



Groundwater Quality at a Dedicated Facility for Land Applications of Municipal Wastewater and Residuals in the North Carolina Piedmont

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Cover photo: Monitor (regolith and bedrock) wells in the foreground of a dedicated field for residuals application at the City of Gastonia's Resource Recovery Farm. Wooded areas buffer the application field from the nearby streams.

Contents

Abstract	5
Introduction.....	6
Study Area.....	7
Geologic Setting	7
Hydrogeologic Setting	8
Land Application of Residuals and Wastewater	8
Methods.....	9
Results and Discussion	11
Hydrogeologic Characteristics.....	11
Groundwater Quality	13
Summary	17
Acknowledgments	17
References	18

Tables

1. Total residuals loads and loading rates of nutrients and metals for 2008 and 2009 and cumulative metal loading rates since 1995.....	21
2. Well construction details for shallow regolith (S) and transition-zone (T) monitoring wells and bedrock (B) water-supply wells at PMRS.....	22
3. Summary statistics of groundwater parameters measured in unfiltered samples of regolith, transition zone, and bedrock wells at PMRS.....	23
4. Groundwater characteristics of monitoring and water-supply wells at PMRS based on four sampling events.....	24
5. Water quality characteristics in unfiltered stream water and unfiltered groundwater from stream-bed piezometers.....	30
6. Groundwater characteristics of private water-supply wells sampled near the PMRS.....	31

Figures

1a. Location of Pasour Mountain groundwater monitoring and research station (PMRS) in Gaston County, North Carolina.....	33
1b. Site map / aerial photo of the PMRS, showing well locations, application fields, and the two segments of the PMRS stream.....	34
2. Geologic map of the Pasour Mountain groundwater monitoring and research station (PMRS) from Pippin and others (2003).....	35
3. Hydrogeologic section along a A-A' profile at the Pasour Mountain research station.....	36
4. Groundwater levels below land surface in the PMRS monitoring wells from 12/2008 through 12/2010.....	37
5. Groundwater elevations in monitoring wells located in different topographic settings at PMRS from 12/2008 through 12/2010.....	38
6. Continuous and periodic water level measurements in up-slope well PM-14 and near-stream well PM-17 and periodic water level measurements in near-stream piezometer PZ-2 at PMRS.....	39

7. Continuous groundwater temperatures in regolith monitoring wells PM-14, PM-17, and PM-19 and stream piezometers PZ-1 and PZ-2.....	40
8. Concentrations of nitrate and pH in monitoring wells GMW-1 through GMW-5 reported (three times a year) by the City of Gastonia from 1995 through 2009.....	41
9. Major ionic concentrations of groundwater at the PMRS are shown on a Piper diagram.....	42
10. Major ionic concentrations in the water-supply wells sampled near the PMRS shown on a Piper diagram.....	43
11. Scatter plots of nitrates (NO ₂ +NO ₃) with chloride and total phosphorus in groundwater and stream water at PMRS.....	44

Groundwater Quality at a Dedicated Facility for Land Applications of Municipal Wastewater and Residuals in the North Carolina Piedmont

Abstract

Groundwater quality was determined through hydrogeologic characterization and sampling of wells installed in the regolith, transition zone, and bedrock at a facility dedicated for application of wastewater and residuals from wastewater treatment. Since 1995, wastewater-residuals have been land-applied at the facility, the Resource Recovery Farm (RRF). The RRF is located on a clay-rich, thick-regolith that mantles mica schists and interbedded quartzites of the Kings Mountain geologic belt in Gaston County. Groundwater levels show significant (10 – 20-ft) seasonal fluctuations in the unconfined aquifer. Groundwater flow appears to occur through a network of steeply-dipping fractures from recharge area on the slopes to discharge areas near the stream. Groundwater compositions reflect a change from a sodium-potassium mixed-anion type water in the regolith to calcium-bicarbonate type water in the bedrock. Trace metals are generally present in low levels in groundwater, except for arsenic (As) that is elevated in a bedrock well. Elevated levels of iron (Fe) and manganese (Mn) are noted in unfiltered samples, but relatively low levels are noted in the filtered samples, indicating an abundance of Fe and Mn as particulate or colloidal matter in groundwater. Groundwater samples from 25 water-supply wells near the study site show major ionic concentrations comparable to that of bedrock wells at the RRF.

There is a measurable but low impact noted on ambient groundwater quality from land applications of wastewater and residuals. At the study site, groundwater is enriched in nitrate plus nitrite (NO_3+NO_2), total phosphorus (P), and chloride (Cl), downgradient of the application fields; however, the concentrations are below the groundwater quality standards of North Carolina and the drinking water quality standards of U.S. Environmental Protection Agency. Downgradient of application fields, NO_3+NO_2 levels correlate with Cl, which suggests a NO_3 source from the application fields. Stream water is also slightly enriched in $\text{NO}_3 + \text{NO}_2$, total P, and Cl, suggesting groundwater movement from application fields to the stream. Chemical composition of stream water reflects mixed cation – mixed anion type water and suggests groundwater contributions from the regolith, transition zone and bedrock. Although measured groundwater constituents are currently within water quality standards, the potential for long-term impacts of groundwater quality need to be investigated through continued monitoring of nutrients and metals. Future assessments need to consider soil buildup and plant uptake of nutrients and metals, and surface water loadings to explain the attenuated levels of nutrients and metals in groundwater noted in this study.

Introduction

Land applications of treated wastewater and residuals (treated sewage sludge) from treatment of wastewater provide nutrients for plant uptake from the soil and improvements to soil structure. Thus, land application is a cost-effective means to derive beneficial use from the residuals of wastewater treatment containing carbon (C), nitrogen (N), and phosphorus (P). However, land application of residuals at excessive rates can potentially cause nitrate (NO_3) contamination of groundwater (e.g. Showers and others, 2006) and soil P buildup (e.g. Shober and Sims, 2003). Because of its high solubility, NO_3 tends to persist in groundwater until taken up by plants or removed by denitrification (e.g. Spalding and Exner, 1993). Excessive NO_3 in drinking water is potentially harmful to human and animal health (e.g. Jennings and Sneed, 1996), while runoff from soils with excessive P can contribute to eutrophication of surface water (e.g. Penn and Sims, 2002). Therefore, land applications of wastewater residuals may be governed by state and federal regulations that are intended to protect human health and environment, including groundwater quality.

The City of Gastonia is permitted (#WQ0001793) by the North Carolina Division of Water Quality (DWQ) to land-apply treated wastewater and residuals at its facility known as the Resource Recovery Farm (RRF), which is located near Bessemer City in Gaston County (Figure 1a). Since 1995, residuals were land-applied to approximately 177 acres at the RRF (Figure 1b). The RRF sits west of Pasour Mountain in the headwater area of an unnamed headwater stream draining to Long Creek, a tributary to the South Fork Catawba River. The Long Creek watershed (20,238-acres) was the site of an 8-year comprehensive watershed restoration project initiated in 1993 to improve stream water quality primarily through improved land management practices (Line and Jennings, 2002).

As a part of the Long Creek watershed monitoring program, the DWQ established the Pasour Mountain groundwater monitoring and research station (PMRS) at the RRF site in 1995 for the hydrogeologic characterization of the Long Creek watershed (Mew, 1997). The characterization involved geologic mapping (Pippin and Heller, 1998) and construction of an array of monitoring wells for water level monitoring and aquifer testing (Mew, 1997; Pippin and others, 2003). In 2008, the PMRS was redeveloped under the DWQ Resource Evaluation Program (REP) to study the groundwater quality at the site within the framework of groundwater quality in the Kings Mountain geologic belt. The PMRS is intended for (1) long-term water level and water quality monitoring in the thick-regolith – fractured bedrock aquifer system in the schist hydrogeologic unit (Daniel and Dahlen, 1992) of the Kings Mountain geologic belt and (2) to study the impact of land application of wastewater-residuals on groundwater quality at the site.

The primary objective of this study is to evaluate current groundwater quality at the RRF in response to land application of residuals and treated wastewater from municipal sources. To accomplish this objective, surface water quality and groundwater

quality were determined at PMRS and a nearby 2 square-mile area between August 2008 and September 2010. Results from this study show slightly enriched levels of NO_3+NO_2 , total P, and chloride (Cl) in groundwater and surface water downgradient of the application fields, but the concentrations are below the groundwater and surface water quality standards of North Carolina.

Study Area

The PMRS is located in southwest Piedmont physiographic province of North Carolina. Regionally, the study area is a moderately dissected upland of low relief but linear hills and ridges underlain by a resistant quartzite and quartz-pebble conglomerate that rises abruptly 100 to 800-ft above the surface of low relief (Horton, 2008). The landscape is rural, characterized by farmlands and mixed forests. Residential wastewater is generally discharged to individual septic systems. Residences in the surrounding area rely on potable water from wells drilled into the bedrock. Thus, protection of groundwater quality is crucial to the region.

The PMRS consists of farmland and mixed forest; the wooded areas are mostly in the draws and near the two stream segments. The main stream segment meets the Long Creek shear zone at a right angle and then closely parallels the shear zone (Figure 2), reflecting a structural control on the drainage pattern. The stream is represented as an intermittent stream on the (1:24,000) topographic map of U.S. Geological Survey. During the study period, August 2008 – December 2010, the main stream segment generally had surface flow, except during parts of the summer and fall seasons. The eastern segment was dry for a longer period than the main segment.

Geologic Setting

Regionally, the PMRS is located in the Kings Mountain (geologic belt) sequence as referred by Horton (2008). The Kings Mountain sequence lies on the western flank of the Carolina terrane (Horton, 2008) and contains late Neo-Proterozoic age (1000 – 542 Ma) rocks having for the most part sedimentary or volcanic protoliths (Goldsmith and others, 1988; Horton, 2008). Rocks in the Kings Mountain sequence are grouped into two formations: the Battleground Formation overlain by the Blacksburg Formation. The lower part of Battleground Formation consists of metavolcanic rocks and interlayered schist, while the upper part consists of quartz-sericite phyllite and schist interlayered with quartz-pebble metaconglomerate, aluminous quartzite, micaceous quartzite, and lesser amounts of metavolcanic rocks (Horton, 2008). The Blacksburg Formation consists of phyllitic metasilstone interlayered with marble, laminated micaceous quartzite, hornblende gneiss, and amphibolite with minor calc-silicate interlayers (Horton, 2008).

Locally, the PMRS is located in the Blacksburg Formation, underlain largely by quartz-muscovite schist with interbedded quartzite (Bowerman, 1954). Detailed geologic

mapping by Pippin and Heller (1998) indicate that PMRS is underlain, from east to west, by meta-graywacke, quartzo-feldspathic muscovite schist, and meta-arenite (Figure 2). Pippin and Heller (1998) identified two shear zones: a central shear zone coincident with the mapped contact between the mica schist and the western outcropping of meta-arenite that is equivalent to the Long Creek shear zone of Goldsmith and others (1988), and an unnamed eastern shear zone at the contact between the meta-arkose and the eastern outcropping of meta-arenite. Gold, pyrite, and iron deposits have been mined along some of the shear zones in the Kings Mountain area (Horton, 1981). Gold mining existed in the past along the Long Creek shear zone, at the northern portion of the RRF.

Hydrogeologic Setting

In the Piedmont of North Carolina, groundwater flow is conceptually described by the slope-aquifer model of LeGrand (2004). In this model of crystalline bedrock hydrogeology, the aquifer consists of three zones: shallow regolith, transition zone, and bedrock. The shallow regolith zone consists of soil, residuum, and saprolite, and generally has low hydraulic conductivity but provides the greatest storage compared to the other zones. The transition zone consists of partially weathered rock and is characterized by abundant fractures, moderate hydraulic conductivity and storage capacity. The fractures in the bedrock have the least storage but provide water at sustainable levels because of a network of fractures connected to the transition zone above. Topographic highs represent recharge areas in this model, while topographic lows, such as streams, are groundwater discharge areas. Thus, groundwater flow occurs from recharge to discharge areas, roughly following the slope of the land (LeGrand, 2004).

The PMRS is located in the schist (SCH) hydrogeologic unit of Daniel and Payne (1990). The SCH unit covers about 5% area of the Blue Ridge and Piedmont Provinces and hosts high-yielding wells (Daniel and Dahlen, 2002). At the PMRS, a relatively thick-regolith zone that includes a shallow clay-rich soil zone over a thick layer of saprolite, grades into mica-schist bedrock through a transition zone (Mew, 1997). Aquifer tests conducted at the PMRS indicate differing degrees of anisotropy and heterogeneity in each of the three zones (Pippin and others, 2003). The degree of anisotropy decreases from the bedrock zone characterized by fracture flow to the saprolite zone characterized by porous flow (Pippin and others, 2003). Although three zones are recognized in the subsurface with distinctive characteristics, the aquifer system at the PMRS functions as a single unconfined system, based on hydrogeologic data and water quality data obtained in this study. Thus, groundwater at PMRS is susceptible to contamination from surficial sources.

Land Application of Residuals and Wastewater

The City of Gastonia is permitted to land-apply residuals on 2,053 acres of farmland in Cleveland, Gaston, and Lincoln counties. Of this total permitted area, 177.3

acres are located at the RRF. The RRF is owned and operated by the City of Gastonia as a dedicated site for land application of residuals. The residuals are brought in from Crowders Creek wastewater treatment plant (WWTP) and the Long Creek WWTP, and are land-applied or stored in lagoons for later application. The RRF has two storage lagoons that have a combined capacity of 8 million gallons, and a three-quarter million gallon decant storage lagoon. Currently, wastewater effluent from the decant lagoon is sprayed on to fields 3 and 4 (Figure 1b), whereas class B residuals are applied to other fields. Class B refers to residuals that meet the class B requirements for metals, pathogens, and vector attraction reduction, and are applied on agricultural crop land at agronomic rates. Reported activities at the RRF generally comply with the permit requirements and no significant violations have been reported.

A summary of land applications at the RRF is provided in Table 1, which is based on the 2008 and 2009 annual reports submitted by the City of Gastonia. Table 1 indicates considerable differences in the amount of wastewater and residuals applied between the two successive years. The differences are mainly due to the conversion of field #3 to a dedicated wastewater spray field during mid-2008. Cumulative metal loading rates to the RRF since 1995 (Table 1) are below the pollutant loading rates established by North Carolina Administrative Code 15A NCAC 02T.1105.

Methods

Fourteen monitoring wells were established by DWQ at the RRF to monitor water level and water quality (Table 2) and are collectively referred to as the PMRS wells in order to distinguish from the RRF wells, which are part of the City of Gastonia's well network. There are five pairs of PMRS wells, each pair consisting of a regolith well and a transition zone well; the remaining four wells are shallow regolith wells. In addition, two existing bedrock wells (PM-O and PM-R) at the site are used to monitor groundwater quality in the bedrock. Bedrock well PM-R is a water-supply well for an onsite residence, while bedrock well PM-O is an old water-supply well that is used occasionally for non-potable purposes.

The monitoring wells are located approximately along a WNW-ESE line across the site (Figure 1b), roughly perpendicular to the foliations that generally trend N20E to N30E and dip 75 to 85 degrees to the northwest (Bowerman, 1954). Monitoring wells (PM-6, PM-7, PM-17, PM-18, PM-19, and PM-O) are located near the stream segments (Figure 1b); these wells are located in bedrock consisting of mica schist (Figure 2). Well pair PM-17 and PM-18 is located along the main stream segment and side-gradient of residual application field #5 (Figure 1b). Well pair PM-6 and PM-7, and well PM-19 are located near the eastern stream segment, downgradient of wastewater spray field #4. Well pair PM-1 and PM-2 are located in the middle of a wastewater spray field (#4). Monitoring wells PM-3, PM-9, PM-22, and PM-25 are underlain by meta-graywacke, and topographically located in a draw that also receives drainage from the spray field, while PM-5 and PM-14 are located in topographically higher areas. Monitoring well PM-15 was damaged during the study and was therefore abandoned in December 2009.

Characterization of the topographic setting of monitoring wells is based on distance to nearest stream as detailed in Daniel and others (1997).

Two piezometers were hand-augered to 10-ft below the streambed. Piezometer PZ-1 is located on the eastern stream segment near monitoring wells PM-6 and PM-7, while piezometer PZ-2 is located on the main segment near monitoring wells PM-17 and PM-18. Groundwater temperature measurements were continuously logged every hour using StowAway® TidbiT™ temperature data loggers in the piezometers and in monitoring well PM-19 from October 2009 through December 2010. Water level and temperature data using YSI® Data Scout™ were obtained from monitoring wells PM-14 and PM-17 between February and December 2010. Instrument or operator errors and vandalism caused partial data loss during the monitoring period.

