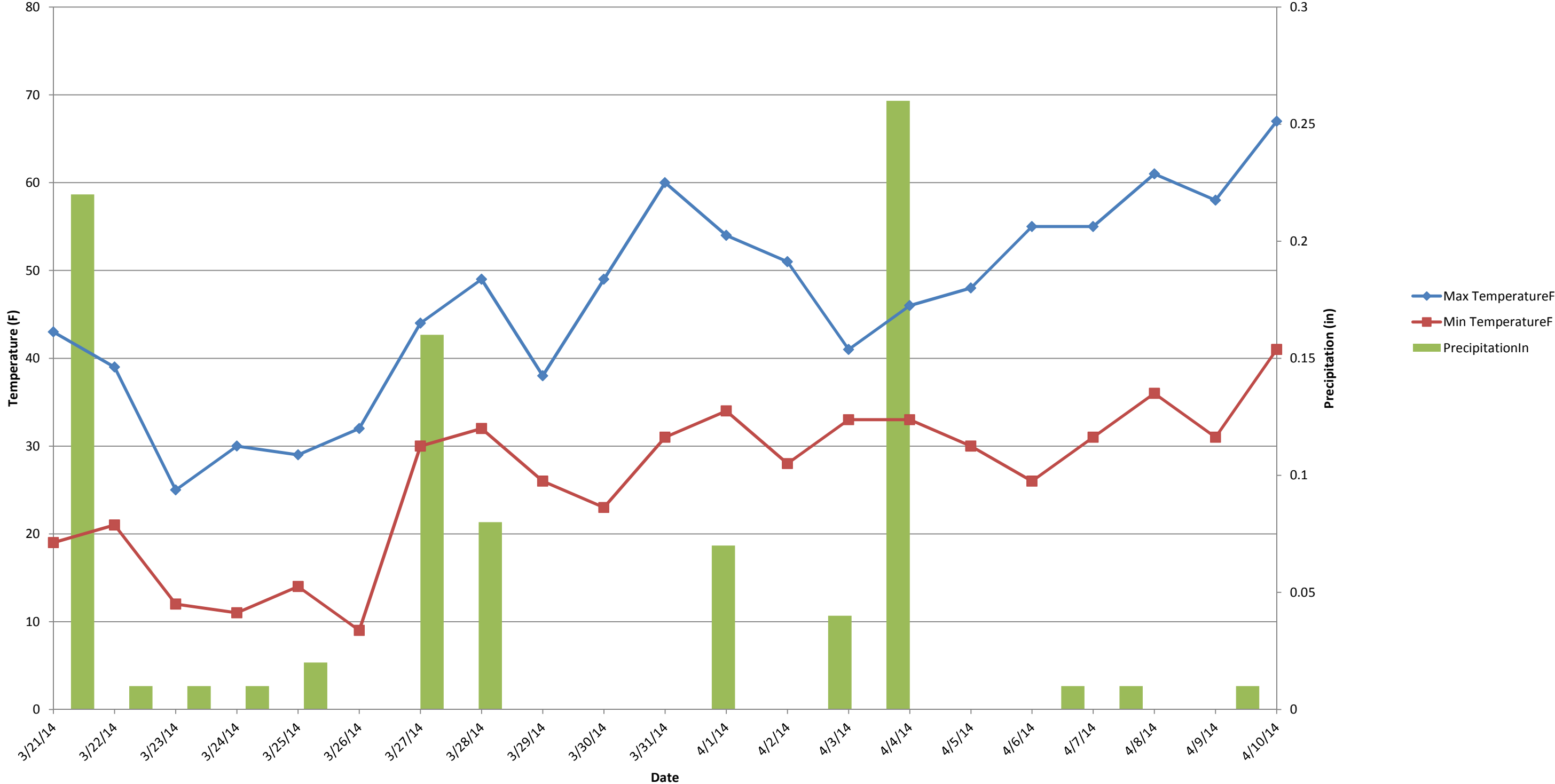


Attachment 1

Racer Lansing Transducer Plots

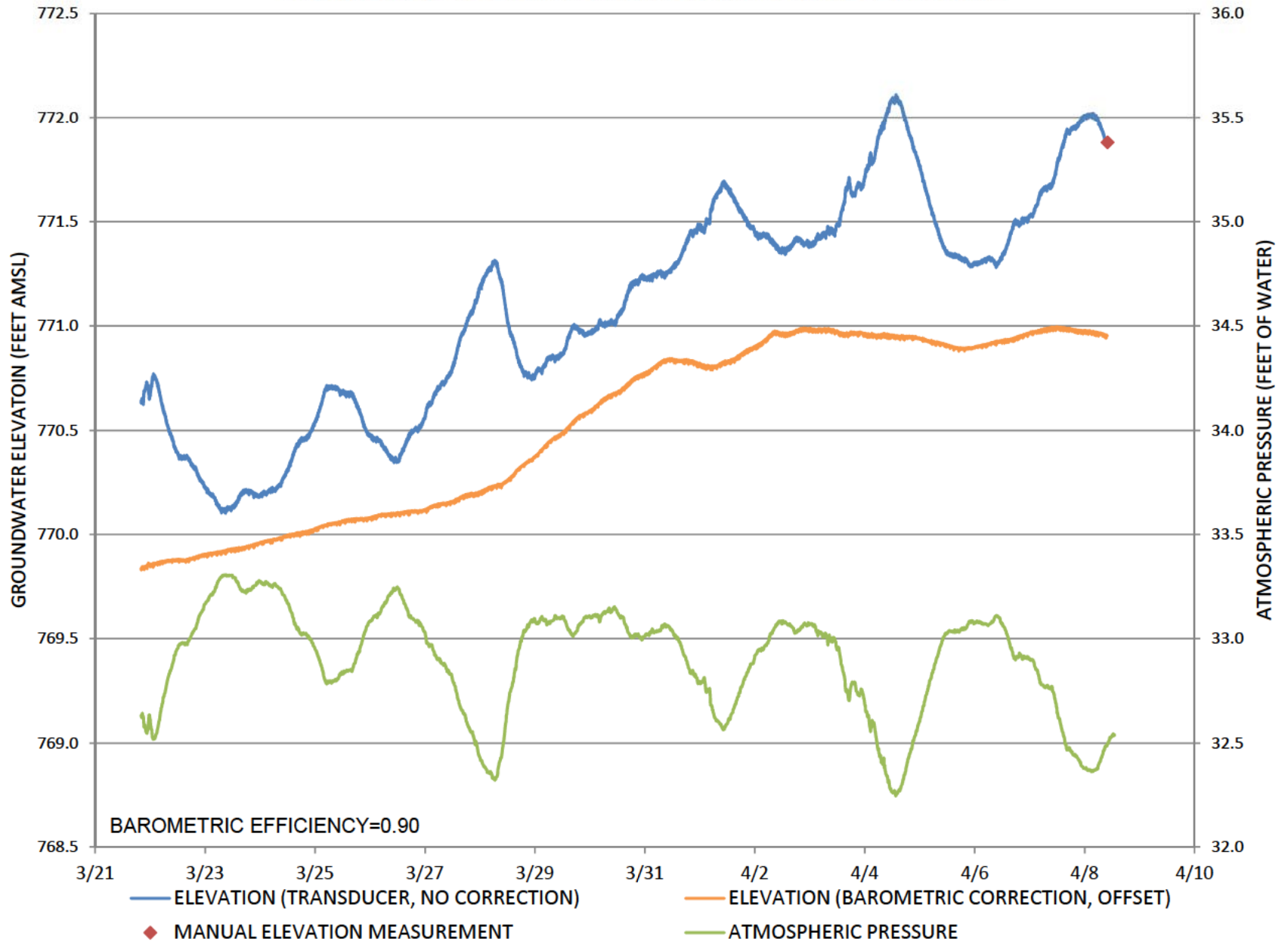
Weather- Lansing, Michigan

March 21 - April 10, 2014

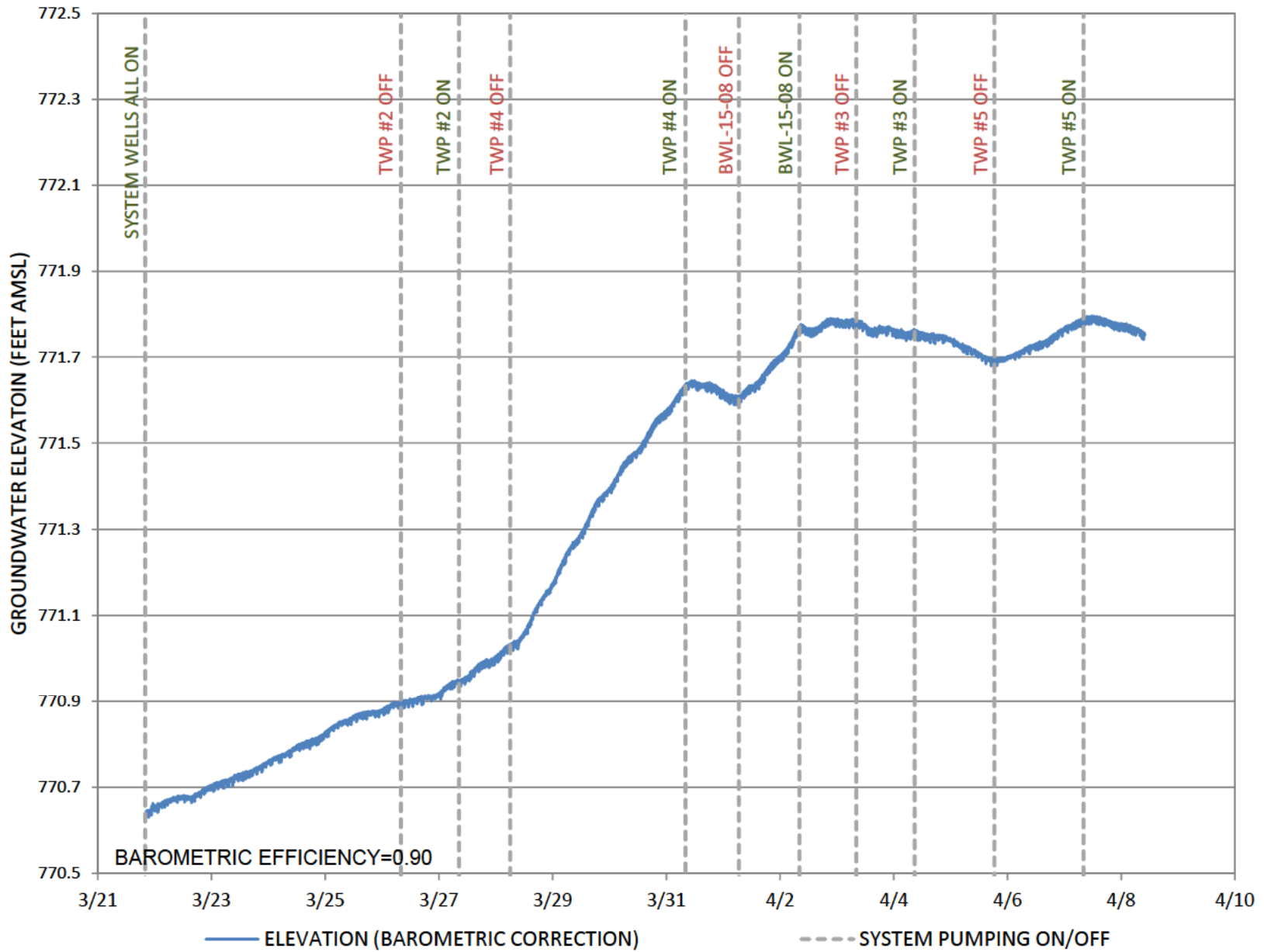


BWL 10-10

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

