Report No. 118018/1

2010 GROUNDWATER QUALITY REVIEW
ANVIL RANGE MINING COMPLEX, YUKON TERRITORY

Prepared for:

Yukon
Government

Assessment and Abandoned Mines

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EXECUTIVE SUMMARY

Recent trends in groundwater quality in different reaches of the Anvil Range Mining Complex (ARMC) were reviewed in order to identify changes in the condition of groundwater that occurred during the 2010 monitoring period. The main conclusions of this review can be summarized as follows:

Faro Mine Site

Groundwater in the Mill Site area remains impacted by conservatively-transported species (like SO4 and Mg) but metals concentrations remain low and there were no appreciable changes in water quality in 2010.

Surface water and groundwater quality near X23 (downgradient of the Main WRD) improved considerably during the 2010 monitoring period (in particular for metals such as zinc) suggesting a cyclical leaching pattern likely controlled by the precipitation pattern and advance of wetting fronts through the waste rock dump. However, longer-term time trends indicate an overall increase in all contaminant concentrations with time, suggesting a gradual “breakthrough” of acid rock drainage (ARD) products and increased loading to the ETA area.

Shallow groundwater in the ETA area remains highly-impacted by ARD and water quality conditions continued to deteriorate over the current monitoring period. Groundwater quality in overburden soils at the mouth of the Faro Creek canyon did not show any significant improvement in water quality despite operation of the ETA SIS. However, contaminant concentrations at this location are significantly lower than in the ETA suggesting some dilution by local recharge.

In the S-cluster area, highly impacted groundwater in several bedrock wells continued to improve significantly due to operation of two recovery wells. Furthermore, groundwater quality in close proximity of the NFRC (in both overburden and bedrock) continued to improve due to operation of the S-cluster SIS. However, contaminant concentrations in shallow groundwater immediately downstream of the western part of the SIS increased in 2010 suggesting that the western side of the SIS trench may be not be operating as intended.

No significant changes in groundwater quality were observed in the North Fork Rose Creek reach influenced by seepage from the North East Rock Dump and the Zone 2 Pit and associated dumps.

Rose Creek Tailings Facility

Groundwater quality in the Rose Creek alluvial aquifer (RCAA) remains impacted by seepage from coarse, fully-oxidized tailings beaches in the former RCTF and by waste rock seepage from the Faro Mine (FCS) delivered to the valley via the Faro Creek canyon/diversion. FCS appears to impact groundwater quality solely along the northern side of the valley whereas tailings seepage continues to impact groundwater quality on both sides immediately downgradient of tailings beaches. Note also that sealing of the “leaky” wells in 2005 has not resulted in any improvement in groundwater quality. It is therefore concluded that ‘mature’ tailings seepage (from fully oxidized beaches in the Original and Second Impoundment) is the principal cause of highly elevated zinc concentrations observed at select locations in the RCAA.

Groundwater upgradient of the RCTF continues to reflect ‘background’ conditions for the ARMC and hence remains unimpacted by mine waste seepage from either the Main or Intermediate WRDs. Groundwater quality in the RCAA beneath the Original and Second Impoundments continued recent trends of gradual increase in contaminant concentrations, including zinc. Of particular interest were increases in SO4, Mg, and metals of concern (Zn, Mn) throughout the alluvial aquifer at P03-06, which suggest continued seepage from the Faro Creek canyon and/or coarse tailings beaches in the Original Impoundment.

In the reaches of the Intermediate and Cross Valley Dams, groundwater in the RCAA continued to deteriorate as increases in SO4, Mg, and selected metals of interest (in particular Mn but also Zn) were apparent. Note that groundwater continues to be more significantly impacted on the north side of the valley than the south side although water quality in both areas have deteriorated since the last monitoring period (i.e. at X24D, X25A/B, and P01-04A/B). These time trends suggest that contaminant loads from FCS (on the north side only) and from seepage of oxidized coarse tailings beaches (on the north and south side) continue to impact the RCAA. The gradual increase in zinc concentrations also suggest that the attenuation capacity of the alluvial aquifer is gradually becoming depleted.

Groundwater from wells near the toe of the Cross Valley Dam clearly indicate that groundwater in deep, fractured bedrock on the northern side of the valley (at well P09-C1) is impacted by mine waste seepage but to a lesser extent groundwater in the overlying RCAA. Very limited, if any, impact is observed in deep bedrock near the center of the valley and deep groundwater appears unimpacted along the southern side of the Rose Creek valley.

Downgradient of the Cross Valley Dam, groundwater quality at wells located near the northern side of the valley continued to deteriorate during the current monitoring period but contamination remains limited to Ca, Mg and SO4 and metals concentrations still remain very low. These data support the assertion from previous reports/studies that a TDS plume is present in this area but that the leading edge of a metals front still resides upgradient.

Grum/Vangorda Mine Site

Groundwater in the shallow overburden soils to the south of the Grum Sulphide Cell (at P96-9A) continues to deteriorate (as it has for nearly ten years). Note that the increases in SO4 and Mg concentrations during the current monitoring period were particularly abrupt and both contaminants reached all-time high concentrations but metals remain quite low. Deeper groundwater near the bedrock-overburden interface remained unimpacted. Groundwater in shallow overburden near the southwestern toe of the Grum Rock Dump also showed a gradual increase in oxidation products (SO4 and Mg) but metals concentrations remain very low.

Shallow groundwater in monitoring well SRK05-09 located downgradient of the Moose Pond showed a significant increase in zinc concentrations suggesting that the sorption capacity of the local soils for zinc is gradually being depleted in the shallow soils due to continued seepage from Moose Pond.

No significant changes in groundwater quality were observed in the Vangorda Creek drainage (just downgradient of the Vangorda Pit) and just downgradient of Little Creek Dam. In contrast, groundwater quality immediately downgradient of the Vangorda waste rock dump has recently shown first signs of a breakthrough of a TDS front (including SO4 and Mg) and this trend continued during the 2010 monitoring period. Selected wells also showed slightly elevated zinc concentrations in 2010. A gradual increase in sulphate over the last 3-4 years and into 2010 is also evident in all other monitoring wells located along the southern and western toe of the Vangorda WRD.

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1 INTRODUCTION

1.1 Terms of Reference

Routine groundwater monitoring at the Anvil Range Mine Complex (ARMC) has been conducted since 1997 and hence a detailed record of historic trends in groundwater quality exists for the site. In 2004, Robertson GeoConsultants Inc. (RGC) completed an initial review of the groundwater quality monitoring data collected near the Faro and Grum/Vangorda rock dumps in order to assist in the design of additional field programs and develop water and contaminant load balances for the Rose Creek Tailings Facility (see RGC, 2006a).

In 2007, RGC was commissioned to carry out a more comprehensive review of groundwater quality across the ARMC that included the description of conditions in the Rose Creek Tailings Facility, the Zone 2 Pit outwash area, and the areas surrounding the Grum and Vangorda rock dumps (RGC, 2008). Since then, RGC has conducted an annual review of groundwater quality data in order to identify any changes in groundwater quality that may have occurred since the previous monitoring period and recommend changes to the ARMC's routine monitoring program based on this review.

1.2 Study Objectives

The objectives of this report were to:

- Review groundwater quality data collected between November 2009 and October 2010 across the ARMC and identify any changes in groundwater quality during that period; and

- Evaluate the ARMC's routine groundwater monitoring program in terms of the frequency of water quality sampling and the number of wells monitored.

The focus of this monitoring report is to highlight changes in groundwater quality over time and hence a detailed geochemical assessment of the available data is beyond its scope.

1.3 Scope of Work

Groundwater quality data were collected from monitoring wells in the following geographic areas of the ARMC:

- Faro mine site
- Rose Creek valley
- Grum and Vangorda mine sites

For ease of reference, these areas are discussed separately in Sections 2, 3, and 4 of this report.

Groundwater quality data reviewed in this report were downloaded from the Faro database (“emLine”) on December 13, 2010. A complete QA/QC check of the data was beyond the scope of this review so time trends were based on the raw data that was downloaded. These data are considered reliable though and any minor errors are not expected to affect the interpretation of water quality time trends.

2 FARO MINE SITE

2.1 Geographic Overview

The Faro mine site consists of the Faro Pit, the surrounding Faro waste rock dumps (WRDs), the Mill Site area, and the Emergency Tailings Area (ETA). The general layout of the mine site and the locations of groundwater monitoring wells are illustrated in Figure 2-1. Note that only wells installed since 2008 are labelled in Figure 2-1.

Groundwater monitoring wells have been constructed primarily in areas where an impact from mine waste seepage has been identified at surface. These areas are considered “priority areas” and include:

- the Emergency Tailings Area (ETA) & Main Dump Area;
- the S-Cluster area; and
- the Zone 2 Pit outwash area.

Groundwater quality data in each of these areas are discussed separately in the sections below.

2.2 Emergency Tailings Area (ETA)

2.2.1 Background & Well Locations

Figure 2-2 shows the general layout of the ETA and the groundwater monitoring wells located in this area. Table 2-1 summarizes pertinent information related to the groundwater monitoring wells located in the ETA, including year of construction, installation details (i.e. total depth, screening interval), and the current status of monitoring.

Table 2-1. Monitoring wells in the Emergency Tailings Area (ETA), Faro mine site

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
ETA Area							
P96-8A	1996	4.2	1.15	4.17	1109.39	bi-annual	Alluvium
P96-8B	1996	8.6	5.50	8.52	1109.48	bi-annual	Alluvium
SRK04-3A	2004	11.9	10.40	11.90	1104.55	annual	Tailings/All
SRK04-3B	2004	7.1	5.50	7.00	1104.63	no longer sampled	All/BR
SRK04-4	2004	11.6	7.64	11.6	1104.80	not routinely monitored	Alluvium
SRK05-ETA-BR1	2005	12.4	9	12	1105.21	annual	Alluvium
SRK05-ETA-BR2	2005	18.4	14.6	18.9	1103.75	annual	BR (Schist)
ETA-05-1	2005	7.3	4.3	7.3	1105.13	not routinely monitored	Tailings
ETA-05-2	2005	7.5	5	7.5	1105.06	not routinely monitored	Till
ETA-05-3	2005	8.8	7	8.8	1103.98	not routinely monitored	All/Till
ETA-05-4	2005	9.0	6.7	9	1105.37	not routinely monitored	All/Till
ETA-05-5	2005	5.2	2	5.2	1105.44	not routinely monitored	Tailings
P09-ETA1	2009	29.8	26.9	29.8	1074.66	annual	Bedrock
P09-ETA2	2009	17.7	16.15	17.7	1074.46	annual	OB/BR Contact
Main Dump/Mill Site							
SRK08-P9	2008	6.1	3.05	6.1	1144.208	not routinely monitored	Weathered BR
SRK08-P10A	2008	13.1	10.06	13.11	1112.896	annual	Weathered BR
SRK08-P10B	2008	7.6	4.57	7.62	1112.775	not routinely monitored	Overburden
SRK08-P11A	2008	12.2	9.14	12.19	1137.082	bi-annual	Weathered BR
SRK08-P11B	2008	6.1	3.05	6.1	1137.226	bi-annual	Overburden

2.2.2 Review of Time Trends

Time trends for pH, alkalinity, and the concentrations of selected major ions and metals of interest in seepage from the Main WRD (at the V-notch weir at X23) and in groundwater from wells P96-8A/B are shown in Figure 2-3a/b. Recall that wells P96-8A/B are screened in alluvium near the toe of the Main WRD approximately 15 m southwest of X23 and that the V-notch weir at X23 is also referred to as station ‘FCS-1’ in ETA SIS monitoring reports (see RGC, 2010b).

The concentrations of SO_4, Mg, and Zn in seepage collected at X23 decreased during the current monitoring period (Figure 2-3a). These decreases are consistent with a trend towards improved seepage water quality observed over the latter half of the previous monitoring period (RGC, 2010b). Of particular interest are Zn concentrations at X23, which had reached close to ~1,500 mg/L in early 2009 but had decreased to less than 1,000 mg/L by the end of that year. During the current monitoring period, Zn concentrations at X23 decreased even further to ~600 mg/L. Similar “flushes” of zinc and to a lesser extent other metals (e.g. manganese) have been observed in the past (e.g. in 2000/01 and in 2004/05) and suggest a cyclical leaching pattern likely controlled by the precipitation pattern and advance of wetting fronts through the waste rock dumps.

Note that SO_4 and Mg concentrations did not show the same strong cyclical trends that are observed for zinc. Although some inter-annual variability is observed these less reactive constituents show a clear increasing trend over time, suggesting a gradual “breakthrough” of ARD products at X23.

Note also that highly-acidic conditions (pH<3.5) were again observed during the current monitoring period indicating that the buffering capacity within the waste rock dump and the local soils continues to be limited and occasionally be depleted.

Historically, groundwater quality conditions near the toe of the Main WRD (at wells P96-8A/B) have mimicked changes in seepage water quality at X23 and this trend continued over the current monitoring period (see Figure 2-3a/b). As observed at X23, zinc concentrations showed a significant recovery in these two monitoring wells whereas SO_4 and Mg levelled off from last year's peak concentrations but remained significantly higher than in earlier years.

Note that groundwater in these alluvial wells continued to show a declining trend in pH throughout this monitoring period (Figure 2-3b). According to the database, the deeper alluvial well (P96-8B) showed more acidic conditions (pH <4.5 and no alkalinity) than the shallow alluvial well (P96-8A). This trend is not expected since earlier time trends consistently showed higher metal and lower pH in the shallow well P96-8A. Field notes on total depth recorded during sampling should be checked to determine whether there is a mix-up between those two wells. In any case, the observed decrease in groundwater pH at P96-9A/B could be the first sign of an acid front in the alluvial soils of the ETA area and should therefore be monitored carefully.

Wells SRK08-P09, SRK08-P10A/B, and SRK08-P11A/B are each located in the Mill Site area downgradient of the Main WRD (see Figure 2-1). Specifically, wells SRK08-P10A/B are located downgradient of the mill near the ETA and wells SRK08-P11A/B are located near Guardhouse Creek, whereas well SRK08-P09 is located below the toe of the Main WRD to the southeast of the mill. Elevated SO_4 levels are observed in each of these wells but Zn (and other metals of interest) remain relatively low and alkalinity high (see Figure 2-3c/d). High alkalinity and low metal concentrations suggest that groundwater from these wells is affected by seepage from the Main WRD but to a lesser extent than groundwater in the ETA (see below). Preliminary trends suggest that groundwater quality in the Mill Site area is relatively stable at this time but additional discussion is deferred until more data is available.

Figure 2-4a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater upgradient of the mine access road in the ETA and near the mouth of Faro Creek canyon. Groundwater from wells screened in the alluvial sediments of the Faro Creek channel (at wells SRK04-3A and SRK05-ETA-BR1) is generally more acidic and characterized by higher concentrations of SO_4, Mg, and metals of concern (i.e. Zn, Fe, and Mn) than groundwater that resides in bedrock beneath the alluvium (at well SRK05-ETA-BR2). These differences indicate that groundwater in deep bedrock within the ETA is much less affected by mine waste seepage than the overlying alluvial channel.

Seepage in the alluvial channel of the ETA area continues to show a gradual decrease in pH and an increase in SO_4, Mg, Zn and other metals (e.g. Mn) which is consistent with the time trends observed further upgradient (at P96-8A/B). These data suggest that groundwater in the ETA area is continually deteriorating in response to higher contaminant loading from the Main Dump (X23).

Groundwater from well P09-ETA-01 screened in deep bedrock near the mouth of Faro Creek canyon is slightly alkaline (pH 7.5 or so) and characterized by higher alkalinity and orders-of-magnitude lower concentrations of dissolved metals than groundwater from well P09-ETA-02 (which is screened in overburden just below tailings). These differences indicate that groundwater in deep bedrock near the mouth of the Faro Creek canyon is essentially unimpacted by mine waste seepage whereas groundwater from well P09-ETA-02 is impacted by seepage from tailings and/or FCS from the ETA area. A detailed study of the source of contaminants to groundwater in this area suggests that high concentrations of SO_4, Mn, and Zn in well P09-ETA-02 are more likely related to FCS than tailings porewater yet both sources likely contribute (RGC, 2010a).

Note that a seepage interception system (SIS) was recently installed in the ETA to capture seepage during ice-free months at the ARMC and subsequently divert it to the Intermediate Pond. According to RGC (2010c), this SIS captures almost 90% of total seepage in the ETA during these ice-free months but captures less than 50% of total seepage due to winter shutdown. Although the FCS load to groundwater near the mouth of Faro Creek canyon has certainly been significantly reduced by the ETA SIS there has been no apparent improvement in groundwater quality to date (see Figure 2-4a/b). However, contaminant concentrations at this location are significantly lower than in the ETA suggesting some dilution by local recharge. Further monitoring and analysis will be required to determine whether the lack of significant improvement in water quality is the result of the seepage load that bypasses the SIS or caused by a delayed response in the alluvial sediments due to longer travel times.

2.3 S-Cluster Area

2.3.1 Background & Well Locations

Figure 2-5 shows the general layout of the S-Cluster area and the monitoring wells therein. Aside from well P96-7 (located near the western toe of the Outer Haul Road Rock Dump), wells in this area are located between the southern toe of the Intermediate Rock Dump and the North Fork of Rose Creek (NFRC) near the S-Cluster SIS. Table 2-2 summarizes pertinent information related to wells in the S-Cluster area, including year of construction, installation details, and the current monitoring status.

Table 2-2. Monitoring wells in the S-Cluster area, Faro mine site

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
S-cluster Area							
S1A	1989	12.0	9.2	12.2	1085.43	bi-annual	BR (phyllite)
S1B	1989	3.8	1.3	4.3	1085.27	no longer sampled	Till
S2A	1989	11.2	9.2	12.2	1086.03	bi-annual	BR (phyllite)
S2B	1989	7.0	3.7	6.7	1086.30	annual	Till
S3	1989	4.8	2.6	5.6	1085.53	no longer sampled	Till
P96-7	1996	9.2	6.26	9.24	~1127	bi-annual	Overburden/BR
SRK04-2B	2004					no longer sampled	Alluvium
SRK04-2A	2004					no longer sampled	Alluvium
SRK05-SP-1A	2005	19.2	13.7	19.2	1091.99	annual	Overburden/BR
SRK05-SP-1B	2005	12.3	9	12.3	1091.94	annual	Overburden
SRK05-SP-2	2005	11.0	7.9	11	1086.70	annual	Alluvium/BR
SRK05-SP-3A	2005	22.9	17.4	21.9	1088.50	annual	Overburden
SRK05-SP-3B	2005	12.3	8.3	11.4	1088.41	annual	Overburden
SRK05-SP-4A	2005	21.6	16.5	21	1087.27	bi-annual	Overburden/BR
SRK05-SP-4B	2005	4.0	0.6	3.5	1087.44	not routinely monitored	Overburden
SRK05-SP-5	2005	14.0	9.4	12.5	1087.53	annual	Overburden/BR
SRK05-SP-6	2005	11.0	3.1	11	1097.73	no longer sampled	BR(Schist)
DP1	2005	n/a	1.14	1.14	1083.97	not routinely monitored	NFRC sediments
DP2	2005	n/a	0.53	0.53	1082.55	not routinely monitored	NFRC sediments
DP3	2005	n/a	0.75	0.75	1081.89	not routinely monitored	NFRC sediments
DP4	2005	n/a	0.94	0.94	1082.19	not routinely monitored	NFRC sediments
SRK08-SP7A	2008	17.75	14.02	17.07	~ 1081.74	quarterly	BR (weath)
SRK08-SP7B	2008	8.49	4.88	7.92	~ 1081.73	quarterly	Overburden
SRK08-SP8A	2008	11.59	7.62	10.67	~ 1077.74	annual	BR (weath)
SRK08-SP8B	2008	7.04	3.05	6.10	~ 1077.78	annual	Overburden
SRK08-SBR1	2008	n/a	27.74	33.83	~ 1087.80	not routinely monitored	BR (weath)
SRK08-SBR2	2008	18.33	12.19	18.29	~ 1087.50	annual	Overburden
SRK08-SBR3	2008	13.22	6.10	12.19	~ 1096.60	annual	BR (weath)
SRK08-SBR4	2008	n/a	15.09	21.49	~ 1087.70	annual	BR (weath)
P09-SIS1	2009	6.3	4.8	6.3	1087.59	bi-annual	Overburden
P09-SIS2	2009	5.5	4.6	5.5	1087.39	quarterly	Overburden
P09-SIS3	2009	3.7	2.2	3.7	1087.36	quarterly	Overburden
P09-SIS4	2009	3.7	2.8	3.7	1087.55	not routinely monitored	Overburden
P09-SIS5	2009	3.7	2.8	3.7	1087.49	not routinely monitored	Overburden
P09-SIS6	2009	4.6	4.6	5.5	1087.39	not routinely monitored	Overburden

2.3.2 Review of Time Trends

Figures 2-6a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater from the historic ‘S’ wells and well P96-7. Similar time trend plots for the ‘SRK05-SP’ and ‘P09-SIS’ well series are shown in Figure 2-7a/b and Figure 2-7c/d, respectively. Time trends for the recently installed bedrock wells in the S-Cluster area (‘SBR’ series) and wells further downgradient of the SIS (wells SRK08-SP7A/B and SRK08-SP8A/B) are shown in Figure 2-8a/b and Figure 2-8c/d, respectively

Groundwater quality in the S-Cluster area can be classified into three broad categories:

- Highly-impacted groundwater (wells S1A, S2A/B, S3, SRK05-SP4B, SRK05-SP5, P09-SIS1, P09-SIS2, P09-SIS3, and P09-SIS4);

- Moderately-impacted groundwater (wells SRK05-SP1A, SRK05-SP3A, SRK05-SP3B, P09-SIS5 and P09-SIS6, and SRK05-SP4A, SRK08-SP7B, SRK08-SP8A, SRK08-SBR4);
- Slightly-impacted groundwater (wells S1B, SRK05-SP1B, SRK05-SP2, SRK08-SP7A, SRK08-SP8B, SRK08-SBR1, SRK08-SBR2, and SRK08-SBR3).

Concentrations of SO_4, Mg, and metals of interest in groundwater that is classified as either moderately-impacted or slightly-impacted by ARD (including SRK05-SP1A/B, SRK05-SP2 and SRK05-P3A/B located to the east of the S-cluster SIS) have been relatively stable in recent years and this trend generally continued during the current monitoring period.

In contrast, significant changes were observed in groundwater quality in immediate vicinity of the SIS where highly impacted groundwater is present. Recall that concentrations of major ions and metals of interest in the immediate vicinity of the SIS in highly-impacted groundwater had generally increased since 2000 and had reached their highest levels to date during the previous monitoring period, i.e. in mid-2009 (RGC, 2010b). For instance, water quality data for wells S1A, S2A, and S2B typify highly-impacted groundwater in the S-Cluster area (see Figure 2-6a/b).

During the current monitoring period the condition of highly-impacted groundwater at wells S1A and S2A (both screened in bedrock) improved significantly due to seepage recovery upgradient via recovery well SRK05-SPW2. Note also that the groundwater quality in the bedrock screened at SRK08-SBR4 did improve since the last monitoring period indicating a strong hydraulic connection within the bedrock aquifer.

In contrast, groundwater quality in the overlying overburden soils (e.g. at well S1B) continued to deteriorate significantly. For example, SO_4 concentrations in S1B reached nearly 8,000 mg/L and over 100 mg/L Mn and Zn in September 2010. This lack of improvement in water quality at well S2B suggests a poor hydraulic connection between the overburden till (screened by S2B) and the bedrock screened by recovery well SRK05-SPW2 (and wells S1A and S2A).

Despite continuous operation of the S-Cluster interception trench, highly-impacted groundwater in shallow sediments immediately downgradient of the SIS trench also did not show any improvement over the current monitoring period. In fact, contaminant concentrations in shallow groundwater at P09-SIS1, P09-SIS2 and P09-SIS-3 actually deteriorated significantly since monitoring began in 2009. It is interesting to note that water quality trends in SIS2 and SIS3 were almost identical suggesting a common source. This deterioration in groundwater quality immediately downgradient of the SIS is unexpected and suggests that the west side of the SIS trench is not performing as intended. One possible reason for these observations is clogging of the trench (possibly due to silt entrained during construction). A detailed performance review of the S-cluster SIS was beyond the scope of this monitoring report but should be completed in the near-term to evaluate the cause for this latest deterioration in groundwater quality along the west side of the SIS trench.

The pair of nested monitoring wells (SRK08-SP7A/B) located downgradient of the S-cluster SIS near the NFRC showed a different trend than those in close proximity to the SIS. SO_4, Mg, and metals of interest in groundwater in the shallower overburden well (SRK08-SP7B) have decreased considerably since 2008 and remained low during the current monitoring period. These decreases are likely due in part to the operation of the S-Cluster SIS and recharge of shallow groundwater by very dilute stream water from the NFRC. Note that concentrations of SO_4, Mg, and metals of interest in the deeper groundwater at this location (at well SRK08-P7B) had not previously decreased in tandem with shallow groundwater but concentrations in deeper groundwater did decrease over the current monitoring period. This suggests that seepage recovery upgradient (possibly aided by dilution from the NFRC) has caused a significant improvement in water quality throughout the shallow overburden aquifer in the vicinity of these wells.

About 200 m downstream of wells SRK08-SP7A/B, SO_4, Mg, and metals of interest concentrations in groundwater from wells SRK08-SP8A/B remained relatively low and comparable to concentrations observed in 2008 (when they were last sampled). Groundwater in this area therefore remains ‘moderately-impacted’ and there was no sign of additional impact by ARD during the current monitoring period.

2.4 North Fork of Rose Creek (NFRC) Reach

2.4.1 Background & Well Locations

Figure 2-9 shows the general layout of the NFRC reach upstream of the rock drain. Note that the NFRC valley is filled with permeable, alluvial sediments and groundwater in this alluvial aquifer generally flows down the valley before discharging to the Rose Creek alluvial aquifer. The NFRC alluvial aquifer is influenced by seepage from the Northeast Rock Dumps, the Zone 2 Pit (backfilled with waste rock) and the Intermediate Dump. No surficial drainage of waste rock seepage is observed in this part of the ARMC as seepage from the waste rock dumps reports to the NFRC alluvial aquifer solely via overburden soils and/or fractured bedrock.

The NFRC reach can be subdivided into four reaches:

- NFRC upgradient of the Faro Mine
- Northeast Waste Rock Dump Reach
- Zone 2 Pit outwash area
- Intermediate Waste Rock Dump Reach

Figure 2-9 shows the locations of wells upgradient and downgradient of the Zone 2 Pit outwash area whereas Figure 2-10 magnifies the Zone 2 Pit outwash area (where the majority of monitoring wells are located). Pertinent information related to the groundwater monitoring wells located in the NFRC reach is provided in Table 2-3.

Table 2-3. Monitoring wells in the Zone 2 Pit outwash area, Faro mine site

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Zone 2 Outwash Area							
BH1	1992	5.2				Not routinely monitored	n/a
BH2	1992	4.8			1099.70	Not routinely monitored	n/a
BH4	1992	2.5			1097.02	Not routinely monitored	n/a
BH5	1994	7.6	6.01	7.62	1095.57	Annual	Alluvium
BH6	1994	6.3	4.72	6.25	1097.84	Annual	Alluvium
BH7D (A)	1994	8.8	6.71	8.84	1100.70	Not routinely monitored	Overburden (?)
BH7S (B)	1994	6.4	4.27	6.4	1101.16	Not routinely monitored	BR (phyllite?)
BH8	1994	20.6	19.05	20.57	1123.37	Annual	BR (phyllite?)
BH9	1994	54.9	53.34	54.86	1141.30	Abandoned	BR (Biotite-schist)
BH10A	1994	36.6	35.05	36.58	1101.73	Annual	BR (Biotite-schist)
BH10B	1994	54.9	53.34	54.84	1101.72	Annual	BR (phyllite/schist)
BH05-01	2005	3.8	2.3	3.81	1095.57	Abandoned	Outwash Sed
P05-04	2005	6.3	2.19	6.34	1097.70	Not routinely monitored	Alluvium
RGC-PW3	2005	7.4	5.5	7	1097.92	Not routinely monitored	Alluvium
DP5	2005	n/a	n/a	n/a	1095.73	Not routinely monitored	NFRC sediments
DP6	2005	n/a	n/a	n/a	1094.71	Not routinely monitored	NFRC sediments
Zone 2 Pumping Well (X26)	n/a					bi-annual	waste rock (?)
SRK08-P13A	2008		7.32	10.36		Not routinely monitored	Weathered BR
SRK08-P13B	2008		3.05	6.1		Not routinely monitored	Overburden
Well ID	**Year of Construction**	**Total Depth (m bgs)**	**Top of Screen (m bgs)**	**Bottom of Screen (m bgs)**	**Top of Casing Elevation (m asl)**	**Current Status of Monitoring**	**Formation**
Toe of Northeast Dumps (NFRC)							
BH12A	1994	3.1	1.53	3.05	1157.39	Not routinely monitored	BR (weath)
BH12B	1994	8.2	6.1	8.23	1157.50	Not routinely monitored	BR (phyllite/schist)
BH13A	1994	3.8	2.29	3.81	1187.91	Bi-annual	A
BH13B	1994	8.2	6.71	8.23	1188.18	Bi-annual	BR (phyllite/schist)
BH14A	1994	6.3	4.72	6.25	1157.52	Bi-annual	BR (weath)
BH14B	1994	9.3	7.77	9.3	1158.16	Bi-annual	BR (Qtz/diorite)
Toe of Intermediate Dump (NFRC)							
P96-6	1996	20.1	18.07	20.12	~1102	Bi-annual	Alluvium
Near NFRC							
SRK08-P12A	2008	12.19	9.14	12.19	12.19	Annual	BR
SRK08-P12B	2008	7.62	4.57	7.62	7.62	Annual	BR
P09-UN1	2009	5.2	3.7	5.2	1114.21	Not routinely monitored	Overburden
P09-UN2	2009	6.7	5.2	6.7	1114.72	Not routinely monitored	Overburden
P09-UN3	2009	8.8	7.3	8.8	1115.26	Not routinely monitored	Overburden

2.4.2 Review of Time Trends

Groundwater quality in the four sub-reaches of the NFRC reach is reviewed separately in the following sub-sections.

2.4.2.1 NFRC Upgradient of Faro Mine

Water quality data for the ‘P09-UN’ wells series and wells SRK08-P12A/B are shown in Figure 2-11a/b. Note that each of ‘P09-UN’ wells is screened in the NFRC alluvial aquifer ~50 m downstream of the NFRC-Faro Creek diversion channel confluence whereas wells SRK08-P12A/B are screened in weathered bedrock/alluvial sediments upstream of the Zone 2 Pit outwash area (and are shown in Figure 2-11a/b for purposes of comparison). Samples were not collected from the ‘P09-UN’ wells during the current monitoring period as groundwater quality in each of these wells is known to reflect background conditions for the Faro site.

No significant changes in groundwater quality were observed in the two wells SRK08-P12A/B located immediately upstream of the Zone 2 outwash area. Groundwater from these wells remains slightly impacted by ARD (Figure 2-11a/b). Specifically, SO_4 concentrations are slightly elevated (80 to 160 mg/L) and Zn concentrations are ~0.2 mg/L in well SRK08-P12B and 1 mg/L in well SRK08-P12A. Note that SRK08-P12A and -P12B are screened in permeable weathered bedrock and highly permeable alluvial sediments suggesting a substantial zinc load in the NFRC valley. The location of these wells (just upgradient of the Zone 2 outwash area) suggests that seepage from the NE waste rock dumps (rather than seepage from the Zone 2 pit and/or leaching of the outwash sediments) is the primary source of this contaminant load (see below).