Groundwater levels were measured periodically in the monitoring wells from December 2008 through December 2010. Groundwater samples were collected from 16 wells (including 2 bedrock wells) during four sampling events: (1) December 2008 - January 2009; (2) June 2009; (3) December 2009; and (4) June 2010. The sampling followed the recommended purging and sampling procedures described in North Carolina Division of Water Quality Standard Operating Procedures— Piedmont and Mountains Groundwater Resource Evaluation Program (2008). During sampling of each well, temperature, pH, specific conductance, dissolved oxygen (DO), and the oxidation-reduction potential (ORP) were monitored until stabilization, and at least three well volumes of water were removed before sample collection, except for bedrock wells that were sampled following stabilization of field parameters. At each well location, both unfiltered and (0.45 micron) filtered samples were collected. Surface water samples were collected under baseflow conditions on June 22, 2009, and December 7, 2009. In addition, groundwater from 25 water-supply wells located within a 2-mile radius of the PMRS was sampled in August 2008. The DWQ Chemistry Lab analyzed the samples for concentrations of major and trace ions including arsenic (As), barium (Ba), bicarbonate (HCO_3), cadmium (Cd), calcium (Ca), chloride (Cl), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), nitrate plus nitrite (NO_3+NO_2), total phosphorus (P), potassium (K), selenium (Se), sodium (Na), sulfide (S), sulfate (SO_4), and zinc (Zn). In addition, concentrations of total organic carbon (TOC), total dissolved solids (TDS), total suspended residue (TSS), silica (Si), and sulfide (S) were determined in the lab. The concentrations of NO_2 levels are assumed to be negligible at the site. Therefore, the concentrations of NO_3+NO_2 are reported as NO_3 in the following discussion.

As a part of the permit requirements, the City of Gastonia monitored the levels of selected constituents (Al, As, Cr, NO_3 , Pb, and TDS) in five shallow monitoring wells at RRF (Figure 1b) from 1995 through 2009. These wells are different from the PMRS monitoring wells (mentioned above) that are monitored by DWQ. Monitoring well GMW-1 is located upgradient of the application fields and is considered to be a background well for the site. Monitoring well GMW-2 is located downgradient of the residuals storage basins to detect contaminants potentially leaching from the storage basins. Three other monitoring wells (GMW-3, GMW-4, GMW-5) are present in different locations generally downgradient of residuals application fields. These wells showed

little impact from application of residuals, possibly due to improper well location or improper screen depth, and therefore, were excluded from the permit in 2009. The revised permit requires monitoring for groundwater quality in GMW-1 that is upgradient of residuals / wastewater spray field #3 and GMW-6 (=PM-19) that is downgradient of wastewater spray field #4.

Results and Discussion

Hydrogeologic Characteristics

The PMRS is characterized by a relatively thick regolith (41-ft to 94-ft) overlying bedrock that ranges in depth from 105-ft to 153-ft. A cross-sectional profile across the PMRS (Figure 3) indicates thicker regolith in the draws than on the hills. The water table is deeper on topographic highs and shallower near the streams. The water table slopes toward the main stream segment near PM-17/18, which represents the lowest elevation along the cross-sectional profile at the study site (Figure 3). Well yields are highest in the draws and valleys (Table 2), indicating favorable well yields in areas with thicker regolith and transition zone and a general groundwater flow direction to topographic lows. The general hydrogeologic characteristics at PMRS are comparable to that of the Indian Creek watershed (Daniel and others, 1997), which is located adjacent to the Long Creek watershed and also drains to the South Fork Catawba River.

Groundwater levels measured at the PMRS show distinct seasonal variations (Figure 4). In general, the depth to water decreased from early winter of 2008 through mid summer of 2009 and then increased through late fall of 2009 in all wells, except for wells PM-17, PM-18, and PM-19, which are located closest to the streams. Depth to water in wells PM-17, PM-18, and PM-19, increased beginning early spring of 2009 (disregarding the spike in June 2009 due to unusually high rainfall) and reached the lowest depth in late summer 2009. Thus, groundwater levels in the near-stream wells responded sooner to seasonal changes than groundwater levels in wells in other topographic settings. Groundwater levels in the draws and hills generally lagged about 2 to 3 months to seasonal changes.

The magnitude of water level changes was greater in wells present on topographically higher areas, reaching a maximum of 20-ft in up-slope well PM-5 in 2010 (Figure 5). Nonetheless, water level changes were also significant in near-stream wells reaching 14-ft in PM-17 in 2010. Thus, water level trends vary across different topographic settings at PMRS.

Water level elevations in pairs of regolith and transition zone wells are similar (Figure 5) in some (recharge area) wells (PM-1 and PM-2, PM-3 and PM-9, PM-22 and PM-25), but were different in near-stream (discharge area) wells (PM-6 and PM-7, PM-17 and PM-18). In a few wells in the recharge area, similar water levels noted in different depths may be due to screen lengths overlapping groundwater zones. Water level elevations in near-stream regolith well (PM-17) were slightly higher than the

elevations in its corresponding transition-zone well (PM-18) during winter and spring (Figure 5), indicating a downward flow (groundwater recharge) during these months. In summer and fall, the water levels are about the same in PM-17 and PM-18, indicating loss of regolith water to evapotranspiration. Comparison of water level elevations in the near-stream wells with elevations in stream-bed piezometers (Figure 5), suggests that the stream may be losing surface water during dry months and gaining groundwater during wet months. In summer and fall of 2010, groundwater levels in the streambed piezometer (PZ-2) on the main stream segment were higher than groundwater levels in PM-17, located about 75-ft away.

Continuous water level data in two wells are shown in Figure 6. Water levels in regolith well PM-14, located in a mid-slope area, showed a gentle seasonal decline but did not respond to rain events. However, water levels in regolith well PM-17, located near the main stream segment, clearly responded to rain events. Water levels increased 1 to 2-ft in PM-17 following rain events, indicating a close connection between surface water and groundwater at the site. Following rainfall events, water levels in PZ-2 rose notably higher than PM-17, indicating a strong response of groundwater level below the streambed. An increase in water levels following rainfall may be from infiltration of surface water or discharge of groundwater due to recharge in the shallow regolith or upslope areas.

Shallow groundwater temperature profiles in piezometers screened from 5-ft to 10-ft below the streambed show a significant decline (about 10 °C) in temperatures from October 2009 through January 2010 (Figure 7), paralleling the (nearly 10-ft) water level increase noted in near-stream wells (Figure 5). An increase in water level elevations with a corresponding decrease in temperatures during cooler months indicates recharge to the saturated zone. Nonetheless, under saturated conditions in late 2009 and early 2010, rainfall events apparently caused increases in groundwater temperatures in piezometer PZ-2 (Figure 7), suggesting discharge from deeper groundwater. Thus, there is a complex interplay between surface water and groundwater in the near-stream area at PMRS. Additional monitoring including continuous water level measurements in streambed piezometers are needed to determine the recharge-discharge relation near the stream.

Stable groundwater temperatures, apparently unaffected by seasonal temperature changes, are noted in PM-14 that is located upslope. Relatively stable groundwater temperatures are observed in near-stream well PM-19, which is screened from 40-ft to 50-ft below land surface. The temperatures in PM-19 are stable during and following precipitation events (Figure 7) but show a gentle seasonal response that is slightly warmer in winter and cooler in summer. This subtle but clear trend indicates a mixing of cooler (deep) groundwater with warmer (shallow) groundwater in summer and vice versa during winter. Diurnal temperature patterns are obscured in the temperature trends at PMRS wells, possibly because the regolith wells are relatively deep to be affected by daily air temperature or because groundwater discharge at near-stream locations keeps the daily temperature relatively stable. Overall, the water level and temperature trends reflect an unconfined nature of the thick-regolith fractured bedrock

aquifer at PMRS, and a strong potential for physical and chemical interactions between the stream and the aquifer during recharge and discharge events and a strong potential for contaminant migration in the aquifer system.

Groundwater Quality

Groundwater quality in the RRF wells monitored by the City of Gastonia (Figure 1b) from 1995 through 2009 indicates that measured constituents are below North Carolina groundwater quality (2L) standards during most of the sampling events (data not shown here). Ammonia exceeded the North Carolina Interim Maximum Allowable Concentration (IMAC) of 1.5 mg/L in well PM-19 (GMW-6) on all three sampling events conducted since 2009. The IMAC for ammonia and several other constituents were established by DWQ in late 2010. On a few occasions, Pb concentrations exceeded the 2L standard of 15 µg/L in three of the five monitoring wells included in the pre-2009 permit. Elevated levels of Pb are attributed to high particulates in the unfiltered samples. Elevated levels of Al (higher than U.S. EPA's secondary standard) are also noted in the turbid samples with high Pb; currently, there is no state standard for Al in groundwater. Among the measured constituents, nitrate and pH levels show variations during the monitoring period and are shown in Figure 8. Nitrate levels increase slightly over time in monitoring well GMW-2 downgradient of the storage basins, but the maximum level of 2.2 mg/L is appreciably below the State standard of 10 mg/L (Figure 8). There is also a small decrease noted in groundwater pH during the monitoring period.

Chemical characteristics of groundwater quality in the PMRS monitoring wells are provided in Table 3, based on analytical results from four sampling events. The data have been grouped by groundwater zones – regolith, transition zone, and bedrock. Only unfiltered samples were used for the summary provided in Table 3. The full analytical results are provided in Table 4, which is also available online at <http://portal.ncdenr.org/web/wq/aps/gwp/groundwater-monitoring>.

Concentrations of metals are generally high only in unfiltered samples (Table 4) indicating its probable association with particulate matter. Concentrations of most trace metals (Cd, Cr, Hg, Ni, Pb, and Se) are below laboratory detection limits in the majority (>95%) of the filtered samples. The detected trace metals are possibly attached to particulates containing Fe and Mn, as indicated by low (below detection) levels of metals noted in the filtered samples (Table 4).

Arsenic concentrations in the bedrock wells range from < 2 µg/L (detection limit) to 27 µg/L (Table 3). Transition zone wells show As levels generally <2 µg/L, except for PM-18 that shows consistently detectable levels (3 µg/L) of As (Table 4). Regolith wells (PM-2, PM-5, PM-14, and PM-15) show concentrations of As ranging from 10 to 45 µg/L in unfiltered samples; however, As concentrations are < 2 µg/L in the corresponding filtered samples. Regolith groundwater samples with detectable levels of As also have high (> 1000 µg/L) levels of Fe. This suggests an association of As with Fe in the particulate phase in regolith groundwater. In the bedrock groundwater, however, both

unfiltered and filtered samples contain similar concentrations of As, suggesting an occurrence of As in the dissolved or colloidal state since the bedrock wells contained much lower levels of particulate matter. Detectable levels of As are also noted in stream water (base flow) and stream-bed piezometers (Table 5), suggesting groundwater discharge possibly from the bedrock may be a major source of As to stream water and near-stream groundwater. Limited data from this study suggests that As is naturally-occurring in groundwater that may be derived from sulfide minerals in the bedrock near the Long Creek shear zone. Additional geochemical analyses of water and rocks are needed to establish the source of groundwater As and formulate a relationship between groundwater As in the regolith and bedrock.

Concentrations of metals in the monitoring wells suggest that unfiltered samples, particularly from the regolith zone, contain high particulate matter and therefore, the unfiltered samples show elevated concentrations of metals. Filtration apparently removed the particulate load, resulting in low concentrations of metals in filtered samples. Current DWQ policy for metals determination required by 15A NCAC 2L for compliance monitoring wells prohibits sample filtration and requires acid preservation in the field (Bush, 2011, policy memorandum for metals determination). Under this policy, some of the results from PMRS and RRF wells may violate 2L standards. Improper well construction and improper well development can result in high particulates in unfiltered samples. Therefore, properly constructed wells and properly developed wells are essential for obtaining an unfiltered sample that is devoid of material from the geological formation but representative of the total concentration of mobile metals. The mobile metals may include dissolved, colloidal, and particulate forms, and therefore, collection and analysis of a representative unfiltered sample is critical for the determination of compliance with 2L standards.

Groundwater in the shallow regolith and transition zone is acidic to neutral, whereas groundwater in the bedrock is slightly alkaline (Table 3). Groundwater pH in the regolith ranges from 4.2 through 6.1, whereas pH in the transition zone ranges from 5.2 through 7.2 and in the bedrock from 7.0 to 7.8. Median concentrations of total dissolved solids (TDS) range from 20 mg/L in the regolith groundwater to 113 mg/L in the bedrock groundwater (Table 3). Median levels of bicarbonate range from 2 mg/L in the regolith to 89 mg/L in the bedrock, while Si levels range from 8 to 19 mg/L, respectively. Major cations – Ca, Mg, Na, and K – also show systematic increases in concentration with depth. The data clearly reflect an increase in ionic concentrations from the regolith through the transition zone to the bedrock.

In each well cluster, higher levels of Na and K are noted in regolith groundwater than in the transition zone (Table 3). In contrast, groundwater in the transition zone and bedrock are characterized by higher levels of Ca and Mg than groundwater in the regolith zone. A plot of major ionic species on a Piper diagram (Figure 9) indicates a hydrochemical facies consisting of Na-K–mixed anion type groundwater in the regolith to Ca-HCO₃ type groundwater in the bedrock; groundwater in the transition zone represents an intermediate composition between the regolith and bedrock. The hydrochemical facies reflect an evolution of groundwater from the regolith to the

bedrock possibly through ion-exchange reactions in the aquifer. Particularly, each well cluster shows a distinct increase in ionic concentrations from the regolith to the transition zone.

Chemical compositions of water-supply wells sampled near the PMRS (Table 6) largely reflect mixed-cation-HCO₃ type water (Figure 10) and are generally comparable to the chemical composition of bedrock wells at PMRS (Figure 9). Although well construction data are incomplete for the water-supply wells sampled for this study, it may be assumed that majority of wells are drilled into the bedrock based on prevalent well-construction practices in the region. A wide scatter in groundwater composition observed in Figure 10 may be due to a few bored (shallow) wells that show chemical composition comparable to that of wells screened in the transition zone (Figure 9).

Since the drainage area covered by the study site was previously used for gold mining and dairy farming and, due to a lack of water quality data prior to establishment of the RRF, this study makes no attempt to distinguish water quality impacts from historical and current land uses. Nonetheless, groundwater quality measured in an upgradient monitoring well GMW-1 since 1995 provides a baseline to evaluate the current groundwater quality. Groundwater quality monitoring of selected constituents in GMW-1 shows average concentrations of < 0.5 mg/L of NO₃-N, < 2 µg/L of As, and < 15 µg/L of Pb, indicating low baseline levels of target elements. Unexpectedly, the upgradient well shows a decline in pH along with other downgradient monitoring wells. The acidification may be a result of two major droughts (2002-03 and 2007-08) that occurred during the 15-year monitoring period.

Downgradient of the application fields and storage lagoons, NO₃ concentrations are higher in the regolith monitoring wells than in the transition zone and bedrock wells (Tables 3, 4). Median NO₃-N concentrations decrease from 0.35 mg/L in the regolith groundwater to less than 0.02 mg/L in the bedrock. The highest concentrations of NO₃-N are observed in regolith wells PM-2 (2.2 mg/L) and PM-19 (3.7 mg/L) that may be affected by spray irrigations in field #4 (Figure 1b).

Phosphorus concentrations are less than 0.2 mg/L in all wells (Table 4), except for regolith wells PM-2 and PM-17 that show slightly elevated levels of phosphorus (P), ranging from 0.34 to 0.95 mg/L. Wastewater and residuals applications fields are the likely sources for P in PM-2 and PM-17. However, there may be other sources for P in these wells, such as an existing septic system at a house in the vicinity, an old septic system at a previous dwelling, or an effect of dairy farming in the past. Regardless of the source(s), P appears attenuated in the regolith zone, possibly through adsorption onto iron oxides.

Chloride concentrations in the regolith wells, excluding PM-2, PM-9, PM-17, and PM-19, range from 1.0 to 1.3 mg/L that reflect Cl levels in regional precipitation (Junge and Werby, 1958). Chloride concentrations in the transition zone and bedrock wells are also within a narrow range from 1.1 to 1.6 mg/L (Table 3). Regolith wells PM-2, PM-9, PM-17, and PM-19 show higher levels of Cl, ranging from 1.5 to 6.6 mg/L. These wells

also have higher levels of NO_3 that show an increasing trend with Cl levels (Figure 11). The correlation between NO_3 and Cl suggests wastewater and residuals application fields as the potential source for NO_3 and Cl. Well PM-19 also shows enriched levels of Na (up to 13.5 mg/L), most likely derived from upgradient wastewater spray field. Thus, infiltration of leachate from residuals and wastewater appears to be the source of enriched levels of Cl and NO_3 in regolith groundwater downgradient of application fields.

Enriched levels of Cl and NO_3 are also noted in stream water downgradient of application fields (Figure 11), suggesting land applications of residuals and wastewater as the source for enriched NO_3 in stream water. Nonetheless, stream water may also be a source of NO_3 and Cl to groundwater at the site, since the stream appears to lose water to the aquifer during part of the year as indicated by reversed head gradients near the stream during part of the year (Figure 5). Continuous and periodic water level measurements in near-stream wells and stream-bed piezometers indicate a significant response of water levels during rainfall events that occurred in fall of 2010 (Figure 6). Corresponding to rainfall events, the water levels in the streambed piezometers increased notably, raising the head gradient toward the near-stream aquifer.

Groundwater composition of stream water, collected under baseflow conditions, is comparable to the groundwater composition of the bedrock zone (Figure 9). The stream water samples generally show higher concentrations of major ions when compared to the regolith and transition zone, except for the stream water sample from the downstream confluence, which reflects a mixed composition from the regolith and transition zone (Figure 9). Chemical composition of groundwater from the streambed piezometer (PZ-2) in the main segment closely matches the bedrock composition, whereas the streambed piezometer (PZ-1) in the eastern (smaller) segment reflects a groundwater composition of the regolith or transition zone (Figure 9).