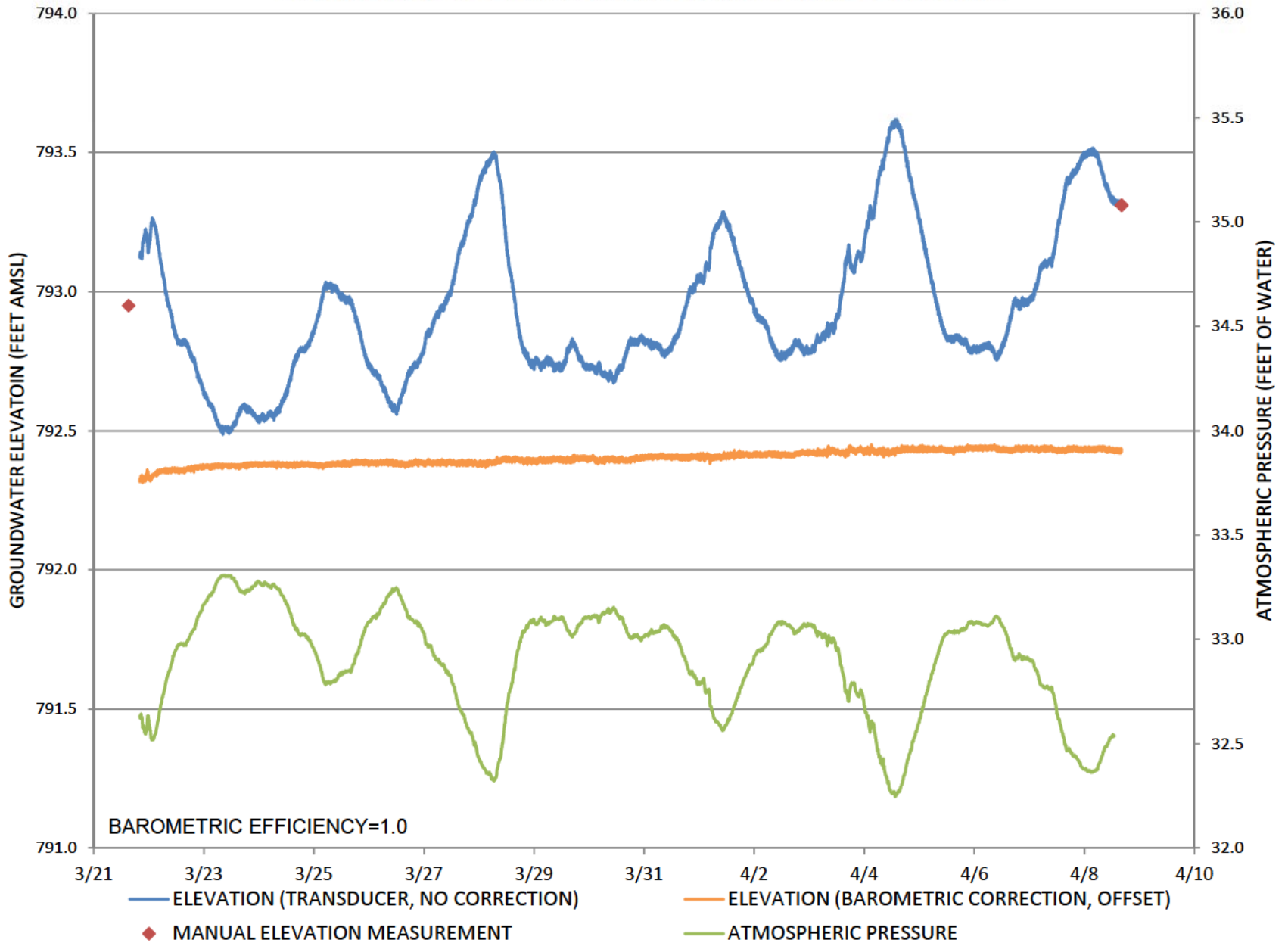


GROUNDWATER ELEVATION AND PUMPING

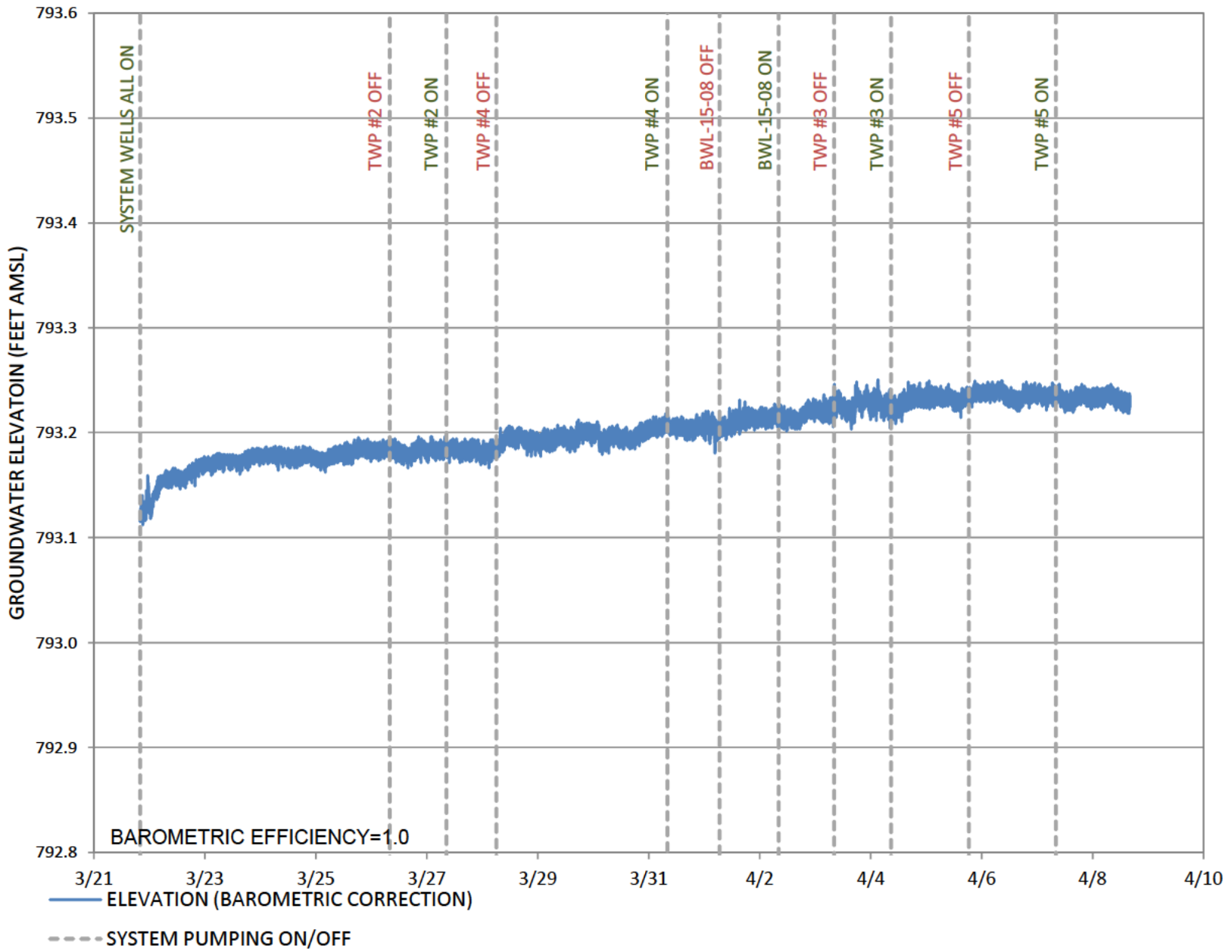


MW 04-04R

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

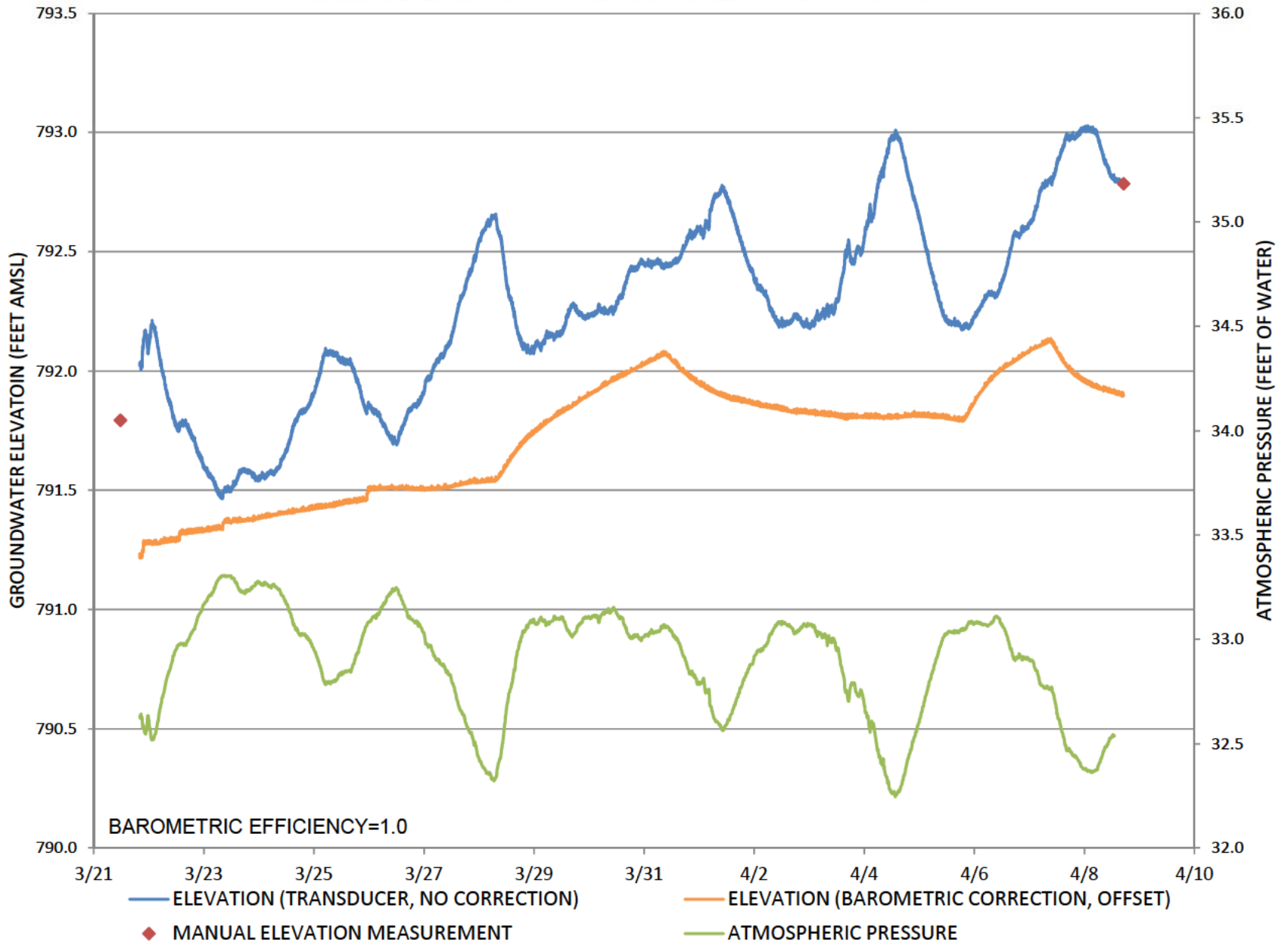


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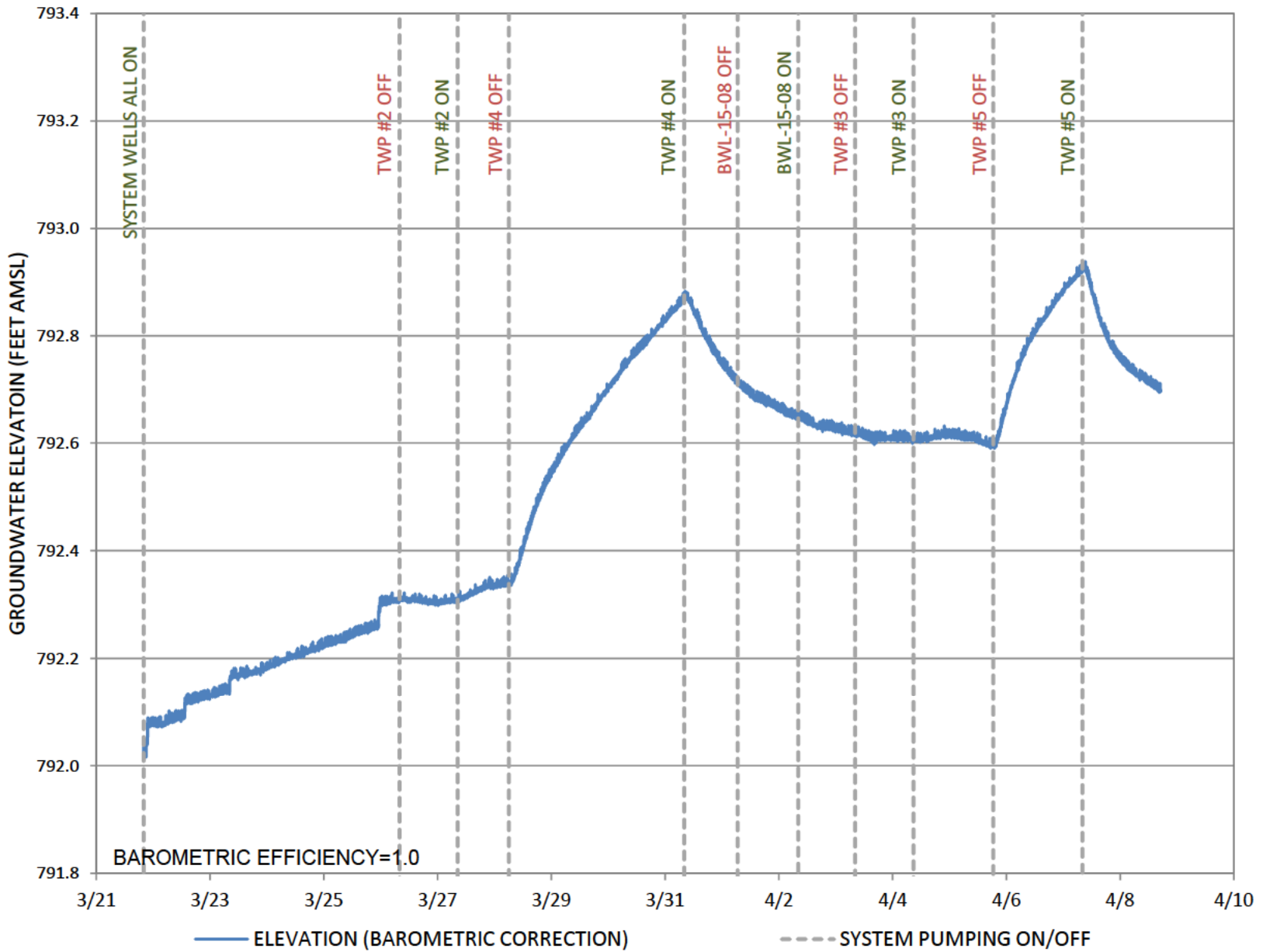