2.4.2.2 Northeast Rock Dump Reach

Time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater from wells BH12A/B, BH13A/B, and BH14A/B are shown in Figure 2-12a/b. Each of these wells is located along the toe of the Northeast Rock Dump (see Figure 2-9).

Historically, groundwater from well BH14A/B has been more impacted by ARD than groundwater from wells BH12A/B and BH13A/B. Moreover SO_4, Mg, Mn, and Zn concentrations in wells BH14A/B increased substantially during the previous monitoring period and concentrations of each contaminant had reached all-time highs in 2009. While SO_4 and Mg have declined somewhat in both wells again during the 2010 monitoring period they remain higher than in earlier years. More importantly, zinc concentrations in BH14A have remained significantly elevated (at around 10 mg/L) suggesting a gradual breakthrough of waste rock seepage over the long-term (see Figure 2-12a/b).

Note that the trend towards higher contaminant concentrations in groundwater from wells BH14A/B is likely indicative of seepage from the sulphide-rich waste rock that has been identified in the Northeast Rock Dump (see RGC, 2008) and that if seepage continues to impact groundwater at wells BH14A/B then concentrations of SO_4, Mg, and Zn may eventually reach similar levels to those observed in the ETA and S-Cluster areas.

As mentioned above, contaminant loads from the Northeast Rock Dump likely explain the elevated Zn and SO_4 concentrations in wells SRK08-P12A/B screened in the permeable NFRC aquifer just upgradient of the Zone area outwash area (see above). The elevated Zn concentrations observed in the highly-permeable NFRC alluvial aquifer (in the order of 1 mg/L) suggest a substantial load from the Northeast Rock Dump to this area but further monitoring is needed to affirm this scenario (and evaluate the future effect of this load on the NFRC water quality).

2.4.2.3 Zone 2 Pit outwash area

Figure 2-13a/b shows the time trends for pH, alkalinity, selected major ions, and metals of interest in Zone 2 Pit water and groundwater from wells screened in bedrock near the toe of the backfilled pit. Figure 2-14a/b shows the same time trends but for monitoring wells located further downgradient in the Zone 2 Pit outwash area.

The Zone 2 Pit outwash area is located immediately downgradient of the backfilled (waste rock) Zone 2 Pit. Concentrations of SO4, Mg, and metals of interest in samples from pumping well X26 reflect the condition of water that accumulates in the backfilled Zone 2 Pit. Seasonal variations in the concentrations of these ions and metals of interest are evident at well X26 due to dilution during periods of recharge in the spring. Note from Figure 2-13a/b that contaminant concentrations in Zone 2 pit water have been relatively stable in recent years but SO_4 and Mg concentrations did increase during the current monitoring period (and were more variable than in the past). Metals of interest concentrations were also rather variable but no trend towards higher concentrations is yet apparent.

Well BH8 is screened in weathered bedrock immediately downgradient of the Zone 2 Pit and has been included in the routine monitoring program since 2008. Groundwater in the vicinity of this well remains highly-impacted by seepage from the Zone 2 Pit but SO_4, Mg, and metals of interest concentrations are not increasing over time (see Figure 2-13a/b). Groundwater quality conditions at wells BH10A/B are similarly stable although much less impacted than groundwater at well BH8 (i.e. SO_4<200 mg/L and 2 to 3 mg/L Zn). Further downgradient in the Zone 2 Pit outwash area itself, no appreciable changes in groundwater quality occurred during the current monitoring period as concentrations of SO_4, Mg, and metals of interest were generally consistent with historic time trends (see Figure 2-14a/b).

Note that a significant decrease in alkalinity and increase in zinc concentrations is observed in the NFRC aquifer along the reach of the Zone outwash area (i.e. between SRK08-P12A/B and BH05) suggesting an incremental metal load from the Zone 2 outwash area. This contaminant load is likely due to seepage from the Zone 2 pit area which enters the NFRC valley aquifer via groundwater flow through weathered and/or fractured bedrock.

2.4.2.4 Intermediate Rock Dump Reach

Figure 2-15a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater from well P96-6. This well is located along the toe of the Intermediate Dump and is used to monitor the condition of groundwater flowing from the area near the toe of Intermediate Rock Dump towards the NFRC. Note that groundwater from this well is moderately impacted by seepage from the Intermediate Rock Dump and concentrations of SO_4 and Mg have increased gradually over the last decade or so. Data from well P96-6 for the current monitoring period were generally consistent with this long-term trend towards higher contaminant concentrations although contaminant concentrations show significant seasonal variations. It is currently believed that groundwater quality in this area reflects a small seepage load from the Intermediate Rock Dump but that no recent changes in the intensity of this load have occurred that would cause a substantive change in groundwater quality.

3 ROSE CREEK VALLEY

3.1 Geographic Overview

Figure 3-1 shows the general layout of the Rose Creek valley and major units/features of the former Rose Creek Tailings Facility (RCTF) therein. Principally, the RCTF is comprised of three historic tailings disposal areas (the Original, Second, and Intermediate Impoundments), the Intermediate Pond (w/ Intermediate Dam), and the Polishing Pond (w/ Cross Valley Dam).

The groundwater monitoring network in the Rose Creek valley is extensive and most of the wells are screened in the highly-permeable Rose Creek alluvial aquifer (RCAA) that runs the entire length of the valley. However, several wells have also been completed in the less permeable bedrock that underlies the RCAA to monitor potential contaminant transport via deep groundwater. Note that the majority of “P01” series of monitoring wells that were installed in 2001 have been decommissioned due to concerns about their integrity (RGC, 2006b). Historic trends in water quality for these so-called “leaky wells” were discussed in RGC (2008) and are not discussed in this report.

For the purpose of this report, the Rose Creek valley is sub-divided into the following geographic areas:

- Upgradient of RCTF
- Original Impoundment
- Second Impoundment
- Intermediate Impoundment
- Toe of Intermediate Dam
- Toe of Cross Valley Dam
- Downstream of Cross Valley Dam

Groundwater quality in each of these areas is discussed separately in the sub-sections below.

3.2 Upstream of Rose Creek Tailings Facility

3.2.1 Background & Well Locations

Groundwater quality upgradient of the RCTF is routinely monitored in well TH86-17 (Table 3-1). This well is located ~450 m southeast of the Original Impoundment and has been sampled routinely since 2002. Several additional ‘background wells’ located upgradient of the RCTF have also been sampled since 2008, including wells TH86-2, TH86-5, TH86-13, and TH86-15.

Table 3-1. Monitoring wells upgradient of and within the Original Impoundment, RCTF

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Original Impoundment							
TH86-17	1986	13.9	n/a	n/a	~1070	Annual	n/a
P03-07-01	2003	38.4	38.10	38.40	1064.98	Not routinely monitored	Alluvium
P03-07-02	2003	33.8	33.53	33.83	1064.98	Not routinely monitored	Alluvium
P03-07-03	2003	29.0	28.65	28.96	1064.98	Not routinely monitored	Alluvium
P03-07-04	2003	21.6	21.34	21.64	1064.98	Not routinely monitored	Alluvium
P03-07-05	2003	20.1	19.81	20.12	1064.98	Not routinely monitored	Alluvium
P03-07-06	2003	18.3	17.98	18.29	1064.98	Not routinely monitored	Tailings
P03-07-07	2003	16.8	16.46	16.76	1064.98	Not routinely monitored	Tailings
P03-07-08	2003	13.7	13.41	13.72	1064.98	Not routinely monitored	Tailings
NA05-11A	2005	14.3	12.8	14.3	1068.35	Not routinely monitored	Alluvium

3.2.2 Review of Time Trends

Figure 3-2a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater from well TH86-17 and nearby piezometers. Very low concentrations of SO_4, Mg, and metals of interest in groundwater from well TH86-17 reflect ‘background’ conditions in the RCAA. Hence there remains no indication that mine waste seepage is present in shallow groundwater southeast of the Original Impoundment.

Note from Figure 3-2a/b that groundwater from well TH86-5 is characterized by appreciably higher concentrations of Mg, Na, and alkalinity than groundwater from well TH86-17 but low concentrations of SO_4 and dissolved metals. These data reflect natural water quality conditions in deeper sediments of the RCAA and support the assertion that neither shallow nor deep groundwater in this area is affected by mine waste seepage from the Main or Intermediate WRDs (nor the NFRC aquifer).

3.3 Original Impoundment

3.3.1 Background

Table 3-1 summarizes pertinent information related to the groundwater monitoring wells located in the Original Impoundment.

3.3.2 Review of Time Trends

Neither the nested piezometers at P03-07 nor well NA05-11A are routinely sampled and hence no additional groundwater quality data for wells in the Original Impoundment were available for the current monitoring period.

3.4 Second Impoundment

3.4.1 Background & Well Locations

Pertinent information related to the groundwater monitoring wells located in the Second Impoundment is provided in Table 3-2.

3.4.2 Review of Time Trends & Water Quality Depth Profiles

Water quality depth profiles for multi-level piezometers within the footprint area of the Second Impoundment are shown in Figures 3-3a/b to 3-8a/b. Data collected from these piezometers over the current monitoring period defined depth profiles similar to those observed in previous years. In accordance with previous findings, the highest levels of SO_4 and metals of interest are still observed in tailings porewater in the southeastern (at P03-01 and P03-03) and northwestern (at P03-06) sections of the Second Impoundment whereas the lowest levels of ARD products are observed in the southwestern section (at P03-05). Also, concentrations of selected major ions and metals of interest are typically highest in piezometers that are screened near the interface between the sand and gravel aquifer and the overlying tailings.

Notable exceptions to these typical depth profiles are seen in multi-level monitoring wells P03-03 and P03-06. At P03-03, SO_4 concentrations are elevated throughout the aquifer and Zn concentrations actually increase at greater depths whereas at P03-06 both SO_4 and Zn concentrations are elevated throughout the aquifer. The depth profiles at wells P03-03 and P03-06 suggest a contribution of SO_4 and metals of interest not only from the overlying tailings profile but also from an upgradient source.

Seepage from the decommissioned ‘leaky wells’ was previously thought to represent such an upgradient source of SO_4 and metals to P03-03 and hence explain the water quality depth profile (RGC, 2006a; RGC, 2008). To eliminate this source, ‘leaky well’ P01-09 (and P01-07) was decommissioned in October 2005 yet there has been no improvement in water quality at P03-03 since then. In fact, SO_4 and Mg concentrations in piezometer P03-03-06 have actually increased since 2007 while concentrations in deeper wells have remained relatively consistent (see Figure 3-9a/b). These data suggest that seepage from the highly-oxidized tailings in the coarse tailings beaches of the Second Impoundment (e.g. near well P03-01) are a more likely source of contaminants to wells P03-03 than “leaky well” P01-09 (and that contamination is more pronounced in the shallow RCAA).

Table 3-2. Monitoring wells in the Second Impoundment, Rose Creek valley

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Second Impoundment							
P03-01-01	2003	46.8	46.48	46.79	1061.11	Not routinely monitored	Alluvium
P03-01-02	2003	38.9	38.56	38.86	1061.11	Annual	Alluvium
P03-01-03	2003	30.6	30.33	30.63	1061.11	Not routinely monitored	Alluvium
P03-01-04	2003	24.5	24.23	24.54	1061.11	Annual	Alluvium
P03-01-05	2003	18.4	18.14	18.44	1061.11	Not routinely monitored	Alluvium
P03-01-06	2003	13.3	12.95	13.26	1061.11	Annual	Alluvium
P03-01-07	2003	10.8	10.52	10.82	1061.11	Not routinely monitored	Alluvium
P03-01-08	2003	9.3	8.99	9.30	1061.11	Annual	Tailings
P03-01-09	2003	7.8	7.47	7.77	1061.11	Annual	Tailings
P03-02-01	2003	33.8	33.53	33.83	1060.60	Not routinely monitored	Alluvium
P03-02-02	2003	30.5	30.18	30.48	1060.60	Not routinely monitored	Alluvium
P03-02-03	2003	22.9	22.56	22.86	1060.60	not routinely monitored	Alluvium
P03-02-04	2003	16.8	16.46	16.76	1060.60	not routinely monitored	Alluvium
P03-02-05	2003	13.7	13.41	13.72	1060.60	not routinely monitored	Alluvium
P03-02-06	2003	12.8	12.50	12.80	1060.60	not routinely monitored	Alluvium
P03-02-07	2003	11.9	11.58	11.89	1060.60	Not routinely monitored	Tailings
P03-02-08	2003	8.8	8.53	8.84	1060.60	not routinely monitored	Tailings
P03-02-09	2003	7.6	7.32	7.62	1060.60	Not routinely monitored	Tailings
P03-03-01	2003	43.0	42.67	42.98	1061.49	Not routinely monitored	Alluvium
P03-03-02	2003	33.2	32.92	33.22	1061.49	Annual	Alluvium
P03-03-03	2003	27.1	26.82	27.13	1061.49	Not routinely monitored	Alluvium
P03-03-04	2003	22.3	21.95	22.25	1061.49	Annual	Alluvium
P03-03-05	2003	18.6	18.29	18.59	1061.49	Not routinely monitored	Alluvium
P03-03-06	2003	17.1	16.76	17.07	1061.49	Annual	Alluvium
P03-03-07	2003	15.2	14.94	15.24	1061.49	Not routinely monitored	Tailings
P03-03-08	2003	12.2	11.89	12.19	1061.49	Annual	Tailings
P03-03-09	2003	9.1	8.84	9.14	1061.49	Annual	Tailings
P03-04-01	2003	58.2	57.91	58.22	1061.21	Not routinely monitored	Alluvium
P03-04-02	2003	47.5	47.24	47.55	1061.21	Annual plus AMP	Alluvium
P03-04-03	2003	41.5	41.15	41.45	1061.21	Not routinely monitored	Alluvium
P03-04-04	2003	35.1	34.75	35.05	1061.21	Annual plus AMP	Alluvium
P03-04-05	2003	26.1	25.76	26.06	1061.21	Not routinely monitored	Alluvium
P03-04-06	2003	17.4	17.07	17.37	1061.21	Annual plus AMP	Alluvium
P03-04-07	2003	15.5	15.24	15.54	1061.21	Not routinely monitored	Alluvium
P03-04-08	2003	13.7	13.41	13.72	1061.21	Annual plus AMP	Tailings
P03-04-09	2003	12.8	12.50	12.80	1061.21	Not routinely monitored	Tailings
P03-05-01	2003	44.5	44.20	44.50	1060.43	Not routinely monitored	Alluvium
P03-05-02	2003	36.9	36.58	36.88	1060.43	Annual	Alluvium
P03-05-03	2003	27.7	27.43	27.74	1060.43	Not routinely monitored	Alluvium
P03-05-04	2003	23.5	23.16	23.47	1060.43	Annual	Alluvium
P03-05-05	2003	21.6	21.34	21.64	1060.43	Not routinely monitored	Alluvium
P03-05-06	2003	18.6	18.29	18.59	1060.43	Annual	Tailings
P03-05-07	2003	14.0	13.72	14.02	1060.43	Not routinely monitored	Tailings
P03-05-08	2003	11.0	10.67	10.97	1060.43	Annual	Tailings
P03-06-01	2003	25.9	25.60	25.91	1062.79	Bi-annual	Alluvium
P03-06-02	2003	22.9	22.56	22.86	1062.79	Bi-annual	Alluvium
P03-06-03	2003	19.8	19.51	19.81	1062.79	Bi-annual	Alluvium
P03-06-04	2003	16.5	16.15	16.46	1062.79	Bi-annual	Alluvium
P03-06-05	2003	14.3	14.02	14.33	1062.79	Bi-annual	Alluvium
P03-06-06	2003	12.5	12.19	12.50	1062.79	Bi-annual	Tailings
P03-06-07	2003	11.0	10.67	10.97	1062.79	Bi-annual	Tailings
NA05-9D	2005	11.0	7.9	10.9	1060.81	Not routinely monitored	Alluvium
NA05-9S	2005	6.1	1.4	4.4	1060.57	Not routinely monitored	Tailings

Note that monitoring well P03-05, located about 500m downgradient of P03-03, has also shown a significant increase in sulphate and zinc over the last two years at greater depth (~15m below the original ground surface) (Figure 3-7). It is likely that this recent “breakthrough” of sulphate, zinc and other metals (including Fe and Mn) represents the leading edge of the contaminant plume observed at the upgradient well P03-03 (at similar depth). The earlier breakthrough observed at greater depth of the alluvial aquifer at P03-03 and P03-05 may be a result of the presence of a high-permeability layer (such as a coarse paleochannel) rather than historic “leakage” of highly contaminated seepage from any of the “leaky wells” screened at greater depth.

Figure 3-10a/b shows the time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater at P03-06. This well is located in the northwest portion of the Second Impoundment near the mouth of Faro Creek canyon. Previous reports have identified substantial increases in the concentrations of SO_4 and metals of interest (and decreasing level of alkalinity) in this area since 2005 and have emphasized that most of the deterioration in water quality has occurred deeper in the aquifer at P03-06 (RGC, 2008; 2009, 2010b). This increasing trend of contaminants at greater depth in P03-06 continued during the current monitoring period (Figure 3-10a/b). Note that contaminant concentrations increased rather abruptly in the shallowest piezometer as P03-06 in late 2010 and that increases of the same magnitude were not apparent in deeper groundwater. These abrupt increases likely reflect a sampling artefact or some contamination of shallow groundwater by seepage from surface but additional monitoring data is needed to confirm either scenario.

According to RGC (2010a), groundwater at P03-06 is impacted primarily by FCS that partially recharges the northern portion of the RCAA. That study suggests that the recent increases in ARD products in the RCAA at P03-06 are therefore the result of the recent deterioration in FCS water quality (see Section 2.2.2). Of particular concern are increases in the concentrations of Mn and Zn and the decrease in alkalinity (which indicates that the buffering capacity of the local aquifer is being overwhelmed). Note that some improvement in groundwater quality at P03-06 might be expected to result from the elimination of at least part of the FCS load to the RCAA by the ETA SIS.

Note that operation of the SIS only started in 2007 and that the SIS has only been operating during the ice-free summer period. One possible explanation for the lack of any significant improvement in groundwater quality at P03-06 to date could be the time required for any contaminant to travel from the old Faro Creek channel to P03-06. Although considered less likely, highly contaminated seepage from the coarse tailings beaches of the Original Impoundment could be an alternative (or additional) source for the observed deterioration in groundwater quality at P03-06.

Time trends for pH, alkalinity, selected major ions, and metals of interest in nested wells at P03-04 are shown in Figure 3-10c/d. P03-04 is located ~140 m downgradient of the decommissioned “leaky wells” at P01-07 and roughly cross-gradient of P03-06 (see Figure 3-1). Groundwater quality in this area has not improved appreciably since “leaky well’ P01-07 was decommissioned (although it has not worsened either). Instead, groundwater in this area remains moderately-impacted by ARD but concentrations of major ions and metals of interest appear to be rather stable. Note that groundwater in the RCAA along the south side of the Rose Creek valley is not impacted to the same extent (if at all) by FCS and hence no improvement is expected to result from operation of the ETA SIS.

3.5 Intermediate Impoundment

3.5.1 Background & Well Locations

Table 3-3 summarizes pertinent information related to the groundwater monitoring wells located in the Intermediate Impoundment.

Table 3-3. Monitoring wells in the Intermediate Impoundment, Rose Creek valley

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Intermediate Impoundment							
X21A-96	1996	8.5	2.43	8.53	1052.09	Bi-annual	Tailings
X21B-96	1996	14.7	11.64	14.69	1052.14	Bi-annual	Alluvium
X21C-96	1996	29.4	27.86	29.37	1052.21	Not routinely monitored	Alluvium
P03-08-01	2003	32.6	32.31	32.61	1048.35	Not routinely monitored	Alluvium
P03-08-02	2003	28.3	28.04	28.35	1048.35	Annual	Alluvium
P03-08-03	2003	24.7	24.38	24.69	1048.35	Not routinely monitored	Alluvium
P03-08-04	2003	23.2	22.86	23.16	1048.35	Annual	Alluvium
P03-08-05	2003	21.6	21.34	21.64	1048.35	Not routinely monitored	Alluvium
P03-08-06	2003	20.1	19.81	20.12	1048.35	Annual	Tailings
P03-08-07	2003	17.1	16.76	17.07	1048.35	Annual	Tailings
P03-08-08	2003	14.0	13.72	14.02	1048.35	Annual	Tailings
NA05-2D	2005	13.7	10.7	13.7	1052.13	Not routinely monitored	Alluvium
NA05-2S	2005	8.8	4.5	7.5	1052.11	Not routinely monitored	Tailings

3.5.2 Review of Time Trends

Time trends for pH, alkalinity, selected major ions, and metals of interest for the ‘X21’ well series are shown in Figures 3-11a/b.

Tailings porewater quality at well X21A continued to deteriorate over the current monitoring period as it has for several years. Specifically, note the rather abrupt decreases in pH and alkalinity since 2007 and the concurrent increases in SO_4, Zn, Fe and Mn concentrations. Note that groundwater quality in the RCAA beneath the tailings profile (at well X21B) also deteriorated over the current monitoring period. The similarity in time trends observed at X21A and X21B suggests that local seepage from the overlying tailings (i.e. the coarse permeable tailings beach of the Intermediate Impoundment) is the main source of this increase in contaminants in the local alluvial sediments. However, contaminant concentrations in groundwater at well X21B are typically still at least an order of magnitude lower than in the tailings porewater and are also much lower than upgradient in the Second Impoundment at P03-06. Groundwater quality conditions in the RCAA near X21B can be expected to deteriorate further until they resemble conditions observed upgradient in the Second Impoundment due to ongoing loads from FCS and seepage from the oxidized tailings beaches in the Original, Second and Intermediate Impoundments.

Figure 3-12a/b shows depth profiles for pH, alkalinity, selected major ions, and metals of interest at P03-08 which is located along the southern side of the Rose Creek valley near the Intermediate Pond (and is the furthest downgradient in the Intermediate Impoundment). Depth profiles for the current monitoring period at P03-08 showed no appreciable changes in water quality at depth in the aquifer. for the 2010 monitoring period. Note, however, that the two ports screened just below and above the tailings-ground surface interphase actually showed a significant decrease in contaminants such as sulphate, magnesium and metals of interest (Zn, Fe and Mn), possibly due to dilution by relatively dilute tailings process water and/or geochemical reactions. In any event, there is no sign of significant advance of a seepage plume to date in vicinity of P03-08.

3.6 Toe of Intermediate Dam

3.6.1 Background & Well Locations

Table 3-4 summarizes pertinent information related to the groundwater monitoring wells located at the toe of the Intermediate Dam.

Table 3-4. Monitoring wells near the Intermediate Dam, RCTF

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Intermediate Dam							
X24A-96	1996	6.5	6.46	6.48	1033.10	Not routinely monitored	Alluvium
X24B-96	1996	11.3	9.8	11.3	1033.05	Not routinely monitored	Alluvium
X24C-96	1996	16.5	14.97	16.47	1033.00	Not routinely monitored	Alluvium
X24D-96	1996	28.3	26.84	28.34	1032.90	Bi-annual plus AMP	Alluvium
X25A-96	1996	8.9	7.44	8.97	1032.08	Bi-annual plus AMP	Alluvium
X25B-96	1996	19.1	17.7	19.17	1032.03	Bi-annual plus AMP	Alluvium
P01-03	2001	9.3	7.78	9.3	1032.21	Bi-annual	Alluvium
P01-04A	2001	34.1	32.53	34.05	1031.90	Bi-annual	Alluvium
P01-04B	2001	53.4	51.89	53.41	1031.89	Bi-annual	Till

3.6.2 Review of Time Trends

Time trends for pH, alkalinity, selected major ions, and metals of interest in wells located near the northern end of the Intermediate Dam are shown in Figure 3-13a/b. SO_4, Mg, and metals of interest concentrations have increased in each of these wells since 2001 and concentrations in wells X24D and P01-03 increased further over the current monitoring period. During the 2010 monitoring period concentrations of SO_4, Fe and Mn have shown particularly sharp increases. It is interesting to note that very similar time trends have been observed throughout the alluvial aquifer, i.e. both at shallow depth (i.e. in P01-03 at 6m bgs) as well as at much greater depth in the aquifer (i.e. at X24D at 28m bgs).

The trend towards higher concentrations of SO_4 and metals of interest in the aquifer at X24D and P01-03 is indicative of the presence of mine waste seepage in the alluvial aquifer on the north side of the Intermediate Dam. As discussed in earlier reports, probable sources include seepage from the coarse tailings beaches along the northern edge of the Intermediate, Second or Original Impoundments and/or FCS delivered to the Second Impoundment from the Faro Creek canyon/diversion channel (RGC, 2008; 2010a). Note that the startup of the ETA SIS (in 2007) is not expected to show any immediate reduction in contaminant concentrations in groundwater beneath the Intermediate Dam due to the considerable transport distances (1,500 to 2,000m).

In earlier assessments, seepage from the Intermediate Pond was not believed to be a major source of contamination. This earlier conclusion is supported by the fact that sulphate concentrations in the alluvial aquifer are now significantly higher than sulphate concentrations currently observed in the Intermediate Pond (~1,000 mg/L). Nevertheless, metal concentrations in the Intermediate Pond have significantly increased since start of discharge of highly contaminated waste rock seepage (collected in the ETA SIS) into the Intermediate Pond in mid-2007. Hence even limited seepage from the Intermediate Pond could affect metal concentrations in the groundwater of the underlying alluvial aquifer. A geochemical and isotopic comparison of water from the Intermediate Pond and groundwater at X24D and P01-03 is currently in progress to evaluate the potential contribution of Intermediate Pond water to the contamination in the underlying RCAA.

Groundwater quality near the southern abutment of the Intermediate Dam (at X25A/B and P01-04A/B) is much less impacted than groundwater to the north but it is also deteriorating rather rapidly (see Figure 3-14a/b). Specifically, SO_4 and Mg concentrations in wells X25A, X25B, and P01-04A have increased steadily since 2004 and two wells (P01-04A and X25A) even show increases in selected metals (Fe and Mn). Note that zinc concentrations continue to be very low in all impacted wells on the south side of the Intermediate Dam. This delay in zinc breakthrough is likely caused by sorption.

The generally lower concentrations of SO_4, Mg, and metals of interest in groundwater near the southern end of the Intermediate Dam compared to the northern abutment are consistent with the observed water quality further upgradient in the Intermediate Impoundment. This difference has been attributed to the lack of impact of highly contaminated FCS on the south side of the valley (RGC, 2008, 2010b). Instead, tailings seepage from the Intermediate and/or Second Impoundment is the most likely source of ARD products to groundwater near the southern end of the Intermediate Dam. The significant delay in the “breakthrough” of the ARD species in groundwater in the southern portion can likely be attributed to the even longer transport distances from the main source areas on the south side, i.e. the coarse beaches in the northernmost portion of the Second Impoundment (near P03-01, P03-02 and P03-03). Based on current trends, it is expected that over the long term groundwater quality on the south side of the Intermediate Dam will also deteriorate and reach similarly high contaminant concentrations currently observed on the north side.

3.7 Toe of Cross Valley Dam

3.7.1 Background & Well Locations

Table 3-5 summarizes pertinent information related to the groundwater monitoring wells located along the toe of the Cross Valley Dam.

Table 3-5. Monitoring wells below the toe of the Cross Valley Dam, RCTF

Well ID	**Year of Construction**	**Total Depth (m bgs)**	**Top of Screen (m bgs)**	**Bottom of Screen (m bgs)**	**Top of Casing Elevation (m asl)**	**Current Status of Monitoring**	**Formation**
Toe of Cross Valley Dam							
P01-02A	2001	14.1	12.54	14.06	1019.73	Bi-annual	Alluvium
P01-02B	2001	28.4	26.88	28.4	1019.71	Bi-annual	Till
P01-11	2001	10.7	9.15	10.67	1017.83	Bi-annual	Alluvium
P03-09-01	2003	35.1	34.75	35.05	1018.51	Not routinely monitored	Alluvium
P03-09-02	2003	32.3	32.00	32.31	1018.51	Bi-annual	Alluvium
P03-09-03	2003	27.1	26.82	27.13	1018.51	Not routinely monitored	Alluvium
P03-09-04	2003	23.8	23.47	23.77	1018.51	Bi-annual	Alluvium
P03-09-05	2003	21.9	21.64	21.95	1018.51	Not routinely monitored	Alluvium
P03-09-06	2003	18.9	18.59	18.90	1018.51	Bi-annual	Alluvium
P03-09-07	2003	13.4	13.11	13.41	1018.51	Not routinely monitored	Alluvium
P03-09-08	2003	9.4	9.14	9.45	1018.51	Bi-annual	Alluvium
P03-09-09	2003	7.6	7.32	7.62	1018.51	Bi-annual	Alluvium
MW1	2005	17.7	1.95/12.19	9.74/17.67	1016.97	Not routinely monitored	Alluvium
MW2	2005	14.9	2.19	14.89	1018.23	Not routinely monitored	Alluvium
P05-01-01	2005	25.5	25.15	25.45	1018.00	Bi-annual	Till/BR
P05-01-02	2005	19.8	19.67	19.82	1018.00	Bi-annual	Alluvium
P05-01-03	2005	16.8	16.62	16.77	1018.00	Bi-annual	Alluvium
P05-01-04	2005	11.3	11.13	11.28	1018.00	Bi-annual	Alluvium
P05-01-05	2005	5.5	5.33	5.48	1018.00	Bi-annual	Alluvium
P05-01-06	2005	3.4	3.20	3.35	1018.00	Bi-annual	Alluvium
P05-02	2005	5.2	1.83	4.88	1016.67	Bi-annual	Alluvium
P05-03	2005	7.6	3.44	7.62	1019.79	Bi-annual	Alluvium
RGC-PW1	2005	21.1	4.19/16.38	5.79/19.59	1017.31	Not routinely monitored	Alluvium
RGC-PW2	2005	16.9	4.19	15.39	1018.64	Not routinely monitored	Alluvium
P09-C1	2009	34.0	32.6	34	1017.36	Bi-annual	Bedrock
P09-C2	2009	59.3	53.5	59.3	1016.58	Bi-annual	Bedrock
P09-C3	2009	48.7	45.8	48.7	1019.65	Bi-annual	Alluvium

3.7.2 Review of Time Trends

Time trends for pH, alkalinity, selected major ions, and metals of interest in groundwater near the toe of the Cross Valley Dam are shown in Figures 3-15a/b to 3-17a/b.

Concentrations of SO_4 and Mg remained relatively low in monitoring wells located along the southern side of the Rose Creek valley (i.e. at P01-02A/B) and hence groundwater in this area remains only modestly impacted by mine waste seepage. Groundwater quality near the middle of the Cross Valley Dam (at P05-03) is more impacted than at P01-02 but less so than groundwater on the northern side of the Cross Valley Dam (at wells P01-11 and P05-02).