The geochemical, temperature, and water level patterns from this study suggest two major flow paths for groundwater at the PMRS: a shallow flow path routes groundwater from the regolith or transition zone to the small, eastern stream segment, and a deep flow path routes groundwater from the bedrock to the main stream segment. Although the general head gradient is towards the main stream segment, the eastern stream appears to be a discharge area for shallow groundwater flow in the regolith as evidenced by the shallow groundwater signature, including enriched levels of NO_3 and Cl. The two groundwater flow paths and the stream flow dynamics may be controlled by shear zone(s) at the site, which could also affect the groundwater quality. Seasonally changing head gradients near the stream and the influx of regolith – transition zone groundwater at the downstream confluence site indicates strong interactions of groundwater and surface water along the stream. Future work should target near-stream hydrogeological investigations to identify the factors and processes shaping the groundwater quality in the thick-regolith fractured bedrock aquifer at PMRS, which would also lead to a better understanding of the hydrogeologic controls shaping groundwater quality across the Kings Mountain geologic belt.

Summary

Groundwater data from PMRS support the LeGrand (2004) hydrogeologic conceptual model of the North Carolina Piedmont. Groundwater flows from topographic highs to lows and groundwater discharges near streams. Groundwater flow in the unconfined aquifer at the study site appears to occur through a network of fractures from the recharge area on the slopes to discharge areas near the stream. The chemical composition of stream water reflects groundwater composition from the transition zone and bedrock. Water level and water chemistry data suggest two paths for groundwater flow at the PMRS – a shallow path from the regolith - transition zone to the eastern stream segment and a deeper path from the transition zone - bedrock to the main stream segment. Compared to other hydrogeologic settings in the Piedmont, groundwater levels in the thick-regolith, mica-schist-mantled bedrock at PMRS show significant seasonal fluctuations, ranging 10 to 20-ft in the regolith and transition zone; water level monitoring in the bedrock zone was not feasible for this study.

Downgradient of the application fields, groundwater is enriched in NO₃, P, and Cl compared to levels in upgradient wells, but the concentrations are below North Carolina groundwater quality standards. Stream baseflow is also slightly enriched in NO₃, P, and Cl, indicating groundwater movement from the application fields to the stream. Downgradient of the application fields, NO₃ levels correlate with increasing Cl, suggesting a nitrate source from the application fields. Data from this study show a small but measurable impact of residuals and wastewater applications on ambient groundwater quality. Nonetheless, the potential for long-term impacts of groundwater quality should be investigated through continued monitoring of nutrients and metals. Monitoring efforts should also consider soil P buildup, and runoff nutrient levels for evaluation of nutrient loadings from the application fields. To explain the attenuated levels of nutrients and metals noted in this study, future assessments need to consider nutrients and metals uptake by plants and soils and surface water loadings. Also, geologic and geochemical assessment of bedrock cores and groundwater would help increase our understanding of natural and anthropogenic impacts on groundwater quality near shear zones, particularly concerning the occurrence and geochemistry of groundwater As in the Kings Mountain geologic belt. Future work should evaluate groundwater quality at PMRS for exceedence of metals and nutrients with recently established IMACs and 2L standards and may also consider monitoring emerging contaminants in water. Emerging contaminants include many chemical and microbial contaminants derived from wastewater sources that are not commonly monitored due to lack of detection methods or synthesis of new chemicals, etc., but have the potential to cause ecological or human health effects (U.S. Geological Survey, <http://toxics.usgs.gov/regional/emc/>, accessed on September 24, 2010).

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Table 1. Total residuals loads and loading rates of nutrients and metals¹ for 2008 and 2009 and cumulative² metal loading rates since 1995 (compiled from the 2008 and 2009 annual reports provided by the City of Gastonia)

2008

Field#	Area	Crop	Total residuals (gallons)	Total residuals (dry tons)	Plant Available Nitrogen (lbs/ac/yr)	P (lbs/a c/yr)	As ¹ (lbs/ac/yr)	As ² (lbs/a c/yr)	Cd ¹ (lbs/ac/yr)	Cd ² (lbs/a c/yr)	Cr ¹ (lbs/ac/yr)	Cr ² (lbs/a c/yr)	Cu ¹ (lbs/a c/yr)	Cu ² (lbs/a c/yr)	Hg ¹ (lbs/a c/yr)	Hg ² (lbs/a c/yr)	Ni ¹ (lbs/ac/yr)	Ni ² (lbs/a c/yr)	Pb ¹ (lbs/a c/yr)	Pb ² (lbs/a c/yr)	Se ¹ (lbs/a c/yr)	Se ² (lbs/ac/yr)	Zn ¹ (lbs/a c/yr)	Zn ² (lbs/ac/yr)
99-1	27.5	Corn	571,753	57.32	118.5	180.7	0.0183	0.638	0.0086	0.54	0.53	0.53	1.315	76	0.006	1.006	0.3358	17	0.1070	15	0.019	0.27	6.355	166
99-2	45.3	Rye	84,485	7.47	10.9	13.4	0.0015	0.677	0.0008	0.57	0.04	0.04	0.096	65	0.000	0.138	0.0270	16	0.0079	12	0.001	0.27	0.482	231
99-3	42.2	Fescue	624,011	17.19	19.5	17.1	0.0072	1.677	0.0006	0.75	0.03	0.03	0.123	166	0.000	0.206	0.0485	41	0.0155	28	0.003	0.44	0.442	280
99-4	13.4	Fescue	2,233,640	50.65	182.9	184.2	0.0807	2.585	0.0073	0.25	0.28	0.28	1.126	44	0.008	0.067	0.5340	12	0.1319	7	0.028	0.47	3.962	113
99-5	22	Fescue	273,000	24.12	64.6	84.9	0.0108	1.397	0.0047	0.13	0.19	0.19	0.615	43	0.003	0.075	0.1788	7	0.0477	7	0.010	0.30	2.965	103
99-7	6.5	Fescue	136,500	13.27	114.5	159.3	0.0181	0.018	0.0080	0.01	0.42	0.42	1.379	1.4	0.008	0.008	0.3417	0.3	0.1043	0.10	0.019	0.02	6.233	6
99-8	20.4	Corn	65,000	7.59	20.8	33.3	0.0028	0.014	0.0015	0.01	0.10	0.10	0.233	1	0.001	0.007	0.0543	0.3	0.0201	0.11	0.004	0.01	1.176	8
Total	177.3		3,988,389	177.62	531.75	673	0.1394	7.007	0.0315	2.26	1.59	1.59	4.887	396	0.027	1.506	1.5201	94	0.4344	68	0.084	1.78	21.61	906

2009

Field#	Area	Crop	Total residuals (gallons)	Total residuals (dry tons)	Plant Available Nitrogen (lbs/ac/yr)	P (lbs/a c/yr)	As ¹ (lbs/ac/yr)	As ² (lbs/a c/yr)	Cd ¹ (lbs/ac/yr)	Cd ² (lbs/a c/yr)	Cr ¹ (lbs/ac/yr)	Cr ² (lbs/a c/yr)	Cu ¹ (lbs/a c/yr)	Cu ² (lbs/a c/yr)	Hg ¹ (lbs/a c/yr)	Hg ² (lbs/a c/yr)	Ni ¹ (lbs/ac/yr)	Ni ² (lbs/a c/yr)	Pb ¹ (lbs/a c/yr)	Pb ² (lbs/a c/yr)	Se ¹ (lbs/a c/yr)	Se ² (lbs/ac/yr)	Zn ¹ (lbs/a c/yr)	Zn ² (lbs/ac/yr)
99-1	27.5	Corn	403,013	36.80	50.8	85.4	0.0228	0.660	0.0027	0.545	0.13	0.656	0.506	76.85	0.001	1.007	0.1606	17.35	0.0669	14.74	0.012	0.28	2.037	168
99-2	45.3	Sorg	816,759	82.60	95.9	139.1	0.0233	0.700	0.0047	0.574	0.38	0.423	1.080	65.89	0.006	0.144	0.2268	16.35	0.1258	11.76	0.019	0.29	5.344	236
99-3	42.2	Fescue	3,388,787	113.37	161.5	218.5	0.0352	1.712	0.0097	0.763	0.57	0.598	1.814	167.3	0.008	0.214	0.2971	41.11	0.2298	28.10	0.025	0.46	7.399	288
99-4	13.4	Fescue	1,594,090	30.33	163.6	188.0	0.0307	2.616	0.0092	0.255	0.32	0.598	1.492	45.82	0.005	0.072	0.2244	12.26	0.2057	6.75	0.025	0.49	5.661	118
99-5	22	Fescue	662,992	60.89	163.2	215.3	0.0330	1.430	0.0075	0.139	0.59	0.780	1.730	44.72	0.010	0.084	0.3417	7.79	0.1891	7.52	0.031	0.34	8.800	112
99-7	6.5	Fescue	141,999	14.68	104.1	168.2	0.0316	0.050	0.0064	0.014	0.49	0.903	1.337	2.72	0.007	0.014	0.2722	0.61	0.1592	0.26	0.019	0.04	5.725	12
99-8	20.4	Sorg	39,000	2.10	8.60	7.6	0.0011	0.015	0.0003	0.012	0.01	0.112	0.065	1.09	0.000	0.007	0.0113	0.29	0.0047	0.12	0.001	0.02	0.331	8.11
Total	177.3		7,046,640	340.77	748	1022	0.1777	7.18	0.0405	2.30	2.48	4.070	8.024	404	0.037	1.542	1.5341	96	0.9812	69	0.132	1.92	35.30	941

¹ The first column for a metal is the annual loading rate. ² The second column for a metal is the cumulative loading rate since 1995. For example, the cumulative loading rate for As in 2008 plus the annual loading of As in 2009 will be the cumulative loading of As in 2009.

Table 2. Well construction details for shallow regolith (S) and transition-zone (T) monitoring wells and bedrock (B) water-supply wells at PMRS.

Well No	Type	Diameter	Material	Casing depth (ft)	Screen (ft)	Open Hole (ft)	Total depth below land surface (ft)	TZ thickness, estimated (ft)	Well yield (gpm) [^]	Topographic setting
PM-1 ^p	T, monitoring	4"	steel	98.4	no screen	6.3	104.7	54	>4.5*	slope
PM-2 ^p	S, monitoring	2"	pvc	25.5	15.0	screened	40.7	na	1*	slope
PM-3 ^p	T, monitoring	4"	steel	107.0	no screen	20.2	127.2	27	25	draw
PM-9 ^p	S, monitoring	4"	pvc	23.0	70.0	screened	94.1	na	10	draw
PM-5	S, monitoring	2"	pvc	48.0	15.0	screened	62.2	na	3	hill
PM-6 ^p	T, monitoring	4"	steel	110.0	no screen	43.4	153.4	35	20	valley, draw
PM-7 ^p	S, monitoring	2"	pvc	60.0	15.0	screened	75.2	na	2	valley, draw
PM-14	S, monitoring	2"	pvc	38.0	10.0	screened	47.4	na	2	hill
PM-15	S, monitoring	2"	pvc	43.0	10.0	screened	53.7	na	2	slope
PM-17 ^p	S, monitoring	2"	pvc	22.0	10.0	screened	31.0	na	1*	valley, draw
PM-18 ^p	T, monitoring	4"	steel	63.0	no screen	75.0	138.0	34	50	valley, draw
PM-19	S, monitoring	2"	pvc	40.0	10.0	screened	50.0	na	>4.5*	valley, draw
PM-22 ^p	T, monitoring	4"	steel	85.0	no screen	2.6	87.6	27	50	draw
PM-25 ^p	S, monitoring	4"	pvc	20.0	60.0	screened	82.6	na	12	draw
PM-R	B, water-supply	6"		152.0	no screen	148	300.0	na	25	slope
PM-O	B, water-supply	6"						na	>4.5*	valley, draw

^p well pair consisting of a regolith well and a transition zone well

[^] estimated by air lift method during drilling

* estimated during sampling using a 2-inch submersible pump

Table 3. Summary statistics of groundwater parameters measured in unfiltered samples of regolith, transition zone, and bedrock wells at PMRS.

Parameter	REGOLITH					TRANSITION ZONE				BEDROCK			
	Units	Count	Average	Median	Maximum	Count	Average	Median	Maximum	Count	Average	Median	Maximum
Dissolved Oxygen	mg/L	27	7.1	8.3	10	20	6.6	7.2	8.8	7	3.6	1.3	8.4
pH	pH	32	5.0	5.0	6.2	20	5.8	5.8	7.2	7	7.4	7.4	7.8
Oxid-Red Potential	mV	26	310	314	443	19	250	268	337	6	262	271	318
Temperature	C	32	16	16	18	20	16	16	17	7	17	17	17
Specific Conductance	uS/cm	32	38	17	107	20	48	29	123	7	143	157	189
Bicarbonate	mg/L	32	10	1.8	46	20	21	11	58	7	69	65	92
Total Dissolved Solids	mg/L	32	31	21.5	73	20	47	30	97	6	109	107	126
Chloride	mg/L	32	2.3	1.4	8.4	20	1.3	1.3	2.2	7	1.2	1.2	2.2
Silica	mg/L	18	10	7.6	23	10	19	12	36	4	26	25	34
Sulfate	mg/L	32	1.0	1.0	1.0	20	1.5	1.0	3.8	7	2.2	1.0	3.9
Nitrates	mg/L	32	0.90	0.36	5.6	20	0.11	0.11	0.27	7	0.02	0.01	0.04
Total Phosphorus	mg/L	32	0.13	0.05	0.95	20	0.04	0.02	0.09	7	0.04	0.05	0.08
Silver	µg/L	33	<5	<5	<5	20	<5	<5	<5	7	<5	<5	<5
Aluminum	µg/L	33	1495	140	14000	20	<50	<50	<50	7	<50	<50	<50
Arsenic	µg/L	33	4.8	1.0	45	20	1.1	1.0	2.4	7	11	1.0	26
Barium	mg/L	33	23	14	130	20	5.9	5.0	15	7	15	20	25
Calcium	mg/L	33	1.7	0.45	7.2	20	4.2	1.9	12	7	23	22	28
Cadmium	µg/L	33	0.5	0.5	0.5	20	0.5	0.5	0.5	7	<1	<1	<1
Chromium	µg/L	33	6.9	5.0	26	20	5.0	5.0	5.0	7	<5	<5	<5
Copper	µg/L	33	4.8	1.0	25	20	1.7	1.0	8.1	7	<2	<2	<2
Iron	µg/L	33	3653	280	26000	20	3746	1175	28000	7	32	25	68
Potassium	mg/L	33	0.71	0.41	3.8	20	0.55	0.50	0.88	7	1.0	1.0	1.4
Lead	µg/L	33	<10	<10	<10	20	<10	<10	<10	7	<10	<10	<10
Magnesium	mg/L	33	1.9	0.37	15	20	2.0	1.1	5.7	7	4.2	4.3	7.7
Manganese	µg/L	33	158	52	1600	20	64	27	300	7	20	5.0	42
Nickel	µg/L	33	<10	<10	<10	20	<10	<10	<10	7	<10	<10	<10
Selenium	µg/L	33	<5	<5	<5	20	<5	<5	<5	7	<5	<5	<5
Sodium	mg/L	33	4.0	2.0	14	20	3.9	1.9	7.5	7	5.2	6.3	8.7
Zinc	µg/L	33	16	5.0	84	20	<10	<10	1900	7	883	200	1900

Note: For concentrations below detection, one-half the detection levels were used in computations.

Table 4. Groundwater characteristics of monitoring and water-supply wells at PMRS based on four sampling events*.