MW 12-04

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

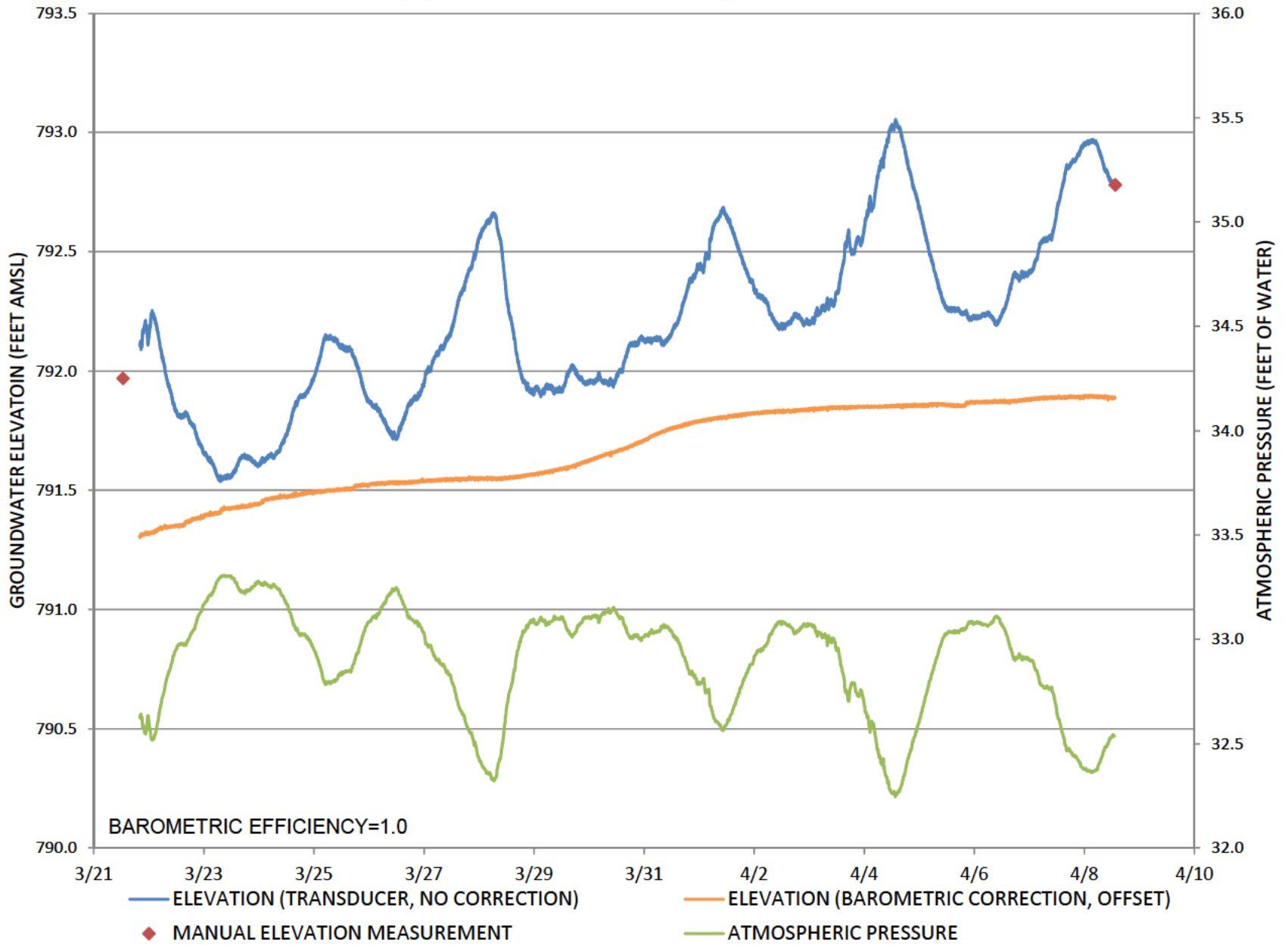


GROUNDWATER ELEVATION AND PUMPING

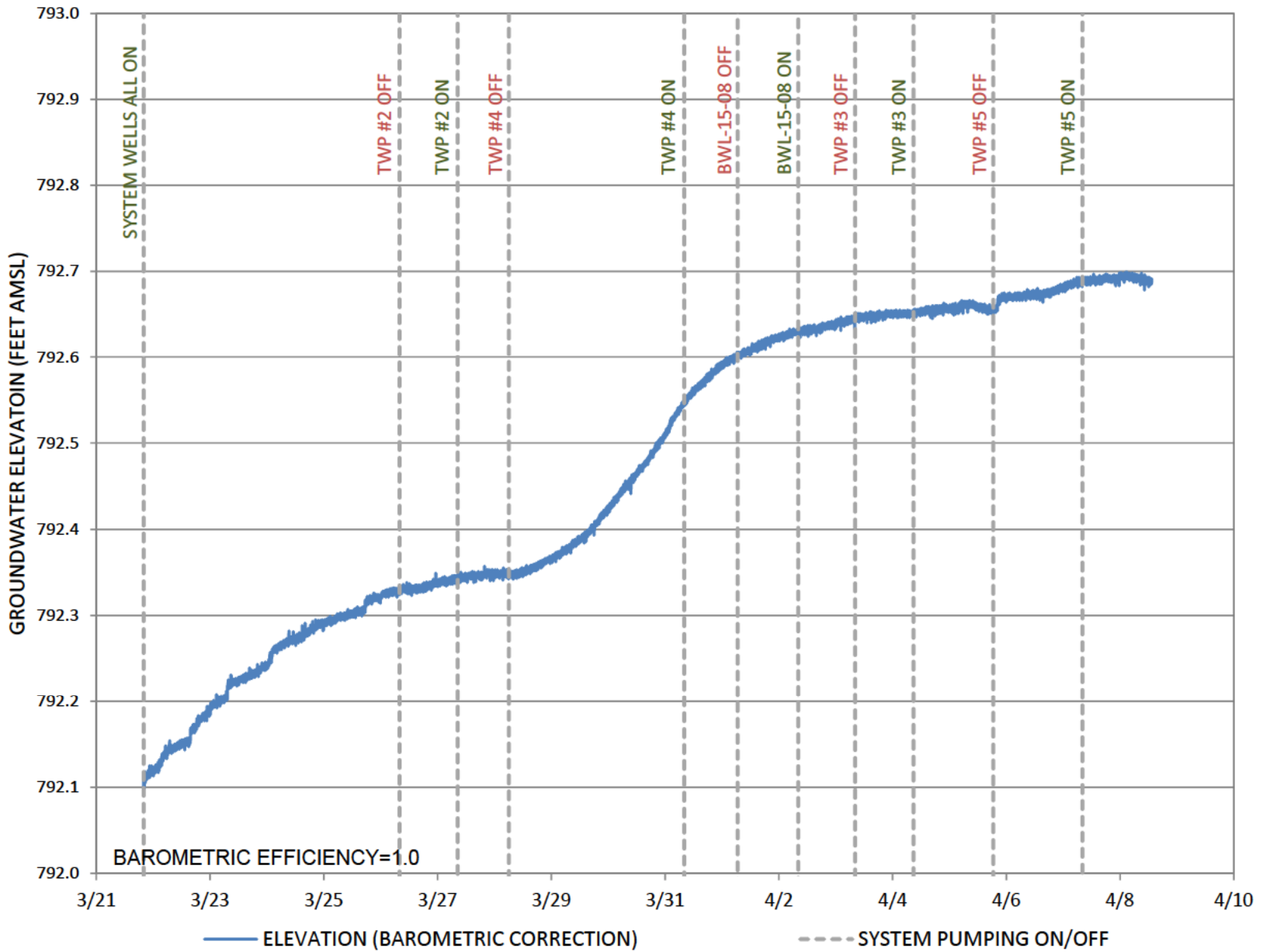


MW 13-22

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

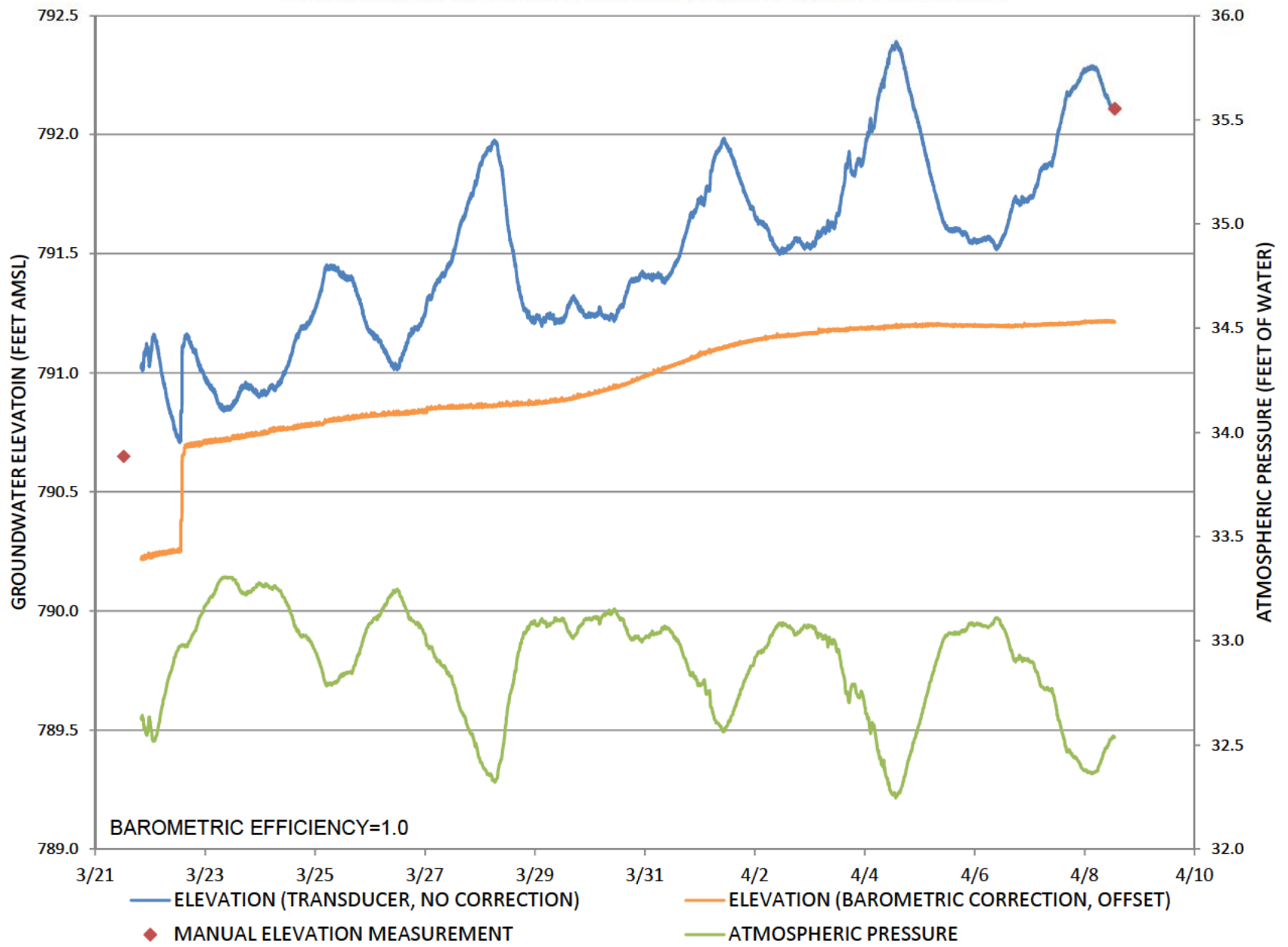


GROUNDWATER ELEVATION AND PUMPING