As observed further upgradient, groundwater quality on the northern side of the Cross Valley Dam also continues to deteriorate. SO_4, Mg concentrations and (to a lesser extent) metals continued to increase in wells P01-11 and P05-02 over the current monitoring period and have now reached all-time highs (see Figure 3-15a). This trend towards higher SO_4 and Mg concentrations likely reflects the ongoing transport of a TDS plume that originates in the Faro Creek canyon and/or the Original Impoundment and subsequently affects groundwater quality in the RCAA along the entire north side of the Rose Creek valley (i.e. in the Second and Intermediate Impoundments and in the Intermediate Dam reach at X24). The similarity in water quality time trends observed at the Intermediate Dam (e.g. X24D) and more recently at the Cross Valley Dam clearly suggests that this is a continuous contaminant plume (not significantly impacted by seepage from the Polishing Pond). Based on the observed time trends sulphate concentrations on the northern side of the Cross Valley Dam can be expected to reach 2,500 - 3,000 mg/L in the next 3-5 years.

Although metal concentrations are still much lower than observed further upgradient (at the Intermediate Dam) they are steadily increasing on the north side of the Cross Valley Dam (Figure 3-13a/b). For example, zinc concentrations exceeded 0.05 mg/L at P05-02 and 0.01 mg/L at P01-11 and P05-03 during the 2010 monitoring period. Based on trends observed further upgradient at the Intermediate Dam, zinc concentrations in groundwater on the north side of the Cross Valley Dam can be expected to exceed 0.1 mg/L in the next 3 to 5 years.

Time trends for pH, alkalinity, selected major ions, and metals of interest in the multilevel wells P03-09 and P05-01 are shown in Figures 3-16a/b and 3-17a/b, respectively. Note that the multilevel piezometers at P05-01 are screened in the RCAA closer to the north side of the Rose Creek valley whereas those at P03-09 are screened in the RCAA near the center of the valley (see Figure 3-1). Groundwater at P05-01 is more impacted by ARD than groundwater at P03-09 due to the FCS load delivered to the former via the RCAA in the Intermediate Dam reach. Note that conditions in both areas continued to deteriorate during the current monitoring period in accordance with trends defined by previously-collected data.

Figure 3-18a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest for the ‘P09-C’ well series. Recall that two of these wells (C1 and C2) are screened in deep bedrock whereas C3 is screened in deep alluvium immediately above bedrock. The groundwater in deep bedrock near the northern abutment of the Cross Valley Dam (at well P09-C1) showed SO_4, Mg, Fe and Mn concentrations which are comparable to concentrations in shallow groundwater in the overlying alluvium and are higher than in groundwater to the south (at well P09-C2). Note that Zn concentrations in groundwater from well P09-C1 were very low (< 0.01 mg/L) in 2008/09 but were significantly elevated in 2010 (0.09 mg/L). These data suggest that groundwater in deep bedrock near the northern abutment of the Cross Valley Dam is impacted to a similar extent as the RCAA in this area but that groundwater in bedrock closer to the southern side of the Rose Creek valley remains unaffected by mine waste seepage.

3.8 Downgradient of the Cross Valley Dam

3.8.1 Background & Well Locations

Four nested piezometers (X16A/B, X17A/B, X18A/B, and P01-01A/B) located downgradient of the Cross Valley Dam are sampled bi-annually as part of the routine groundwater monitoring program (Table 3-6).

Table 3-6. Monitoring wells downgradient of the Cross Valley Dam, RCTF

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Downgradient of Cross Valley Dam							
X16A	1981	6.0	3	6	1016.41	Bi-annual	Alluvium
X16B	1981	34.0	20	34	1016.01	Bi-annual	Alluvium
X17A	1981	6.2	4.5	6.2	1015.45	Bi-annual	Alluvium
X17B	1981	25.0	17	25	1014.89	Bi-annual	Alluvium
X18A	1981	10.6	8.8	10.6	1019.59	Bi-annual	Alluvium
X18B	1981	22.8	16.6	22.8	1019.65	Bi-annual	Alluvium
P01-01A	2001	21.4	19.8	21.36	1015.86	Bi-annual	Alluvium
P01-01B	2001	35.3	33.78	35.3	1015.86	Bi-annual	Alluvium

3.8.2 Review of Time Trends

Figures 3-19a/b show times trends for pH, alkalinity, selected major ions, and metals of interest in wells X16A/B, X17A/B, X18A/B and P01-01A/B. In wells X18A/B and P01-01A/B (both located on the northern side of Rose Creek valley), concentrations of SO_4 and Mg continued to increase in 2010 as they have in recent years although metals concentrations remained very low. The increase in SO_4 and Mg in this area is thought to be caused by the leading edge of a TDS front that has been identified upgradient along the northern side of the Cross Valley Dam (at wells P01-11 and P05-01) and in the Intermediate Dam reach (at well X24) and likely originates from the Faro Creek canyon. Note that groundwater in the center of the valley (at X17A/B) and further downgradient at X16A/B is less impacted (if impacted at all). The lack of any significant groundwater impact by mine waste seepage in this area is believed to be a combination of upwelling and discharge to surface of impacted groundwater and dilution by seepage from the Rose Creek diversion.

Note that the slightly elevated Zn concentrations (~0.01 mg/L) observed in the shallow well X16A are believed to be a result of recharge from the Rose Creek diversion (which shows slightly elevated zinc concentrations) and/or leaching of historic tailings nearby and not the transport of impacted groundwater into the area from upgradient.

4 GRUM & VANGORDA MINE SITE

4.1 Geographic Overview

Figure 4-1 shows the general layout of the Grum and Vangorda mine sites and the locations of groundwater monitoring wells therein. The Grum mine site consists of the Grum Pit, Grum Rock Dump (w/ sulphide cell) and the overburden stockpile, whereas the Vangorda mine site consists of the Vangorda Pit (w/ in-pit rock dumps) and the Vangorda Rock Dump. Groundwater monitoring wells are located primarily along the toes of the various rock dumps in order to monitor potential seepage to groundwater.

Groundwater quality data for the Grum mine site and Vangorda mine site are discussed separately in the sections below.

4.2 Grum Mine Site

4.2.1 Background & Well Locations

Figure 4-2 shows the locations of the monitoring wells located downgradient of the Grum Rock Dump and Table 4-1 lists pertinent information regarding the construction of these wells and their monitoring status.

Table 4-1. Monitoring wells location near Grum Slot, west of Grum Dump, and near Little Creek Dam, Grum/Vangorda mine site

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Grum WRD Area							
P96-9A	1996	9.5	4.96	9.45	~1098	bi-annual	Overburden
SRK04-5A	2004	23.7	22.7	23.7	1103.93	bi-annual	BR (weathered)
SRK04-5B	2004	14.7	13.7	14.7	1103.95	bi-annual	Overburden
BH05-9B-R	2005	18.6	15.5	18.6	1101.06	bi-annual	Overburden/BR
SRK05-05C	2005	3.2	1.5	3	1104.08	bi-annual	Overburden
SRK05-06 ("Moose Well 1")	2005	2.7	0.7	2.7	1073.83	not routinely monitored	Overburden
SRK05-07	2005	5.8	0.75	5.8	1107.30	not routinely monitored	Overburden/BR
SRK05-08	2005	7.6	2.1	7.6	1105.25	not routinely monitored	Overburden
SRK05-09 ("Moose Well 2")	2005	3.7	0.5	3.5	1072.82	not routinely monitored	Overburden
SRK05-09	2005	3.3	0.9	3.3	1060.64	not routinely monitored	Overburden/BR
SRK05-10	2005	2.2	0.7	2.2	1043.40	not routinely monitored	Overburden
SRK08-P14	2008	9.1	6.1	9.1	1234.17	annual	Weathered BR
SRK08-P15	2008	7.6	4.6	7.6	1184.62	annual	Bedrock
SRK08-P16	2008	9.1	6.1	9.1	1108.87	not routinely monitored	Bedrock
P09-GS1A	2009	29.6	23.5	29.6	1230.00	annual	Bedrock
P09-GS1B	2009	6.6	5.1	6.6	1229.98	annual	Overburden/BR
P09-GW1	2009	3.7	1.56	3.66	1280.01	not routinely monitored	Overburden
P09-GW3	2009	2.4	1.4	2.4	1279.80	not routinely monitored	Overburden

4.2.2 Review of Time Trends

Figure 4-3a/b shows time trends for pH, alkalinity, selected major ions, and metals of interest for the monitoring wells located near Grum Creek and downgradient of the Moose Pond. In the former Grum Creek drainage channel only monitoring well SRK05-05C screened in shallow overburden is routinely monitored. Shallow groundwater in SRK05-05C remains modestly-impacted by ARD. However, a small improvement in water quality has been observed in 2010 with a modest decline in SO_4, Mg and Zn concentrations.

Earlier monitoring of the two wells located downgradient of the Moose Pond had indicated a breakthrough of conservative ARD products such as SO_4 and Mg in the overburden soils. Bi-weekly monitoring of SRK09-05 ("Moose Well #2") in 2010 confirmed this trend. Sulphate concentrations were slightly higher than those observed in 2010 (ranging from ~1,000 to 1,400 mg/L) suggesting that breakthrough of seepage from Moose Pond is continuing. Note also that zinc concentrations increased significantly in 2010, reaching concentrations as high as 80 ug/L in October 2010. The recent monitoring trends suggest that the sorption capacity of the local soils for zinc is gradually being depleted and that zinc concentrations may rise further in the coming months and years.

Time trends for pH, alkalinity, selected major ions, and metals of interest in wells located west of Grum Creek are shown in Figure 4-4a/b. Of particular interest are trends for wells P96-9A and BH05-9B-R (which are both located in a narrow side channel from Grum Creek but screened at different depths and in different materials). Deeper groundwater from bedrock screened by well BH05-9B-R remains modestly-impacted by mine waste seepage (i.e. 150 to 200 mg/L SO_4) and there was no change in groundwater quality during the current monitoring period. In contrast, SO_4 and Mg concentrations in shallow groundwater in overburden soils (screened by well P96-9A) are significantly higher and continued to increase during the current monitoring period (as they have for nearly ten years). Note that the increases in SO_4 and Mg concentrations in 2010 were particularly abrupt and both contaminants reached all-time high concentrations (see Figure 4-4a). Moreover, a concurrent increase in Zn was evident although concentrations of Zn and other metals of interest do remain relatively low (i.e. <0.05 mg/L).

The recent increases in SO_4 and Mg (and to a lesser extent zinc) suggest increased flushing of ARD products from the Grum Dump. Based on historic trends observed at the Faro Mine (e.g. ETA area) sulphate concentrations above 3,000 mg/L are typically followed by a breakthrough of metals (in particular zinc) within a few years. Future monitoring of P96-9A will show whether a similar ARD evolution and zinc transport can be expected at the Grum Dump or whether local overburden soils provide a greater attenuation capacity than at the Faro site.

Monitoring well SRK05-07 located further west of P96-9 had insufficient water for sampling on both dates of sampling (June and September).

Time trends for pH, alkalinity, selected major ions, and metals of interest in wells located near Grum Slot (and west of the Grum Dump) are shown in Figure 4-5a/b. Data collected since 2009 suggests that groundwater from wells P09-GS1A and P09-GS1B is moderately-impacted by mine waste seepage. Specifically, SO_4 concentrations in groundwater from both wells are slightly elevated (400 to 600 mg/L) and higher than in standing water from the Grum Slot. Note that the Zn concentration in well P09-GS1B (screened in overburden) is 4 to 5 mg/L or about two orders of magnitude higher than in groundwater from well P09-GS1A. These high Zn concentrations are likely a result of *in situ* leaching of mineralized waste rock observed in the drill cuttings of P09-GS2 (SRK, 2010) and not the transport of ARD products in groundwater from upgradient.

Note that no additional water quality data was available for wells P09-GW1 or P09-GW3 as both wells did not have sufficient water for sampling in June. Data collected in November 2009 suggests that groundwater in the vicinity of well P09-GW1 is impacted though yet metals concentrations remain at or below their respective detection limits. Hence it seems that groundwater at the western toe of the Grum Rock Dump is impacted by a ‘TDS front’ but does not yet receive a substantial load of metals.

Wells SRK08-P14, SRK08-P15, and SRK08-P16 are located along the southwest toe of the Grump Rock Dump (Figure 4-2). Time trends for pH, alkalinity, selected major ions, and metals of interest in these wells are shown in Figure 4-5c/d. Note that monitoring well SRK08-P16 had insufficient water (in September 2010) to collect a sample. SO_4 concentrations in wells SRK08-P14 and SRK08-P15 are close to 900 mg/L and have increased since the last monitoring period. The pH of groundwater remains neutral to slightly alkaline though and metals concentrations are still very low (<0.01 mg/L Zn). The condition of groundwater is therefore consistent with the presence of some mine waste seepage but at this point only the breakthrough of conservatively-transported species has occurred. Future monitoring data will be needed to identify whether SO_4 and Mg concentrations will further increase and when the breakthrough of dissolved metals into groundwater occurs in this area.

4.3 Vangorda Mine Site

4.3.1 Background & Well Locations

Figure 4-6 shows the locations of monitoring wells located downgradient of the Vangorda Rock Dump and Table 4-2 summarizes pertinent information regarding the construction of these wells and their monitoring status.

Table 4-2. Monitoring wells downgradient of Vangorda Rock Dump and near Vangorda Creek, Grum/Vangorda mine site

Well ID	Year of Construction	Total Depth (m bgs)	Top of Screen (m bgs)	Bottom of Screen (m bgs)	Top of Casing Elevation (m asl)	Current Status of Monitoring	Formation
Vangorda WRD Area							
V34	1994	12.5	n/a	n/a	1117.45	Bi-annual	BR
V35	1994	15.5	n/a	n/a	1117.41	Bi-annual	Alluvium
V36	1994	11.9	n/a	n/a	1118.43	Bi-annual	Alluvium
V37	1994	14.1	n/a	n/a	1116.17	Bi-annual	Alluvium
P2001-02A	2001	13.6	n/a	n/a	~1118	Bi-annual	n/a
P2001-02B	2001	27.0	n/a	n/a	~1118	Bi-annual	n/a
P2001-03	2001	n/a	n/a	n/a	~1121	Bi-annual	n/a
P09-VC1	2009	57.9	52.6	57.9	1113.28	Annual	Bedrock
P09-VC2	2009	21.3	18.25	21.3	1110.90	Annual	Overburden
P09-LCD1	2009	6.5	5.97	6.47	1097.53	Bi-annual	Overburden
P09-LCD2	2009	4.8	3.6	4.8	1097.69	Not routinely monitored	Overburden
P09-LCD3	2009	6.0	5.5	6	1093.71	Not routinely monitored	Overburden
P09-LCD4	2009	11.8	10.88	11.78	1093.68	Bi-annual	Overburden
P09-LCD6	2009	7.3	6.41	7.31	1096.21	Bi-annual	Overburden
P09-LCD7	2009	10.4	7.4	10.4	1101.68	Not routinely monitored	Overburden

4.3.2 Review of Time Trends

Time trends for pH, alkalinity, selected major ions, and metals of interest in wells along the toe of the Vangorda Rock Dump are shown in Figure 4-7a/b. Groundwater quality immediately downgradient of the Vangorda waste rock dump has historically shown very little impact of waste rock seepage. However, recent water quality time trends showed first signs of a breakthrough of a TDS front (including SO4 and Mg) and this trend continued during the 2010 monitoring period. Of particular interest is the rather abrupt increase in SO_4 and Mg concentrations (and decrease in pH) in samples from well V36 (which is located at the northwest toe of the Vangorda Rock Dump). Increases in SO_4 and Mg concentrations suggest the breakthrough of a TDS plume in this area. Note that zinc concentrations have also increased in this well and reached ~0.075 mg/L in 2010.

Similarly high sulphate and zinc concentrations have been periodically observed over the last four years at monitoring well V35 (including in 2010).

Although all other monitoring wells located downgradient of the Vangorda waste rock dump showed much lower contaminant concentrations than wells V35 and V37, a gradual increase in sulphate over the last 3-4 years and into 2010 is clearly evident in all wells in this area (see Figure 4-7a/b). Note also that Zn concentration in V34 (located to the south of the Vangorda dump) increased abruptly during the current monitoring period. It is therefore likely that waste rock seepage from the Vangorda dump will – over the long-term - impact most if not all groundwater in the area downgradient of the Vangorda dump.

Figure 4-8a/b shows initial water quality results in three of the five recovery wells recently completed within the Vangorda waste rock dump and first sampled in the fall of 2010 (“DH” series). According to the borehole logs all five DH wells are screened in waste rock near or at the interface with the underlying till (SRK, 2011). However, a comparison of the geodetic elevations of the well screens with pre-mining topography suggests that some of these wells may have been screened in the low-permeability till underlying the waste rock (SRK, 2011). This would explain the low yields and slow water level recovery observed in several of these wells.

Well DH1 showed highly elevated concentrations of SO_4, Mg, alkalinity and selected metals (Fe, Mn) characteristic of neutralized waste rock seepage. In contrast, zinc concentrations remained very low (<0.01 mg/L). Note that this well is located immediately to the west of the Vangorda sulphide cell. The other two DH wells sampled in late 2010 (DH2 and DH3) showed significantly lower contaminant concentrations than observed at DH1, with only moderately elevated sulphate (~1,000 mg/L), magnesium (~90 mg/L) and metal concentrations. These initial seepage water quality results suggest that seepage in the southwestern corner of the Vangorda waste rock dump is not influenced by the sulphide cell.

Note that contaminant concentrations in several downgradient monitoring wells (e.g. at V34, V35 and V36) are in fact already higher than at DH2 and DH3 suggesting that more ‘mature’ waste rock seepage from other parts of the Vangorda rock pile (such as the sulphide cell) are the primary source of contaminants in the local groundwater.

The new DH wells provide valuable insight into the water quality of waste rock seepage entering the groundwater system beneath the Vangorda waste rock dump. We therefore recommend that all five DH wells be included in the routine monitoring program for 2011 (see section 5.4). Note, however, that it is still unclear whether the water sampled in these wells represents pore water (in waste rock) or seepage in the underlying till soils. This uncertainty will have to be resolved in order to properly interpret the water quality results.

Time trends for pH, alkalinity, selected major ions, and metals of interest in monitoring wells located in the Little Creek Dam (LCD) area and near Vangorda Creek are shown in Figure 4-9a/b. Note that SO4 and Mg concentrations in groundwater from the ‘P09-VC’ and ‘P09-LCD’ well series are generally lower than in the other wells near the Vangorda Rock Dump and suggest only modest amounts of seepage is present in groundwater.

Groundwater in the Vangorda Creek drainage immediately downgradient of the Vangorda Pit (at wells P09-VC1 and P09-VC2) continued to show very limited impact from mine waste seepage. Note that Zn concentrations in well P09-VC2 are anomalously high (~0.08 mg/L in 2010) but this is likely the result of mineralized waste rock used for road construction being leached locally (and not the transport of metals via groundwater into this area). In short, there is no evidence of seepage from the Vangorda Pit in overburden and/or fractured bedrock in this area. Moreover, there seems to be little risk of seepage from the Vangorda Pit entering Vangorda Creek if the water level in Vangorda Pit is maintained at or below its current elevation. Wells P09-VC1 and P09-VC2 should both be monitored routinely to ensure that this situation does not change.

Groundwater quality in monitoring wells located immediately downgradient of Little Creek Dam (in the ‘P09-LCD’ wells) did not show any significant changes in 2010. Again, small differences are observed between wells screened in overburden and bedrock but major ion and metal concentrations in each of the wells was generally consistent with groundwater that is only modestly impacted by seepage from the LCD (i.e. SO4 <300 mg/L and low concentrations of metals).

5 CONCLUSIONS & RECOMMENDATIONS

The main conclusions reached by review of data collected from November 2009 to September 2010 at the ARMC are summarized in the sub-sections 5.1 to 5.3 and recommendations regarding future groundwater monitoring are provided in sub-section 5.4.

5.1 Faro Mine Site

- Groundwater in the Mill Site area remains impacted by conservatively-transported species (like SO_4 and Mg) but metals concentrations remain low and there were no appreciable changes in water quality during the current monitoring period;
- Surface water and groundwater quality near X23 (downgradient of the Main WRD) improved considerably during the 2010 monitoring period (in particular for metals such as zinc) suggesting a cyclical leaching pattern likely controlled by the precipitation pattern and advance of wetting fronts through the waste rock dump. However, longer-term time trends indicate an overall increase in all contaminant concentrations with time, suggesting a gradual “breakthrough” of ARD products and increased loading to the ETA area
- Shallow groundwater in the ETA area remains highly-impacted by ARD and water quality conditions continued to deteriorate in 2010. Groundwater quality in overburden soils at the mouth of the Faro Creek canyon did not show any significant improvement in water quality despite operation of the ETA SIS. However, contaminant concentrations at this location are significantly lower than in the ETA suggesting some dilution by local recharge.
- In the S-cluster area, highly impacted groundwater in several bedrock wells continued to improve significantly due to operation of two recovery wells. Furthermore, groundwater quality in close proximity of the NFRC (in both overburden and bedrock) continued to improve due to operation of the SIS. However, contaminant concentrations in shallow groundwater immediately downstream of the western part of the SIS increased in 2010 suggesting that the western side of the SIS trench may be not be operating as intended;
- Near the Northeast Rock Dump, groundwater quality at well BH14A/B improved somewhat since the last monitoring period but the long-term trend in this area suggest a gradual breakthrough of contaminants including metals (zinc); increasing concentrations are likely due to an incremental contaminant load from the NE rock dump; this contaminant load is also believed to affect groundwater quality in the NFRC alluvial aquifer (further downgradient at well SRK08-P12A/B) but groundwater quality in the alluvial aquifer has remained stable since the last monitoring period;

- In the Zone 2 Pit outwash area, groundwater near the toe of the Zone 2 Pit remained highly-impacted by waste rock seepage but groundwater quality did not deteriorate further during the current monitoring period; moreover, groundwater quality in wells screened in outwash sediments further downgradient was also unchanged and hence indicative of relatively stable water quality conditions in this area; the observed decrease in alkalinity and increase in zinc concentrations in the NFRC aquifer along the reach of the Zone outwash area suggesting an incremental metal load due to seepage from the Zone 2 pit area which enters the NFRC valley aquifer via groundwater flow through weathered and/or fractured bedrock.

5.2 Rose Creek valley

Groundwater quality in the Rose Creek alluvial aquifer (RCAA) remains impacted by seepage from coarse, fully-oxidized tailings beaches in the former RCTF and by waste rock seepage from the Faro Mine (FCS) delivered to the valley via the Faro Creek canyon/diversion. FCS appears to impact groundwater quality solely along the northern side of the valley whereas tailings seepage continues to impact groundwater quality on both sides immediately downgradient of tailings beaches. Note also that sealing of the “leaky” wells in 2005 has not resulted in any improvement in groundwater quality. It is therefore concluded that ‘mature’ tailings seepage (from fully oxidized beaches in the Original and Second Impoundment) is the principal cause of highly elevated zinc concentrations observed at select locations in the RCAA.

A summary of other developments in groundwater quality in the Rose Creek valley is provided below:

- Groundwater upgradient of the RCTF continues to reflect ‘background’ conditions for the ARMC and hence remains unimpacted by mine waste seepage from either the Main or Intermediate WRDs;
- Groundwater quality within the Original and Second Impoundments continued recent trends of gradual increase in contaminant concentrations, including zinc. Of particular interest were increases in SO_4, Mg, and metals of concern (Zn, Mn) throughout the alluvial aquifer at P03-06, which suggest continued seepage from the Faro Creek canyon and/or coarse tailings beaches in the Original Impoundment;
- In the reaches of the Intermediate and Cross Valley Dams, groundwater in the RCAA continued to deteriorate as increases in SO_4, Mg, and selected metals of interest (in particular Mn but also Zn) were apparent; note that groundwater continues to be more significantly impacted on the north side of the valley than the south side although water quality in both areas have deteriorated since the last monitoring period (i.e. at X24D, X25A/B, and P01-04A/B); these time trends suggest that contaminant loads from FCS (on the north side only) and from seepage of oxidized coarse tailings beaches (on the north and south

side) continue to impact the RCAA; the gradual increase in zinc concentrations also suggest that the attenuation capacity of the alluvial aquifer is gradually becoming exhausted;

- Groundwater from wells near the toe of the Cross Valley Dam clearly indicate that groundwater in deep, fractured bedrock on the northern side of the valley (at well P09-C1) is impacted by mine waste seepage but to a lesser extent groundwater in the overlying RCAA; very limited, if any, impact is observed in deep bedrock near the center of the valley and deep groundwater appears unimpacted along the southern side of the Rose Creek valley; these data suggest that the same loads that affect groundwater quality in the RCAA also affect deeper groundwater from bedrock;
- Downgradient of the Cross Valley Dam, groundwater quality at wells located near the northern side of the valley continued to deteriorate during the current monitoring period but contamination remains limited to Ca, Mg and SO_4 and metals concentrations still remain very low; these data support the assertion from previous reports/studies that a TDS plume is present in this area but that the leading edge of a metals front still resides upgradient;

5.3 Grum/Vangorda Mine Site

The main conclusions of the groundwater quality review at the Grum/Vangorda mine site are as follows:

- Near the Grum Slot (and west of the Grum Dump), groundwater (at wells P09-GS1A/B) remains moderately impacted by mine waste seepage (and contains higher concentrations of certain contaminants than standing water from the Grum Slot) but elevated Zn concentrations are likely the result of *in situ* leaching of mineralized waste rock and not the transport of ARD products in groundwater from upgradient.
- Groundwater in the shallow overburden soils to the south of the Grum Sulphide Cell (at P96-9A) continues to deteriorate (as it has for nearly ten years); note that the increases in SO_4 and Mg concentrations during the current monitoring period were particularly abrupt and both contaminants reached all-time high concentrations but metals remain quite low; deeper groundwater near the bedrock-overburden interface (at BH05-9B-R) remained unimpacted
- Groundwater in shallow overburden near the southwestern toe of the Grum Rock Dump (at ‘SRK08-P’ wells) also showed a gradual increase in oxidation products (SO_4 and Mg) but metals concentrations remain very low;
- Shallow groundwater in soils downgradient of the Moose Pond continues to be impacted by seepage from the Moose Pond which is used as an infiltration pond for seepage from the Grum waste rock dump. In 2010, zinc concentrations increased significantly (at Moose Well #2) in 2010, reaching 80 ug/L in October 2010. The recent monitoring trends suggest that the

sorption capacity of the local soils for zinc is gradually being depleted and that zinc concentrations may rise further in the coming months and years.

- Groundwater in the Vangorda Creek drainage immediately downgradient of the Vangorda Pit (at wells P09-VC1 and P09-VC2) continued to show no evidence of seepage from the Vangorda Pit in overburden and/or fractured bedrock in this area. Groundwater quality in monitoring wells located immediately downgradient of Little Creek Dam (in the 'P09-LCD' wells) also did not show any significant changes in 2010.
- Groundwater quality immediately downgradient of the Vangorda waste rock dump has recently shown first signs of a breakthrough of a TDS front (including SO4 and Mg) and this trend continued during the 2010 monitoring period. Of particular interest is the rather abrupt increase in SO4 and Mg concentrations (and decrease in pH) in samples from well V36 (which is located at the northwest toe of the Vangorda Rock Dump); note that zinc concentrations have also increased in this well and reached ~0.075 mg/L in 2010. Similarly high sulphate and zinc concentrations have been periodically observed over the last four years at monitoring well V35 (including in 2010). A gradual increase in sulphate over the last 3-4 years and into 2010 is also evident in all other monitoring wells located along the southern and western toe of the Vangorda WRD;

5.4 Recommendations

Numerous changes to the ARMC's routine monitoring program were made as a result of recommendations from the last monitoring report, including adding wells installed in 2009, increasing the frequency of monitoring at a selection of wells in the S-Cluster area, and reducing (or discontinuing) sampling of selected wells in the Zone 2 outwash area and Rose Creek valley. As these changes were rather comprehensive in scope we see no need to alter the program further based on data from the current monitoring period and hence the only change we recommend is that the wells recently installed near the Vangorda WRD be added to the routine monitoring program (see Tables 5-1 to 5-3).

In addition we recommend that annual performance reviews be completed for the two currently operating seepage interception systems (SIS), i.e. the ETA-SIS and the S-Cluster SIS. Of particular relevance is the apparent deterioration in water quality in shallow wells on the west side of the S-cluster interceptor trench which suggests that the interceptor trench is not working as intended.

Table 5.1.

Recommended Scope of Groundwater Monitoring in 2011, Faro Mine Site

Well ID	Region	Northing UTM z8 NAD27	Easting UTM z8 NAD27	Proposed Frequency
Faro Mine Site				
P96-8A	ETA Area	6913898	583328	Bi-annual
P96-8B	ETA Area	6913898	583328	Bi-annual
SRK04-3A	ETA Area	6913824	582977	Annual
SRK05-ETA-BR1	ETA Area	6913846	582972	Annual
SRK05-ETA-BR2	ETA Area	6913825	582987	Annual
P09-ETA1	ETA Area	6913635	582807	Annual
P09-ETA2	ETA Area	6913633	582832	Bi-annual
S1A	S-cluster Area	6912942	584539	Bi-annual
S1B	S-cluster Area	6912942	584539	Bi-annual
S2A	S-cluster Area	6912944	584577	Bi-annual
S2B	S-cluster Area	6912944	584577	Bi-annual
P96-7	S-cluster Area	6913105	584225	Bi-annual
SRK05-SP-1A	S-cluster Area	6912901	584727	Annual
SRK05-SP-1B	S-cluster Area	6912901	584726	Annual
SRK05-SP-2	S-cluster Area	6912861	584791	Annual
SRK05-SP-3A	S-cluster Area	6912924	584651	Annual
SRK05-SP-3B	S-cluster Area	6912924	584652	Annual
SRK05-SP-4A	S-cluster Area	6912939	584612	Bi-annual
SRK05-SP-4B	S-cluster Area	6912939	584611	Bi-annual
SRK05-SP-5	S-cluster Area	6912956	584576	Bi-annual
SRK05-SP-6	S-cluster Area	6912975	584492	Annual
SRK08-SP7A	S-cluster Area			Quarterly
SRK08-SP7B	S-cluster Area			Quarterly
SRK08-SBR2	S-cluster Area			Annual
SRK08-SBR3	S-cluster Area			Annual
SRK08-SBR4	S-cluster Area			Annual
P09-SIS1	S-cluster Area	6912954	584585	Quarterly
P09-SIS2	S-cluster Area	6912950	584594	Quarterly
P09-SIS3	S-cluster Area	6912944	584602	Quarterly
P09-SIS4	S-cluster Area	6912936	584617	Quarterly
P09-SIS6	S-cluster Area	6912934	584625	Bi-annual
SRK08-P9	Toe Main Dump	6913440	583804	Bi-annual
SRK08-P10A	Mill Site	6914055	582720	Bi-annual
SRK08-P11A	Mill Site	6914573	582585	Bi-annual
SRK08-P11B	Mill Site	6914574	582584	Bi-annual
BH5	Zone 2 Outwash	6913377	585194	Annual
BH6	Zone 2 Outwash	6913466	585198	Annual
BH8	Zone 2 Outwash	6913599	585253	Annual
BH10A	Zone 2 Outwash	6913533	585190	Annual
BH10B	Zone 2 Outwash	6913533	585191	Annual
P05-04	Zone 2 Outwash	6913475	585224	Annual
SRK08-P12A	Zone 2 Outwash	6913506	585348	Annual
SRK08-P12B	Zone 2 Outwash	6913509	585345	Annual
Zone 2 Pumping Well (X26)	Zone 2 pit	6913770	584868	Bi-annual
BH13B	NE Dumps	6914339	585844	Bi-annual
BH14A	NE Dumps	6913826	585676	Bi-annual
BH14B	NE Dumps	6913826	585676	Bi-annual
P96-6	Intermediate Dump (NFRC)	6913133	584999	Bi-annual

Finally, we recommend that earlier predictions of contaminant transport (in particular sulphate and zinc) in the Rose Creek valley be reconciled with the currently observed advance of the contaminant plume in the northern and southern portions of the RCAA. Using previous predictions and recently observed advances of contaminants such as sulphate and zinc, the time required for the breakthrough of zinc at the Cross Valley Dam should be estimated. Such semi-empirical estimates will provide a time frame for the planning of design and implementation of a seepage interception system downstream of the Rose Creek TSF.