Well ID	Collect date	Water level	Sampling depth	DO	pH	ORP	Temperature	Specific Cond.	Bicarbonate	Carbonate	Residue, Suspend	Dissolved solids	Org. Carbon	Chloride	Fluoride	Sulfide	Silica	Sulfate	Nitrite + Nitrate as N
		Below MP	Below MP	field	field	field	field	field	total	total	total	total	total	total	total	total	total	total	total
		(ft)	(ft)	(mg/L)	(std)	(mV)	(oC)	uS/cm	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
PM-1	12/15/2008	47.47	85	7.5	5.5	268	16.8	32	11	<1	<6.2	31	<2	1.3	<0.4	<0.1J6	12	<2.0	0.12
PM-1	6/8/2009	38.15	85	8.0	5.6	269	16.7	29	11	<1	na	29	na	1.3	<0.4	na	12	<2.0	0.12
PM-1	12/1/2009	39.70	85	7.5	5.8	189	16.5	29.1	11	<1	na	28	na	2.0	0.4	na	na	<2.0	0.13
PM-1	6/22/2010	31.18	90	6.4	5.1	277	17.0	28	10	<1	na	25	na	1.2	<0.4	na	na	<2.0	0.20
PM-2	6/22/2009	39.10	42	na	5.5	na	18.4	44	3.8	<1	na	38	na	4.3	<0.4	na	11	<2.0	2.20
PM-2	12/1/2009	40.53	42	na	na	na	na	na	na	na	na	na	na	4.6	<0.4	na	na	<2.0	1.30
PM-2	6/22/2010	32.05	39	7.4	4.8	230	17.4	38	3.3 J2	<1	na	28	na	4.3	<0.4	na	na	<2.0	1.30
PM-3	12/15/2008	47.24	110	8.0	5.4	268	16.6	25	6.8	<1	<6.2	26	<2	1.4	<0.4	<0.1J6	11	<2.0	0.20
PM-3	6/8/2009	37.07	110	7.6	5.2	292	16.6	22	5.2	<1	na	24	na	1.3	<0.4	na	11	<2.0	0.21
PM-3	12/7/2009	40.38	110	8.5	5.3	301	16.7	22.2	7.9	<1	na	31	na	<1.0	<0.4	na	na	<2.0	0.22
PM-3	6/21/2010	30.30	100	7.0	5.0	275	17.0	22	6.4	<1	na	18	na	1.2	<0.4	na	na	<2.0	0.27
PM-5	12/15/2008	54.30	60	na	4.7	na	15.4	16	2.7	<1	131	18	<2	1.4	<0.4	<0.1J6	7.8	<2.0	0.34
PM-5	6/22/2008	41.45	60	na	4.2	na	16.3	16	1	<1	na	16	na	1.3	<0.4	na	7.9	<2.0	0.26
PM-5	12/7/2009	47.32	60	9.1	3.9	321	15.5	12.5	<1	<1	na	24	na	<1.0	<0.4	na	na	<2.0	0.27
PM-5	6/21/2010	36.16	60	8.4		443	17.1	12	<1	<1	na	14	na	1.2	<0.4	na	na	<2.0	0.26
PM-6	1/22/2009	41.85	70	2.5	6.4	159	15.0	57	26	<1	38	62	<2	1.2	<0.4	<2.0	31	<2.0	<0.02
PM-6	6/15/2009	35.28	130	7.2	6.1	229	16.4	58	24	<1	na	70	na	1.2	<0.4	na	36	<2.0	<0.02
PM-6	12/1/2009	38.15	150	6.5	6.2	152	16.4	56	30	<1	na	66	na	1.9	<0.4	na	na	<2.0	<0.02
PM-6	6/21/2010	35.81	110	5.3	5.9	239	16.6	49	28	<1	na	86	na	<1.0	<0.4	na	na	<2.0	<0.02
PM-7	1/22/2009	38.29	70	9.0	5.4	306	15.1	18	5.2	<1	100	62	<2	<1.0	<0.4	<0.1	7.5	<2.0	0.02
PM-7	6/15/2009	31.82	70	9.2	4.9	250	16.6	14	1.8	<1	na	20	na	1.7	<0.4	na	7.5	<2.0	<0.02
PM-7	12/1/2009	38.63	72	8.9	5.2	224	15.5	16	1.8	<1	na	18	na	1.6	<0.4	na	na	<2.0	<0.02
PM-7	6/21/2010	31.36	60	8.0		303	16.2	13	3.2	<1	na	28	na	<1.0	<0.4	na	na	<2.0	<0.02
PM-9	12/15/2008	47.24	90	7.6	4.9	na	15.9	22	<1	<1	<6.2	23	<2	1.8	<0.4	<0.1J6	7.3	<2.0	1.0
PM-9	6/8/2009	37.08	90	8.9	4.5	393	16.5	20	<1	<1	na	20	na	1.6	<0.4	na	7.6	<2.0	1.0
PM-9	12/7/2009	40.39	55	8.8	4.3	332	15.5	19	<1	<1	na	25	na	1.0	<0.4	na	na	<2.0	1.1
PM-9	6/21/2010	30.20	60	8.3		372	15.5	20	<1	<1	na	28	na	1.6	<0.4	na	na	<2.0	0.76
PM-14	1/21/2009	40.49	45	8.8	5.1	271	14.4	14	<1	<1	186	<12	<2	1.2	<0.4	<0.1	6.8	<2.0	0.42
PM-14	6/22/2008	na	na	na	na	na	na	na	na	na	na	na	na	1.2	<0.4	na	7.3	<2.0	x2
PM-14	12/7/2009	35.95	50	na	4.9	na	14.1	14	<1	<1	na	19	na	<1.0	<0.4	na	na	<2.0	0.39
PM-14	6/29/2010	31.75	46	7.9		438	16.9	13	<1	<1	na	<12	na	1.1	<0.4	na	na	<2.0	0.43
PM-15	1/21/2009	38.03	48	na	5.2	na	15.6	17	2.7	<1	148	<12	<2	1.4	<0.4	<0.1	7.5	<2.0	0.35
PM-15	6/22/2008	34.41	53	8.0	4.8	414	16.8	15	2.8	<1	na	16	na	1.2	<0.4	na	7.4	<2.0	0.35

Well ID	Collect date	Water level	Samp-ling depth	DO	pH	ORP	Tempe- rature	Speci- fic Cond.	Bicarb- onate	Carbo- nate	Residue, Suspend	Dissolv- ed solids	Org. Carbo- n	Chlori- de	Flourid- e	Sulfide	Silica	Sulfate	Nitrite + Nitrate as N
		Below MP	Below MP	field	field	field	field	field	total	total	total	total	total	total	total	total	total	total	total
		(ft)	(ft)	(mg/L)	(std)	(mV)	(oC)	uS/cm	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
PM-17	1/21/2009	12.28	28	5.2	6.1	228	14.4	100	42	<1	460	43	<2	2.9	<0.4	<0.1	23	<2.0	0.26
PM-17	6/15/2009	9.05	30	9.5	6.1	370	15.0	92	45	<1	na	73	na	2.5	<0.4	na	23	<2.0	0.26
PM-17	12/1/2009	9.24	30	7.6	5.7	170	14.6	91	46	<1	na	70	na	3.3	<0.4	na	na	<2.0	0.24
PM-17	6/29/2010	13.85	30	6.1	6.2	284	14.5	101	44	<1	na	39	na	2.4	<0.4	na	na	<2.0	0.25
PM-18	1/21/2009	13.00	80	4.3	7.2	217	15.1	123	57	<1	<6.2	97	<2	1.3	<0.4	<0.1	30	3.8	0.04
PM-18	6/15/2009	10.42	119	4.6	7.0	253	16.0	113	58	<1	na	91	na	1.3	<0.4	na	30	3.7	0.05
PM-18	12/1/2009	11.45	120	4.6	7.1	170	16.0	108	56	<1	na	88	na	2.2	<0.4	na	na	3.0	0.05
PM-18	6/29/2010	14.25	110	3.6	6.7	229	16.3	107	54	<1	na	84	na	1.2	<0.4	na	na	3.2	0.05
PM-19	1/21/2009	13.26	47	0.5	5.6	245	15.2	107	29	<1	<6.2	58	<2	8.4	<0.4	<0.1	14	<2.0	1.80
PM-19	6/22/2008	8.88	50	0.7	5.5	249	15.8	95	28	<1	na	63	na	5.8	<0.4	na	14	<2.0	3.70
PM-19	12/1/2009	11.00	48	0.8	5.5	197	15.1	86	27	<1	na	62	na	5.6	<0.4	na	na	<2.0	3.40
PM-19	6/29/2010	8.39	48	0.3	5.2	293	15.5	106	22	<1	na	64	na	4.7	<0.4	na	na	<2.0	5.60
PM-22	12/15/2008	52.81	85	8.0	5.9	na	16.1	27	8.8	<1	<6.2	25	<2	1.1	<0.4	<0.1J6	9.5	<2.0	0.06
PM-22	6/8/2009	42.50	87	8.4	5.4	312	16.6	18	5.3	<1	na	20	na	1.3	<0.4	na	9.2	<2.0	0.11
PM-22	12/7/2009	45.85	87	8.8	4.6	305	16.3	22	5.1	<1	na	27	na	1	<0.4	na	na	<2.0	0.11
PM-22	6/22/2010	35.62	85	7.2		337	16.9	18	5.4	<1	na	15	na	1.1	<0.4	na	na	<2.0	0.15
PM-25	12/15/2008	53.51	75	8.9	4.4	361	16.3	13	<1	<1	21	20	<2	1.2	<0.4	<0.1J6	7.4	<2.0	0.32
PM-25	6/8/2009	43.03	70	9.1	4.6	321	16.5	14	<1	<1	na	18	na	1.4	<0.4	na	7.6	<2.0	0.36
PM-25	12/7/2009	46.68	67	8.4	4.1	357	15.3	14	<1	<1	na	18	na	1.4	<0.4	na	7.6	<2.0	0.36
PM-25	6/21/2010	36.31	70	7.6		328	16.0	16	<1	<1	na	16	na	1.3	<0.4	na	na	<2.0	0.33
PM-R	1/21/2009	n/a	n/a	0.3	7.6	na	16.4	189	89	<1	<6.2	113	<2	1.2	<0.4	<0.1	19	3.9	<0.02
PM-R	6/15/2009	n/a	n/a	1.3	7.3	251	16.7	158	92	<1	na	112	na	1.1	<0.4	na	19	3.9	0.04
PM-R	6/22/2010	n/a	n/a	0.2		318	16.7	175	87	<1	na	na	na	<1.0	<0.4	na	na	3.9	0.02
PM-O	1/22/2009	n/a	n/a	0.3	7.8	233	17.3	157	30	<1	<6.2	126	<2	1.3	<0.4	<0.1	31	<2.0	<0.02
PM-O	6/22/2009	n/a	n/a	8.4	7.0	290	16.9	90	62	<1	na	100	na	1.2	<0.4	na	34	<2.0	<0.02
PM-O	12/1/2009	n/a	n/a	7.3	7.1	185	16.7	116	65	<1	na	102	na	2.2	<0.4	na	na	<2.0	<0.02
PM-O	6/22/2010	n/a	n/a	7.1		292	16.8	116	59	<1	na	100	na	1.1	<0.4	na	na	<2.0	0.03

* held in Dec '08 - Jan '09, June '09, Dec '09, and June '10; PM-R sampled only on three occasions.

total= unfiltered sample; diss = filtered sample

B2 = counts from all filters were zero

Q1 = holding time exceeded prior to receipt at lab

J2 = reported value failed to meet QC criteria

J6 = unpreserved or improperly preserved sample

Table 4. Continued

Well ID	Phosphorus	Silver	Silver	Aluminum	Aluminum	Arsenic	Arsenic	Barium	Barium	Calcium	Calcium	Cadmium	Cadmium	Chromium	Chromium	Copper	Copper	Iron	Iron
	total	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss
	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
PM-1	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.9	1.8	<1.0	<1.0	<10	<10	5.2	<2.0	3600	110
PM-1	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.8	1.7	<1.0	<1.0	<10	<10	<2.0	<2.0	240	71
PM-1	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.8	1.8	<1.0	<1.0	<10		<2.0	<2.0	310	61
PM-1	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.9	1.9	<1.0	<1.0	<10	<10	<2.0	<2.0	570	100
PM-2	0.37	<5.0	<5.0	860	<50	18	<2.0	32	<10	5.0	1.7	<1.0	<1.0	<10	<10	22	<2.0	7200	<50
PM-2	0.95	<5.0	na	710	na	13	na	28	na	1.8	na	<1.0	na	<10	na	14	na	5100	na
PM-2	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	13	12	1.0	1.0	<1.0	<1.0	<10	<10	<2.0	<2.0	57	<50
PM-3	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.3	1.3	<1.0	<1.0	<10	<10	<2.0	<2.0	260	90
PM-3	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.3	1.3	<1.0	<1.0	<10	<10	<2.0	<2.0	260	87
PM-3	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.3	1.3	<1.0	<1.0	<10	<10	<2.0	<2.0	210	100
PM-3	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	1.3	1.3	<1.0	<1.0	<10	<10	<2.0	<2.0	2300	280
PM-5	0.19	<5.0	<5.0	1400	<50	9.6	<2.0	18	<10	0.60	0.46	<1.0	<1.0	<10	<10	4.8	<2.0	9200	<50
PM-5	0.10	<5.0	<5.0	1600	<50	10	<2.0	25	<10	2.50	0.17	<1.0	<1.0	<10	<10	4.8	<2.0	10000	<50
PM-5	0.14	<5.0	<5.0	700	<50	<2.0	<2.0	13	<10	0.16	0.10	<1.0	<1.0	<10	<10	<2.0	<2.0	2700	<50
PM-5	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	11	<10	0.16	22.00	<1.0	<1.0	<10	<10	<2.0	<2.0	280	<50
PM-6	0.09	<5.0	<5.0	<50	na	<2.0	na	15	na	4.8	na	<1.0	na	<10	na	<2.0	na	18000	na
PM-6	0.05	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	6.0	6.1	<1.0	<1.0	<10	<10	<2.0	<2.0	4500	76
PM-6	0.05	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	6.0	6.0	<1.0	<1.0	<10	<10	8.1	<2.0	6600	120
PM-6	0.08	<5.0	<5.0	<50	<50	<2.0	<2.0	13	<10	5.7	5.7	<1.0	<1.0	<10	<10	4.5	<2.0	28000	270
PM-7	0.06	<5.0	<5.0	2000	na	<2.0	na	25	na	1.3	na	<1.0	na	<10	na	<2.0	na	1200	na
PM-7	0.02	<5.0	<5.0	580	na	<2.0	na	15	na	0.24	na	<1.0	na	<10	na	<2.0	na	540	na
PM-7	0.18	<5.0	<5.0	5200	<50	3.0	<2.0	89	10	0.28	0.11	<1.0	<1.0	13	<10	25	<2.0	8200	<50
PM-7	<0.02	<5.0	<5.0	430	<50	<2.0	<2.0	14	<10	0.55	0.22	<1.0	<1.0	<10	<10	<2.0	<2.0	250	<50
PM-9	<0.02	<5.0	<5.0	<50	<50	<2.0	na	14	15	0.16	0.13	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-9	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	14	14	0.14	<0.10	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-9	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	14	14	0.11	<0.10	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-9	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	18	17	0.12	0.11	<1.0	<1.0	<2.0	<2.0	<2.0	<2.0	<50	<50
PM-14	0.13	<5.0	<5.0	1400	<50	45	<2.0	12	<10	0.23	0.20	<1.0	<1.0	<10	<10	7.7	<2.0	7100	<50
PM-14	x2	na	<5.0	na	<50	na	<2.0	na	<10	na	0.20	na	<1.0	na	<10	na	<2.0	na	<50
PM-14	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.19	0.21	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-14	<0.02	<5.0	<5.0	66	<50	<2.0	<2.0	<10	<10	0.20	0.19	<1.0	<1.0	<10	<10	<2.0	<2.0	240	<50
PM-15	0.16	<5.0	<5.0	2500	<50	20	<2.0	21	<10	0.54	0.44	<1.0	<1.0	<10	<10	13	<2.0	10000	<50
PM-15	<0.02	<5.0	<5.0	260	<50	<2.0	<2.0	<10	<10	0.45	0.4	<1.0	<1.0	<10	<10	<2.0	<2.0	1000	<50

Well ID	Phosphorus	Silver	Silver	Aluminum	Aluminum	Arsenic	Arsenic	Barium	Barium	Calcium	Calcium	Cadmium	Cadmium	Chromium	Chromium	Copper	Copper	Iron	Iron
	total	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss
	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
PM-17	0.54	<5.0	<5.0	14000	68	8.0	<2.0	130	11	6.6	4.9	<1.0	<1.0	26	<10	12	<2.0	26000	60
PM-17	0.34	<5.0	<5.0	5700	<50	3.5	<2.0	58	11	5.7	5.1	<1.0	<1.0	16	<10	6.9	<2.0	11000	<50
PM-17	0.48	<5.0	<5.0	9500	<50	5.2	<2.0	99	12	7.2	5.5	<1.0	<1.0	21	<10	9.1	<2.0	16000	100
PM-17	0.18	<5.0	<5.0	1900	<50	<2.0	<2.0	29	12	6.5	6.2	<1.0	<1.0	<10	<10	3.2	<2.0	3400	<50
PM-18	0.07	<5.0	<5.0	<50	<50	2.1	3.0	<10	<10	12	12	<1.0	<1.0	<10	<10	<2.0	<2.0	550	<50
PM-18	0.06	<5.0	<5.0	<50	<50	<2.0	2.9	<10	<10	11	12	<1.0	<1.0	<10	<10	<2.0	<2.0	550	<50
PM-18	0.07	<5.0	<5.0	<50	<50	2.4	2.8	<10	<10	12	12	<1.0	<1.0	<10	<10	<2.0	<2.0	950	<50
PM-18	0.07	<5.0	<5.0	<50	<50	<2.0	3.0	<10	<10	12	12	<1.0	<1.0	<10	<10	<2.0	<2.0	1500	<50
PM-19	0.07	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	3.2	3.2	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-19	0.05	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	3.3	3.2	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-19	0.06	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	2.8	2.9	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-19	0.04	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	3.4	3.4	<1.0	<1.0	<10	<10	<2.0	<2.0	56	<50
PM-22	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.90	0.85	<1.0	<1.0	<10	<10	<2.0	<2.0	2200	<50
PM-22	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.73	0.69	<1.0	<1.0	<10	<10	<2.0	<2.0	310	<50
PM-22	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.72	0.84	<1.0	<1.0	<10	<10	<2.0	<2.0	1400	670
PM-22	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.73	0.72	<1.0	<1.0	<10	<10	<2.0	<2.0	2600	130
PM-25	0.03	<5.0	<5.0	140	<50	<2.0	<2.0	<10	<10	0.23	0.19	<1.0	<1.0	<10	<10	2.1	<2.0	730	<50
PM-25	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.16	0.12	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-25	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.15	0.24	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-25	<0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	<10	<10	0.12	0.1	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-R	0.08	<5.0	<5.0	<50	<50	23	25	<10	<10	26	27	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-R	0.06	<5.0	<5.0	<50	<50	25	27	<10	<10	26	26	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-R	0.06	<5.0	<5.0	<50	<50	26	26	<10	<10	28	28	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-O	0.05	<5.0	<5.0	<50	<50	<2.0	3.3	25	25	22	22	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-O	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	20	21	18	19	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-O	0.02	<5.0	<5.0	<50	<50	<2.0	<2.0	21	22	20	20	<1.0	<1.0	<10	<10	<2.0	<2.0	<50	<50
PM-O	0.02	<5.0	<5.0	<50	<50	<2.0	na	21	na	19	na	<1.0	na	<10	na	<2.0	na	68	na