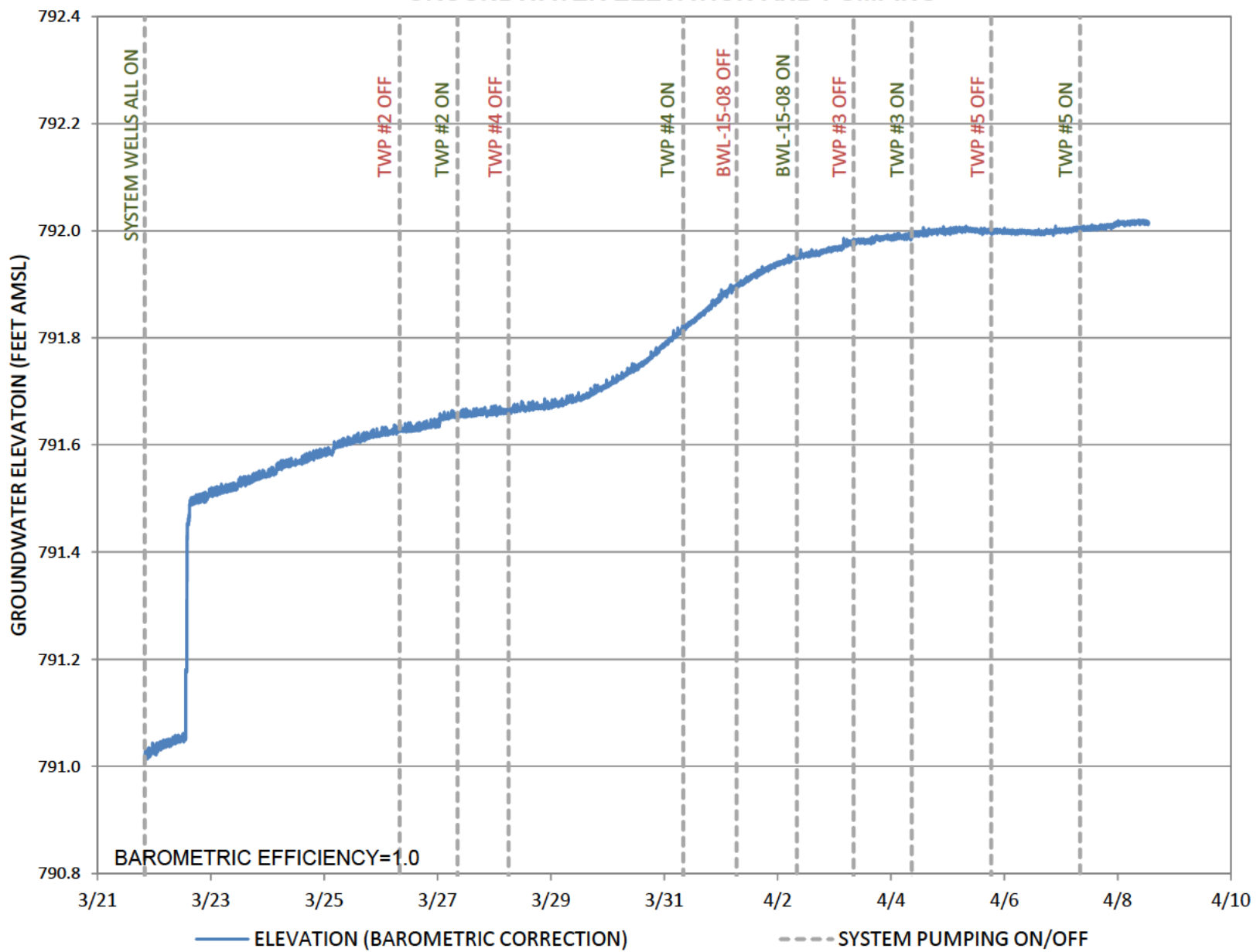


MW 13-28

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE



GROUNDWATER ELEVATION AND PUMPING

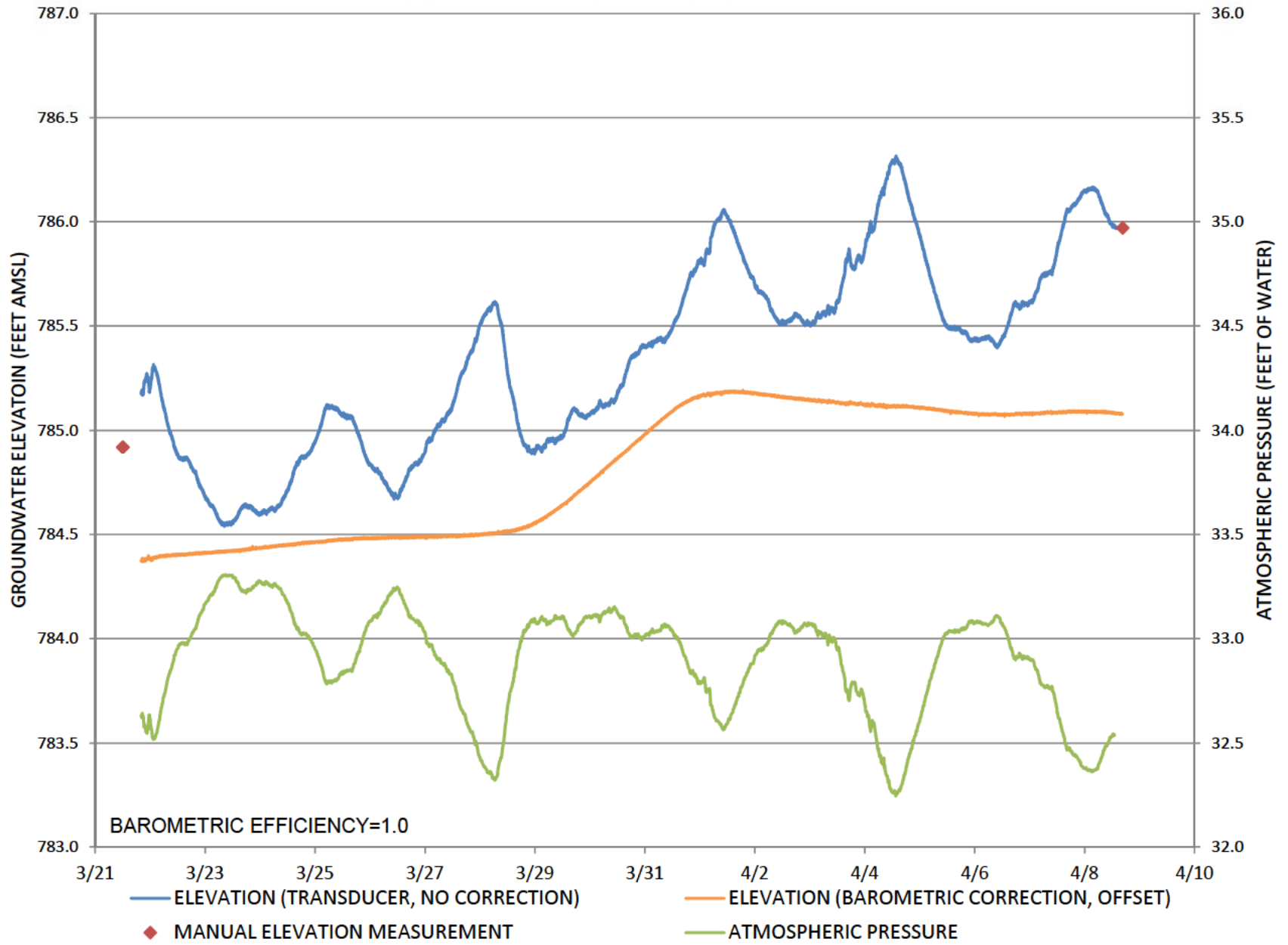


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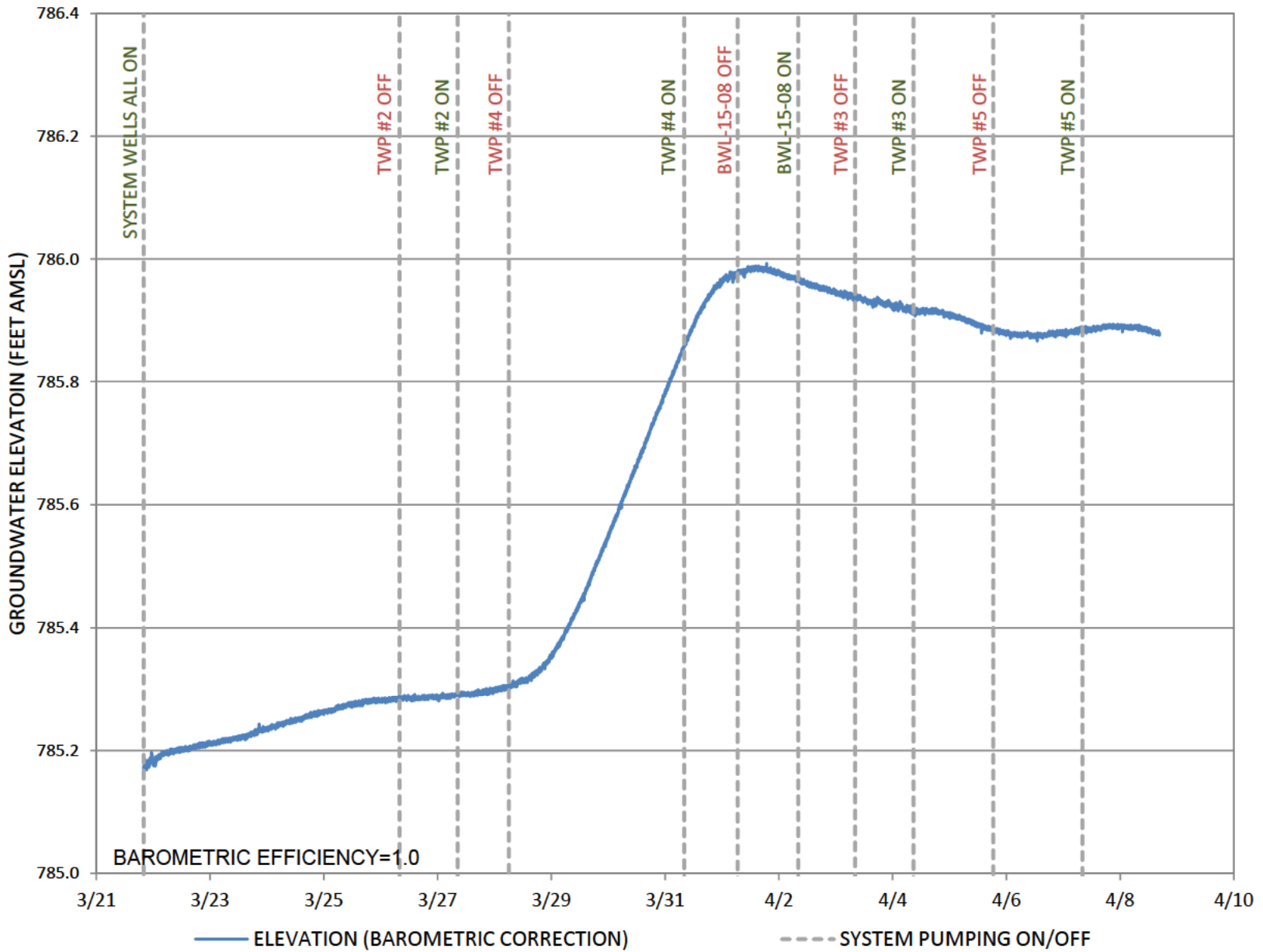
Suspected transducer shift of 0.44 feet at approximately 13:00 on 3/21/14.