Table 5.2

Recommended Scope of Groundwater Monitoring for 2011, Rose Creek Tailings Facility

Well ID	Region	Northing UTM z8 NAD27	Easting UTM z8 NAD27	Proposed Frequency
Rose Creek Tailings Facility				
TH86-2	upgradient	?	?	Annual
TH86-5	upgradient	?	?	Annual
TH86-17	upgradient	6912489	583943	Annual
P03-01 (-02,-04,-06,-08,-09)	Second Impoundment	6912580	583301	Annual
P03-03 (-02,-04,-06,-08,-09)	Second Impoundment	6912698	583068	Annual
P03-04 (-02,-04,-06,-08)	Second Impoundment	6913186	582085	Annual
P03-05 (-02,-04,-06,-08)	Second Impoundment	6912934	582605	Annual
P03-06 (all ports)	Second Impoundment	6913309	582573	Bi-annual
X21A-96	Intermediate Impoundment	6913417	581989	Bi-annual
X21B-96	Intermediate Impoundment	6913417	581989	Bi-annual
P03-08 (-02,-04,-06,-07,-08)	Intermediate Impoundment	6913514	580980	Annual
X24D-96	Intermediate Dam	6914124	580655	Bi-annual
X25A-96	Intermediate Dam	6913945	580519	Bi-annual
X25B-96	Intermediate Dam	6913945	580519	Bi-annual
P01-03	Intermediate Dam	6914071	580639	Bi-annual
P01-04A	Intermediate Dam	6913893	580496	Bi-annual
P01-04B	Intermediate Dam	6913893	580496	Bi-annual
P01-02A	Cross Valley Dam	6914044	580051	Bi-annual
P01-02B	Cross Valley Dam	6914044	580051	Bi-annual
P01-11	Cross Valley Dam	6914306	580214	Bi-annual
P03-09 (-02,-04,-06,-08,-09)	Cross Valley Dam	6914229	580065	Bi-annual
P05-01 (all ports)	Cross Valley Dam	6914335	580165	Bi-annual
P05-02	Cross Valley Dam	6914265	580144	Bi-annual
P05-03	Cross Valley Dam	6914171	580088	Bi-annual
P09-C1	Cross Valley Dam	6914314	580171	Bi-annual
P09-C2	Cross Valley Dam	6914228	580119	Bi-annual
P09-C3	Cross Valley Dam	6914143	580078	Bi-annual
X16A	Downgradient of CVD	6914672	579574	Bi-annual
X16B	Downgradient of CVD	6914672	579574	Bi-annual
X17A	Downgradient of CVD	6914475	579874	Bi-annual
X17B	Downgradient of CVD	6914475	579874	Bi-annual
X18A	Downgradient of CVD	6914539	580105	Bi-annual
X18B	Downgradient of CVD	6914539	580105	Bi-annual
P01-01A	Downgradient of CVD	6914675	579819	Bi-annual
P01-01B	Downgradient of CVD	6914675	579819	Bi-annual

Table 5.3

Recommended Scope of Groundwater Monitoring for 2011, Grum/Vangorda Mine Site

Well ID	Region	Northing UTM z8 NAD27	Easting UTM z8 NAD27	Proposed Frequency
Grum/Vangorda Mine Site				
P96-9A	Grum Rock Dump	6903165	592753	Bi-annual
BH05-9B-R	Grum Rock Dump	6903172	592747	Bi-annual
SRK05-05C	Grum Rock Dump	6903208	592873	Bi-annual
SRK05-07	Grum Rock Dump	6903011	592477	Bi-annual
SRK05-08	Grum Rock Dump	6903063	592690	Bi-annual
SRK05-09 ("Moose Well 2")	Grum Rock Dump	6902986	593058	Bi-annual
SRK08-P14	Grum Dump Southwest	6903706	591761	Annual
SRK08-P15	Grum Dump Southwest	6903534	591961	Annual
SRK08-P16	Grum Dump Southwest	6902964	592322	Annual
P09-GW1	Grum Dump West			Annual (Spring)
P09-GW3	Grum Dump West			Annual (Spring)
P09-GS1A	Grum Slot Area	6904658	592593	Bi-annual
P09-GS1B	Grum Slot Area	6904657	592601	Bi-annual
V34	Vangorda Rock Dump	6902295	593553	Bi-annual
V35	Vangorda Rock Dump	6902371	593293	Bi-annual
V36	Vangorda Rock Dump	6902733	593243	Bi-annual
V37	Vangorda Rock Dump	6902913	593420	Bi-annual
P2001-02A	Vangorda Rock Dump	6902880	593098	Bi-annual
P2001-02B	Vangorda Rock Dump	6902880	593098	Bi-annual
P2001-03	Vangorda Rock Dump	6902865	593131	Bi-annual
DH1	Vangorda Rock Dump	6903022	593577	Bi-annual
DH2	Vangorda Rock Dump	6902814	593212	Bi-annual
DH3	Vangorda Rock Dump	6902669	593221	Bi-annual
DH4	Vangorda Rock Dump	6902508	593738	Bi-annual
DH5	Vangorda Rock Dump	6902681	593561	Bi-annual
P09-LCD1	Little Creek Dam	6903138	593468	Bi-annual
P09-LCD4	Little Creek Dam	6903097	593436	Bi-annual
P09-LCD6	Little Creek Dam	6903073	593421	Bi-annual
P09-VC1	Vangorda Creek	6903244	593627	Bi-annual
P09-VC2	Vangorda Creek	6903259	593623	Bi-annual

6 CLOSURE

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We trust that the information provided in this report meets your requirements at this time. Should you have any questions or if we can be of further assistance, please do not hesitate to contact the undersigned.

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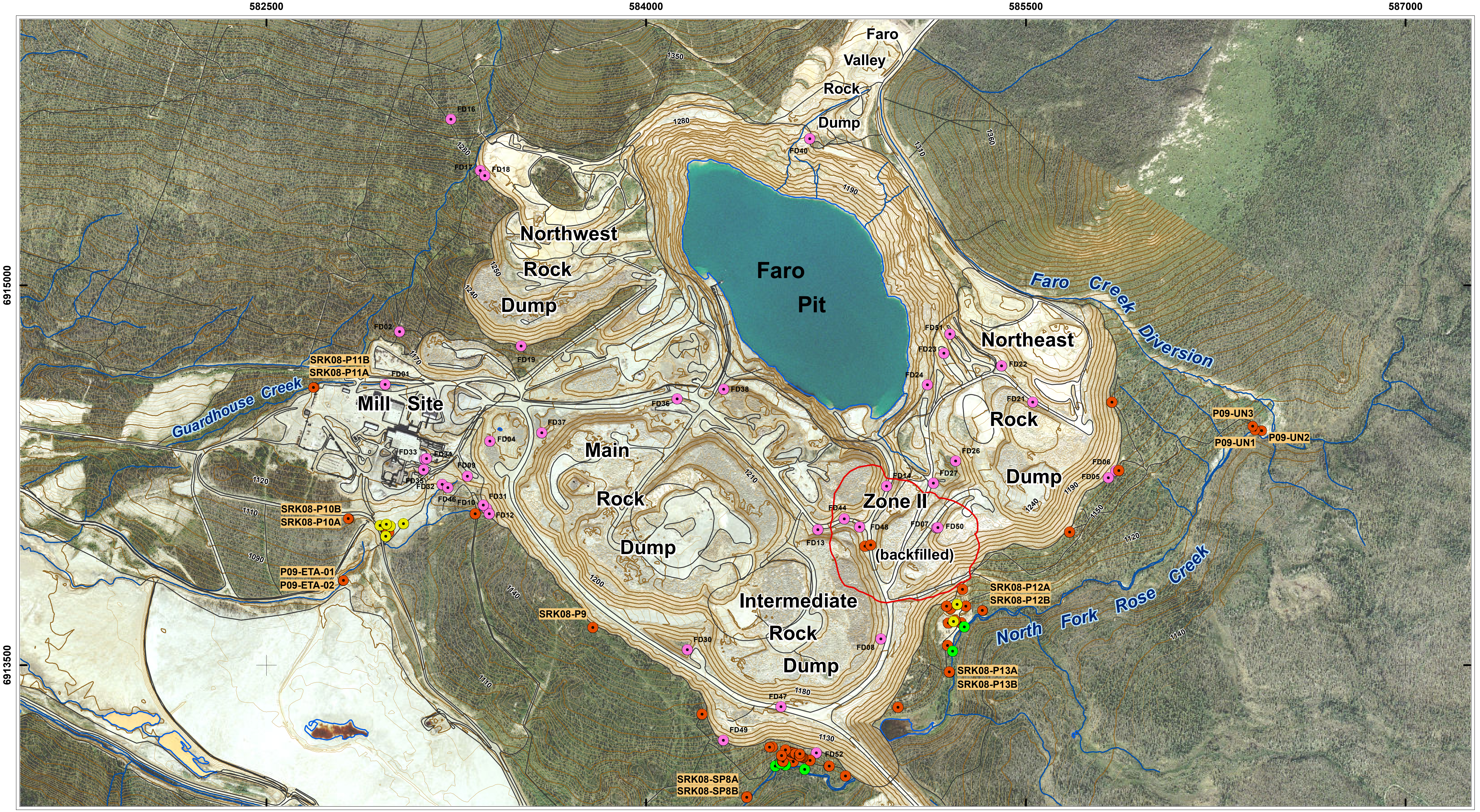
FIGURES



LEGEND

- ● Monitoring Well
- ● Other Well (not Monitored Routinely)
- ⊠ Abandoned Well
- ● Drive Point
- ● Seep Monitoring Station
- — Zone II Pit Outline

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2M

N
W E
S

Layout of Faro Mine Site

Anvil Range Mining Complex

SCALE
0 200 400 600 800 1,000 Meters

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CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 2-1

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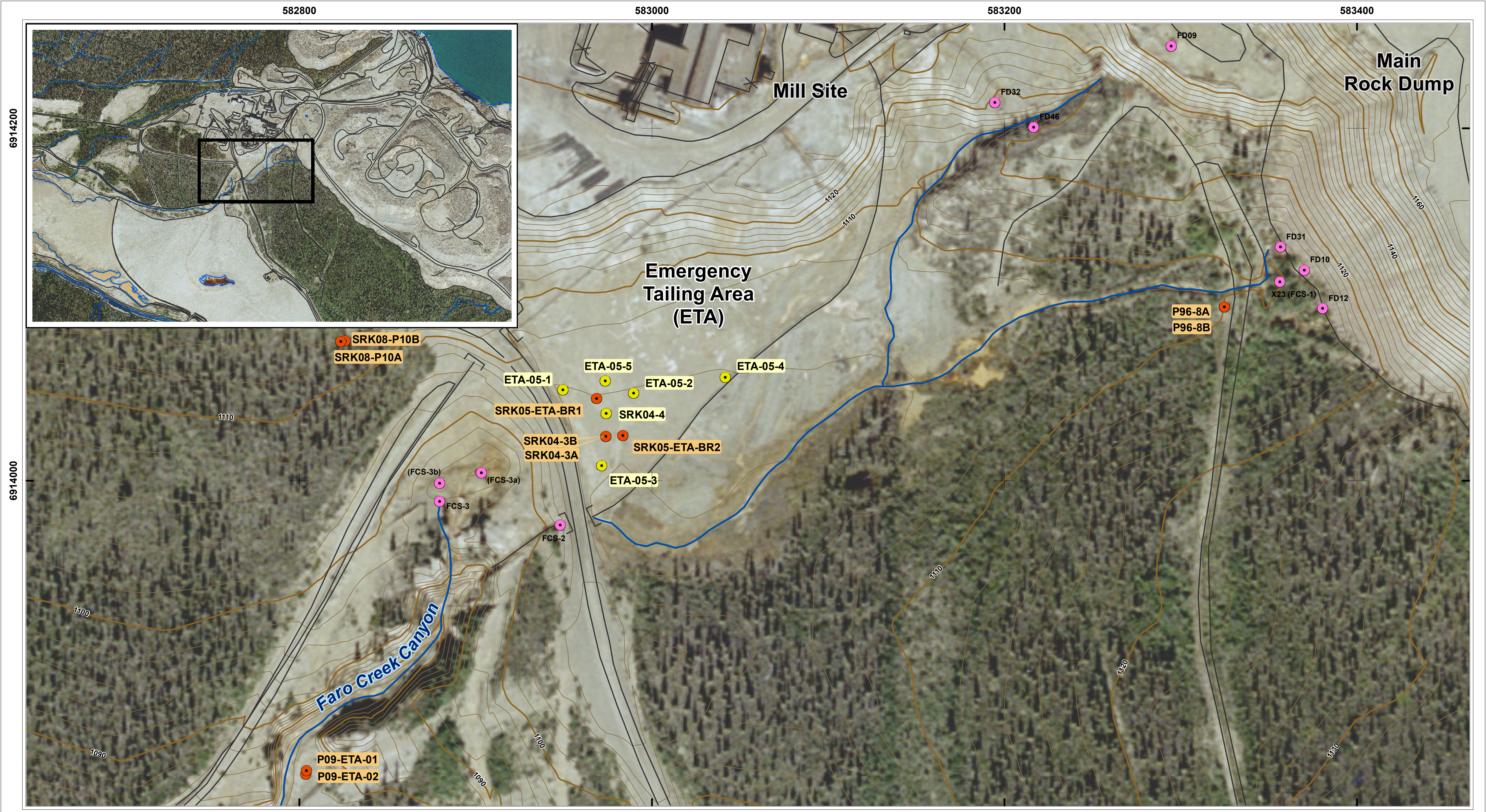

Groundwater Monitoring Wells
ETA Area
Faro Mine Site

LEGEND

🔴	Monitoring Well
🟡	Other Well (not Monitored Routinely)
●	Seep Monitoring Station

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

N
W E
S

SCALE
0 50 100 150 200 Meters

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LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 2-2

DATE: 032411
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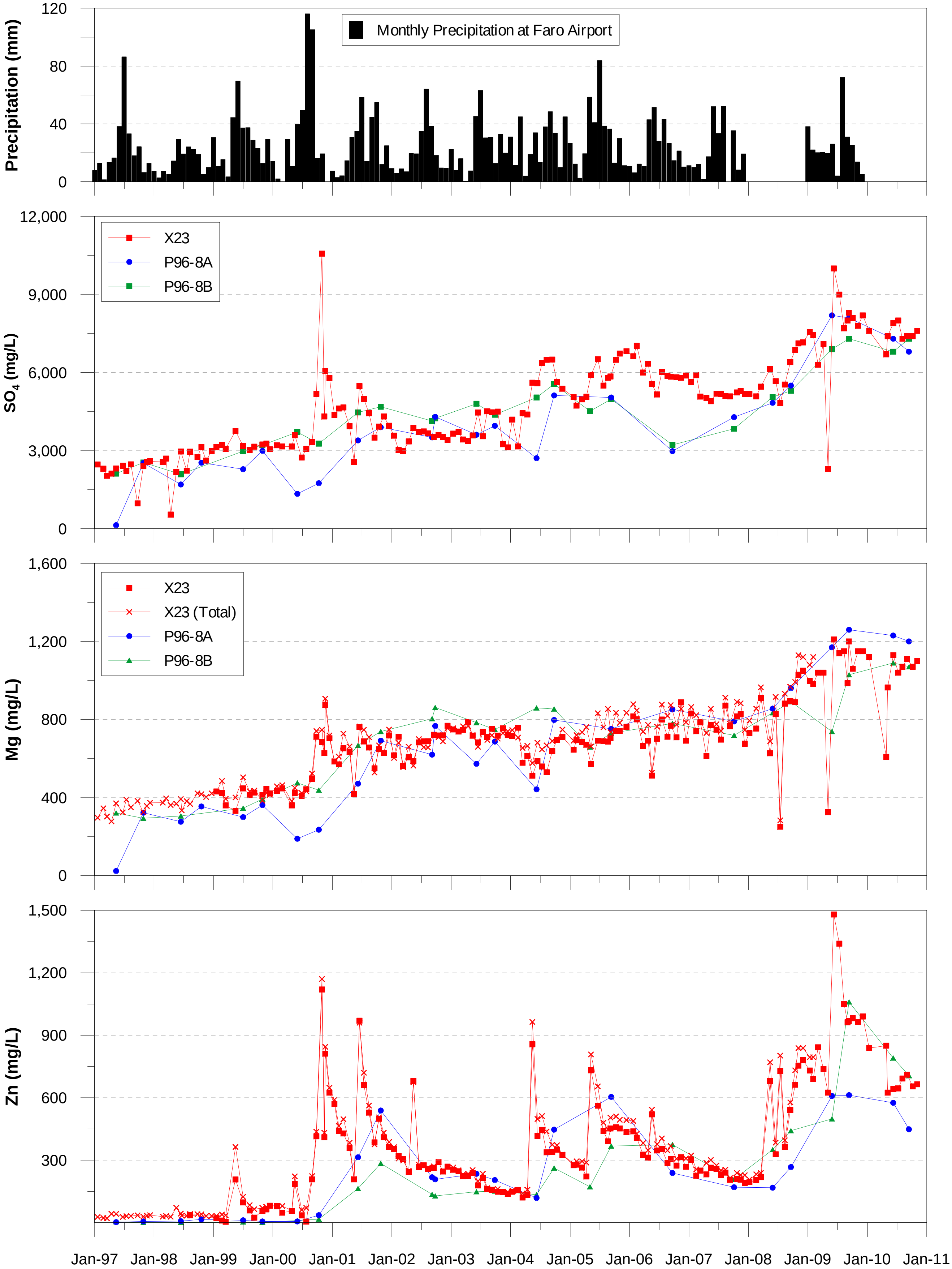


Figure 2-3a. Time trends for SO_4, Mg and Zn at X23 and P96-8A/B

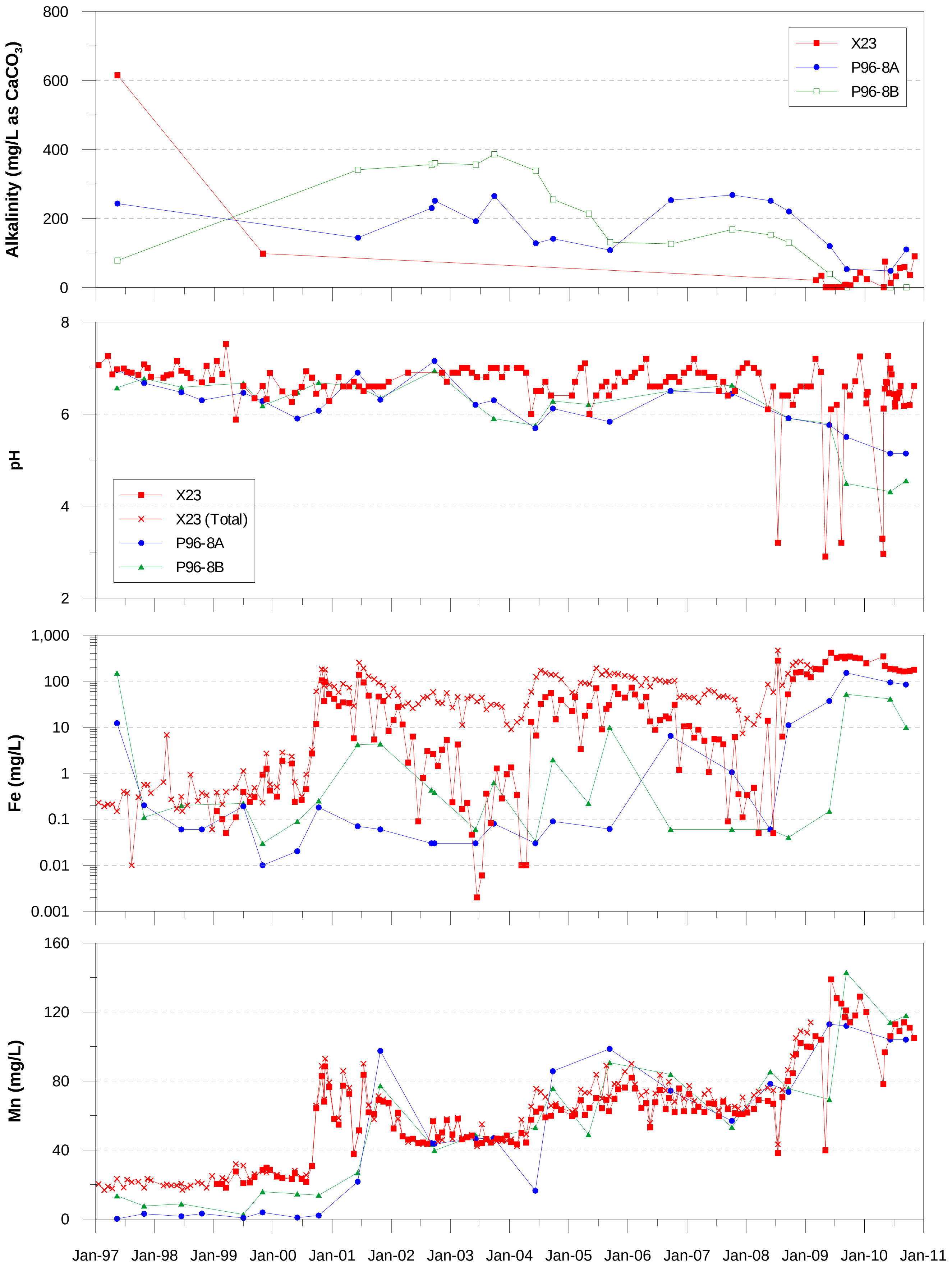


Figure 2-3b. Time trends for alkalinity, pH, Fe and Mn at X23 and P96-8A/B

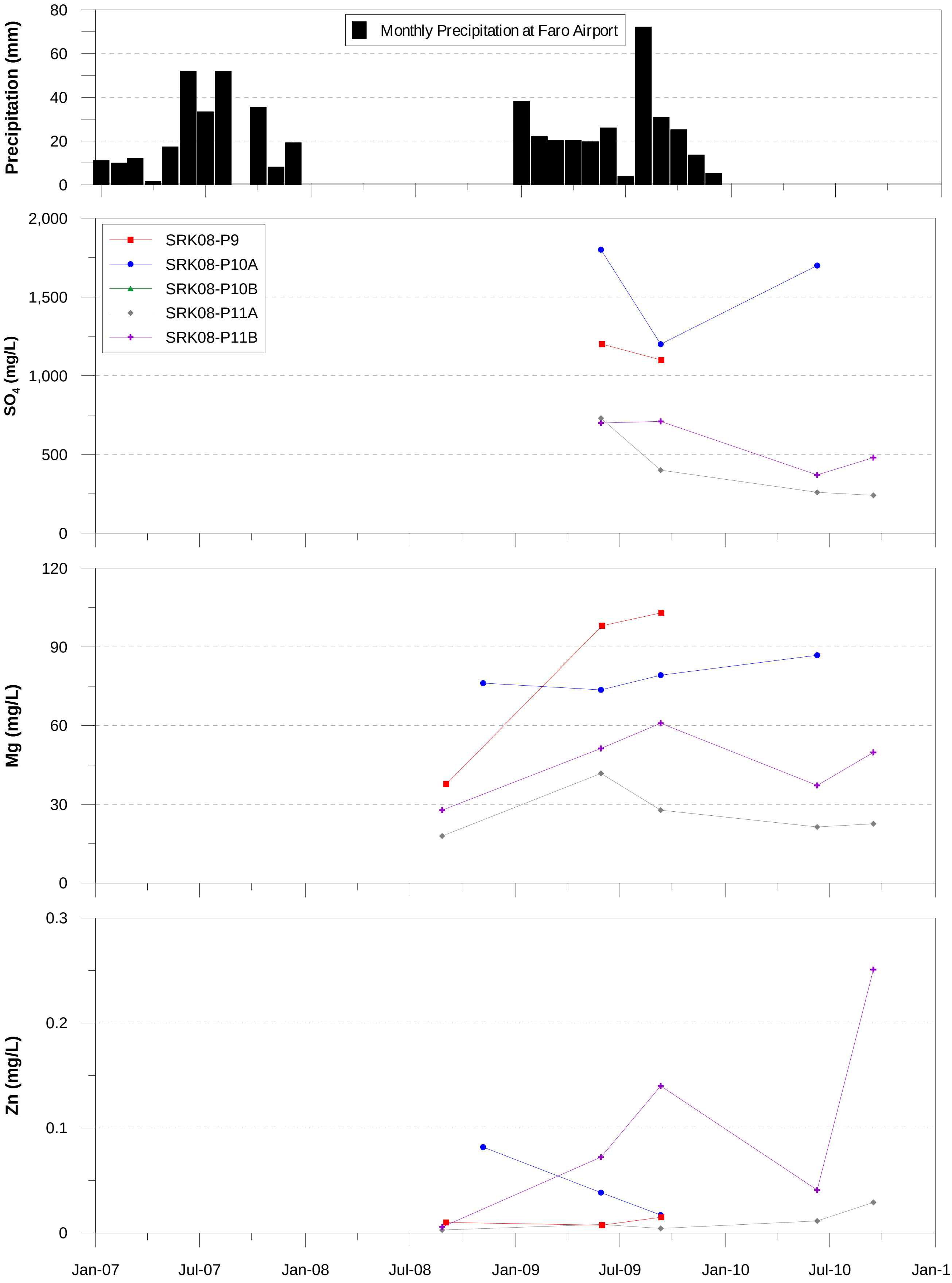


Figure 2-3c. Time trends for SO$_4$, Mg and Zn in SRK08 wells located in Main Rock Dump and Mill Site areas

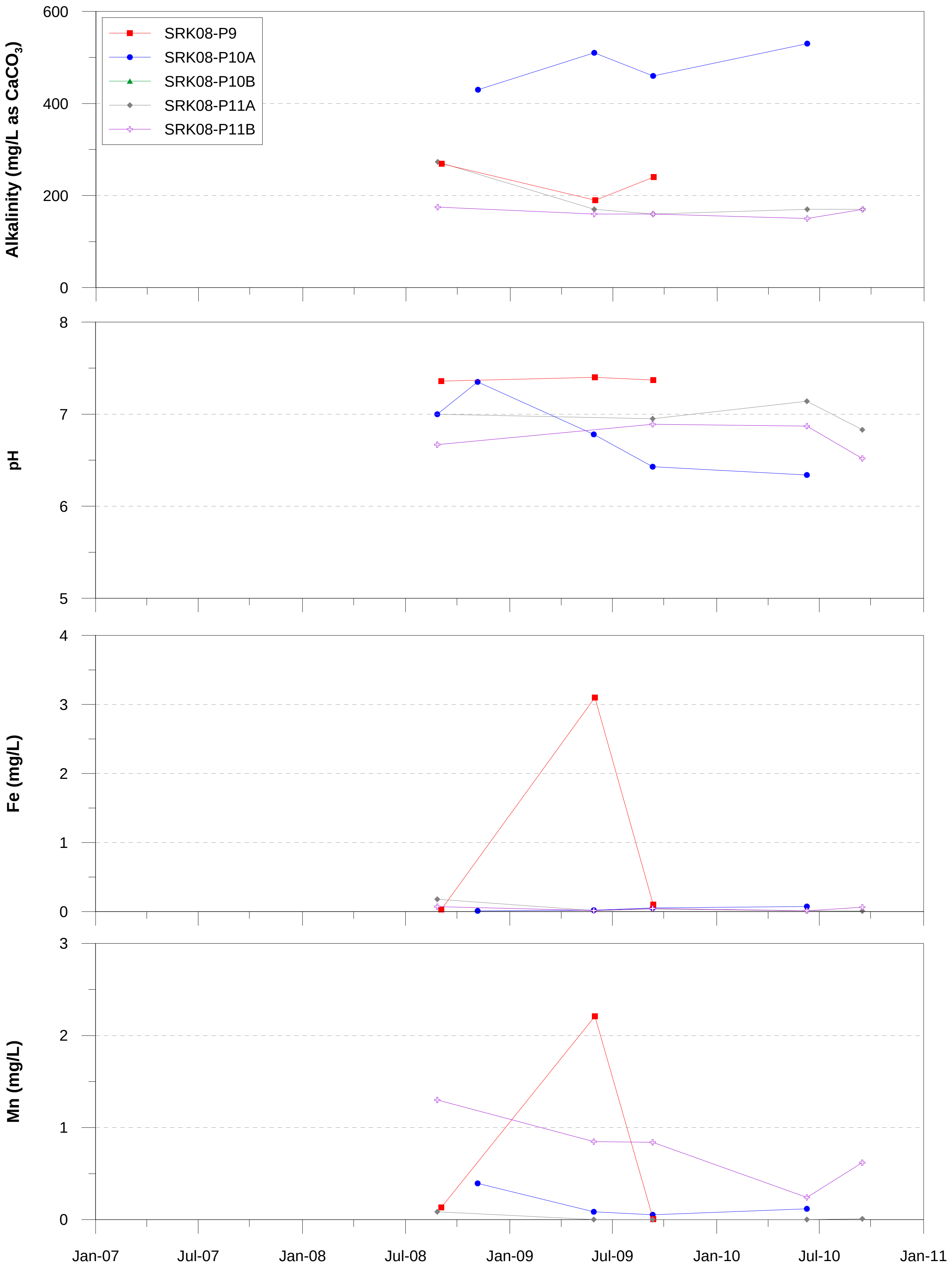


Figure 2-3d. Time trends for alkalinity, pH, Fe and Mn in SRK08 wells located in Main Rock Dump and Mill Site areas