Table 4. Continued

Well ID	Mercury	Mercury	Potassium	Potassium	Magnesium	Magnesium	Manganese	Manganese	Sodium	Sodium	Nickel	Nickel	Lead	Lead	Selenium	Selenium	Zinc	Zinc	Coliform	Boron
	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	total
	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(cfu/100ml)	(ug/L)
PM-1	<0.20	<0.20	0.51	0.51	1.8	1.9	21	22	1.9	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-1	<0.20	<0.20	0.45	0.43	1.7	1.7	13	13	1.8	1.7	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-1	na	na	0.48	0.50	1.8	1.8	19	19	1.8	1.9	<10	<10	<10	<10	<5.0	<5.0	<10	<10	1 B2Q1	na
PM-1	na	na	0.50	0.47	1.9	1.9	24	25	1.9	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-2	<0.20	na	0.93	0.75	2.4	1.7	480	130	3.4	3.3	18	<10	<10	<10	<5.0	<5.0	40	<10	na	na
PM-2	na	na	0.77	na	1.7	na	350	na	3.4	na	14	na	<10	na	<5.0	na	35	na	na	na
PM-2	na	na	0.83	0.80	1.2	1.2	26	24	4.4	4.3	14	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-3	<0.20	<0.20	0.47	0.41	1.1	1.1	96	91	1.8	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-3	<0.20	<0.20	0.41	0.38	1.0	1.0	78	78	1.7	1.7	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-3	na	na	0.41	0.36	1.1	1.1	74	77	1.8	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	1 B2Q1	na
PM-3	na	na	0.42	0.40	1.1	1.1	84	83	1.8	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-5	<0.20	<0.20	0.41	0.28	0.23	0.19	250	49	1.7	1.6	<10	<10	<10	<10	<5.0	<5.0	16	<10	na	na
PM-5	<0.20	<0.20	0.43	0.26	0.76	0.16	310	35	1.8	1.7	<10	<10	<10	<10	<5.0	<5.0	20	<10	na	na
PM-5	na	na	0.29	0.21	0.19	0.16	150	44	1.5	1.4	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-5	na	na	0.26	0.23	0.19	0.13	41	35	1.6	1.5	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-6	na	na	0.71	na	0.57	na	300	na	7.2	na	<10	na	<10	na	<5.0	na	<10	na	na	na
PM-6	<0.20	<0.02	0.50	0.51	0.65	0.66	120	110	7.0	7.0	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-6	na	na	0.61	0.59	0.67	0.67	130	120	7.5	7.5	<10	<10	<10	<10	<5.0	<5.0	<10	<10	2 Q1	na
PM-6	na	na	0.64	0.60	0.64	0.65	190	75	7.2	7.1	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	87
PM-7	na	na	0.48	na	0.40	na	180	na	4.5	na	<10	na	<10	na	<5.0	na	12	na	na	na
PM-7	<0.20	na	0.16	na	0.19	na	100	na	2.0	na	<10	na	<10	na	<5.0	na	<10	na	na	na
PM-7	na	na	0.70	0.12	0.50	0.13	1600	57	1.5	1.6	<10	<10	<10	<10	<5.0	<5.0	28	<10	1 B2Q1	na
PM-7	na	na	0.19	0.13	0.20	<0.10	79	29	2.8	2.7	<10	<10	<10	<10	<5.0	<5.0	18	<10	na	<50
PM-9	<0.20	<0.20	0.25	0.24	0.32	0.32	47	49	2.3	2.3	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-9	<0.20	<0.20	0.26	0.24	0.29	0.29	52	51	2.1	2.1	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-9	na	na	0.26	0.22	0.31	0.31	50	51	2.4	2.4	<10	<10	<10	<10	<5.0	<5.0	<10	<10	1 B2Q1	na
PM-9	na	na	0.40	0.36	0.37	0.37	56	54	1.8	1.8	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-14	na	na	0.66	0.19	0.29	0.21	220	28	1.5	1.4	<10	<10	<10	<10	<5.0	<5.0	11	<10	na	na
PM-14	na	<0.20	na	0.18	na	0.2	na	29	na	1.3	na	<10	na	<10	na	<5.0	na	<10	na	na
PM-14	na	na	0.20	0.18	0.21	0.23	24	27	1.4	1.3	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-14	na	na	0.30	0.21	0.23	0.22	33	27	1.5	1.5	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-15	na	na	0.64	0.22	1.3	0.79	110	18	1.3	1.3	<10	<10	<10	<10	<5.0	<5.0	24	<10	na	na
PM-15	<0.20	na	0.26	0.21	0.78	0.73	29	18	1.2	1.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na

Well ID	Mercury	Mercury	Potassium	Potassium	Magnesium	Magnesium	Manganese	Manganese	Sodium	Sodium	Nickel	Nickel	Lead	Lead	Selenium	Selenium	Zinc	Zinc	Coliform	Boron
	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	diss	total	total
	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(cfu/100ml)	(ug/L)
PM-17	na	na	3.80	0.89	15	6.1	420	12	8.5	8.7	11	<10	<10	<10	<5.0	<5.0	77	<10	na	na
PM-17	<0.20	<0.20	1.80	0.78	9.1	6.2	170	<10	6.9	6.8	<10	<10	<10	<10	<5.0	<5.0	41	<10	na	na
PM-17	na	na	2.80	0.88	13	6.6	290	<10	7.0	7.1	<10	<10	<10	<10	<5.0	<5.0	84	<10	1 B2Q1	na
PM-17	na	na	1.30	0.90	8.4	7.3	53	<10	6.3	6.5	<10	<10	<10	<10	<5.0	<5.0	19	<10	na	<50
PM-18	na	na	0.88	0.81	5.7	5.8	<10	<10	7.4	7.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-18	<0.20	<0.20	0.78	0.79	5.3	5.4	<10	<10	6.8	6.7	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-18	na	na	0.84	0.86	5.5	5.6	<10	<10	7.3	7.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	1 B2Q1	na
PM-18	na	na	0.86	0.91	5.7	5.8	<10	<10	7.2	7.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-19	na	na	0.98	0.97	1.3	1.3	46	47	14.0	14.0	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-19	<0.20	<0.20	0.84	0.80	1.2	1.2	50	50	13	13	<10	<10	<10	<10	<5.0	<5.0	11	<10	na	na
PM-19	na	na	0.92	0.93	1.1	1.2	42	44	13	13	<10	<10	<10	<10	<5.0	<5.0	12	11	8 Q1	na
PM-19	na	na	1.20	1.20	1.3	1.3	52	52	14	14	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-22	<0.20	<0.20	0.49	0.44	1.1	1.0	22	21	1.4	1.3	<10	<10	<10	<10	<5.0	<5.0	1900	1600	na	na
PM-22	<0.20	<0.20	0.37	0.34	0.71	0.7	34	33	1.2	1.3	<10	<10	<10	<10	<5.0	<5.0	650	640	na	na
PM-22	na	na	0.35	0.35	0.75	0.78	29	31	1.3	1.3	<10	<10	<10	<10	<5.0	<5.0	950	900	na	na
PM-22	na	na	0.39	0.34	0.75	0.76	23	21	1.3	1.2	<10	<10	<10	<10	<5.0	<5.0	1400	990	na	na
PM-25	<0.20	<0.20	0.28	0.24	0.28	0.27	51	32	1.3	1.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-25	<0.20	<0.20	0.20	0.18	0.23	0.22	37	37	1.2	1.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-25	na	na	0.20	0.20	0.25	0.25	37	36	1.3	1.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	na
PM-25	na	na	0.30	0.28	0.26	0.26	43	41	1.3	1.2	<10	<10	<10	<10	<5.0	<5.0	<10	<10	na	<50
PM-R	na	na	1.40	1.40	7.5	7.7	39	41	2.8	2.8	<10	<10	<10	<10	<5.0	<5.0	190	240	na	na
PM-R	<0.20	<0.20	1.30	1.30	7.2	7.3	42	43	2.7	2.8	<10	<10	<10	<10	<5.0	<5.0	70	90	na	na
PM-R	na	na	1.4	1.4	7.7	7.6	38	38	2.8	2.7	<10	<10	<10	<10	<5.0	<5.0	200	160	na	na
PM-O	na	na	0.54	0.52	4.3	4.4	<10	<10	8.7	8.9	<10	<10	<10	<10	<5.0	<5.0	120	120	na	na
PM-O	<0.20	<0.20	0.65	0.61	0.8	0.86	<10	<10	6.3	6.2	<10	<10	<10	<10	<5.0	<5.0	1900	1900	na	na
PM-O	na	na	0.68	0.66	0.90	0.92	<10	<10	6.8	6.8	<10	<10	<10	<10	<5.0	<5.0	1900	1900	5 Q1	na
PM-O	na	na	0.72	na	0.88	na	<10	na	6.6	na	<10	na	<10	na	<5.0	na	1800	na	na	na

Table 5. Water quality characteristics in unfiltered stream water and unfiltered groundwater from stream-bed piezometers.

Stream / Well ID	Collect date	Sampling depth	Dissolved Oxygen	pH	ORP	Temperature	Specific Cond.	Bicarbonate	Carbonate	Dissolved solids	Chloride	Fluoride	Sulfate	Nitrate	Phosphorus	Silver	Aluminum
		(ft)	(mg/L)	(std)	(mV)	(oC)	uS/cm	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(ug/L)	(ug/L)
stream - east	6/22/2009	na	na	na	na	na	na	24	<1	na	3.7	<0.4	<2.0	0.56	0.03	<5.0	<50
PZ-1 in stream - east	6/29/2010	10	5.7	4.51	467	15.7	33	9	<1	28	1.8	<0.4	<2.0	0.07	0.07	<5.0	2600
stream - main	6/22/2009	na	na	na	na	na	na	48	<1	na	4.0	<0.4	2.6	0.93	0.14	<5.0	460
PZ-2 in stream - main	6/29/2010	10	2.8	6.24	203	19.5	169	66	<1	123	2.7	<0.4	7.7	<0.02	0.26	<5.0	55000
stream at confluence	12/7/2009	na	na	6.3	na	7.8	64	15	<1	na	2.8	<0.4	5.4	0.82	0.06	<5.0	180

Stream / Well ID	Collect date	Arsenic	Barium	Calcium	Cadmium	Chromium	Copper	Iron	Mercury	Potassium	Magnesium	Manganese	Sodium	Nickel	Lead	Selenium	Zinc
		(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(mg/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
stream - east	6/22/2009	<2.0	10	5.8	<1.0	<10	<2.0	720	<0.2	1.8	2.3	43	3.1	<10	<10	<5.0	13
PZ-1 in stream - east	6/29/2010	3.1	18	1.5	<1.0	<10	6.1	5800	na	1.2	0.97	1600	2.8	<10	<10	<5.0	38
stream - main	6/22/2009	9.8	16	16	<1.0	<10	2.7	1100	<0.2	2.8	2.2	11	3.8	<10	<10	<5.0	<10
PZ-2 in stream - main	6/29/2010	100	250	23	<1.0	98	47	120000	na	7.3	14	540	6.2	24	56	<5.0	300
stream at confluence	12/7/2009	3.0	19	6.4	<1.0	<10	<2.0	760	na	2.7	1.9	48	2.9	<10	<10	<5.0	<10

B2 = counts from all filters were zero

Q1 = holding time exceeded prior to receipt at lab

J2 = reported value failed to meet QC criteria

J6 = unpreserved or improperly preserved sample

Table 6. Groundwater characteristics of private water-supply wells sampled near the PMRS.

Well	County	Date Sampled	pH	Oxidation-Reduction Potential (mV)	Dissolved Oxygen (mg/L)	Specific Conductance (uS/cm)	Analysis*	Silver (ug/L)	Aluminum (ug/L)	Arsenic (ug/L)	Barium (ug/L)	Calcium (mg/L)	Cadmium (ug/L)	Chromium (ug/L)
And	Gaston	7/21/2008	6.14	-34	6.6	95	Total	<5.0	<50	9.3	<10	8.2	<1.0	<10
Bla-1	Gaston	7/21/2008	5.31	-37	6.9	56	Total	<5.0	<50	<5.0	11	6.3	<1.0	<10
Bla-2	Gaston	7/21/2008					Dissolved	<5.0	<50	<5.0	11	6.3	<1.0	<10
Bow	Gaston	7/15/2008	6.16	33	6.9	158	Total	<5.0	<50	<5.0	<10	11	<1.0	<10
Bur	Gaston	7/30/2008	6.64	-40	7.3	153	Total	<5.0	<50	<5.0	27	22	<1.0	<10
Can	Gaston	8/5/2008	6.57	-146	6.5	113	Total	<5.0	<50	<5.0	<10	11	<1.0	<10
Car	Gaston	7/16/2008	7.22	20	2.3	107	Total	<5.0	<50	<5.0	<10	11	<1.0	<10
Cos	Gaston	8/5/2008	5.74	-118	6.8	45	Total	<5.0	<50	<5.0	11	5.7	<1.0	<10
Eub	Gaston	7/16/2008	6.09	35	4.6	146	Total	<5.0	<50	<5.0	<10	13	<1.0	<10
Gob	Gaston	8/13/2008	7.96	-269	0.2	143	Total	<5.0	<50	<5.0	<10	21	<1.0	<10
Gre-1	Gaston	8/5/2008	4.24	4	4.2	46	Total	<5.0	<50	<5.0	15	2.7	<1.0	<10
Gre-2	Gaston	8/5/2008					Dissolved	<5.0	<50	<5.0	14	2.8	<1.0	<10
Kru	Gaston	7/31/2008	6.42	-164	2.6	88	Total	<5.0	<50	<5.0	<10	6.7	<1.0	<10
Mcc	Gaston	8/13/2008	7.00	-123	6.0	163	Total	<5.0	<50	<5.0	33	20	<1.0	<10
Mes	Gaston	7/15/2008	6.57			136	Total	<5.0	<50	<5.0	22	15	<1.0	<10
Moo	Gaston	8/13/2008	6.21	-99	9.4	48	Total	<5.0	<50	<5.0	<10	5.6	<1.0	<10
Nec	Gaston	8/5/2008	6.82	-154	7.5	93	Total	<5.0	<50	<5.0	<10	7.4	<1.0	<10
Pas	Gaston	7/15/2008	6.01			139	Total	<5.0	<50	<5.0	<10	17	<1.0	<10
Pea	Gaston	7/21/2008	5.33	-44	7.2	43	Total	<5.0	<50	<5.0	25	2.1	<1.0	<10
Pro	Gaston	8/5/2008	7.93	-246	0.3	257	Total	<5.0	<50	<5.0	24	43	<1.0	<10
Riv-1	Gaston	7/31/2008	5.87	-152	7.4	67	Total	<5.0	<50	<5.0	<10	5.1	<1.0	<10
Riv-2	Gaston	7/31/2008					Dissolved	<5.0	<50	<5.0	<10	5.1	<1.0	<10
Shi	Gaston	7/30/2008	6.18	-11	7.6	55	Total	<5.0	<50	<5.0	<10	4.3	<1.0	<10
Ste	Gaston	7/31/2008	5.61	-107	6.6	32	Total	<5.0	<50	<5.0	<10	1.8	<1.0	<10
Str	Gaston	7/16/2008	6.27	44	7.7	52	Total	<5.0	<50	<5.0	<10	4.5	<1.0	<10
Ste	Gaston	7/15/2008	5.92			58	Total	<5.0	<50	<5.0	<10	4.2	<1.0	<10
Wri	Gaston	7/16/2008	6.16	30	2.8	238	Total	<5.0	<50	<5.0	<10	25	<1.0	<10
Way-1	Gaston	7/30/2008	3.44	19	6.4	30	Total	<5.0	<50	<5.0	22	1.2	<1.0	<10
Way-2	Gaston	7/30/2008					Dissolved	<5.0	<50	<5.0	22	1.2	<1.0	<10

* Total represents unfiltered samples, while dissolved represents 0.45-micron filtered samples.