MW 13-34

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

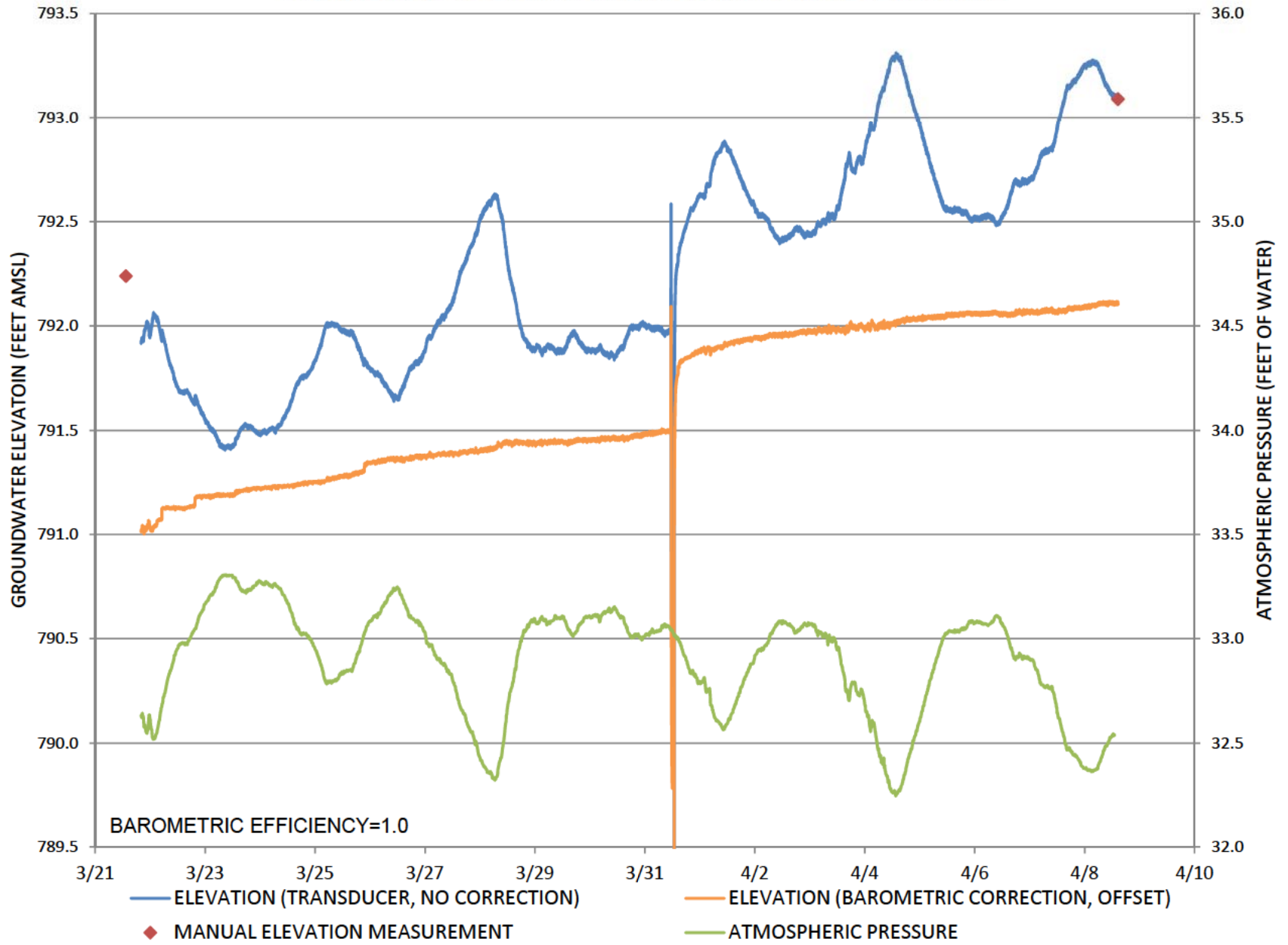


GROUNDWATER ELEVATION AND PUMPING

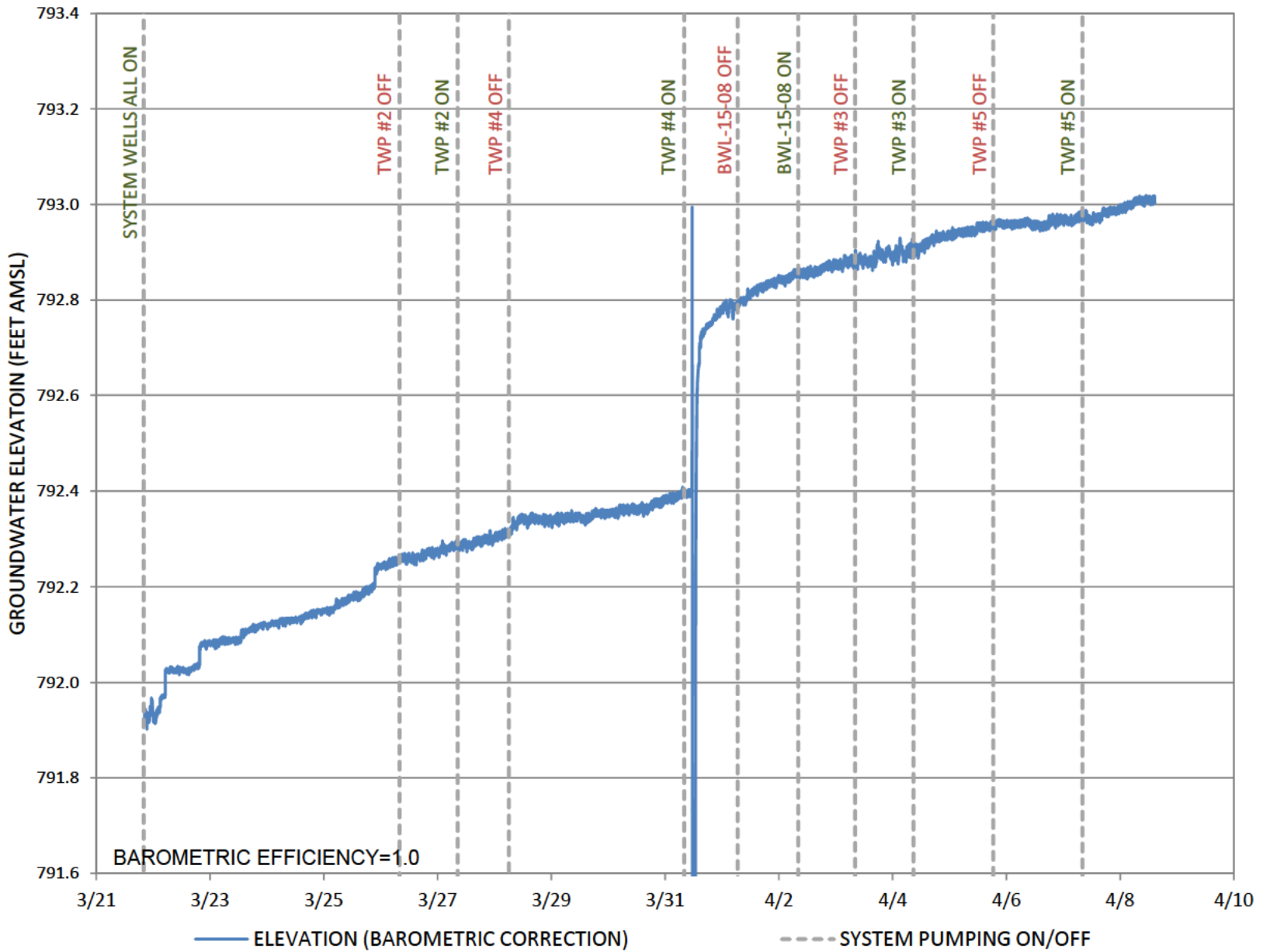


MW 13-39B

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE



GROUNDWATER ELEVATION AND PUMPING

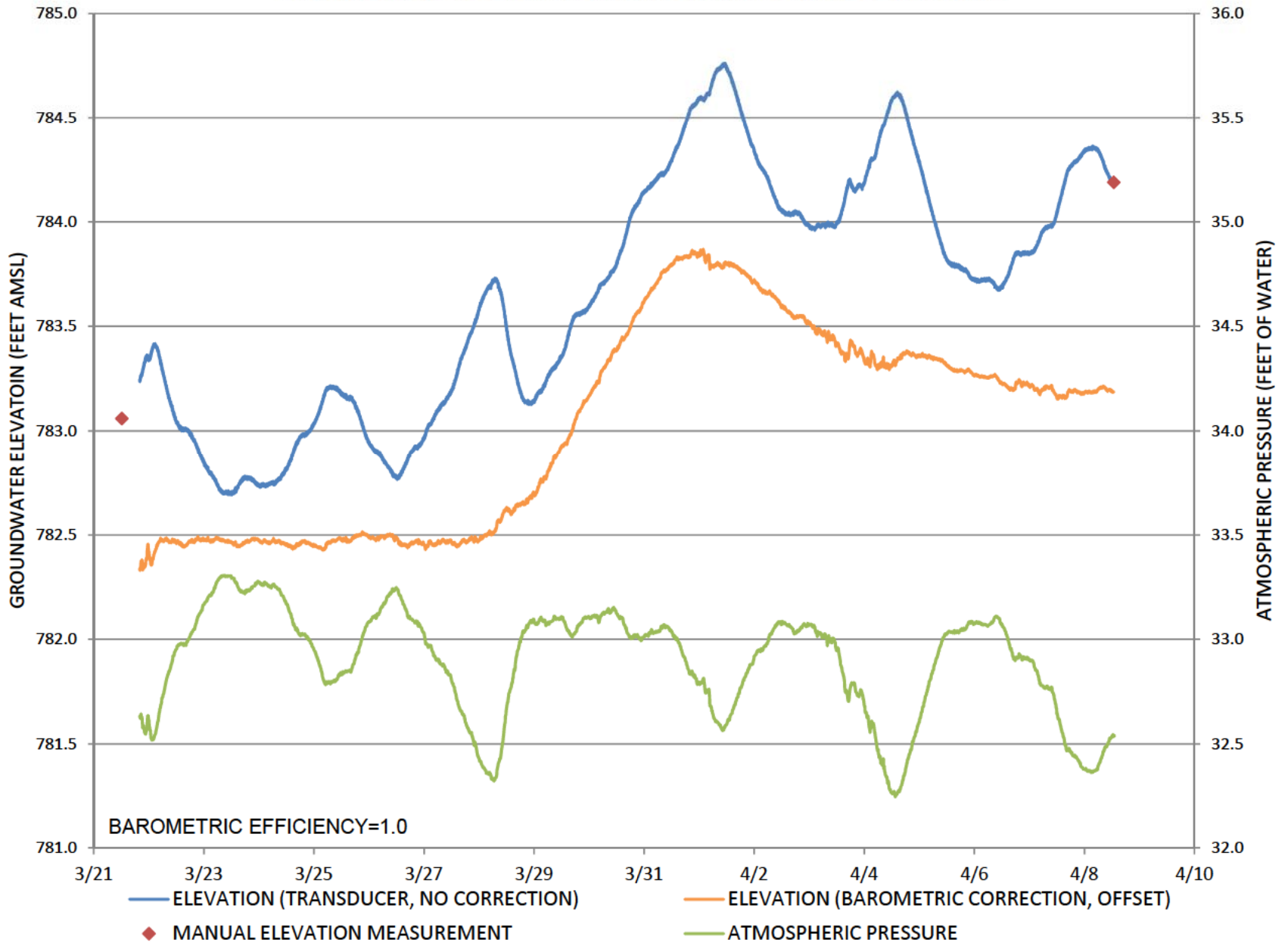


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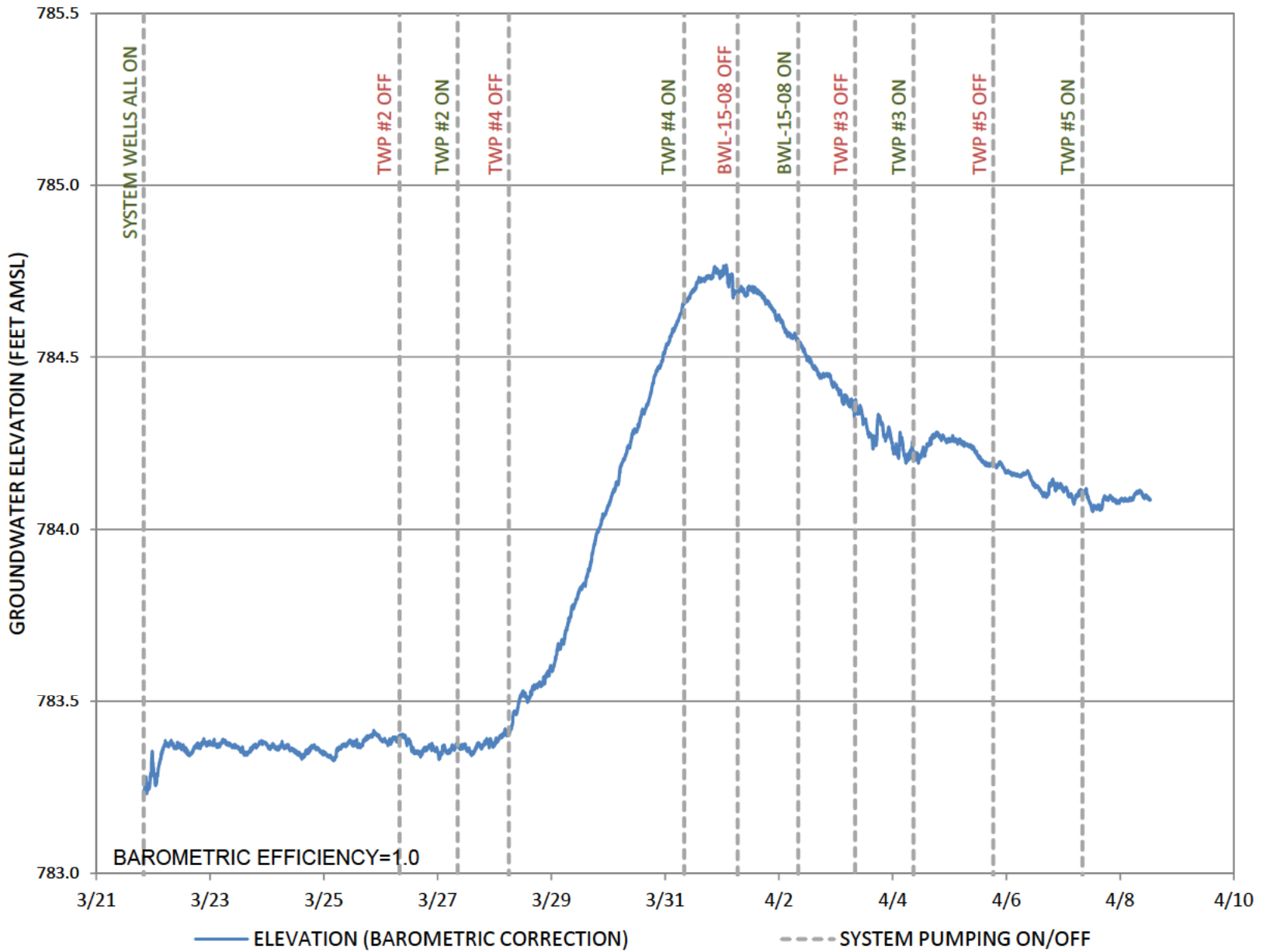
Suspected transducer shift of 0.33 feet at approximately 08:00 on 3/31/14.