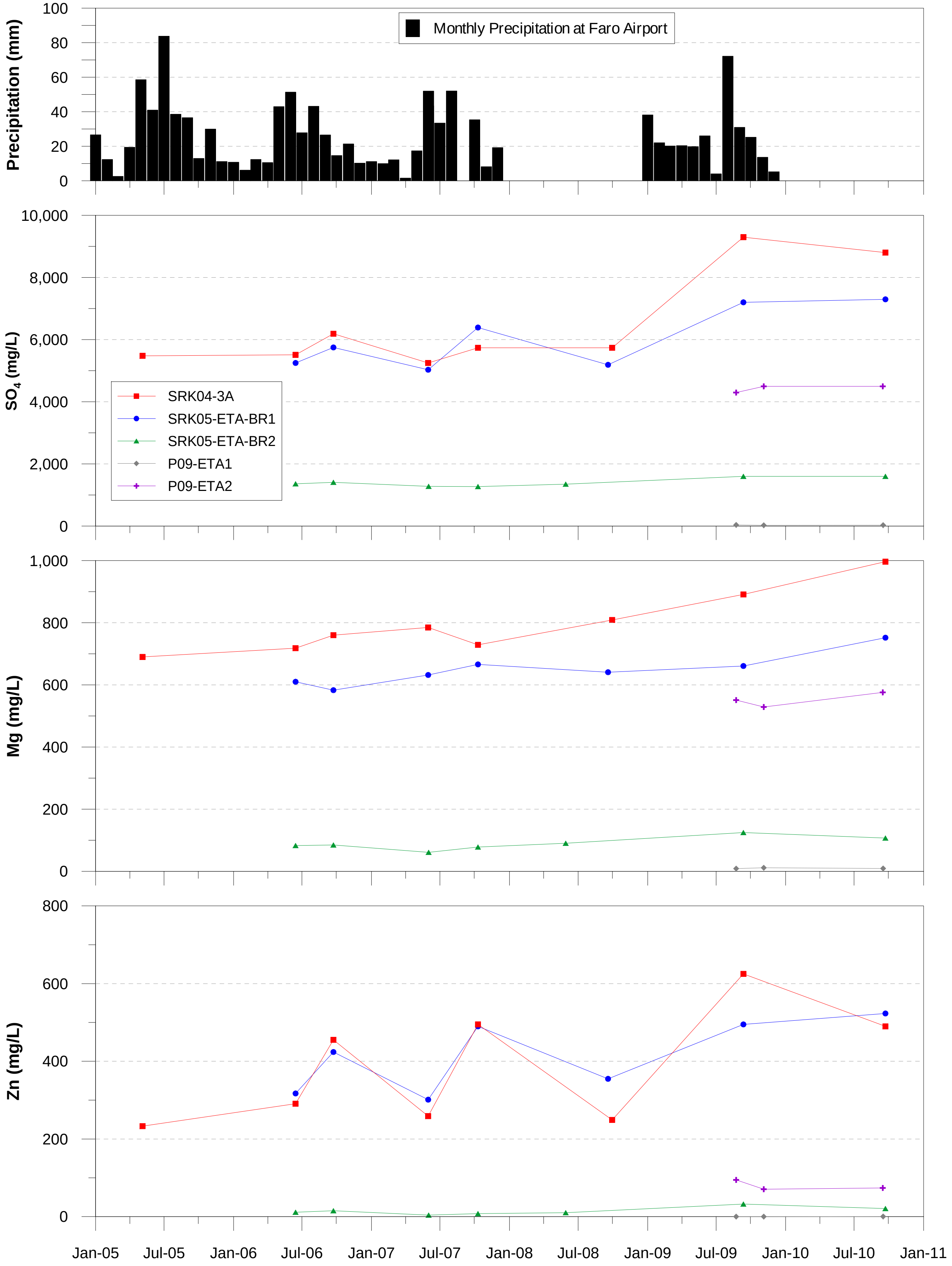


Figure 2-4a. Time trends for SO_4, Mg and Zn in SRK wells in the ETA

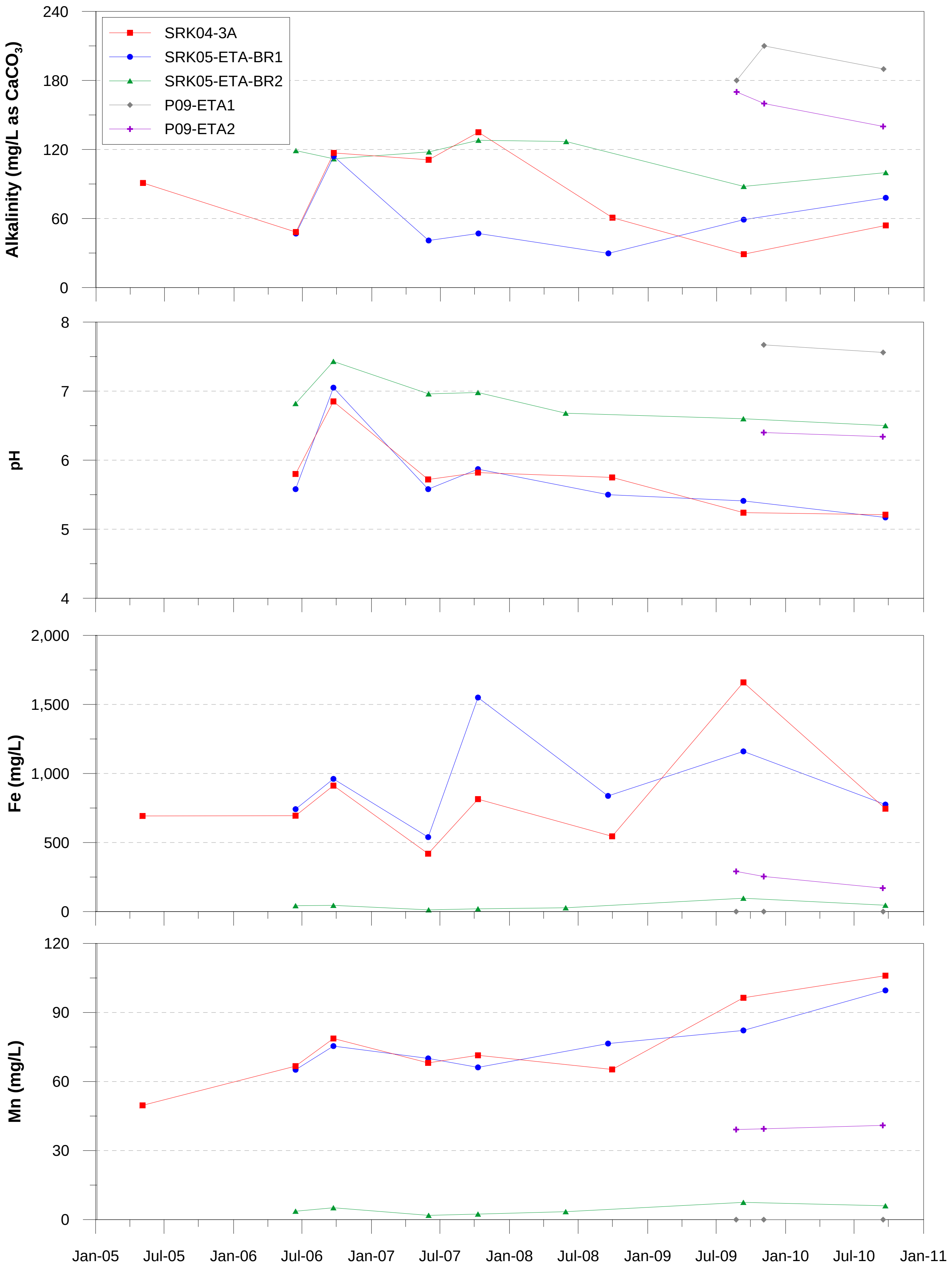
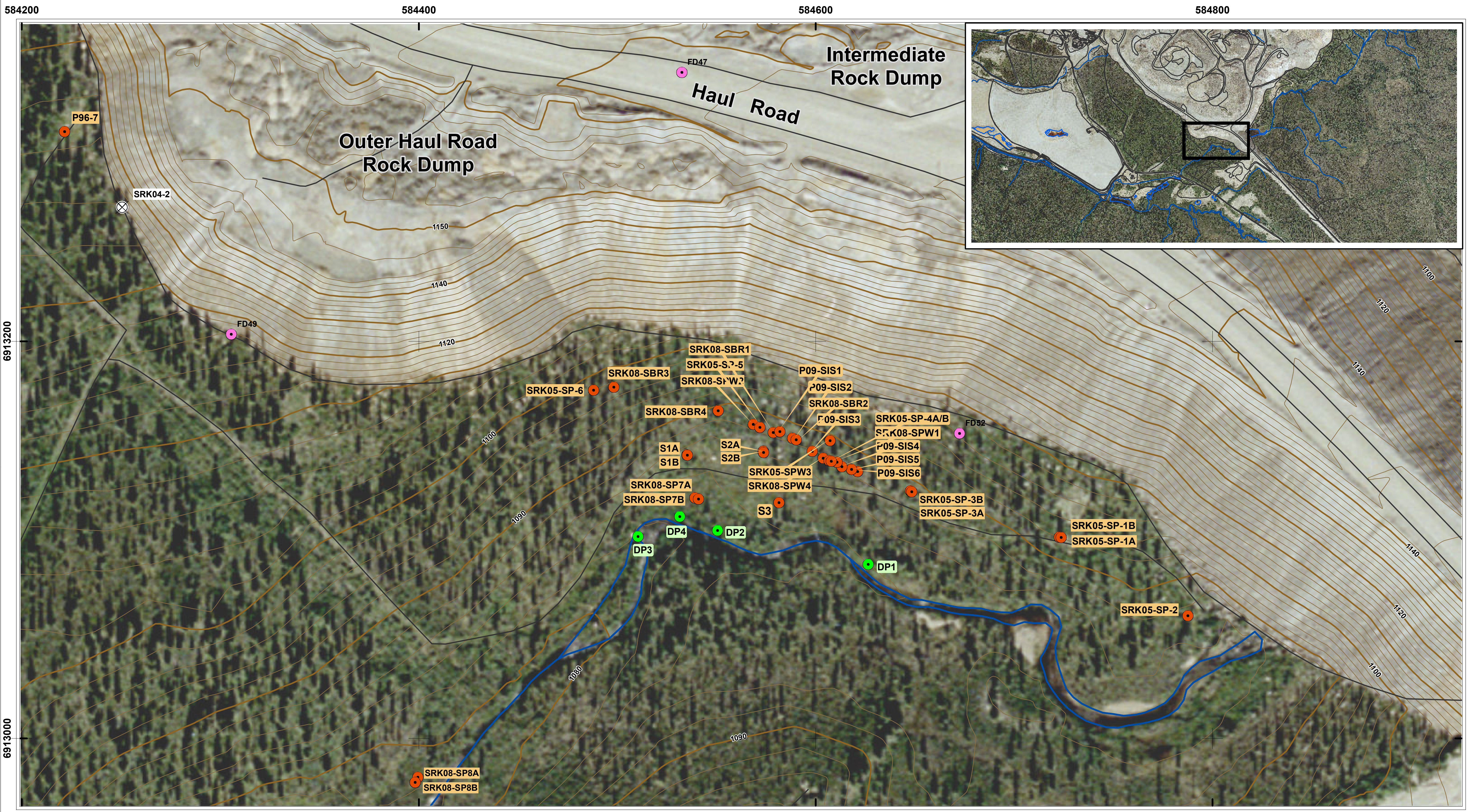


Figure 2-4b. Time trends for alkalinity, pH, Fe and Mn in SRK wells in the ETA



LEGEND

- ● Monitoring Well
- ⊗ Abandoned Well
- ● Drive Point
- ● Seep Monitoring Station

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

N
W E
S

Groundwater Monitoring Wells
S - Cluster Area

Faro Mine Site

SCALE

0 50 100 150 200 Meters

Yukon Government

CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

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FIGURE: 2-5

DATE: 032411
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FILE: Faro_S_Cluster_11.mxd

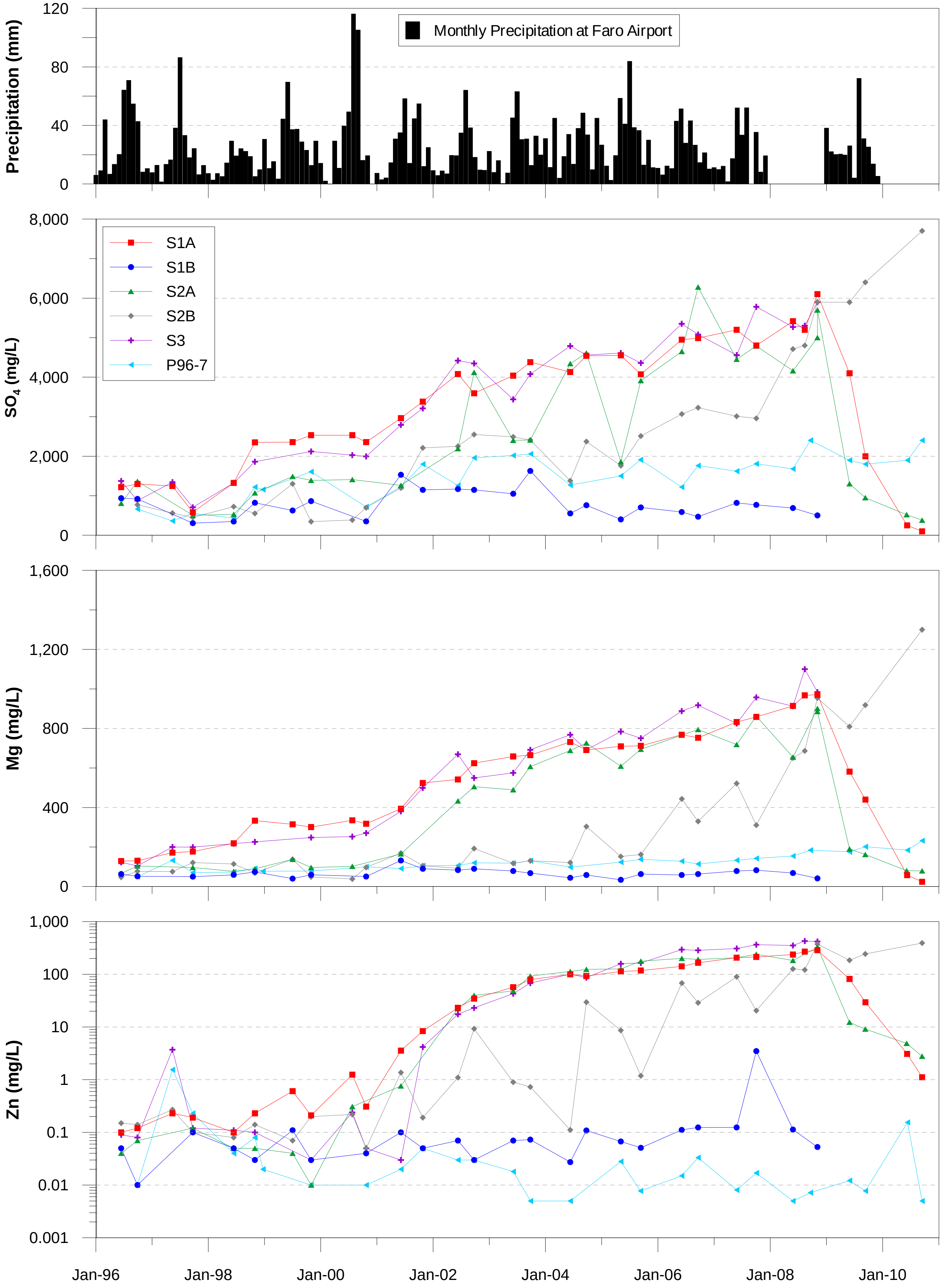


Figure 2-6a. Time Trends for SO$_4$, Mg and Zn in S-Cluster Wells

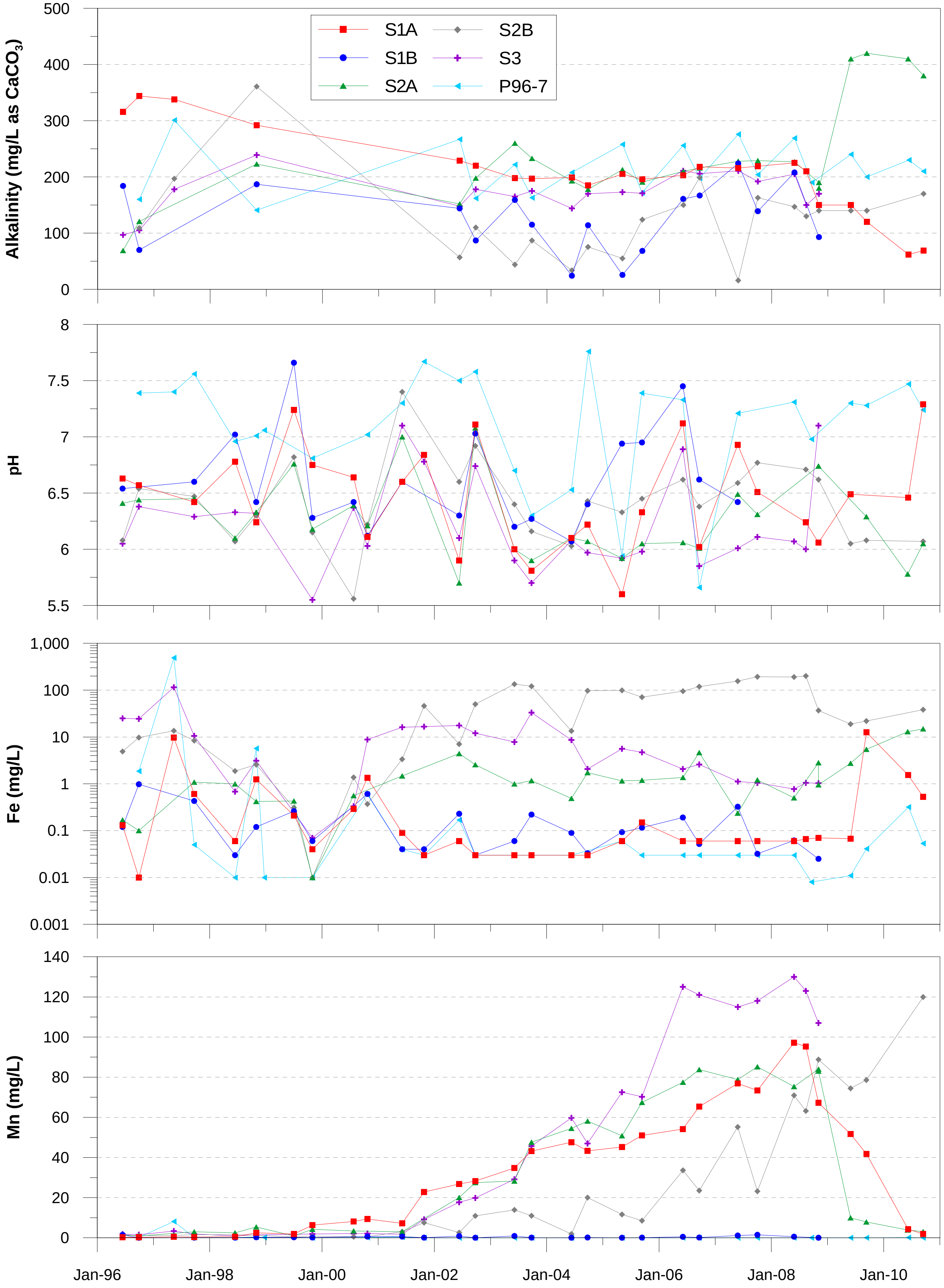


Figure 2-6b. Time trends for alkalinity, pH, Fe and Mn in S-Cluster Wells

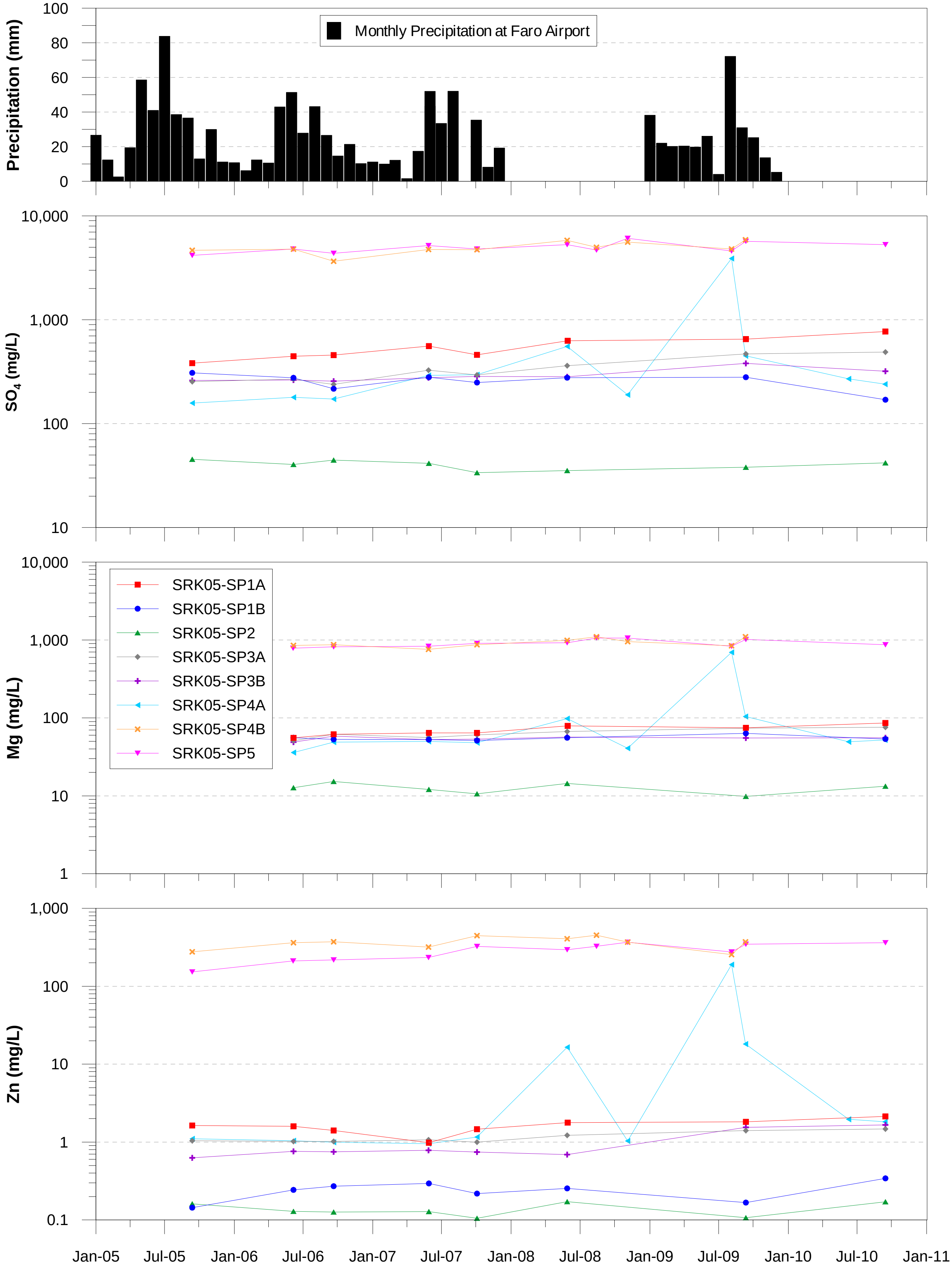


Figure 2-7a. Time trends for SO$_4$, Mg and Zn in SRK-05 wells in S-Cluster Area

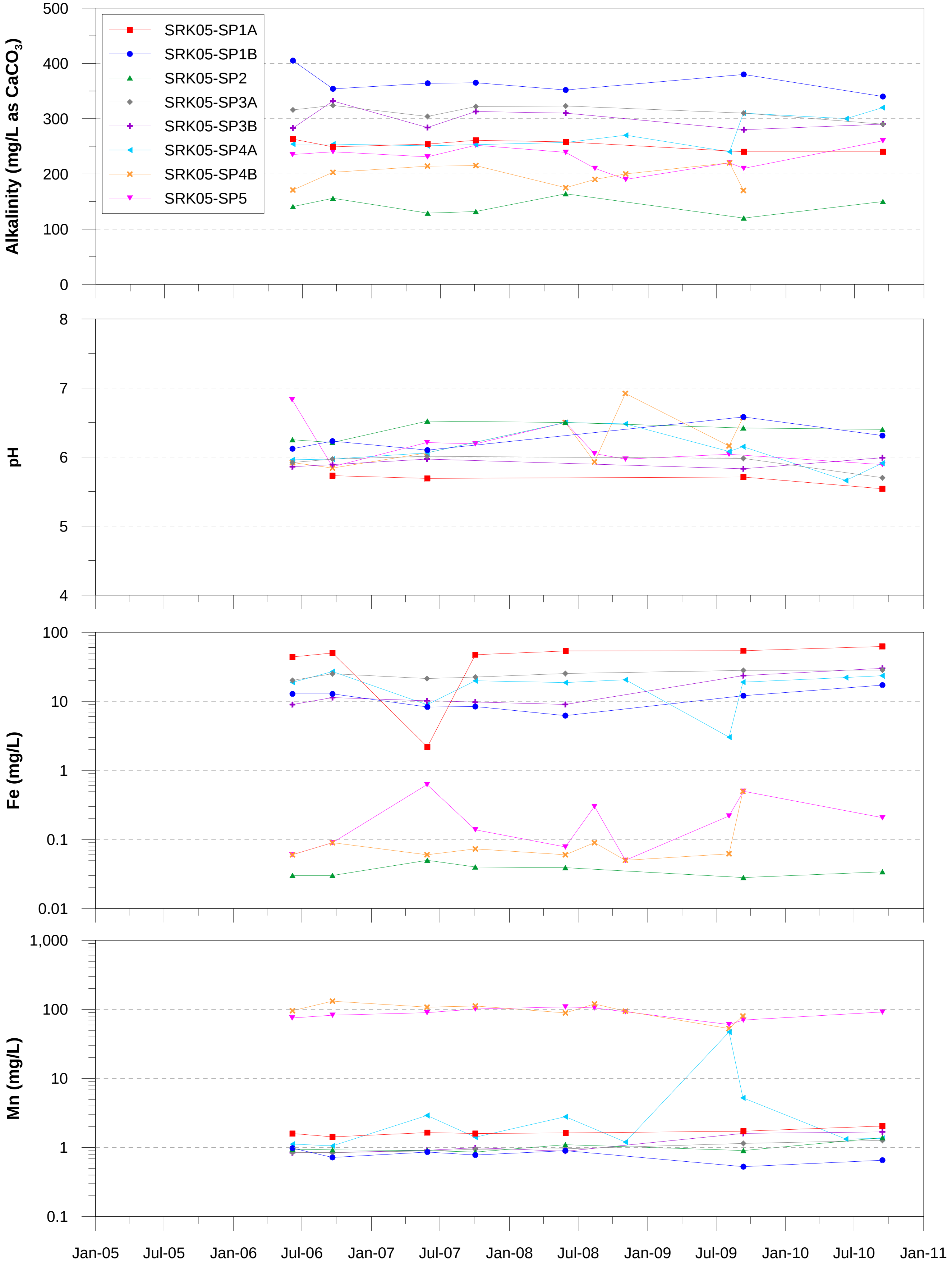


Figure 2-7b. Time trends for alkalinity, pH, Fe and Mn in SRK-05 wells in S-Cluster Area

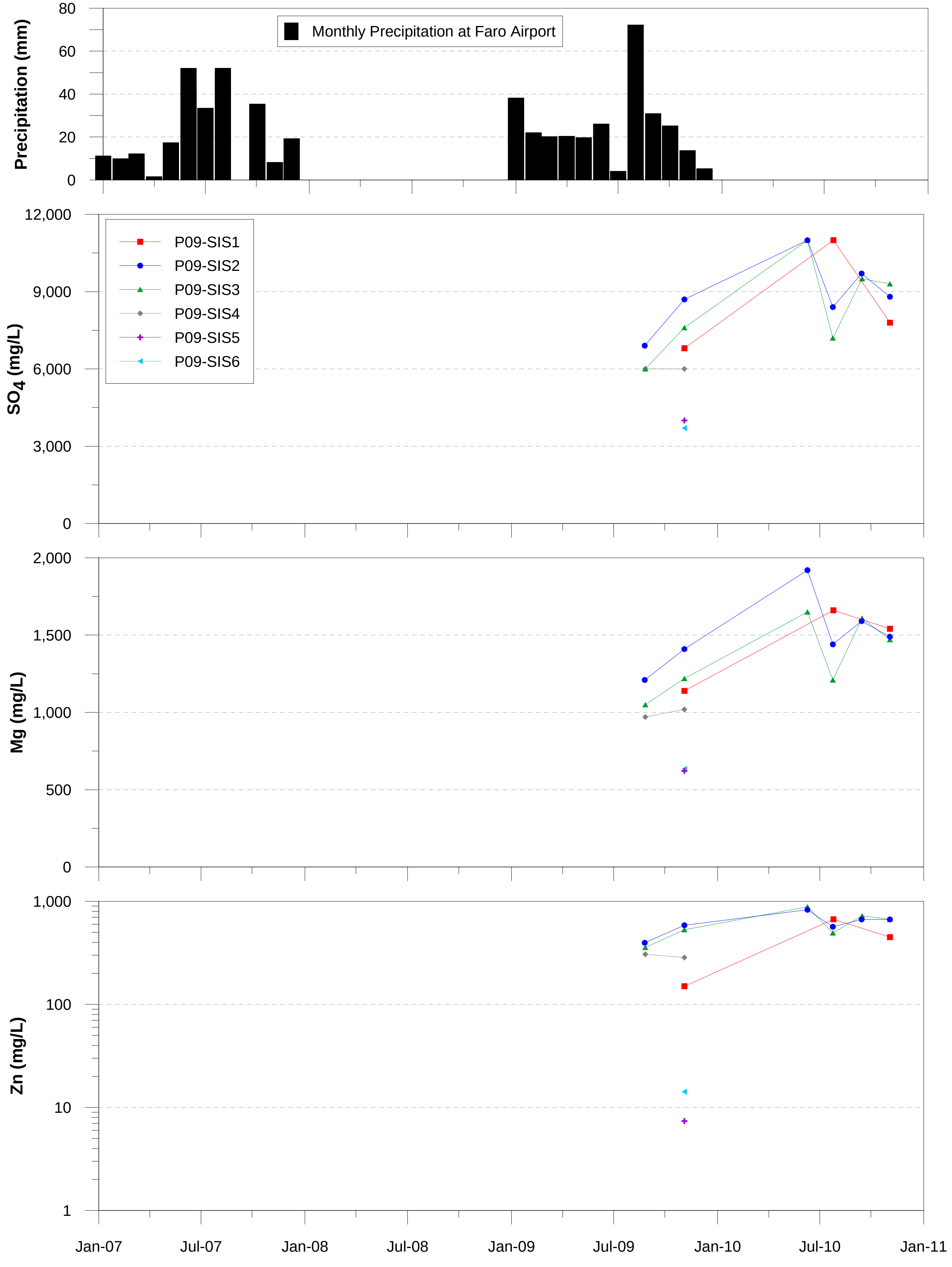


Figure 2-7c. Time trends for SO$_4$, Mg, Na and Zn in P09-SIS wells, S-Cluster Area