Table 6. Continued

Well	Iron (ug/L)	Potassium (mg/L)	Magnesium (mg/L)	Manganese (mg/L)	Sodium (mg/L)	Nickel (ug/L)	Lead (ug/L)	Selenium (ug/L)	Zinc (ug/L)	Nitrate + Nitrite (mg/L)	Phosphorus, total (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Alkalinity- 4.5 (mg/L)
And	<50		6.1	<10	2.9	<10	<10	<5.0	<10	2.80	na	<2.0	3.9	<0.4	27
Bla-1	<50	0.60	2.5	17	2.1	<10	<10	<5.0	<10	0.83	na	<2.0	2.3	<0.4	21
Bla-2	<50	0.65	2.6	na	2.1	<10	<10	<5.0	<10	na	na	na	na	na	na
Bow	<50	0.76	4.6	<10	16.0	<10	<10	<5.0	15	5.9	0.11	<2.0	9	<0.4	34
Bur	<50	0.49	4.4	<10	7.7	<10	<10	<5.0	<10	1.6	na	<2.0	3.1	<0.4	61
Can	<50	0.89	5.8	<10	5.1	<10	<10	<5.0	26	1.7	na	1.4	1.9	<0.4	43
Car	<50	0.99	5.6	<10	4.2	<10	<10	<5.0	<10	0.19	<0.02	4.2	1.8	<0.4	43
Cos	<50	0.19	0.18	18	3.2	<10	<10	<5.0	15	0.41	na	<2.0	2.8	<0.4	14
Eub	<50	0.73	8.1	<10	6.5	<10	<10	<5.0	<10	3.2	0.04	2.3	6.8	<0.4	43
Gob	320	0.86	3.0	33	6.0	<10	<10	<5.0	<10	<.02	<0.02	9.5	1.9	<0.4	55
Gre-1	<50	0.50	1.6	14	3.8	<10	<10	<5.0	12	1.8	na	1.4	2.2	<0.4	6.6
Gre-2	<50	0.48	1.6	13	3.7	<10	<10	<5.0	19	na	na	na	na	na	na
Kru	2500	0.57	4.7	410	1.3	<10	<10	<5.0	<10	0.13	na	4.9	2	<0.4	26
Mcc	<50	1.9	8.6	<10	2.4	<10	<10	<5.0	<10	0.22	0.03	3.0	2.7	<0.4	71
Mes	<50	1.3	5.7	<10	6.2	<10	<10	<5.0	<10	1.8	0.05	2.0	3.5	<0.4	50
Moo	<50	0.40	1.7	<10	1.7	<10	<10	<5.0	62	0.62	<0.02	<2.0	2.3	<0.4	15
Nec	<50	1.2	3.4	<10	8.9	<10	<10	<5.0	<10	<.02	na	1.1	1.5	<0.4	43
Pas	<50	1.1	3.7	11	11.0	<10	<10	<5.0	<10	0.96	0.10	3.5	2.8	<0.4	58
Pea	<50	0.73	1.7	<10	3.8	<10	<10	<5.0	10	1.4	<0.02	<2.0	3.7	<0.4	6.5
Pro	<50	2.9	5.6	<10	7.0	<10	<10	<5.0	<10	1.0	na	6.1	2.5	<0.4	110
Riv-1	<50	0.39	1.5	<10	9.0	<10	<10	<5.0	<10	0.14	na	<2.0	1.7	<0.4	28
Riv-2	<50	0.39	1.5	<10	9.0	<10	<10	<5.0	<10	na	na	na	na	na	na
Shi	<50	0.31	0.91	<10	7.5	<10	<10	<5.0	17	0.2	na	<2.0	1.7	<0.4	22
Ste	<50	0.15	1.8	<10	1.4	<10	<10	<5.0	17	0.19	na	<2.0	3.1	<0.4	4
Str	<50	0.34	2.4	<10	2.9	<10	<10	<5.0	<10	1.40	0.05	<2.0	21	<0.4	14
Ste	<50	1.0	0.97	<10	8.1	<10	<10	<5.0	14	0.41	0.08	<2.0	2.2	<0.4	23
Wri	<50	1.3	14	<10	8.3	<10	<10	<5.0	13	0.48	0.04	13	6	<0.4	87
Way-1	<50	0.23	0.51	31	3.4	<10	<10	<5.0	<10	0.93	na	<2.0	3.2	<0.4	2
Way-2	<50	0.22	0.51	31	3.4	<10	<10	<5.0	<10	na	na	na	na	na	na

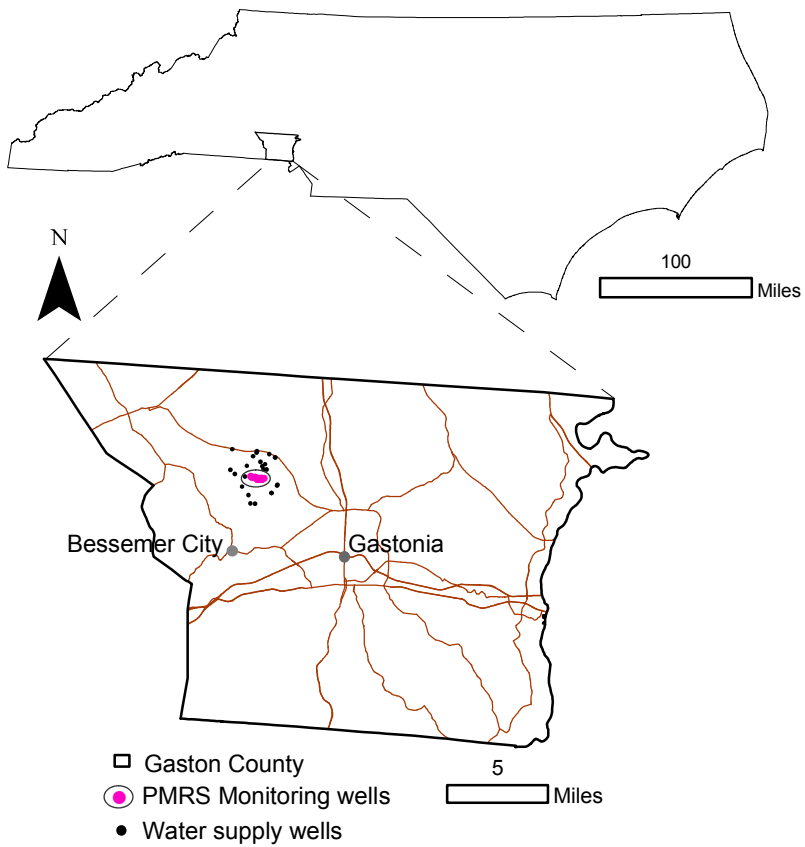
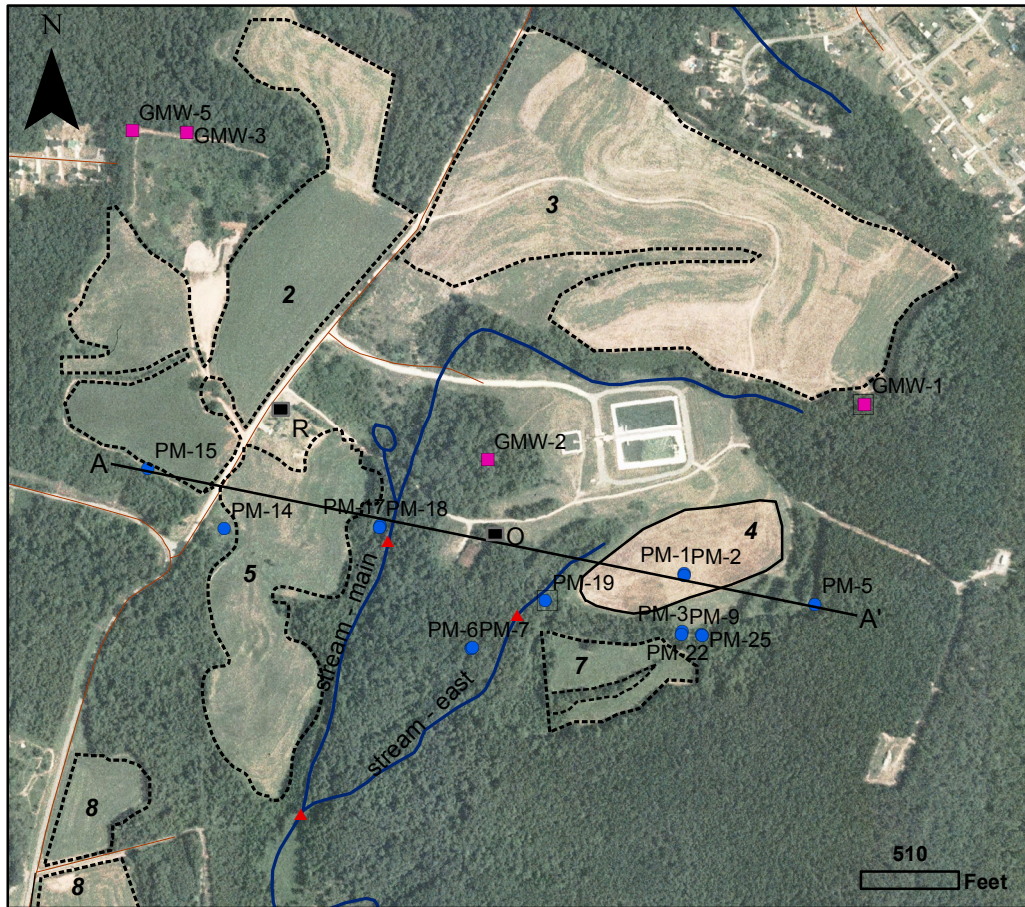


Figure 1a. Location of Pasour Mountain groundwater monitoring and research station (PMRS) in Gaston County, North Carolina. Also shown are locations of water-supply wells sampled near PMRS.



- PMRS Monitoring Wells
 - Bedrock, Water-Supply Wells
 - Gastonia Monitoring Wells, old (pre-2009)
 - Gastonia Monitoring Wells, current (2010) permit
 - Wastewater application field
 - Residuals application field
 - 4 Field Number
- Bess Town Rd
To Bessemer City, NC

Figure 1b. Site map / aerial photo of the PMRS, showing well locations, application fields, and the two segments of PMRS stream. The two bedrock wells are a residential water-supply well (R) and an old well (O) with limited non-potable usage. Field # 1 and GMW-4 are located north of field #3, outside the map area. Since 2009, field # 3 has been used as a wastewater application field.

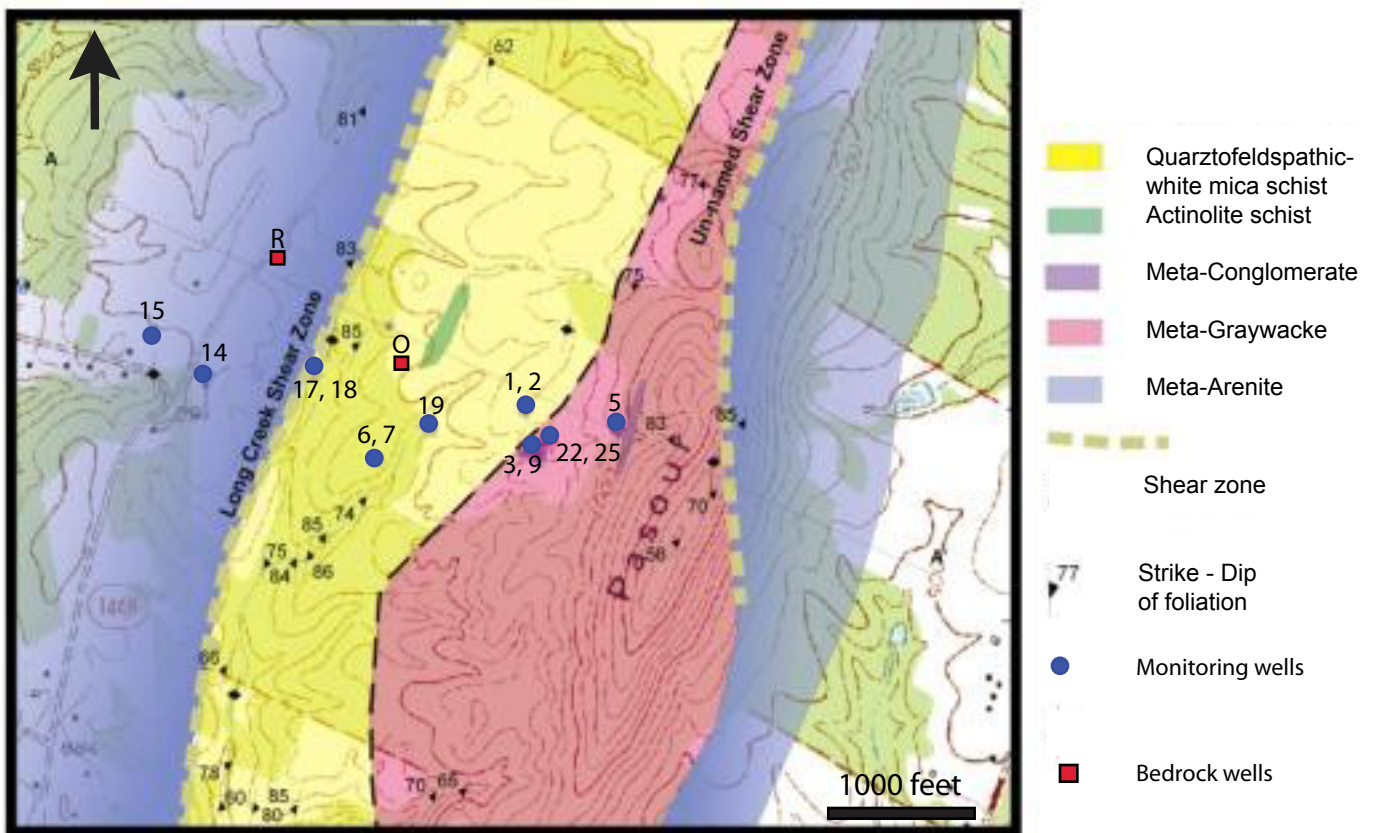


Figure 2. Geologic map of the Pasour Mountain groundwater monitoring and research station (PMRS) from Pippin and others (2003). For well details, see Figure 1b and Table 2.

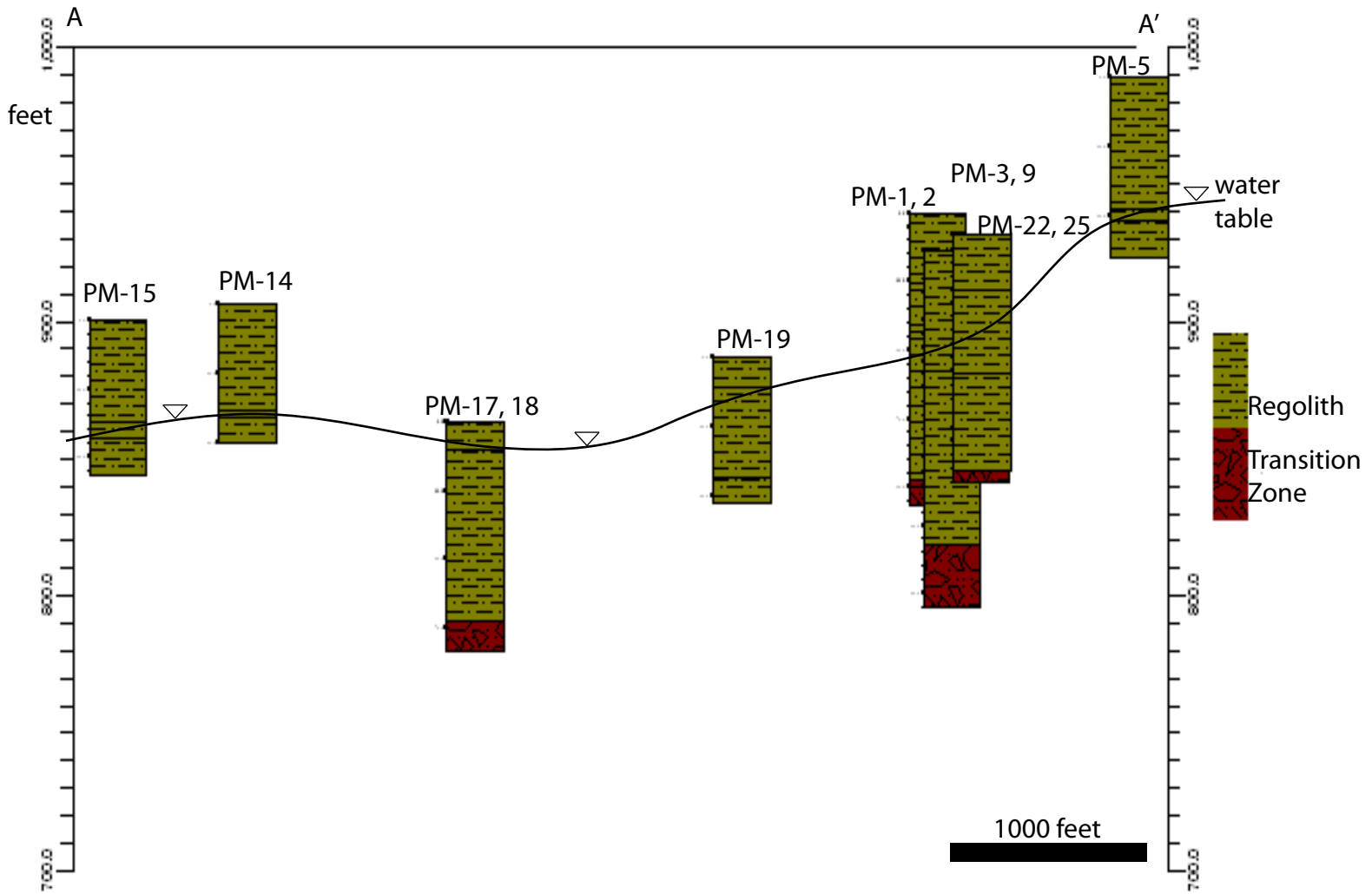


Figure 3. Hydrogeologic section along a A-A' profile (Figure 1) at the Pasour Mountain Research Station. For estimated thickness of transition zone see Table 2.