MW 13-44

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

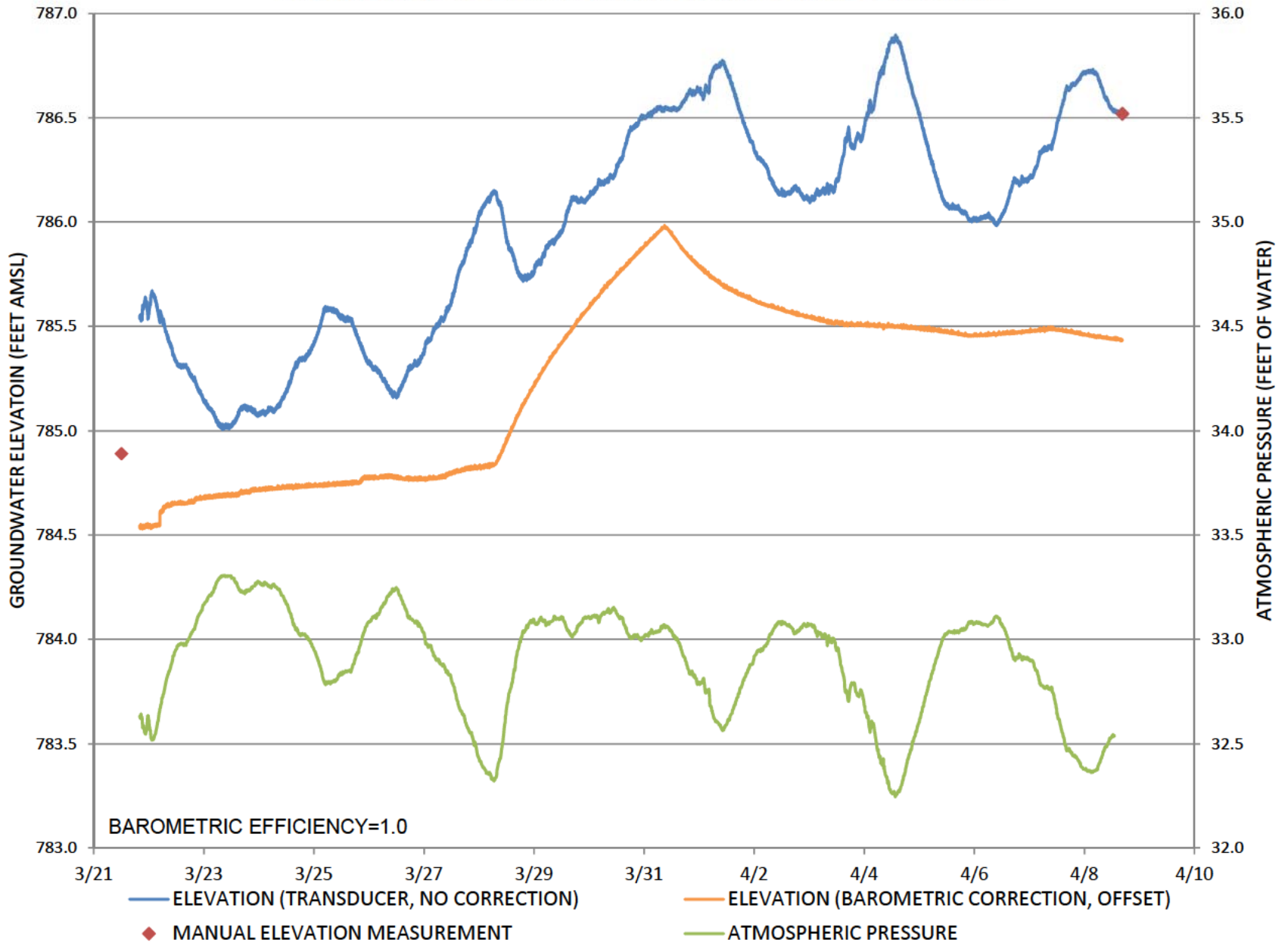


GROUNDWATER ELEVATION AND PUMPING

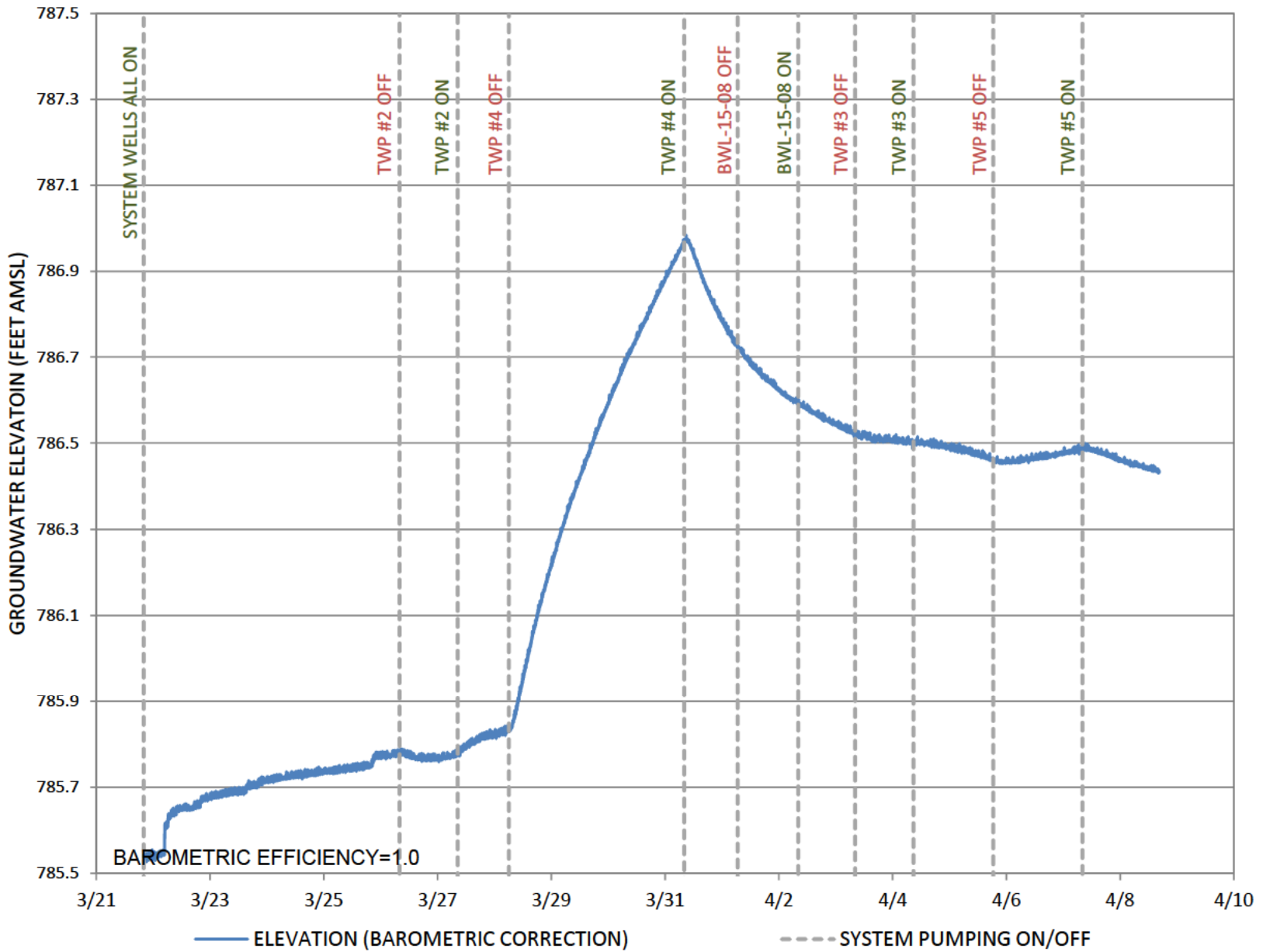


MW 13-47

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

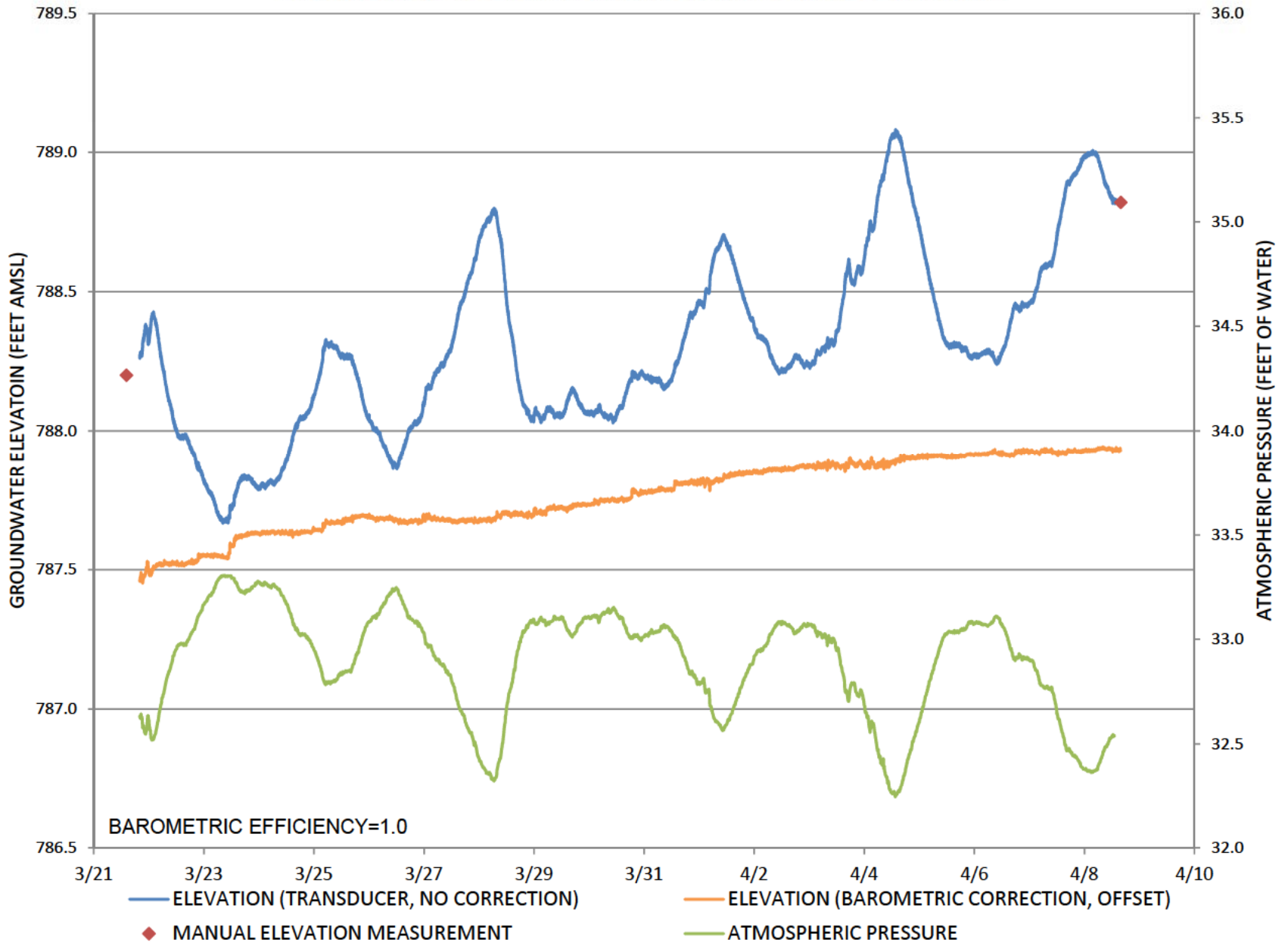