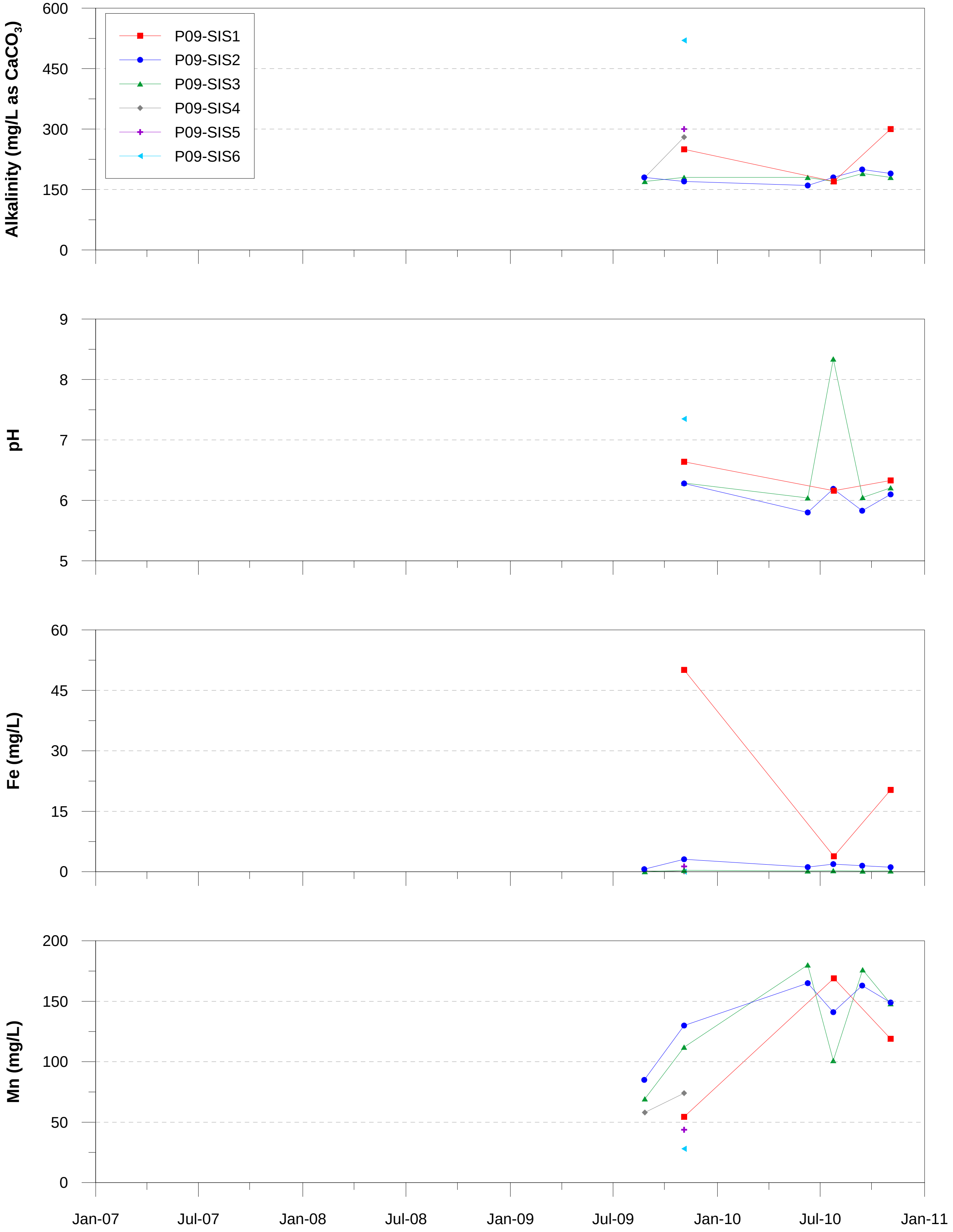


Figure 2-7d. Time trends for alkalinity, pH, Fe and Mn in P09-SIS wells, S-Cluster Area

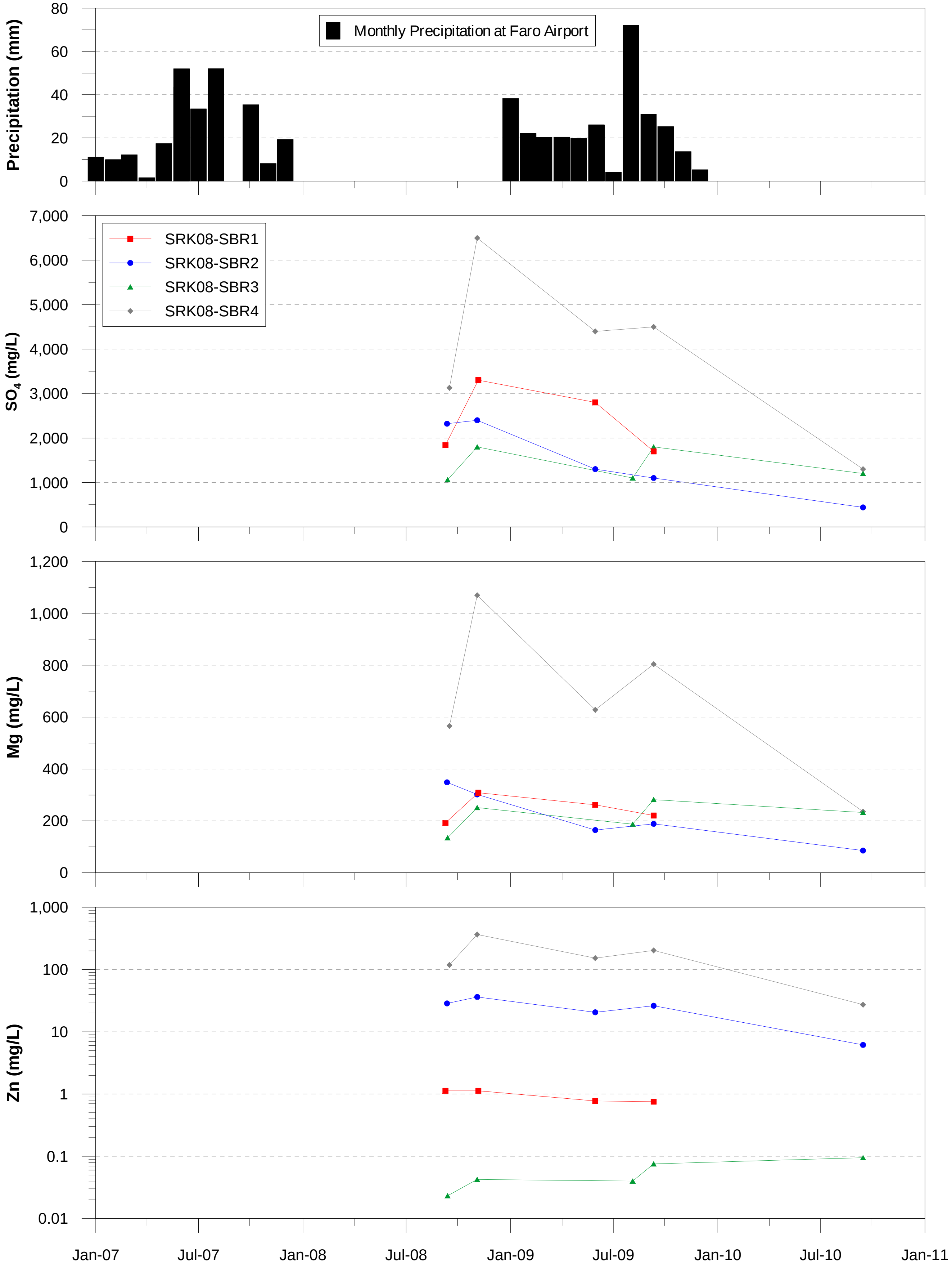


Figure 2-8a. Time trends for SO_4, Mg and Zn in SBR wells in S-Cluster Area

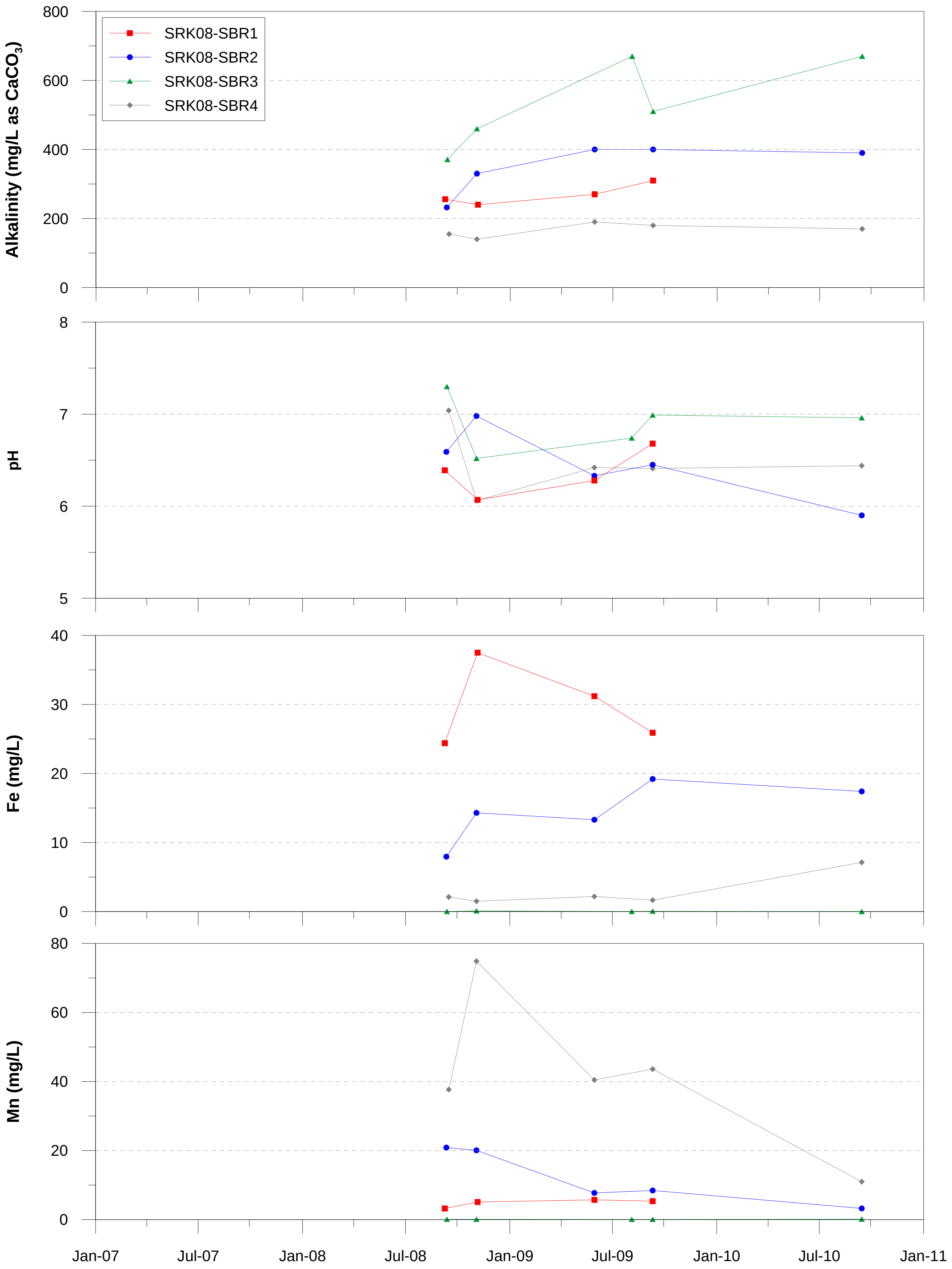


Figure 2-8b. Time trends for alkalinity, pH, Fe and Mn in SBR wells in S-Cluster Area

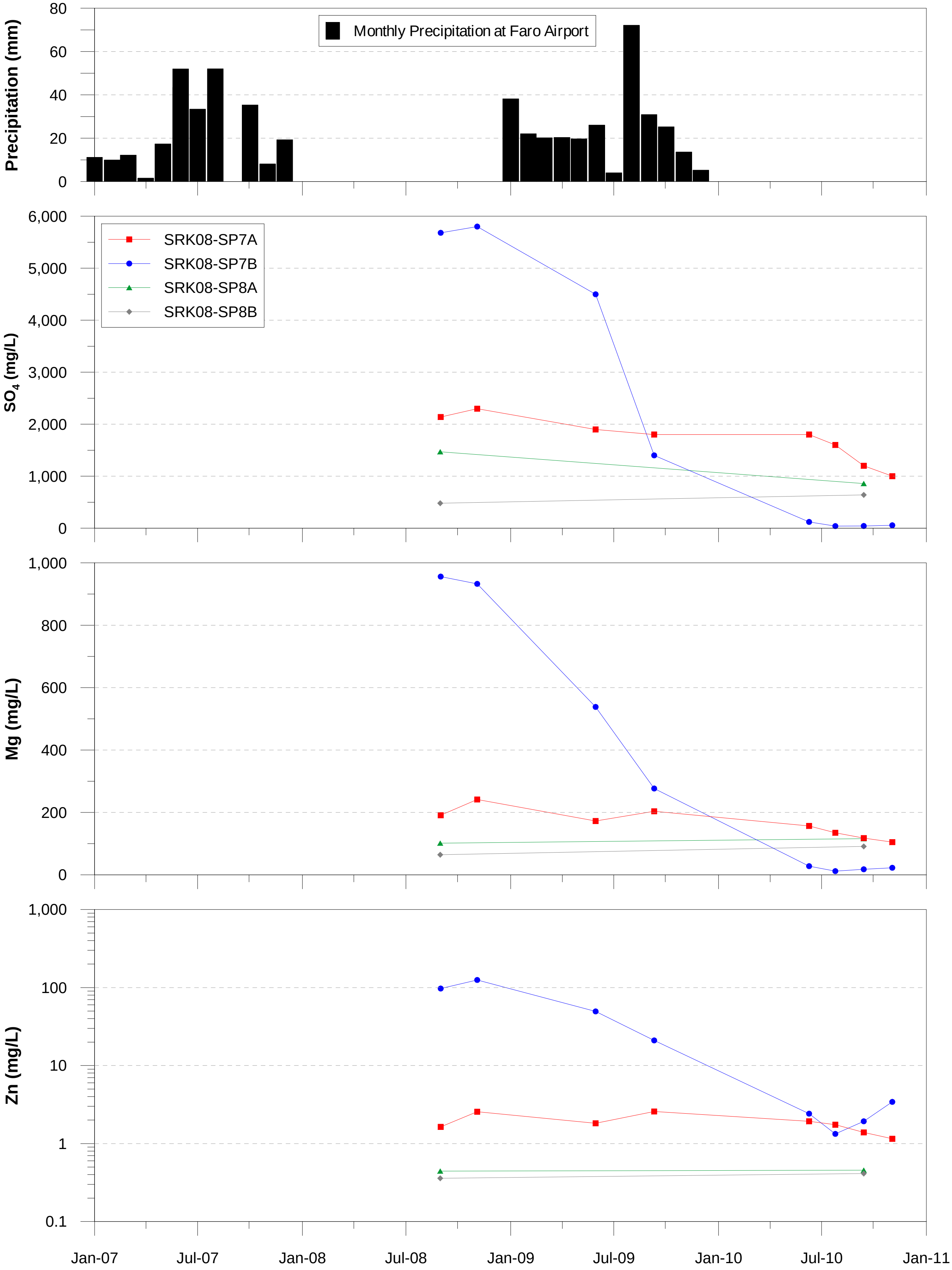


Figure 2-8c. Time trends for SO$_4$, Mg and Zn in SRK08-SP wells in S-Cluster Area

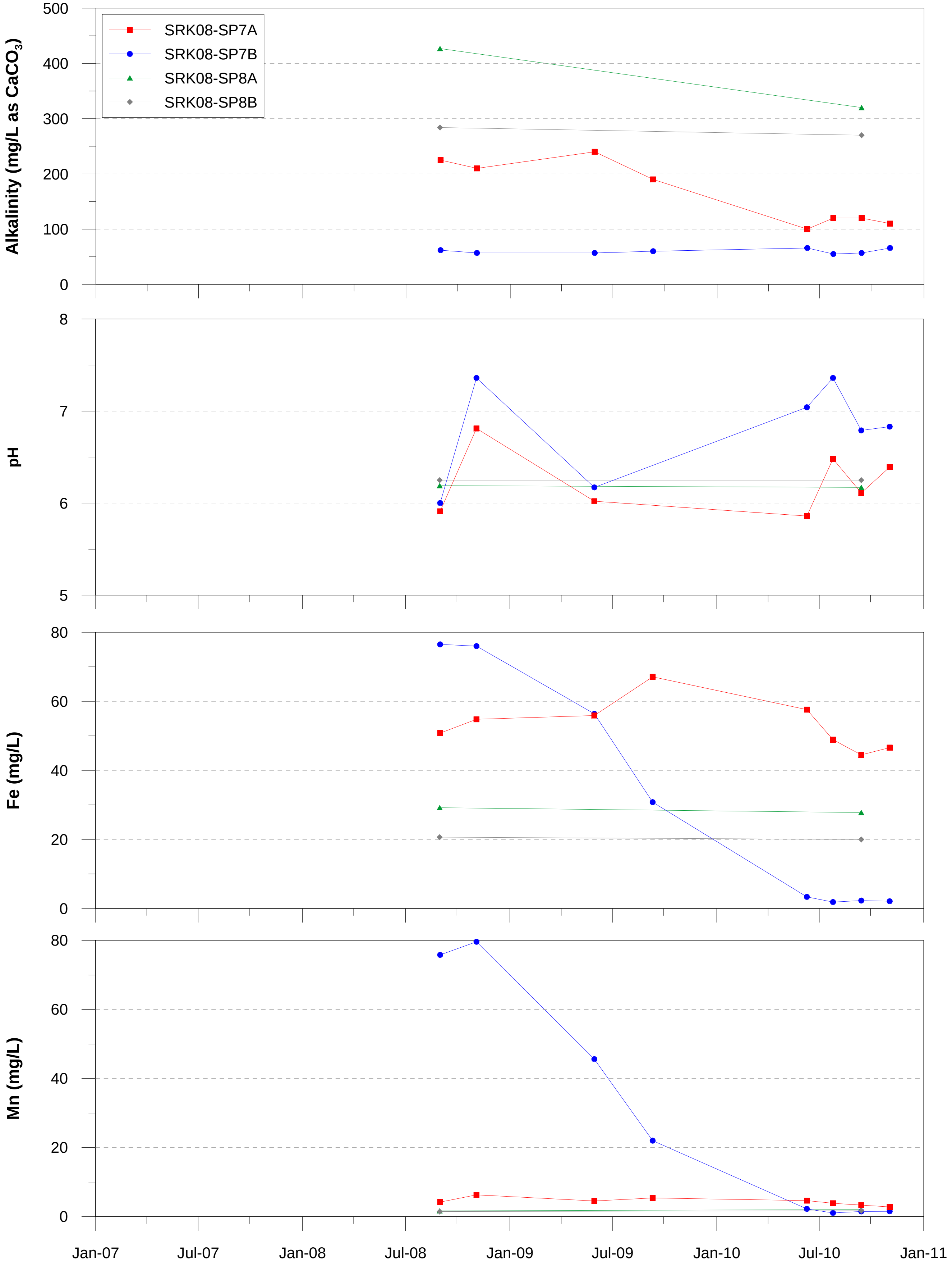
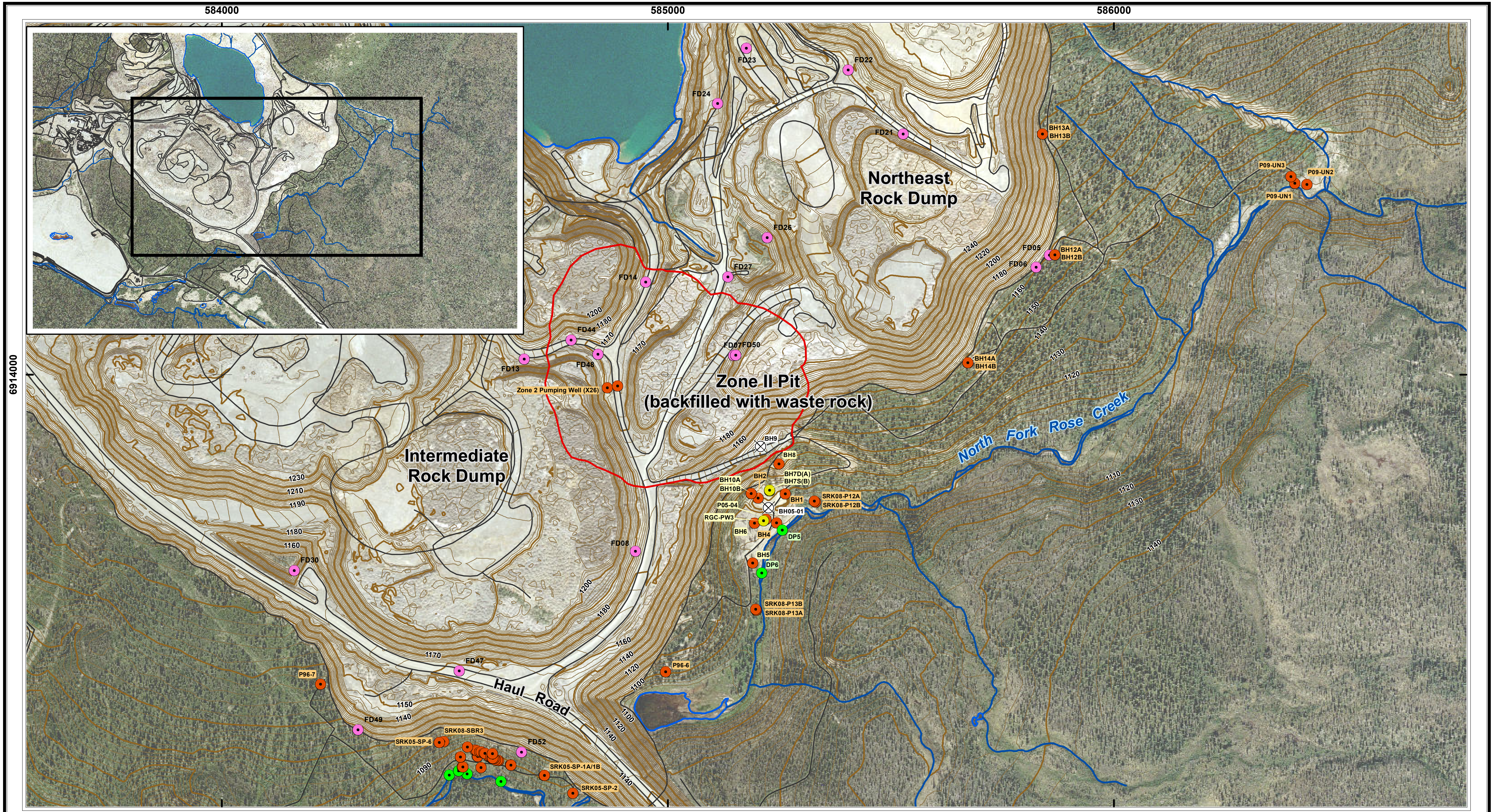


Figure 2-8d. Time trends for alkalinity, pH, Fe and Mn in SRK08-SP wells in S-Cluster Area



LEGEND

- 🟠 Monitoring Well
- 🟡 Other Well (not Monitored Routinely)
- ⊗ Abandoned Well
- 🟢 Drive Point
- 🟣 Seep Monitoring Station
- ― Zone II Pit Outline

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

N
W E
S

Groundwater Monitoring Wells
North Fork Rose Creek Area
Faro Mine Site

SCALE

0 150 300 450 600 Meters

Yukon Government

CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

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FIGURE: 2-9

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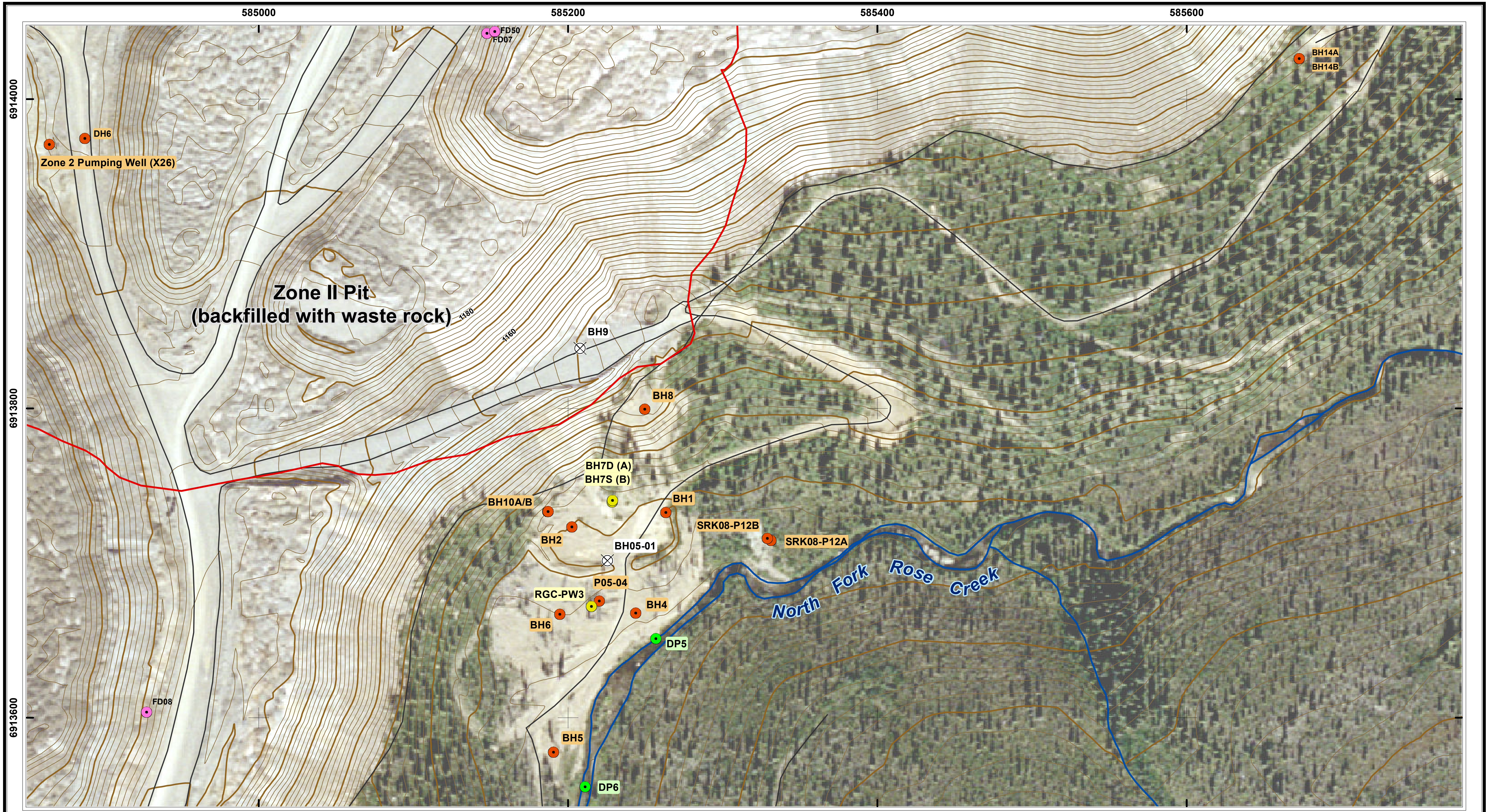

LEGEND

- ● Monitoring Well
- ● Other Well (not Monitored Routinely)
- ⊗ Abandoned Well
- ● Drive Point
- ● Seep Monitoring Station
- — Zone II Pit Outline

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

N
W E
S

Groundwater Monitoring Wells
Zone II Pit Outwash Area
Faro Mine Site

SCALE

0 50 100 150 200 m

Yukon
Government

CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

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FIGURE: 2-10

DATE: 032411
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FILE: Faro_Zone2_area_11.mxd

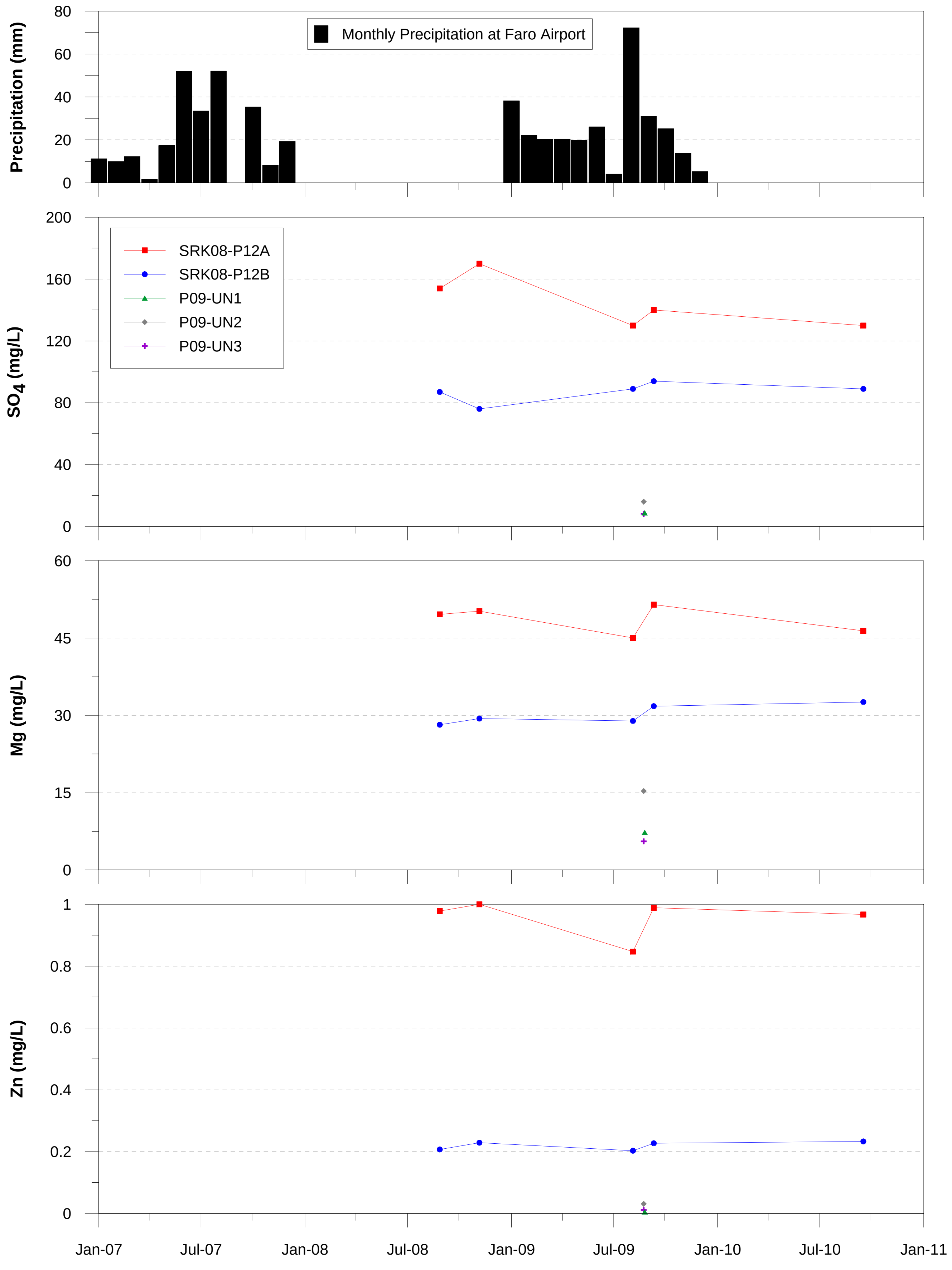


Figure 2-11a. Time trends for SO_4, Mg, Na and Zn in P09-UN wells and SRK08-P12A/B