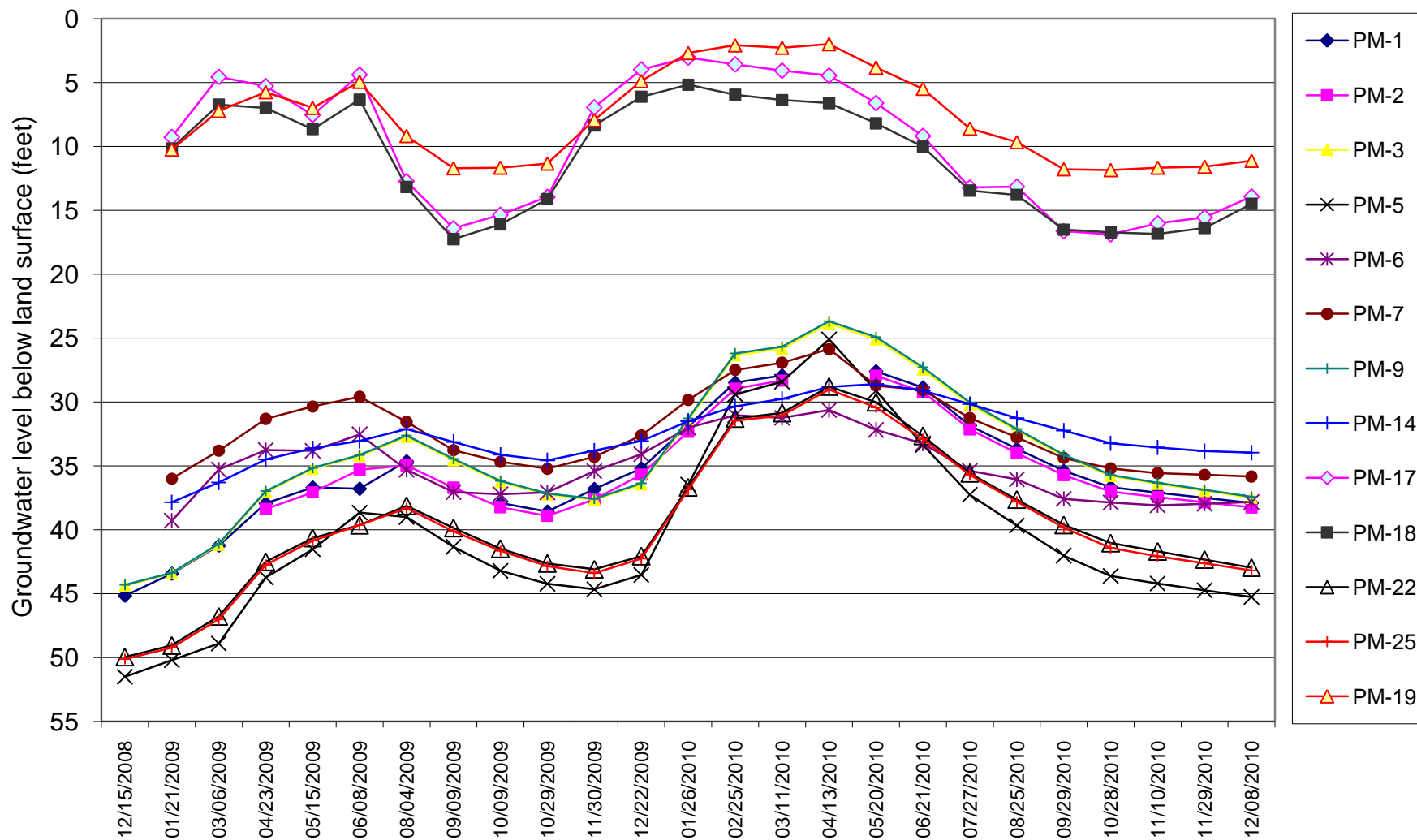


Figure 4. Groundwater levels below land surface in the PMRS monitoring wells from 12/2008 through 12/2010.

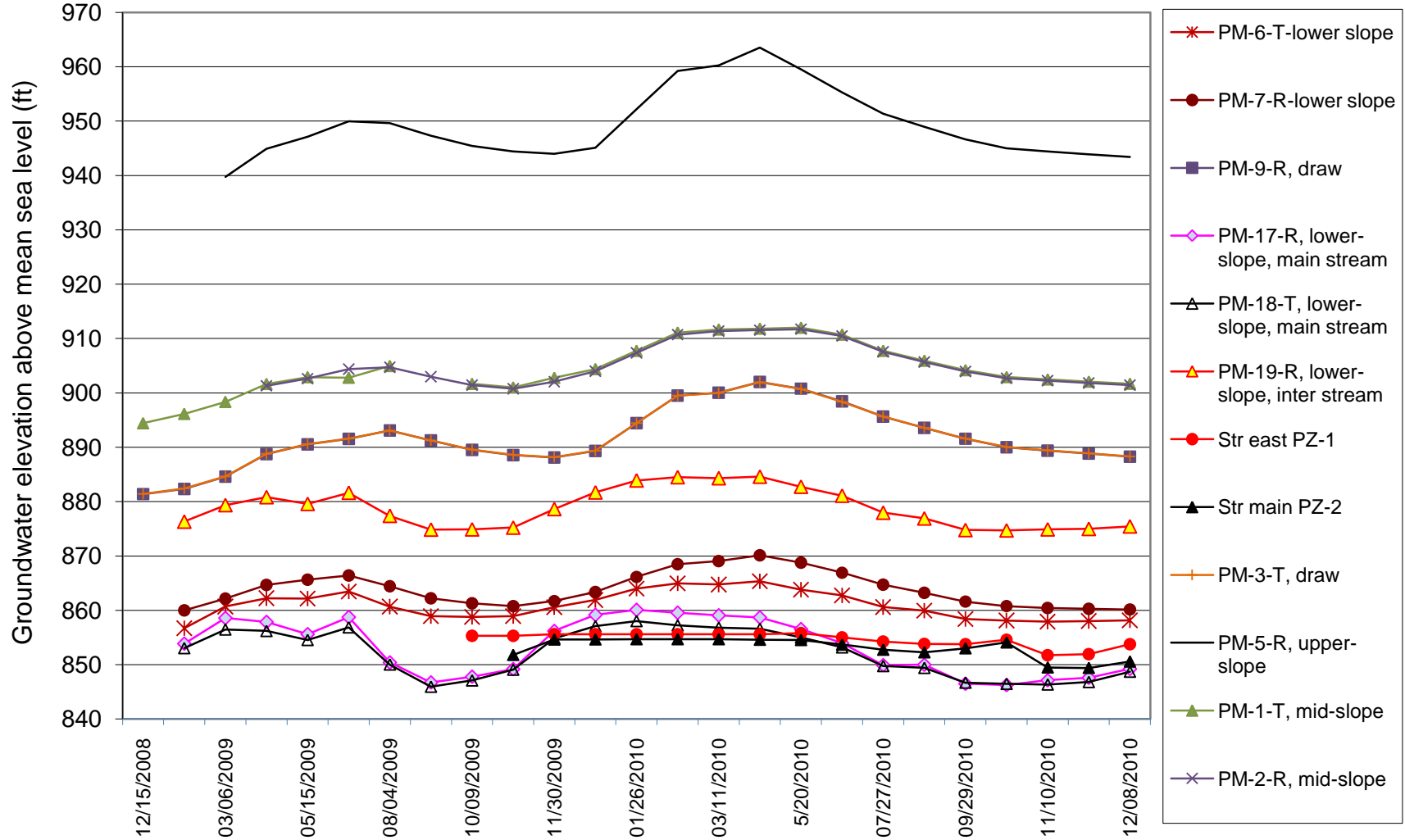


Figure 5. Groundwater elevations in monitoring wells located in different topographic setting at PMRS from 12/2008 through 12/2010. Note: Wells PM-1 and PM-2, PM-3 and PM-9, PM-6 and PM-7, PM-17 and PM-18 are pairs of regolith (R) and transition (T) zone wells located adjacent to each other.

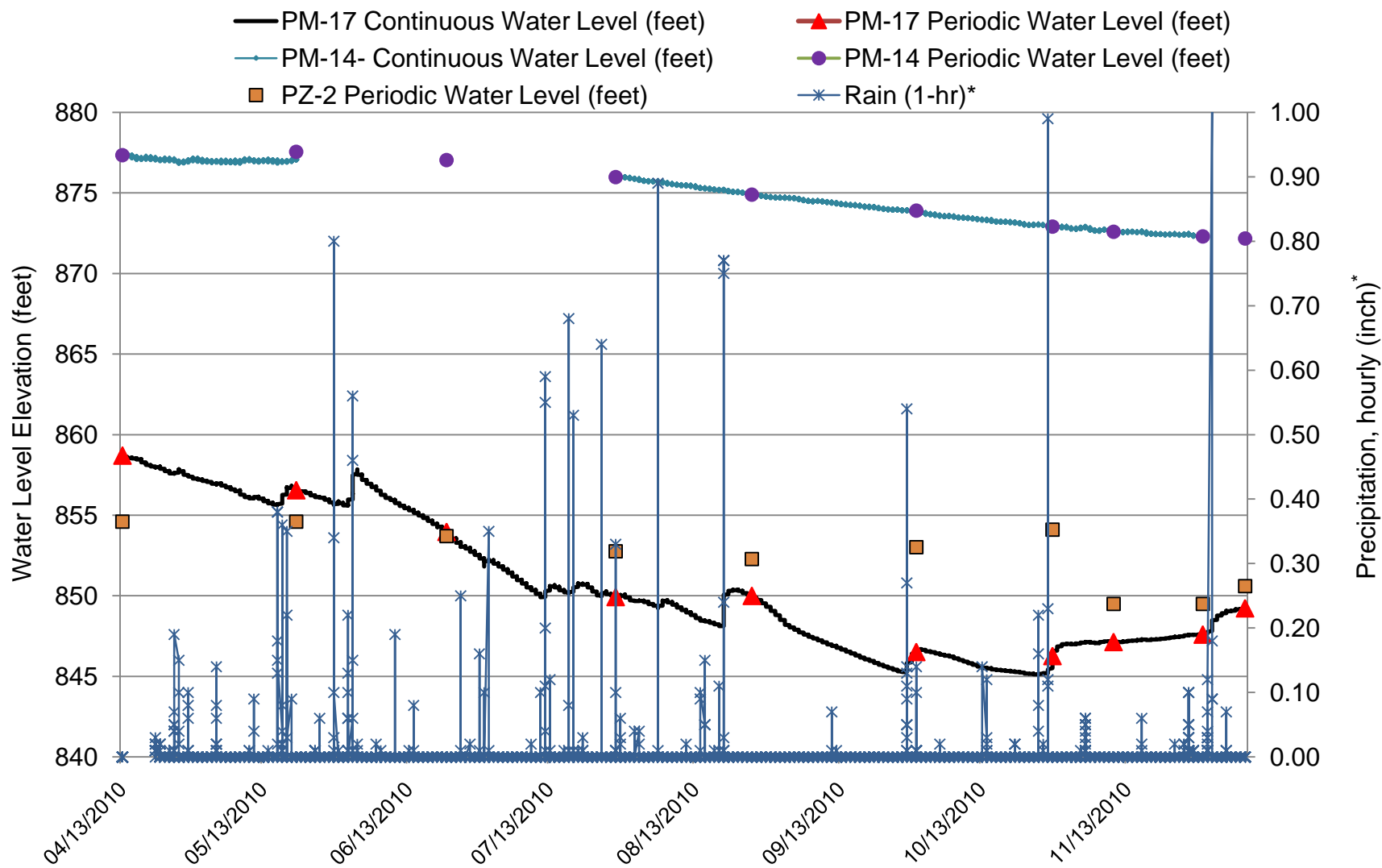


Figure 6. Continuous and periodic water level measurements in up-slope well PM-14 and near-stream well PM-17 and periodic water level measurements in near-stream piezometer PZ-2 at PMRS. Data range from 04-2010 to 12-2010.

*Precipitation data shown here are hourly totals from the provisional 5-minute or 15-minute data reported at an onsite USGS station #352012081154345, or when unavailable from station #351822081140545, located about 5 miles away.

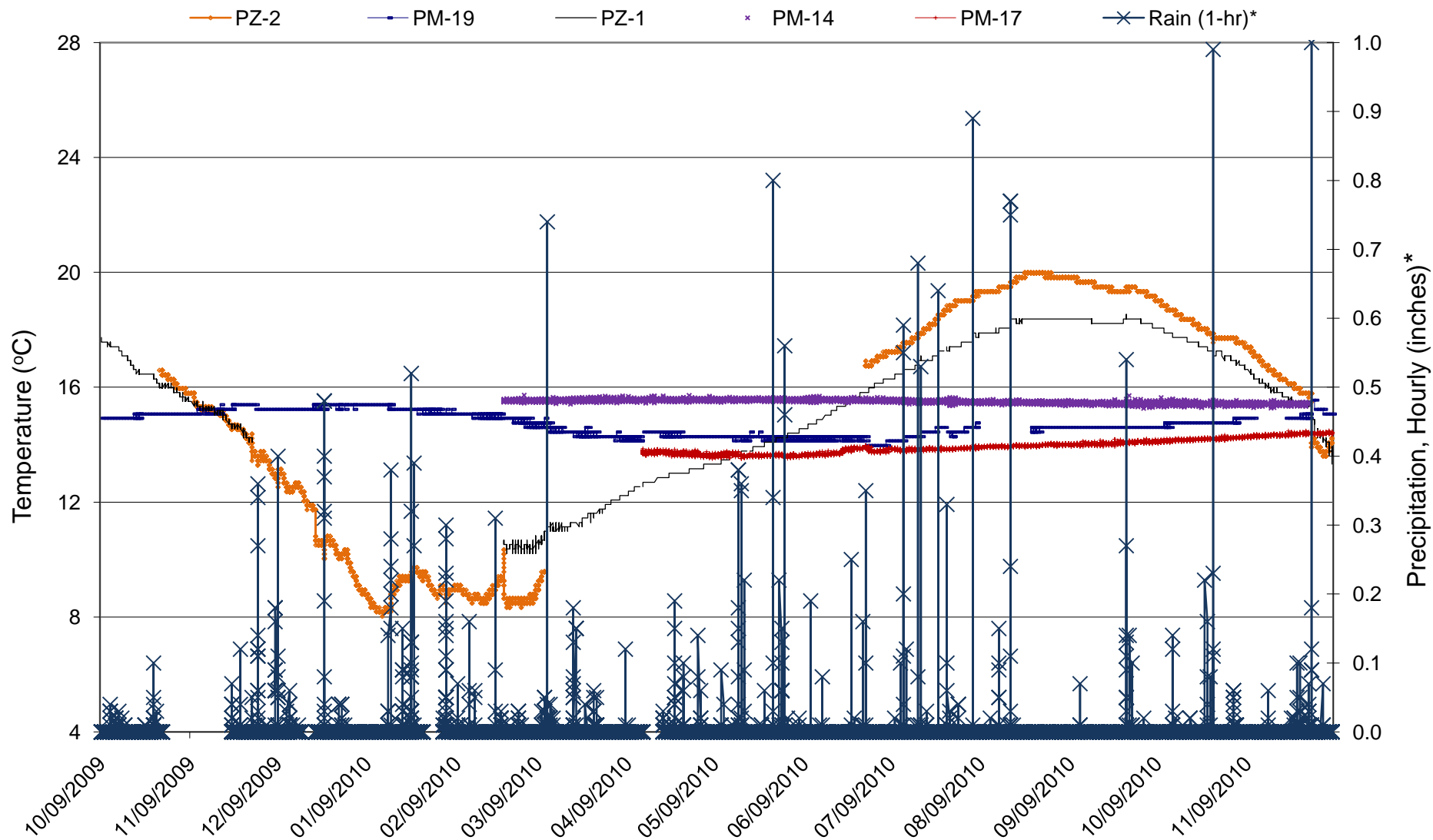


Figure 7. Continuous groundwater temperatures in regolith monitoring wells PM-14, PM-17 and PM-19 and stream piezometers PZ-1 and PZ-2. Partial loss of data occurred in PZ-1 and PZ-2. Data range between 10-2009 and 12-2010.

* Precipitation data shown here are hourly totals from the provisional 5-minute or 15-minute data reported at an onsite USGS station #352012081154345, or when unavailable from station #351822081140545, located about 5 miles away.