GROUNDWATER ELEVATION AND PUMPING

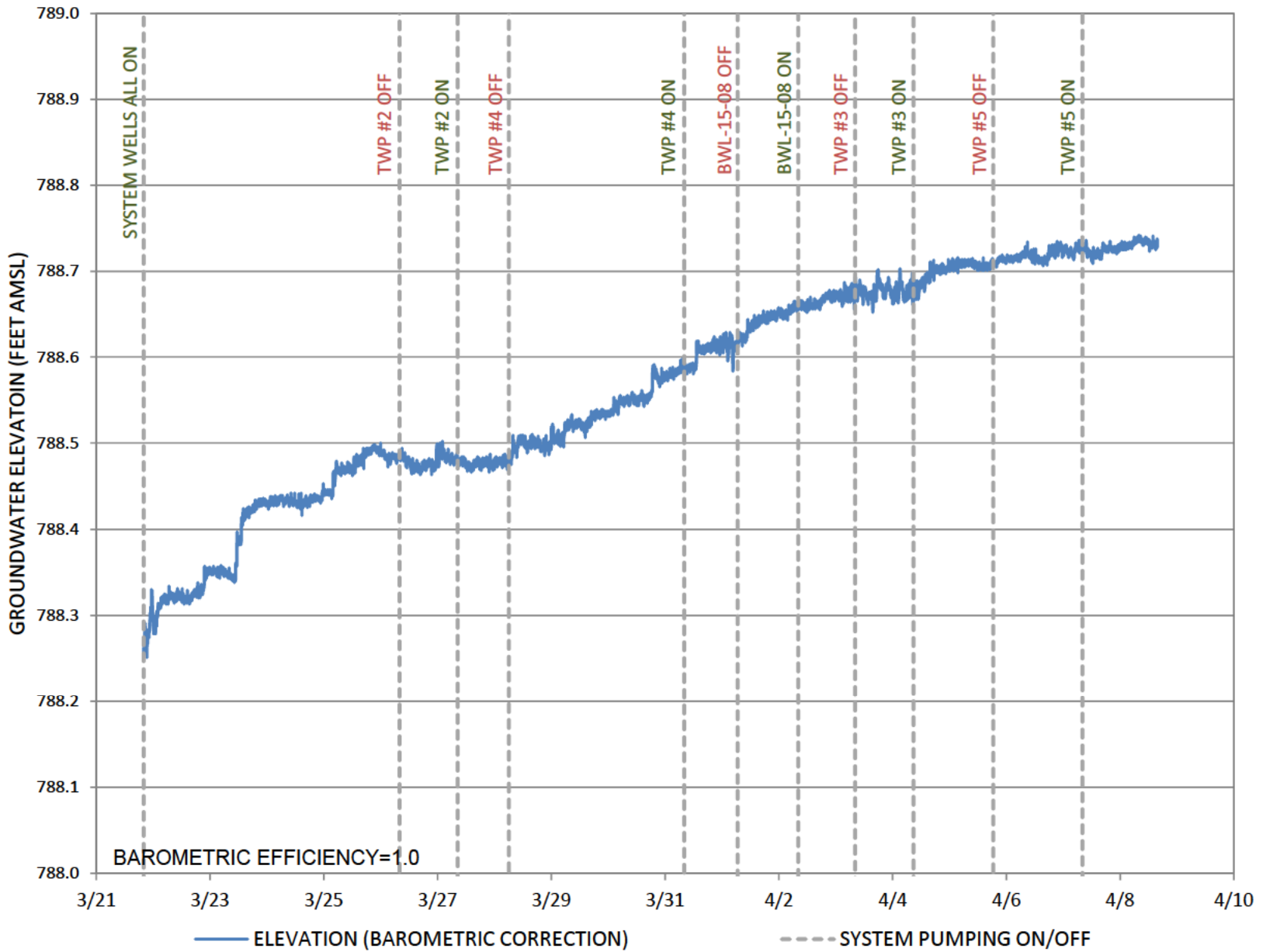


MW 13-50

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE

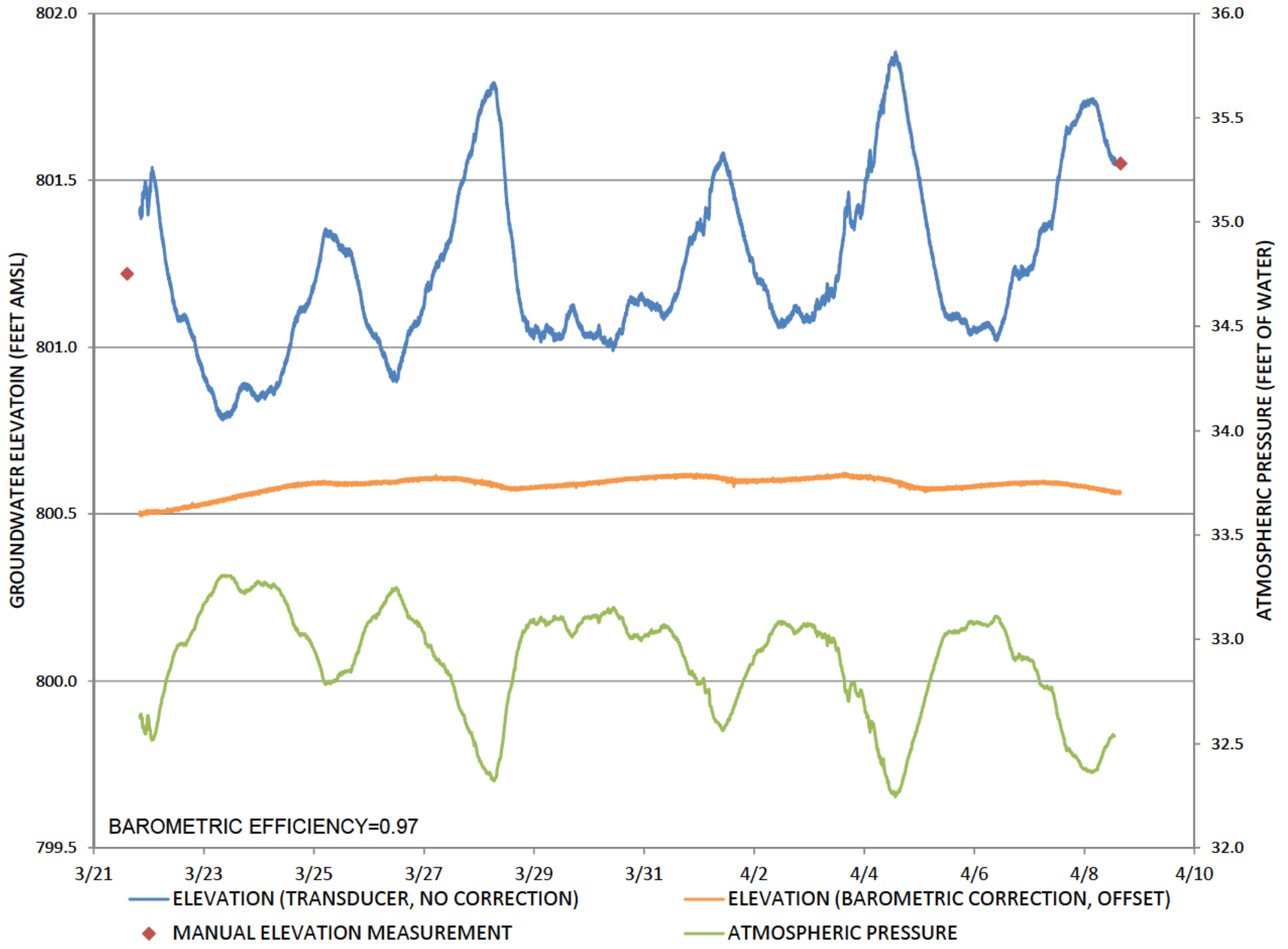


GROUNDWATER ELEVATION AND PUMPING

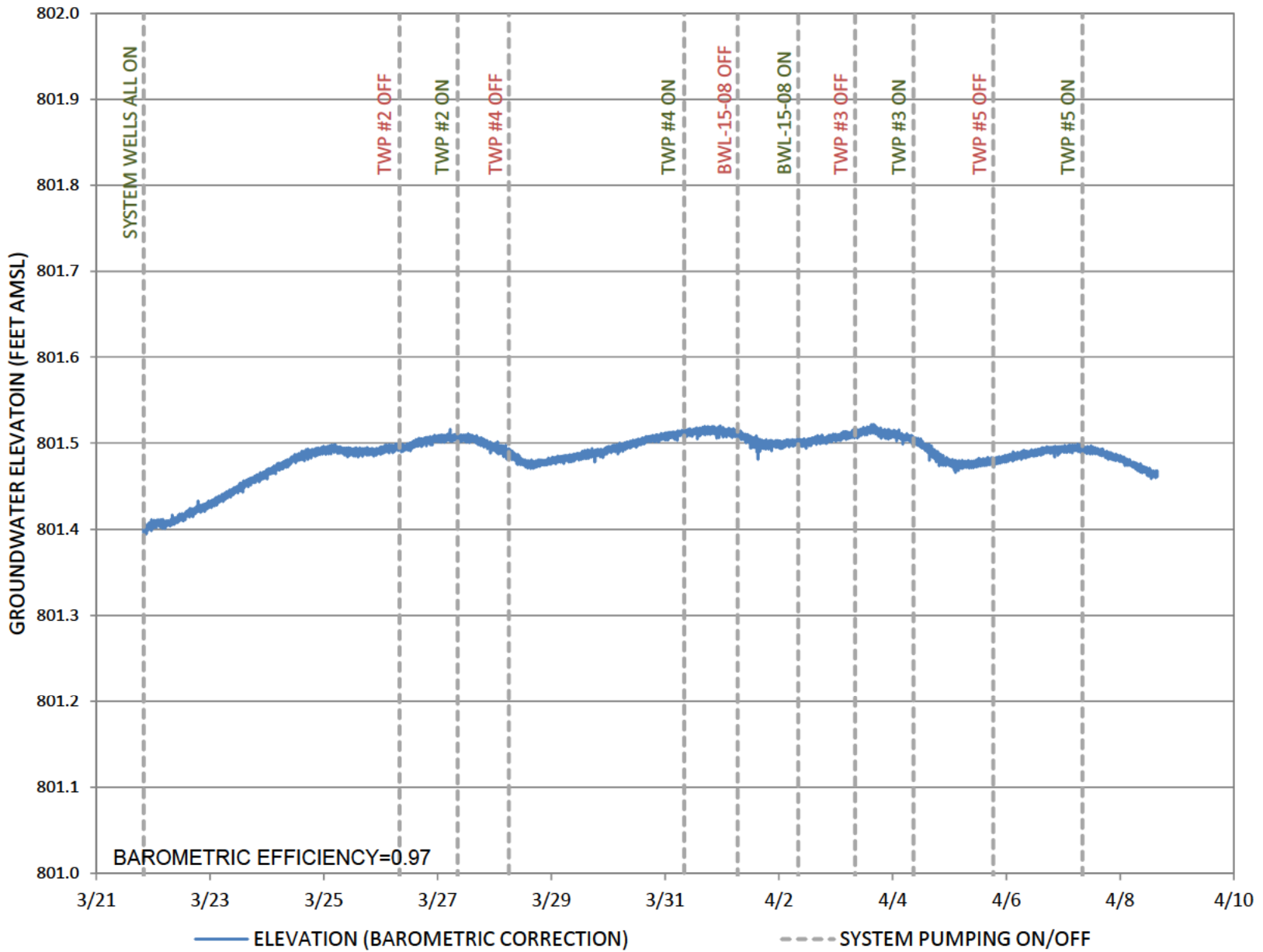


MW 13-52

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE