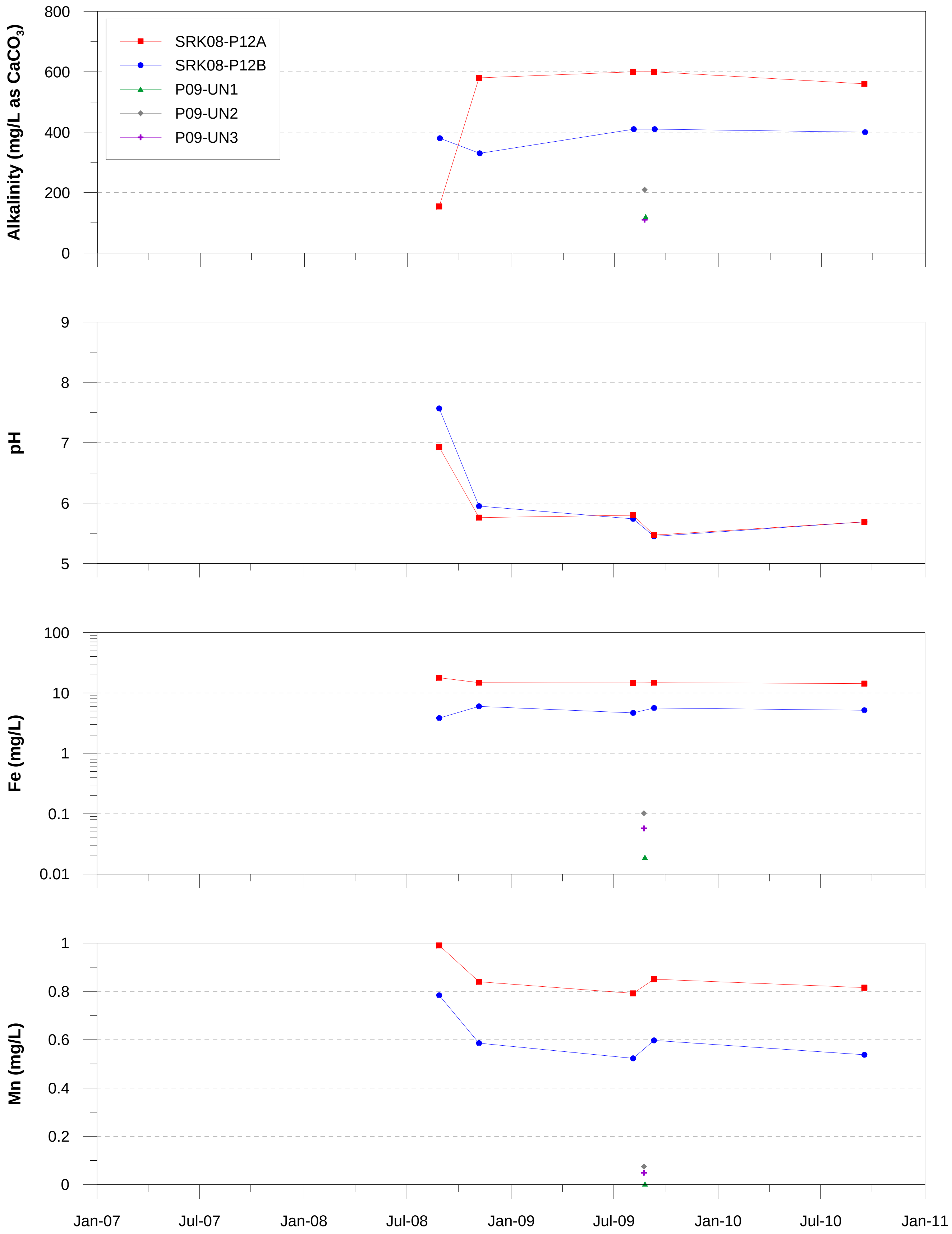


Figure 2-11b. Time trends for Alkalinity, pH, Fe and Mn in P09-UN wells and SRK08-P12A/B

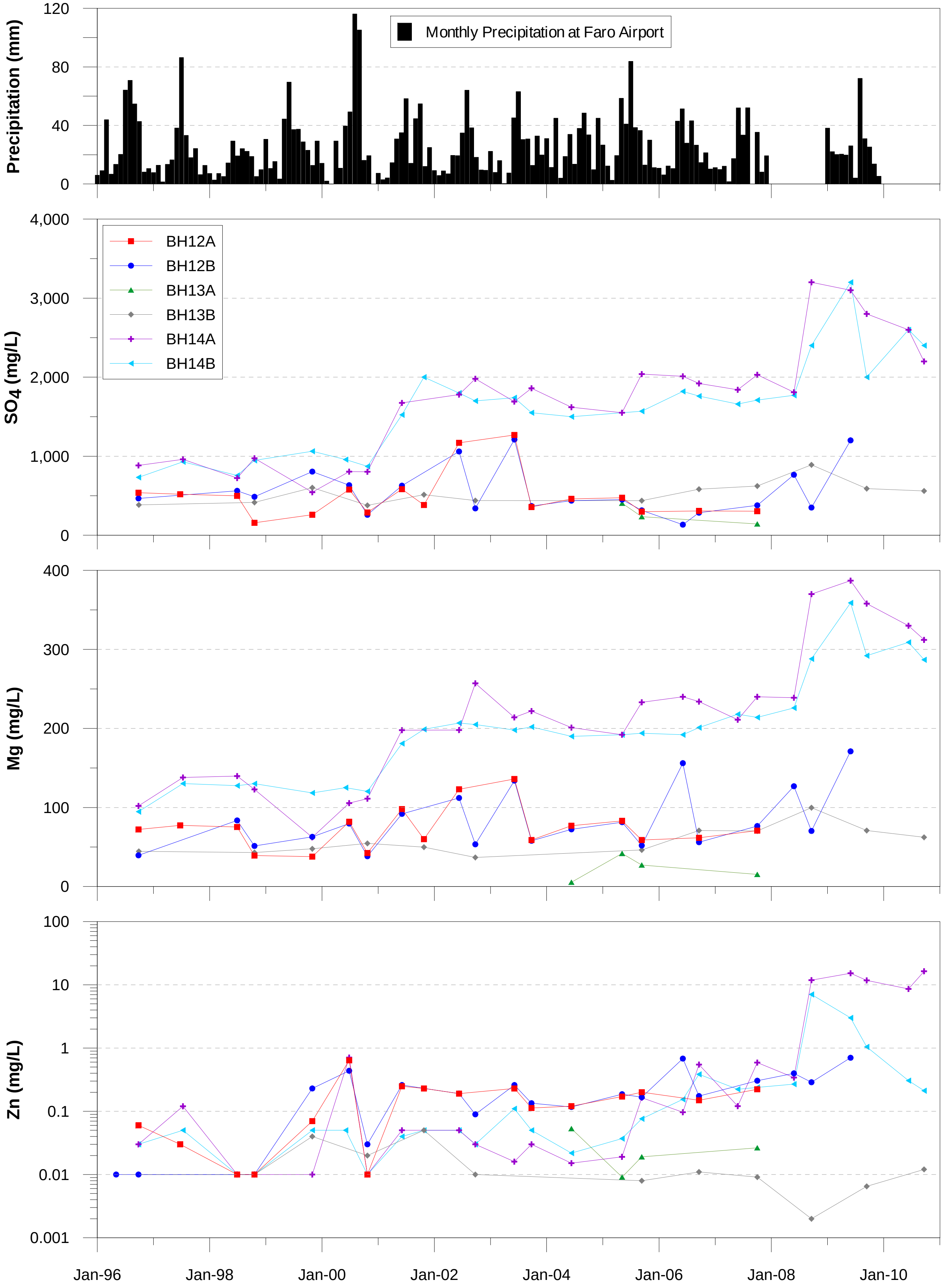


Figure 2-12a. Time trends for SO_4, Mg and Zn in wells at the toe of Northeast Rock Dump

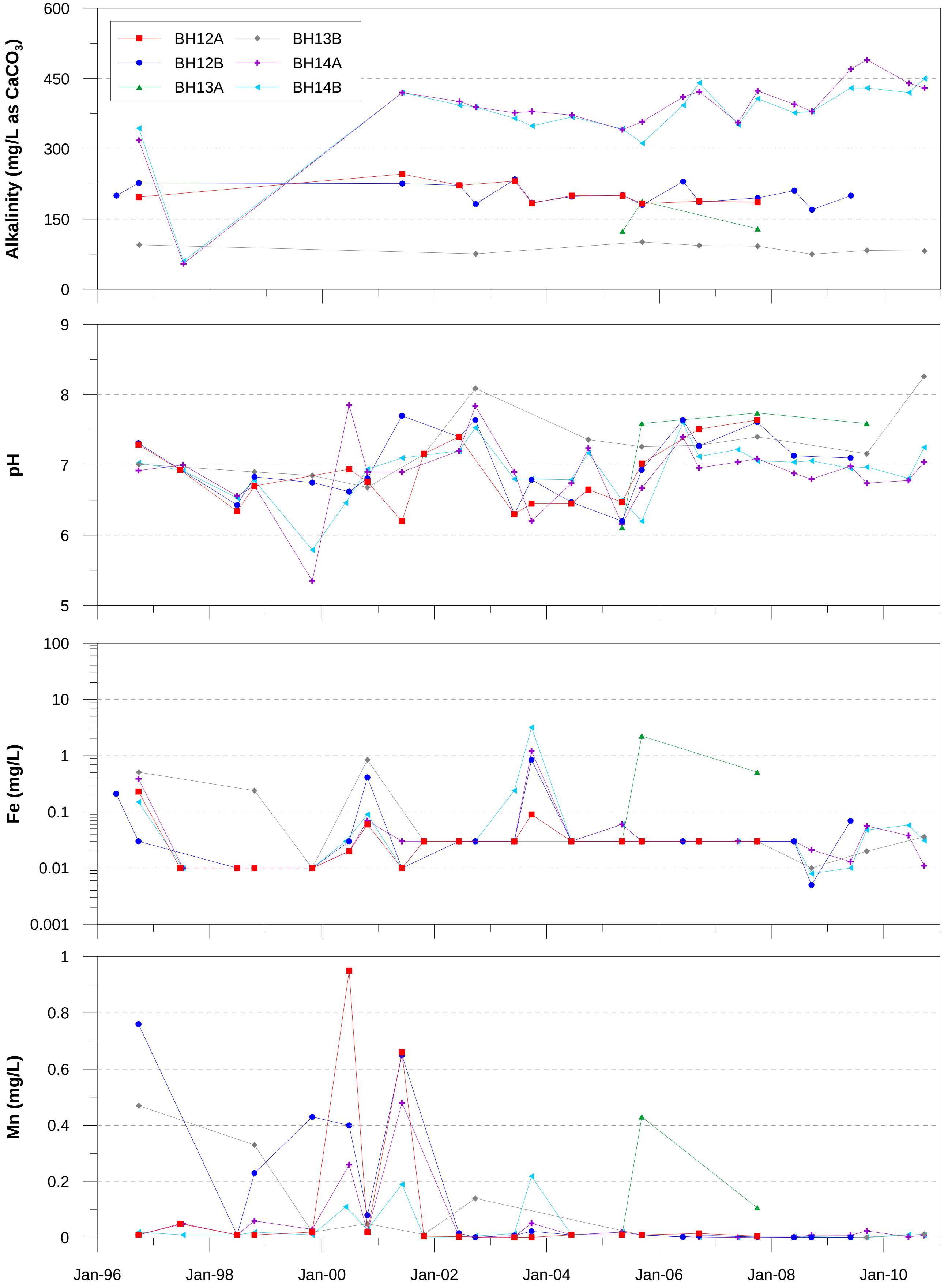


Figure 2-12b. Time trends for alkalinity, pH, Fe and Mn in wells at the toe of Northeast Rock Dump

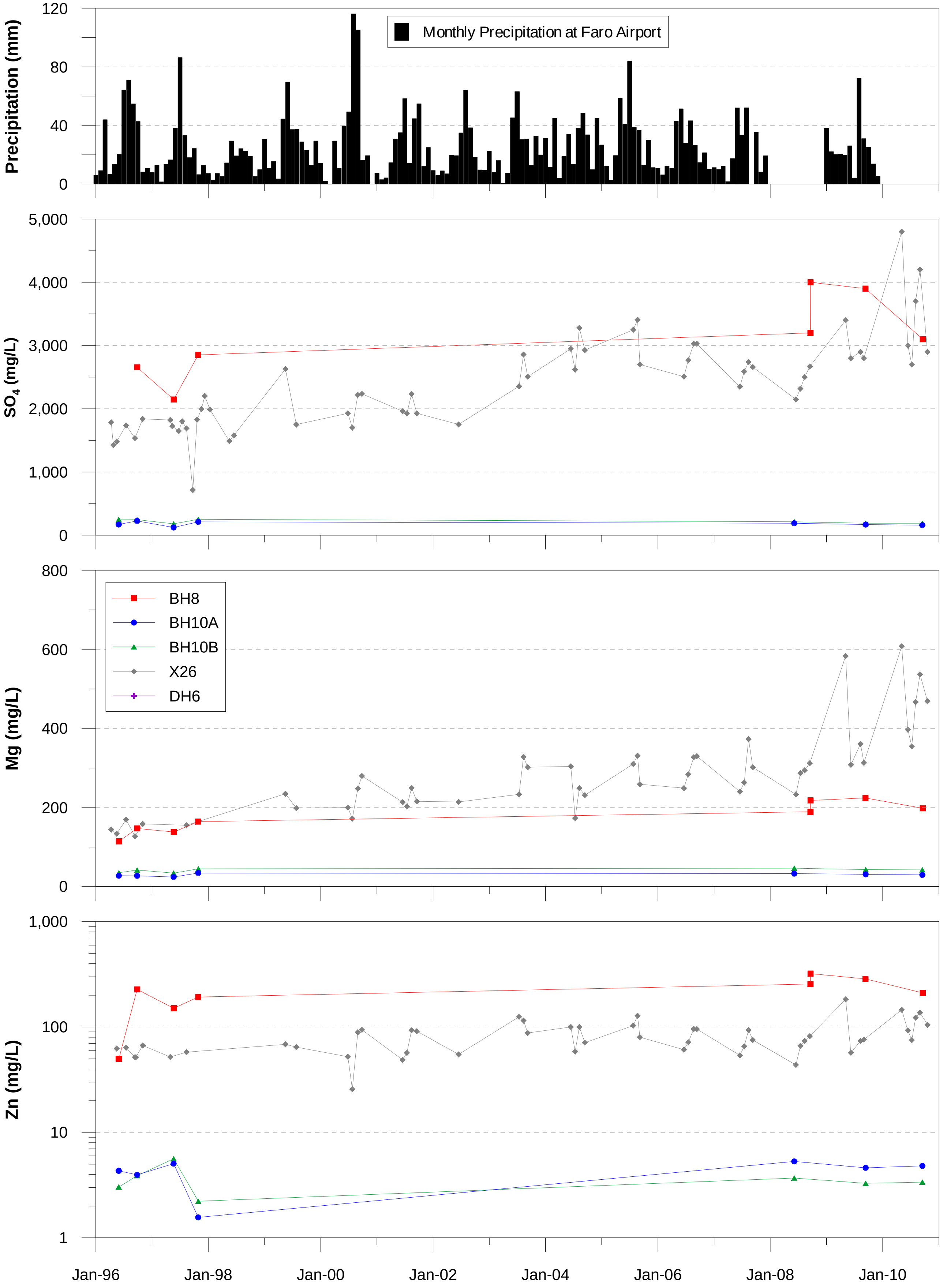


Figure 2-13a. Time trends for SO_4, Mg and Zn for Zone 2 Pit and bedrock wells

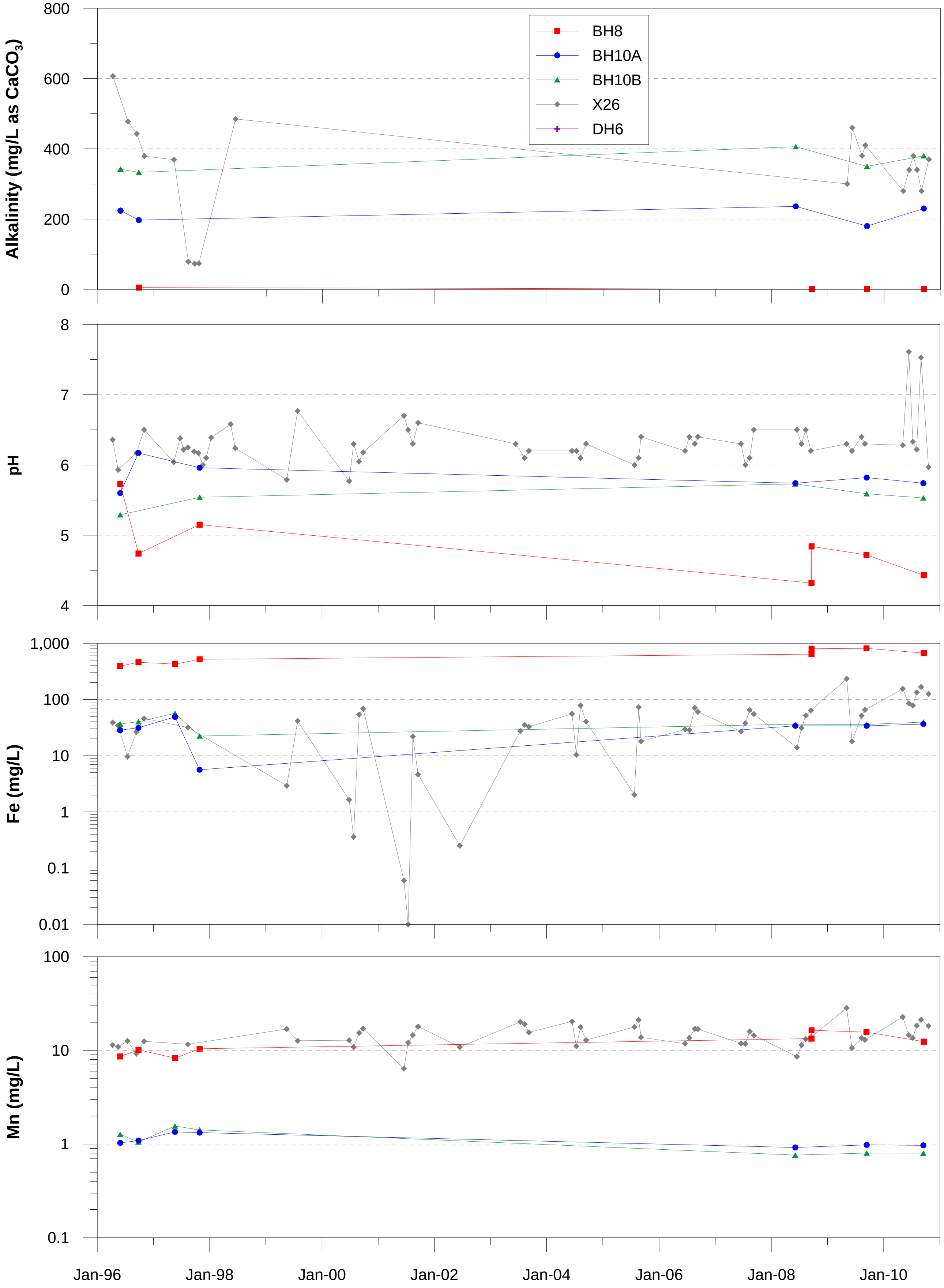


Figure 2-13b. Time trends for alkalinity, pH, Fe and Mn for Zone 2 Pit and bedrock wells

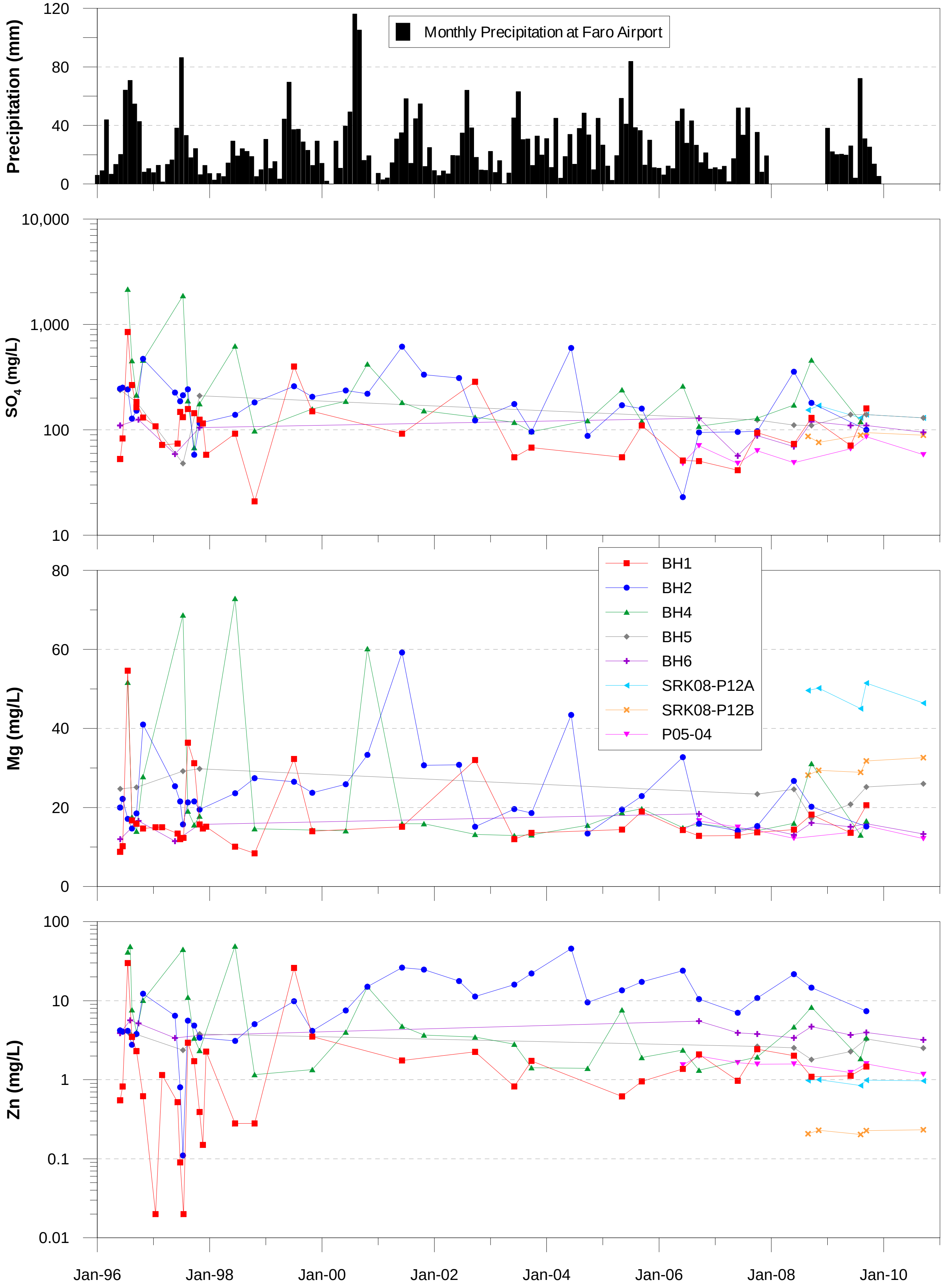


Figure 2-14a. Time trends for SO_4, Mg and Zn for wells in Zone 2 Pit outwash area

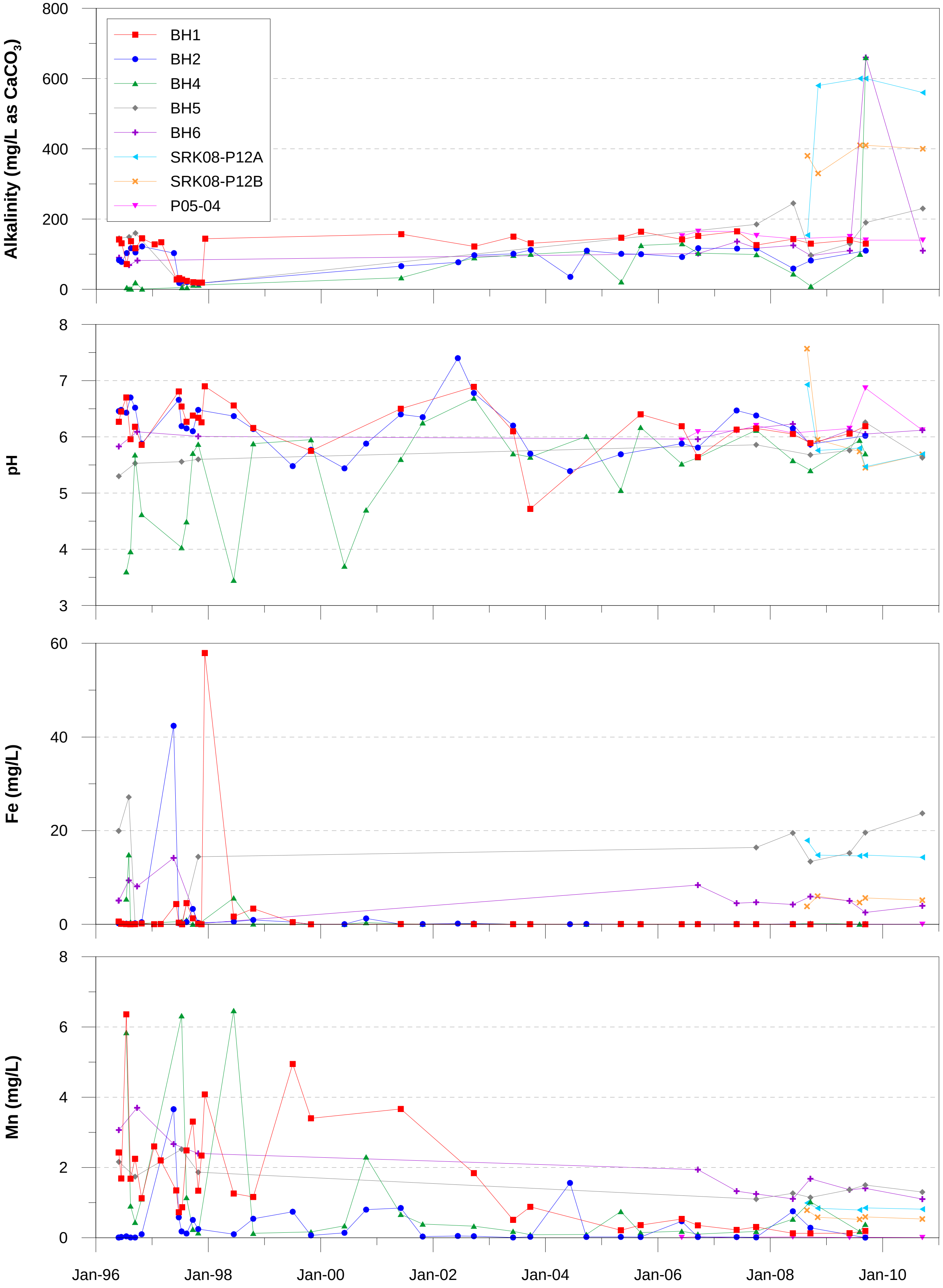


Figure 2-14b. Time trends for alkalinity, pH, Fe and Mn for wells in Zone 2 Pit outwash area

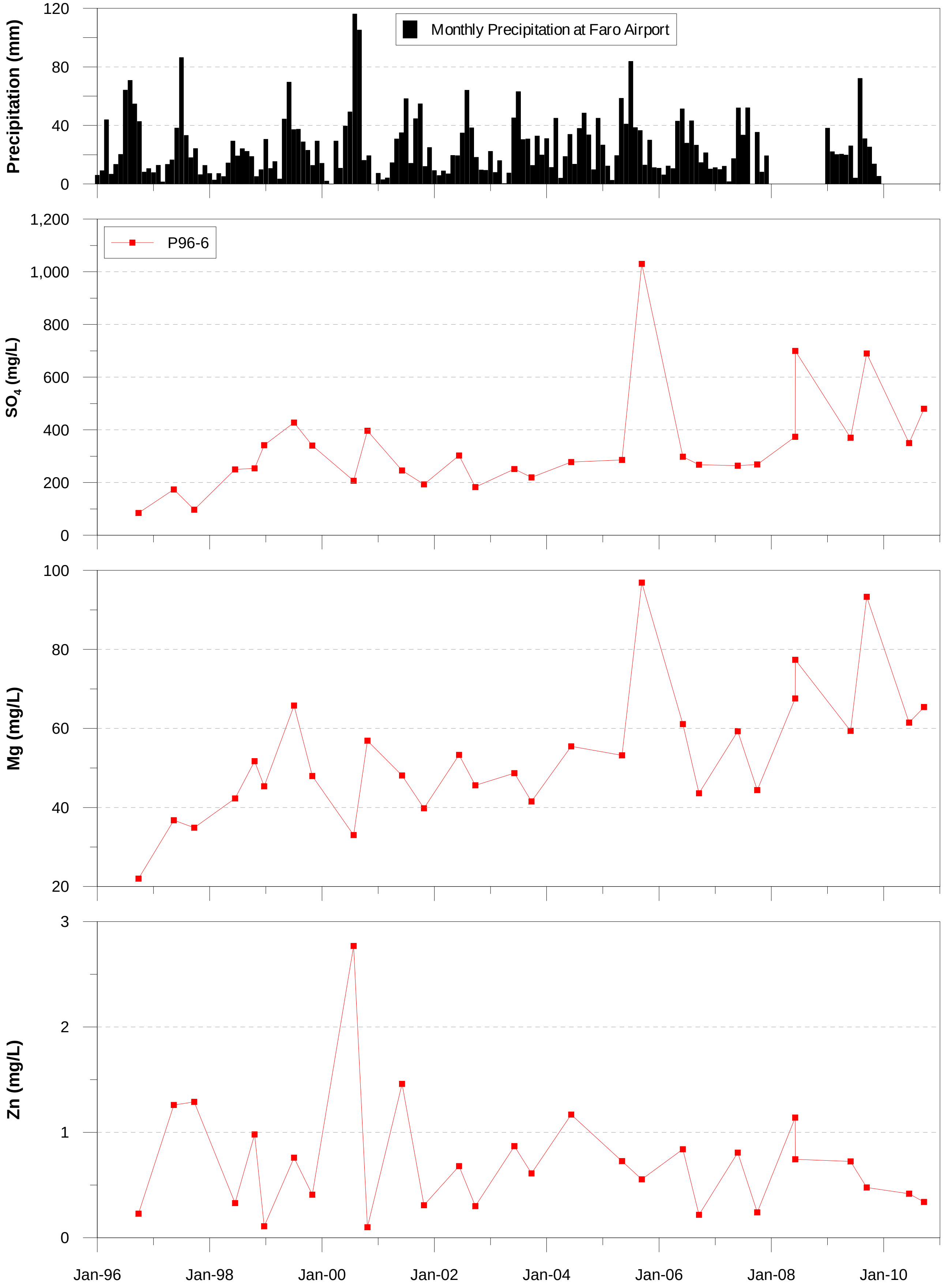


Figure 2-15a. Time trends for SO_4, Mg and Zn in P96-6 at the toe of Intermediate Rock Dump