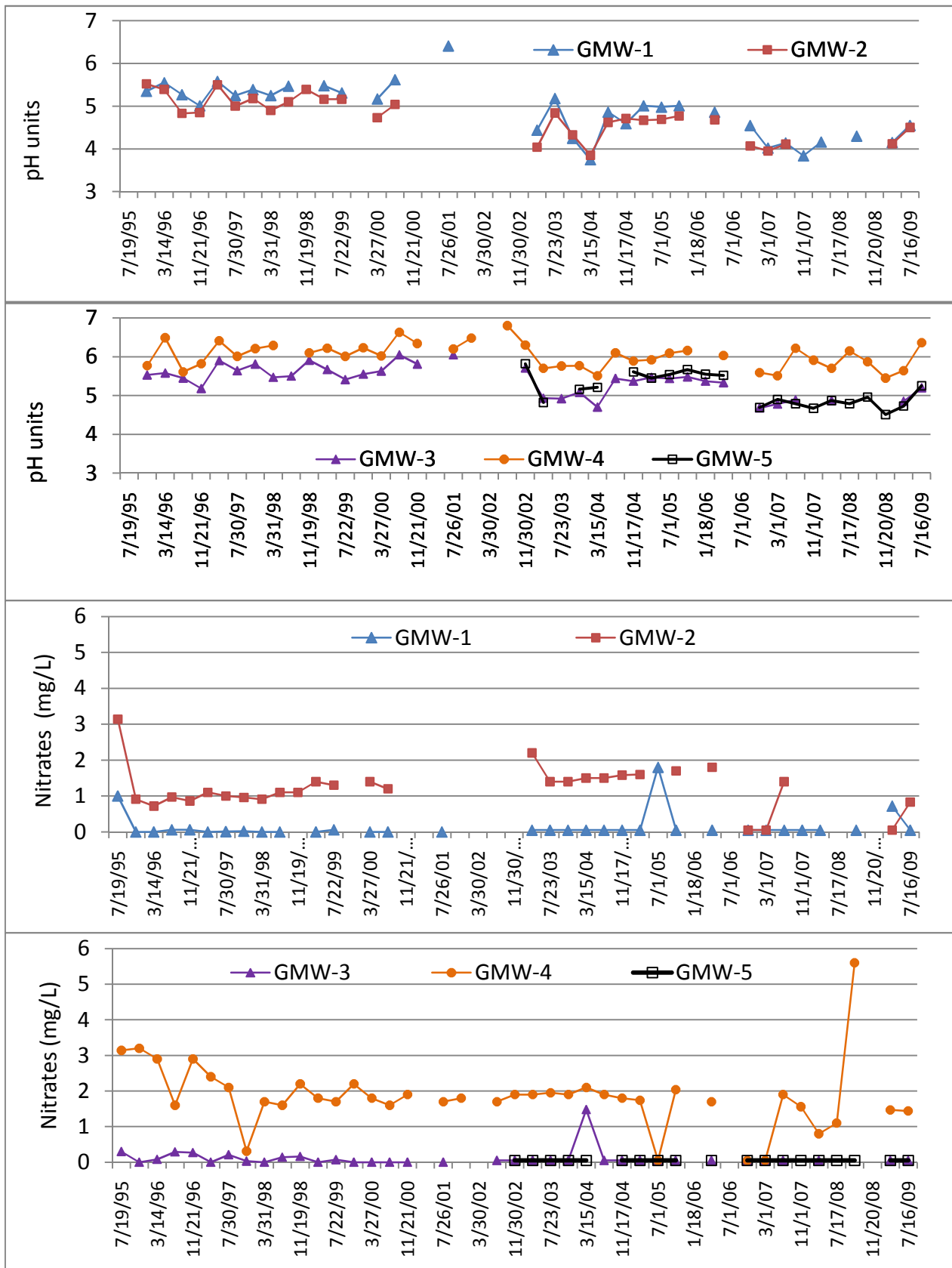


Figure 8. Concentrations of nitrate and pH in monitoring wells GMW-1 through 5 reported (3 times a year) by the City of Gastonia from 1995 through 2009.

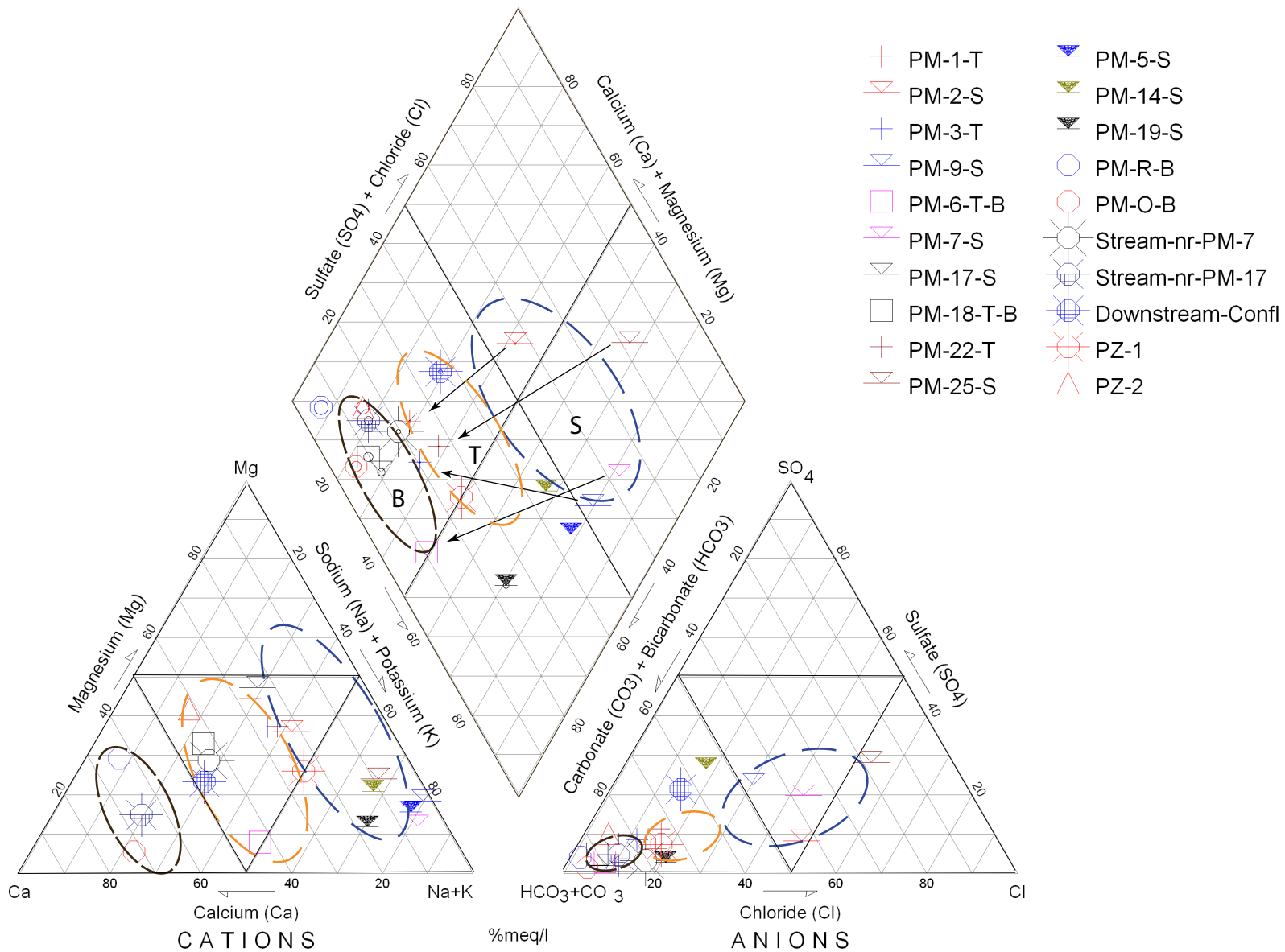


Figure 9. Major ionic concentrations of groundwater at the PMRS are shown on a Piper diagram. Each point represents a well or a stream sample collected on December 1 or 7, 2009, except for upstream samples near PM-7 & 17 that were collected on June 22 2009. The ellipses are approximations shown to group groundwater zones as shallow regolith (S), transition zone (T), and bedrock (B). The arrows indicate groundwater evolution from shallow regolith to the transition zone. Groundwater appears to evolve from a Na-K-mixed-anion type water in the regolith to Ca-HCO₃ type water in the bedrock. Two transition zone wells, PM-6 & PM-18, are interpreted to represent upper bedrock zone (hence the suffix T-B).

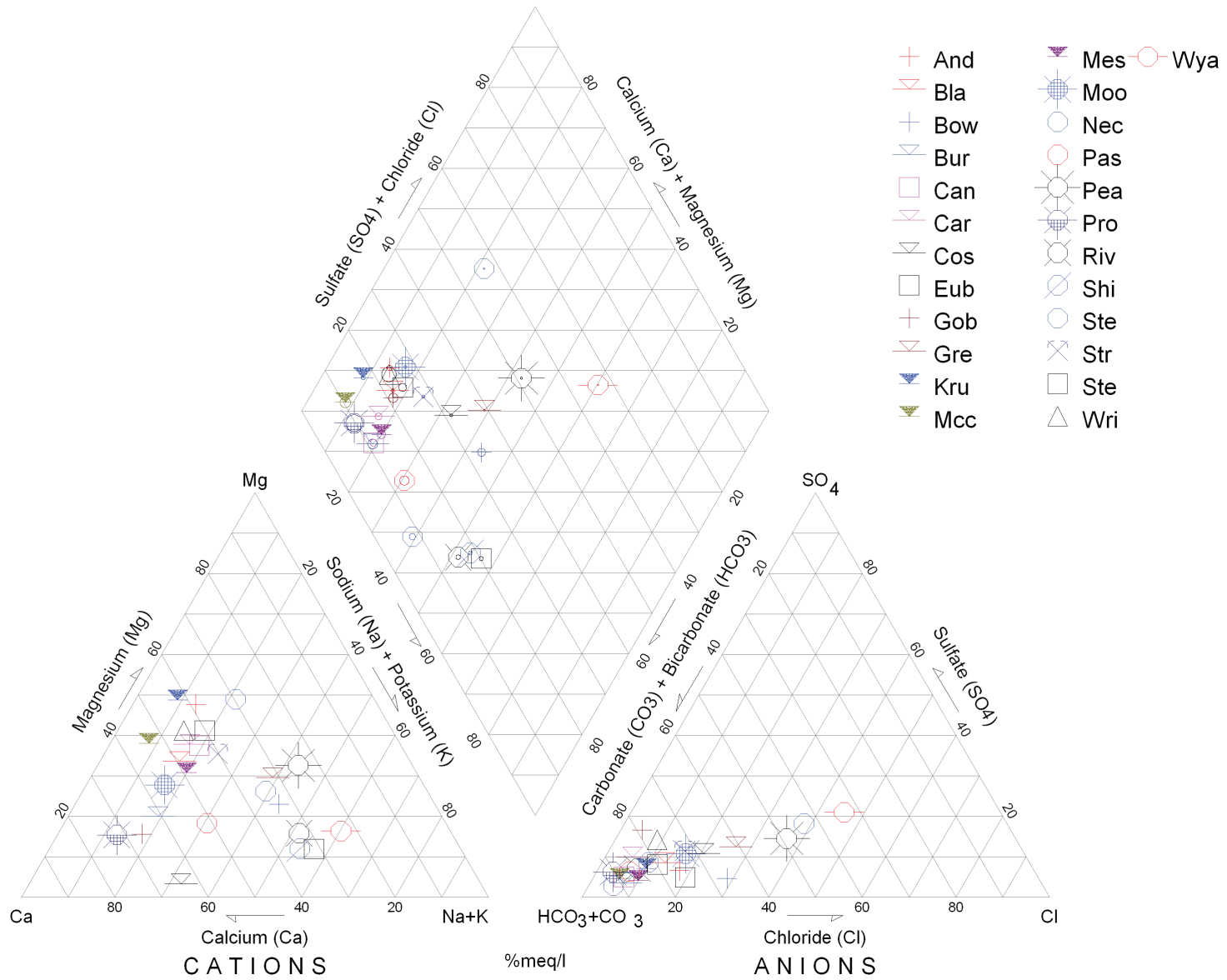


Figure 10. Major ionic concentrations in the water-supply wells sampled near the PMRS shown on a Piper diagram.

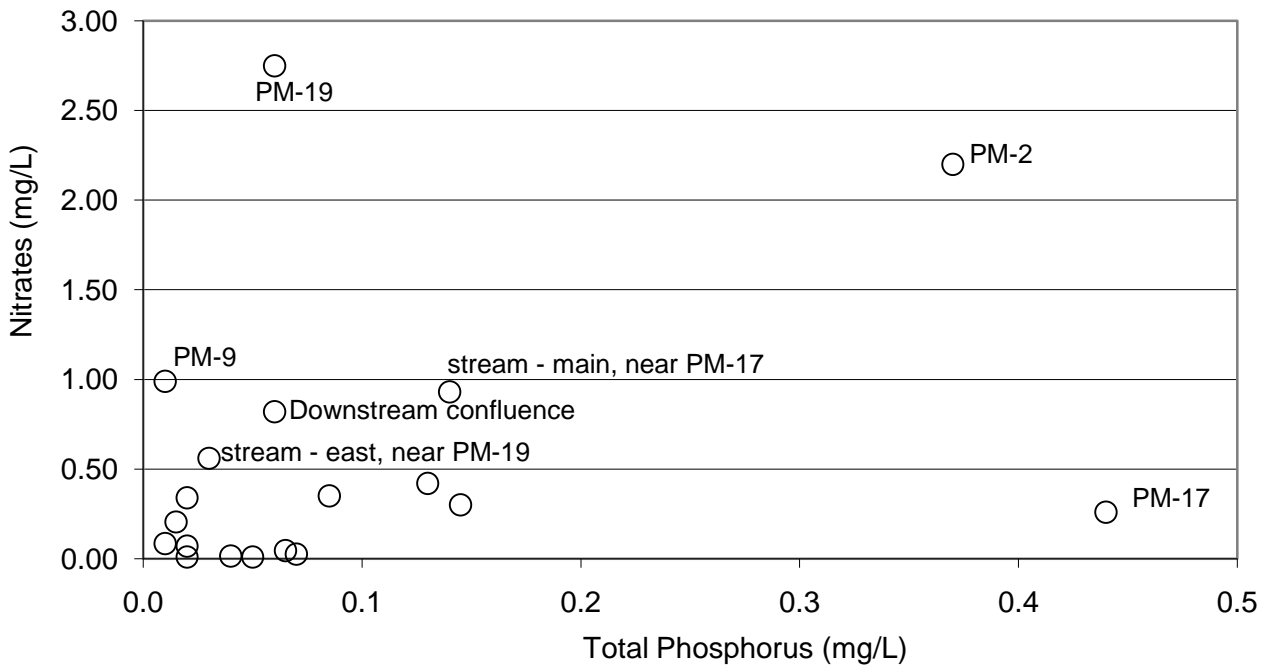
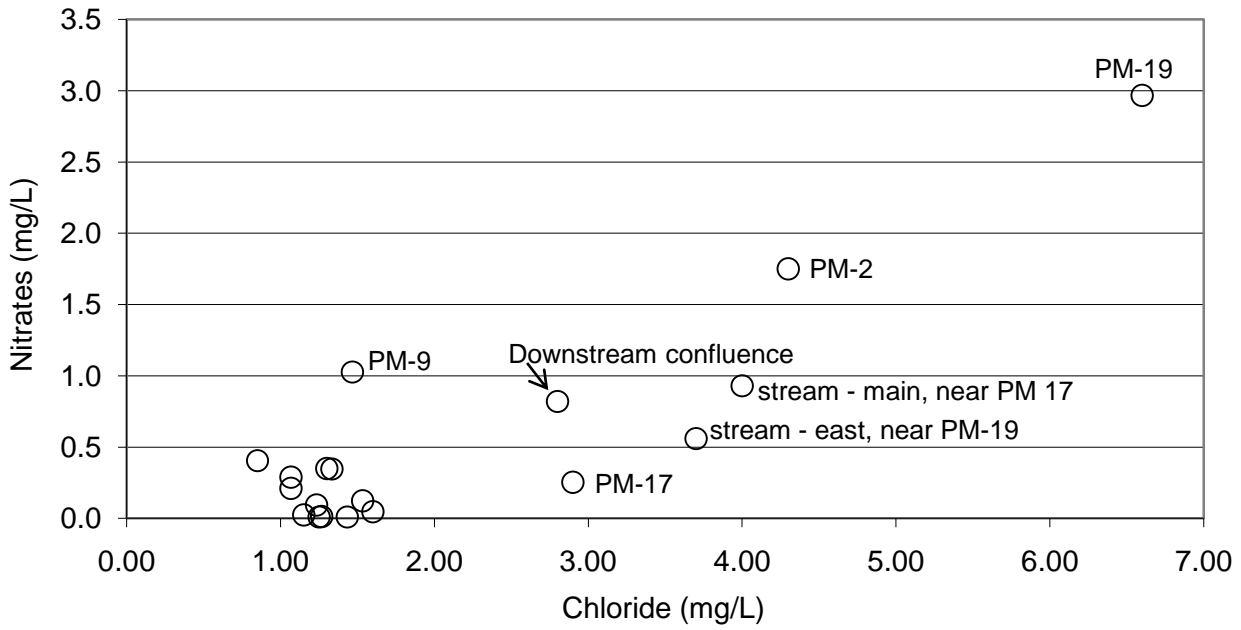


Figure 11. Scatter plots of nitrates ($\text{NO}_2 + \text{NO}_3$) with chloride and total phosphorus in groundwater and streamwater at PMRS