GROUNDWATER ELEVATION AND PUMPING

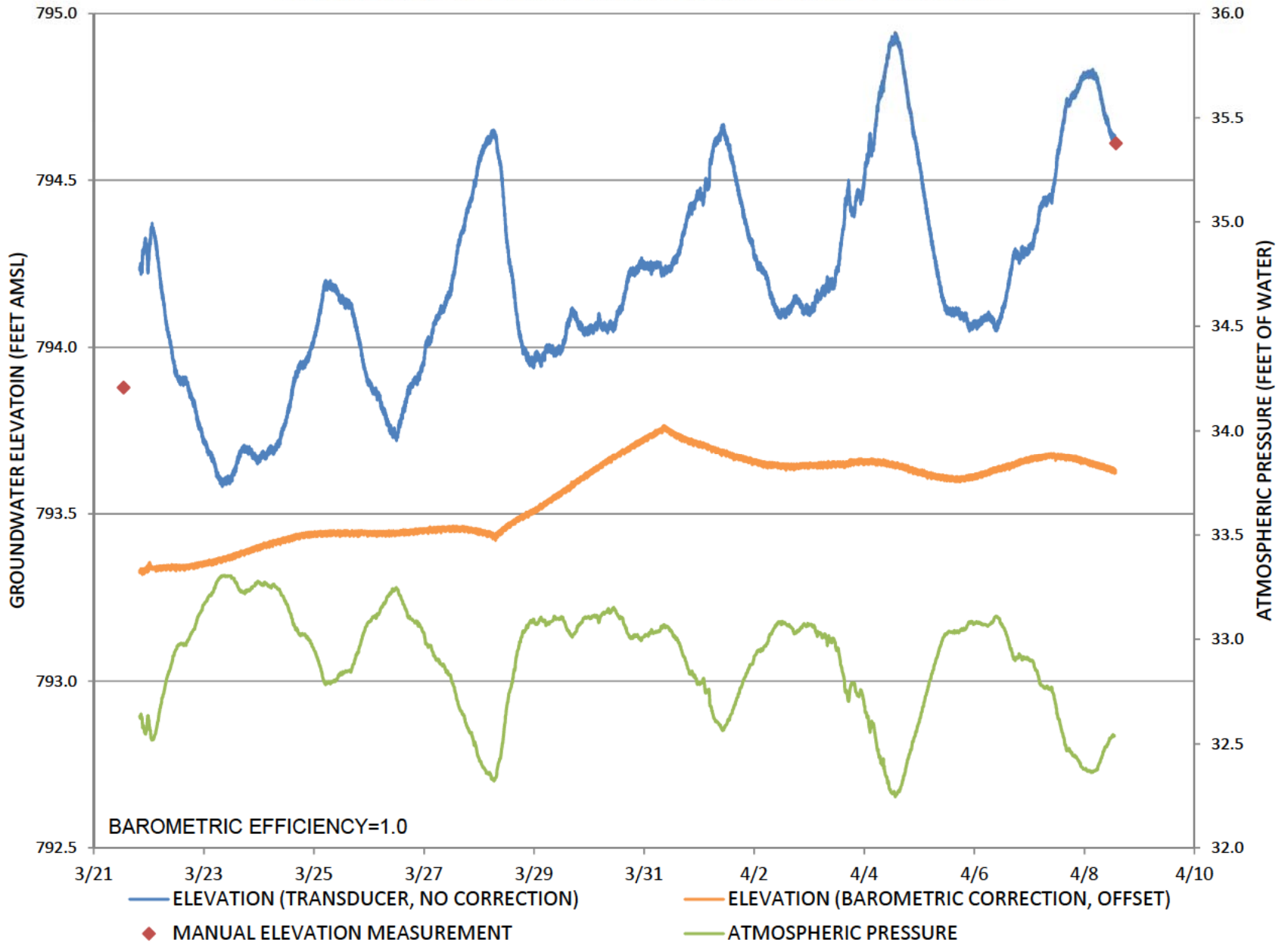


Notes:

Slope inflection points in corrected groundwater elevations are potentially due to incomplete barometric correction.

MW 91-5

GROUNDWATER ELEVATION AND ATMOSPHERIC PRESSURE



GROUNDWATER ELEVATION AND PUMPING