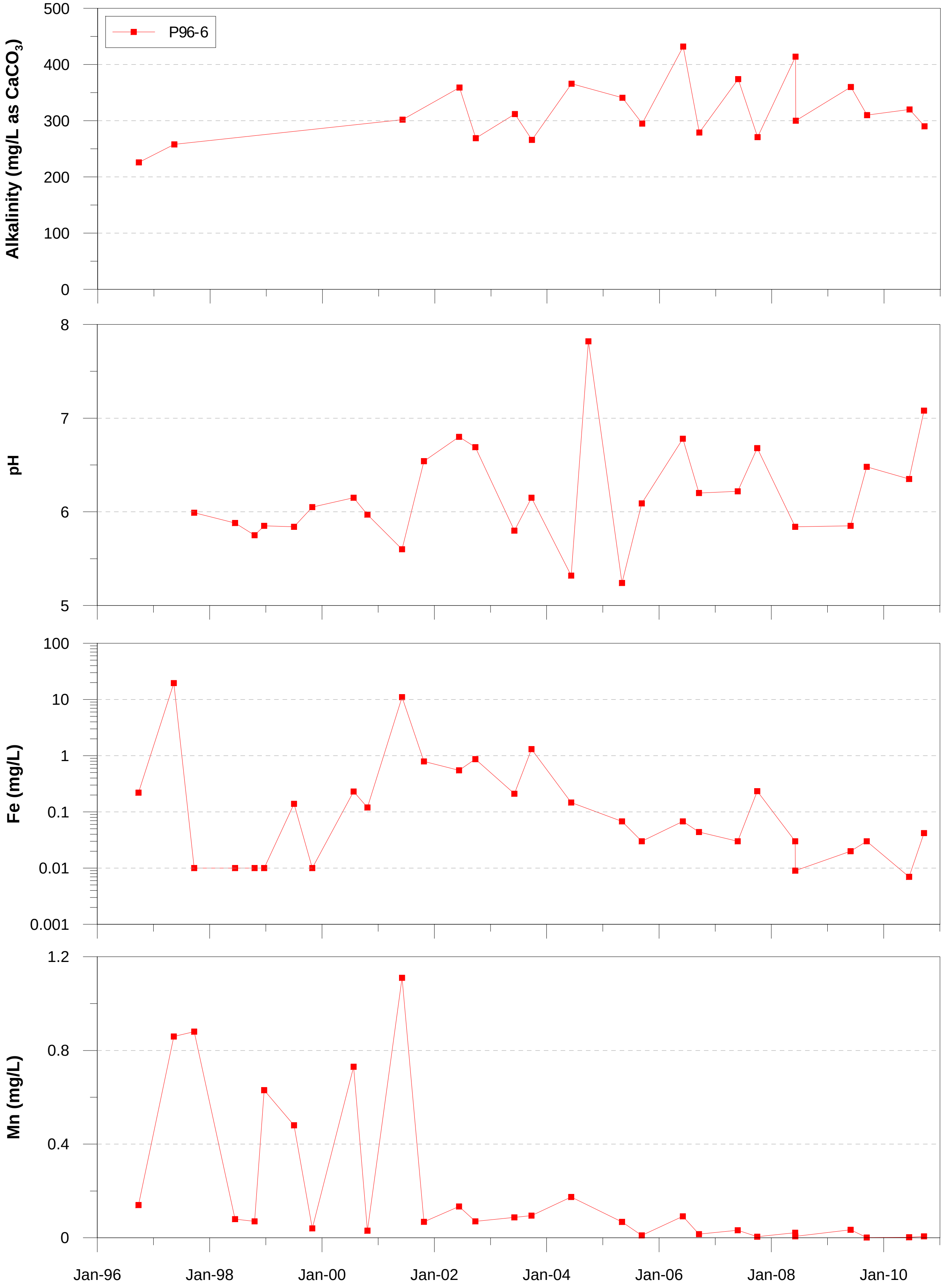
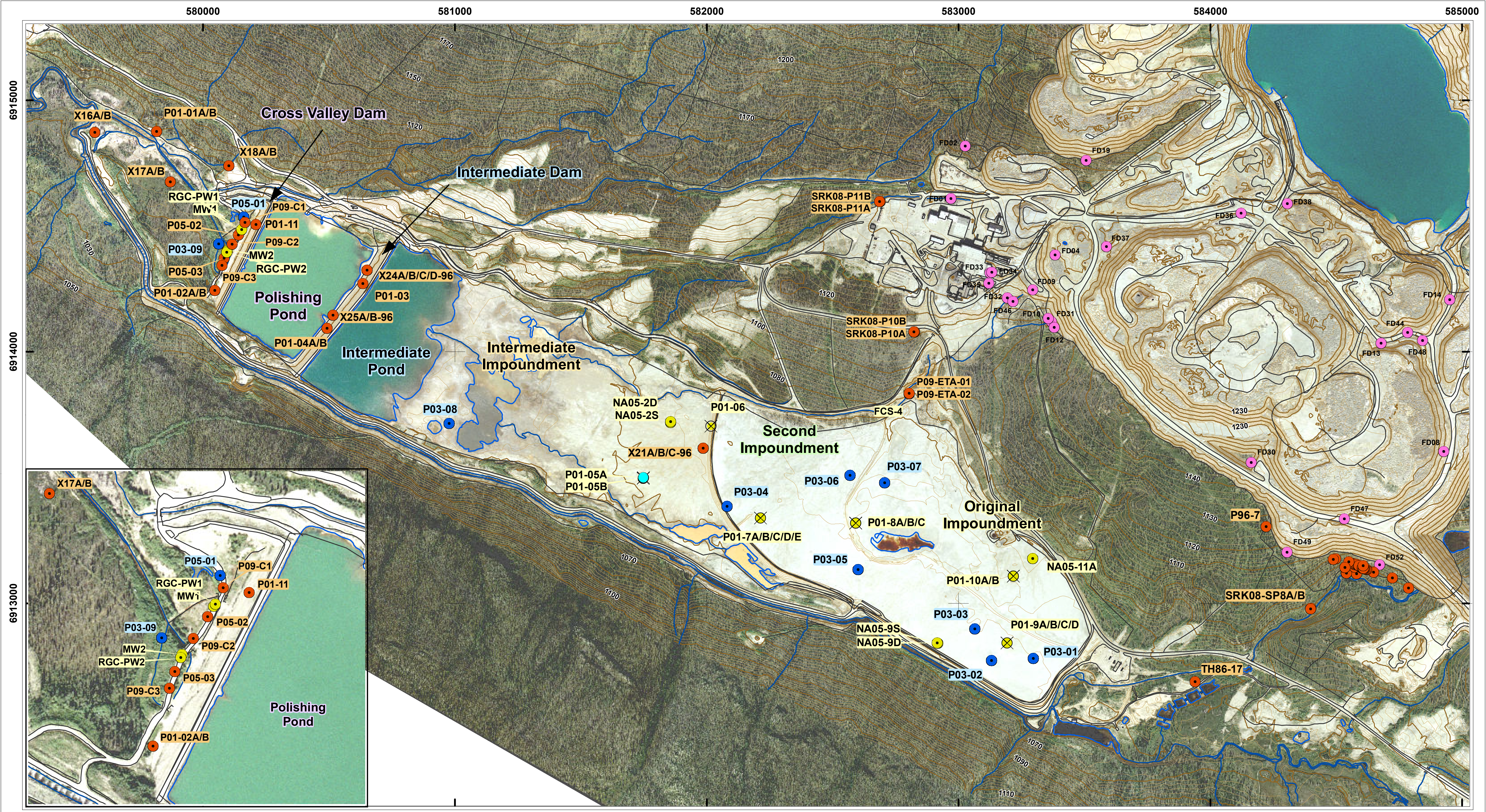


Figure 2-15b. Time trends for alkalinity, pH, Fe and Mn in P96-6 at toe of Intermediate Rock Dump

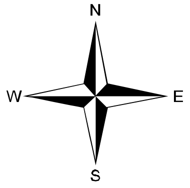


LEGEND

- 🔴 Monitoring Well
- 🔵 Multilevel Monitoring Well
- 🟡 Other Well (not Monitored Routinely)
- ⊗ Decommissioned Well
- 🟣 Seep Monitoring Station

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2M



Groundwater Monitoring Wells
Rose Creek Tailings Facility
Anvil Range Mining Complex

SCALE

0 200 400 600 800 1,000 Meters

Yukon Government

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CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 3-1

DATE: 032411
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FILE: Faro_Tailing_area_11.mxd

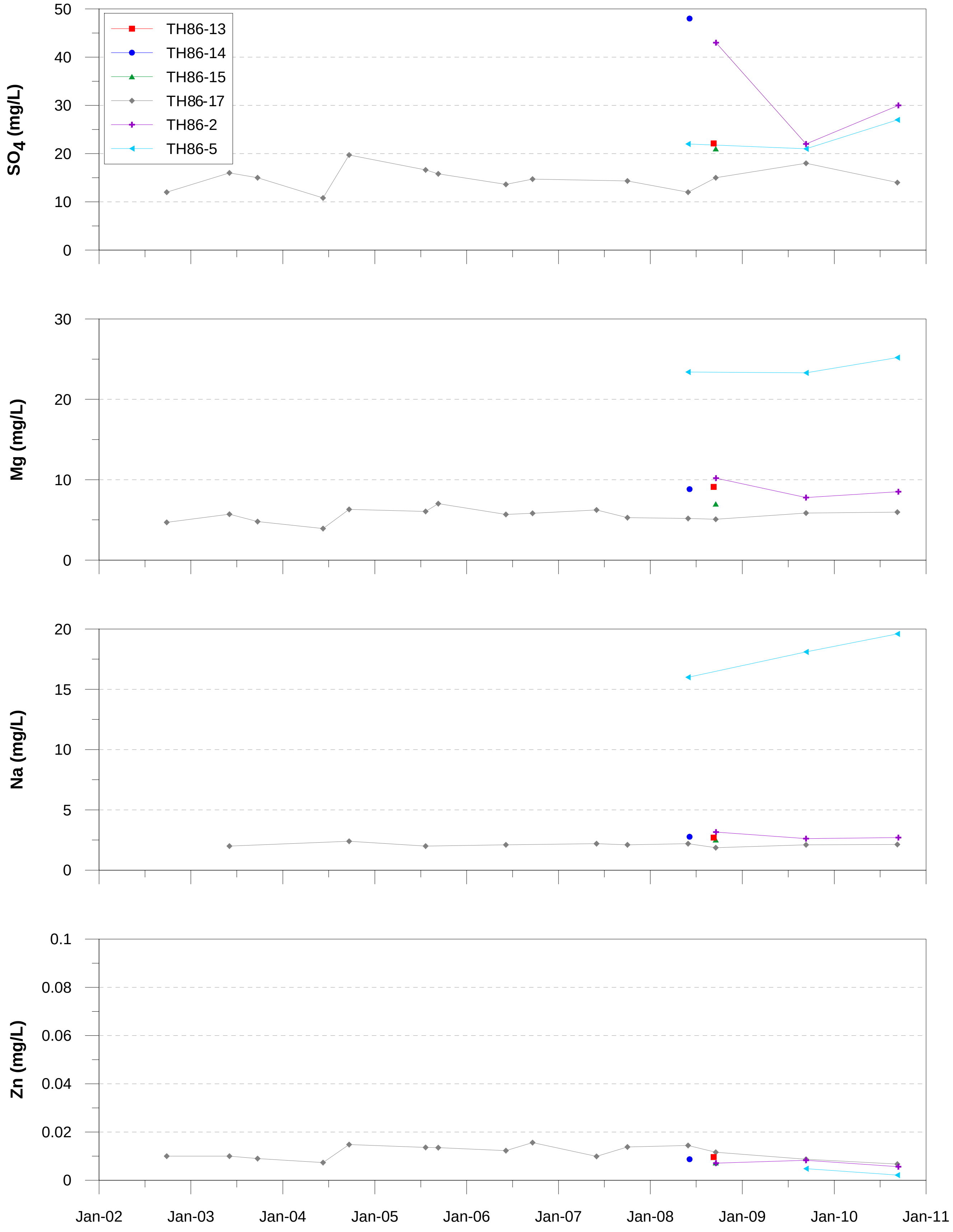


Figure 3-2a. Time trends for SO_4, Mg, Na and Zn in Rose Creek Alluvial Aquifer upgradient of RCTF

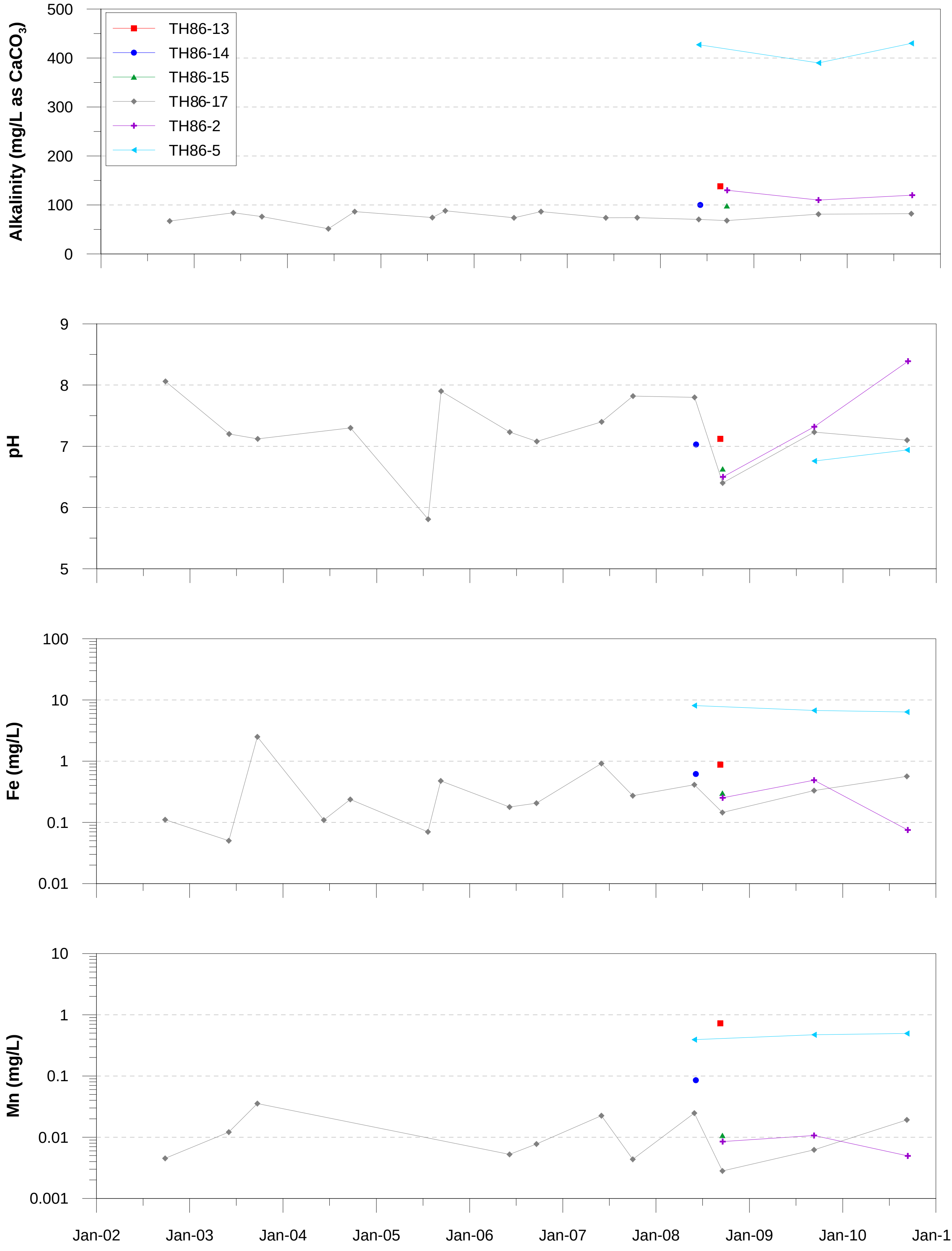


Figure 3-2b. Time trends for alkalinity, pH, Fe and Mn in well Rose Creek Alluvial Aquifer upgradient of RCTF

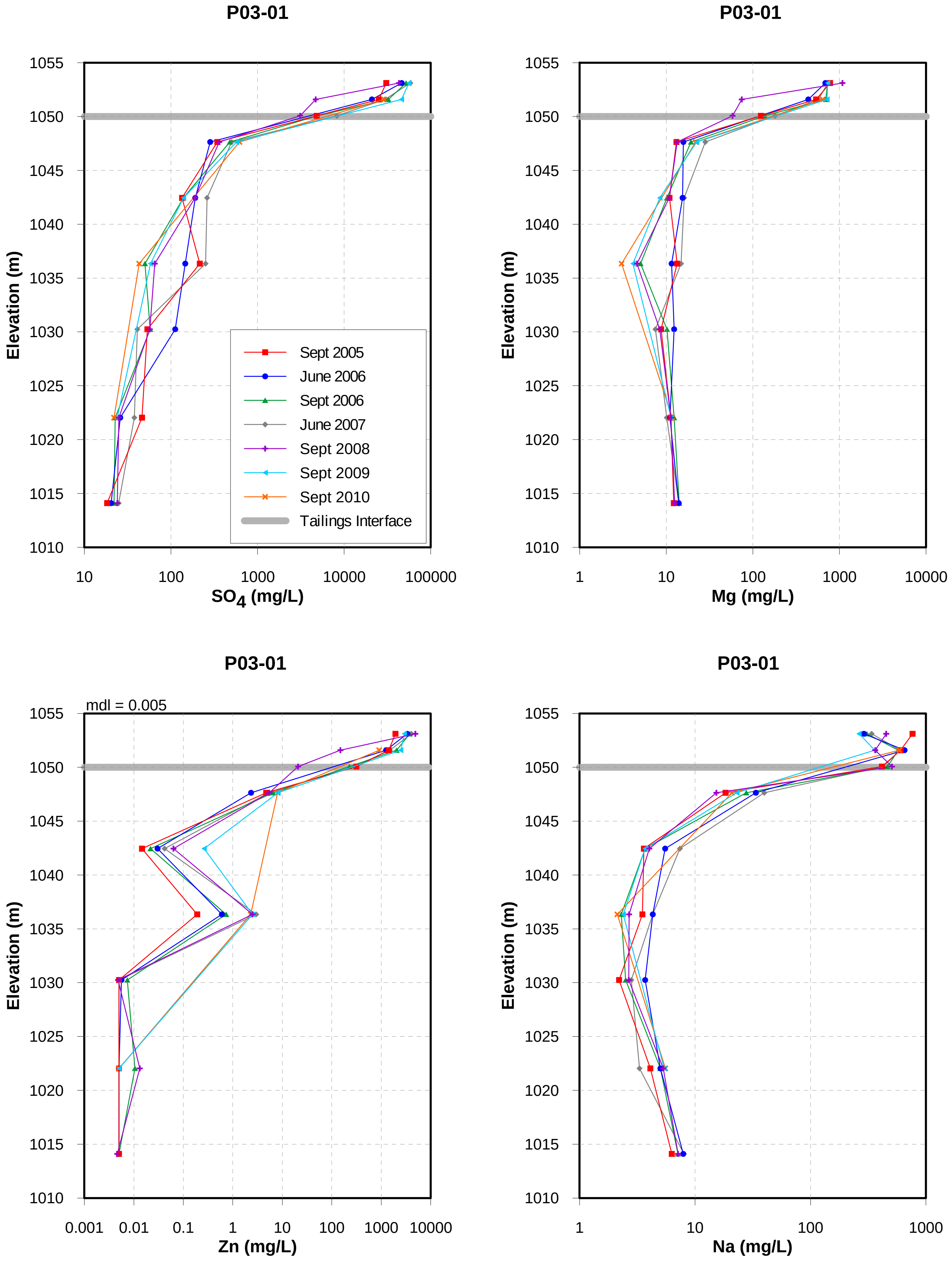


Figure 3-3a. Depth profiles for SO_4, Mg, Zn and Na in P03-01 (Original Impoundment)

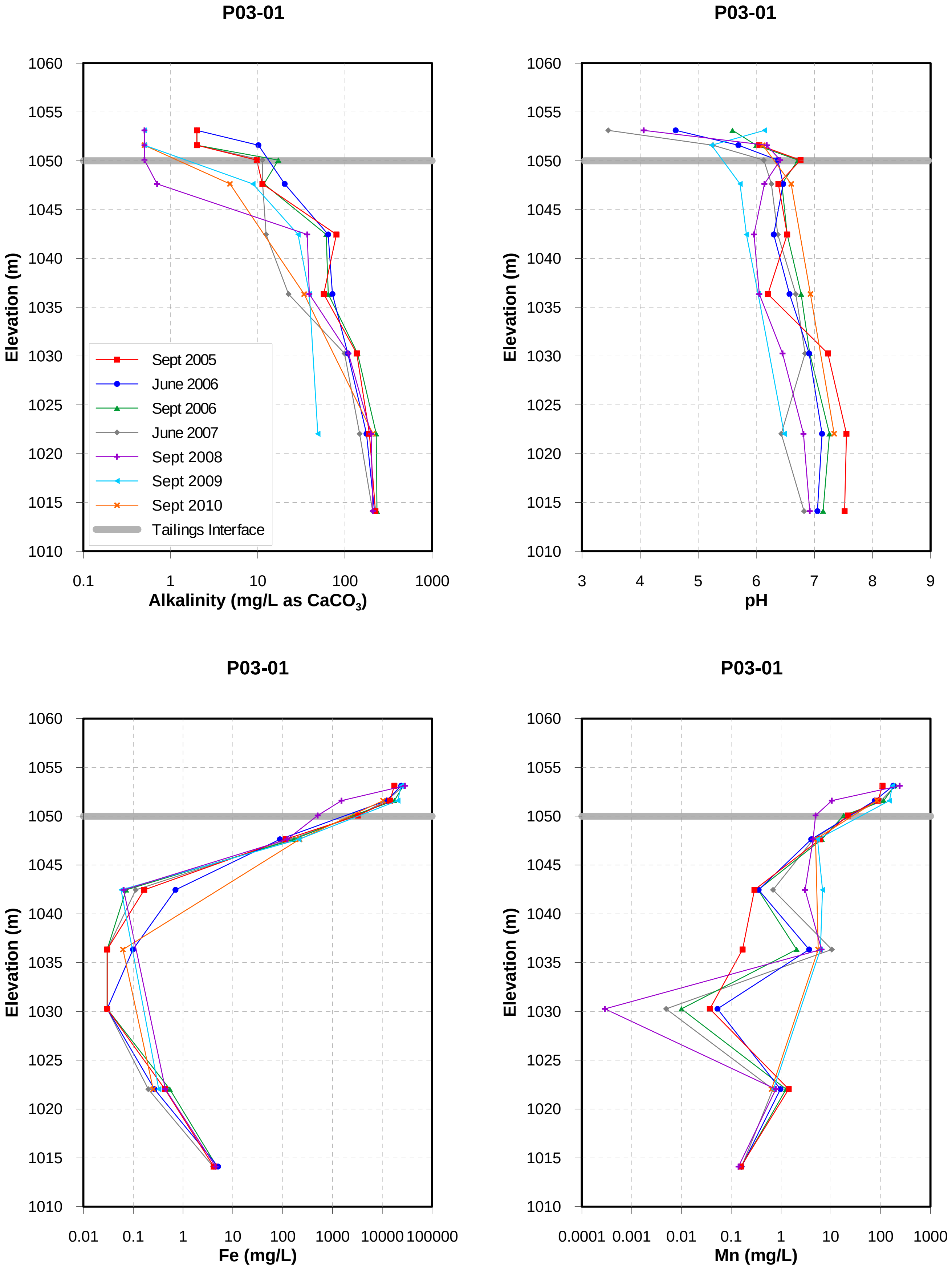


Figure 3-3b. Depth profiles for alkalintiy, pH, Fe and Mn in P03-01 (Original Impoundment)

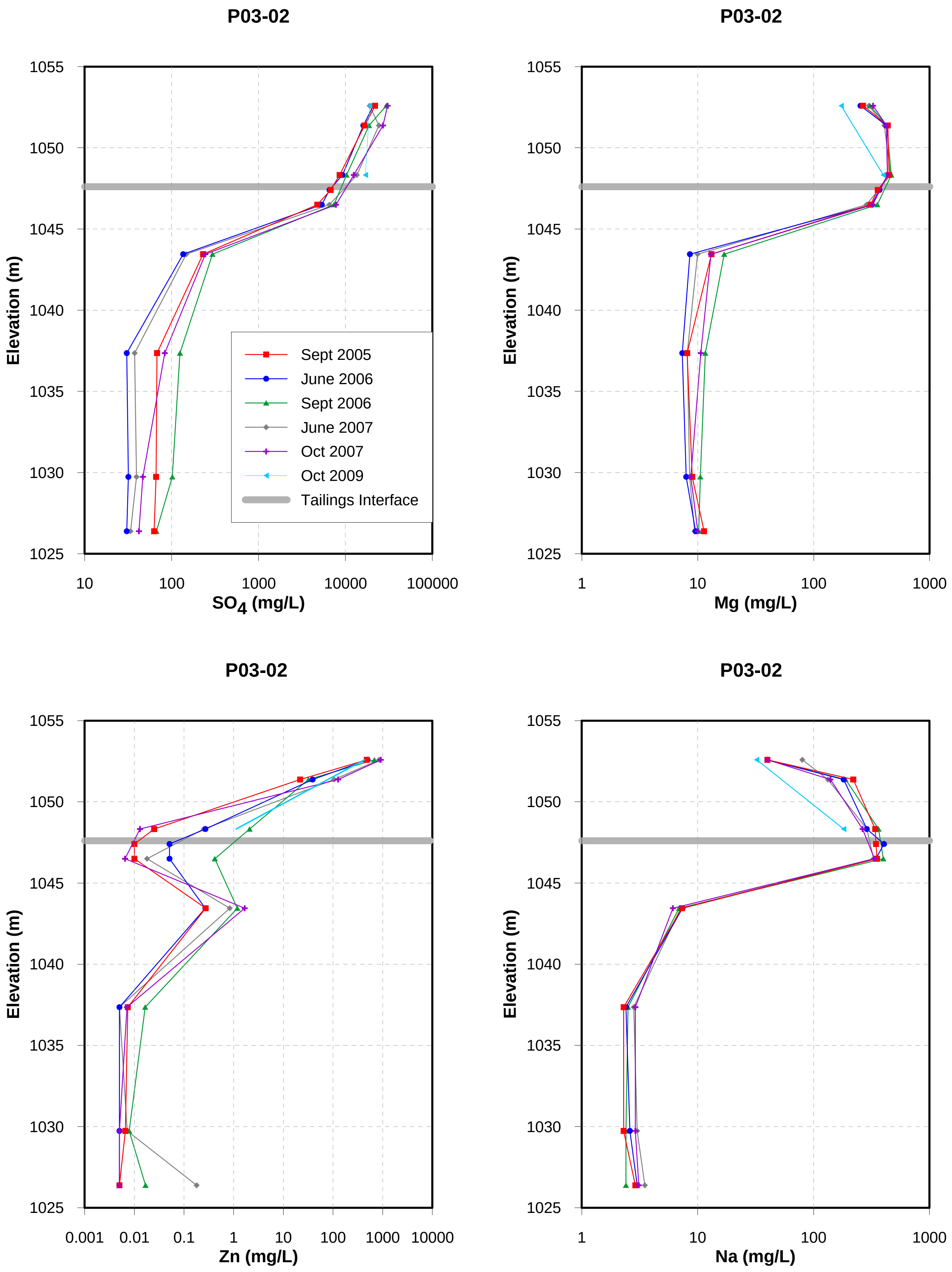


Figure 3-4a. Depth profiles of SO_4, Mg, Zn and Na in P03-02 (Second Impoundment)

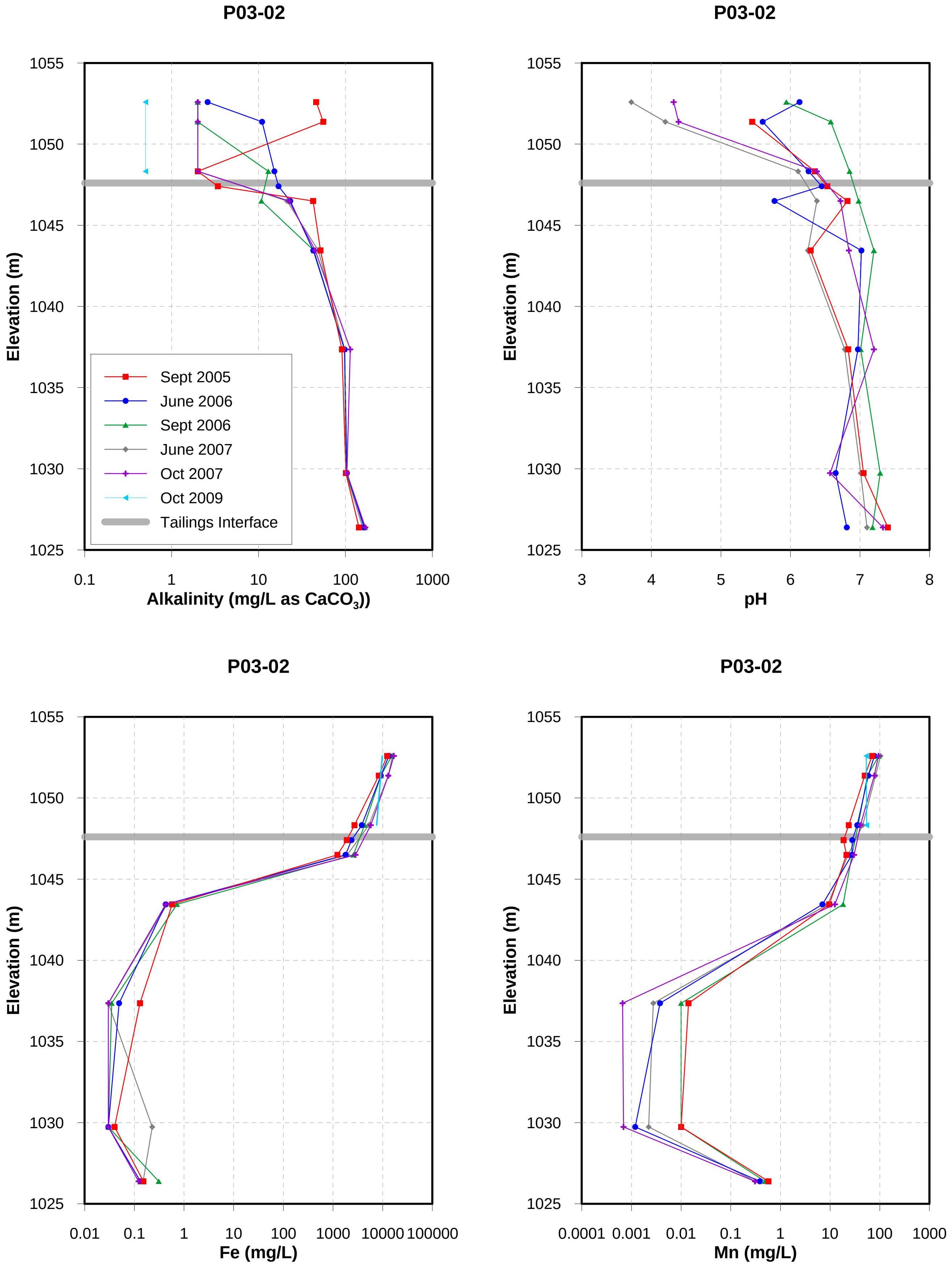


Figure 3-4b. Depth profiles for alkalinity, pH, Fe and Mn in P03-02 (Second Impoundment)

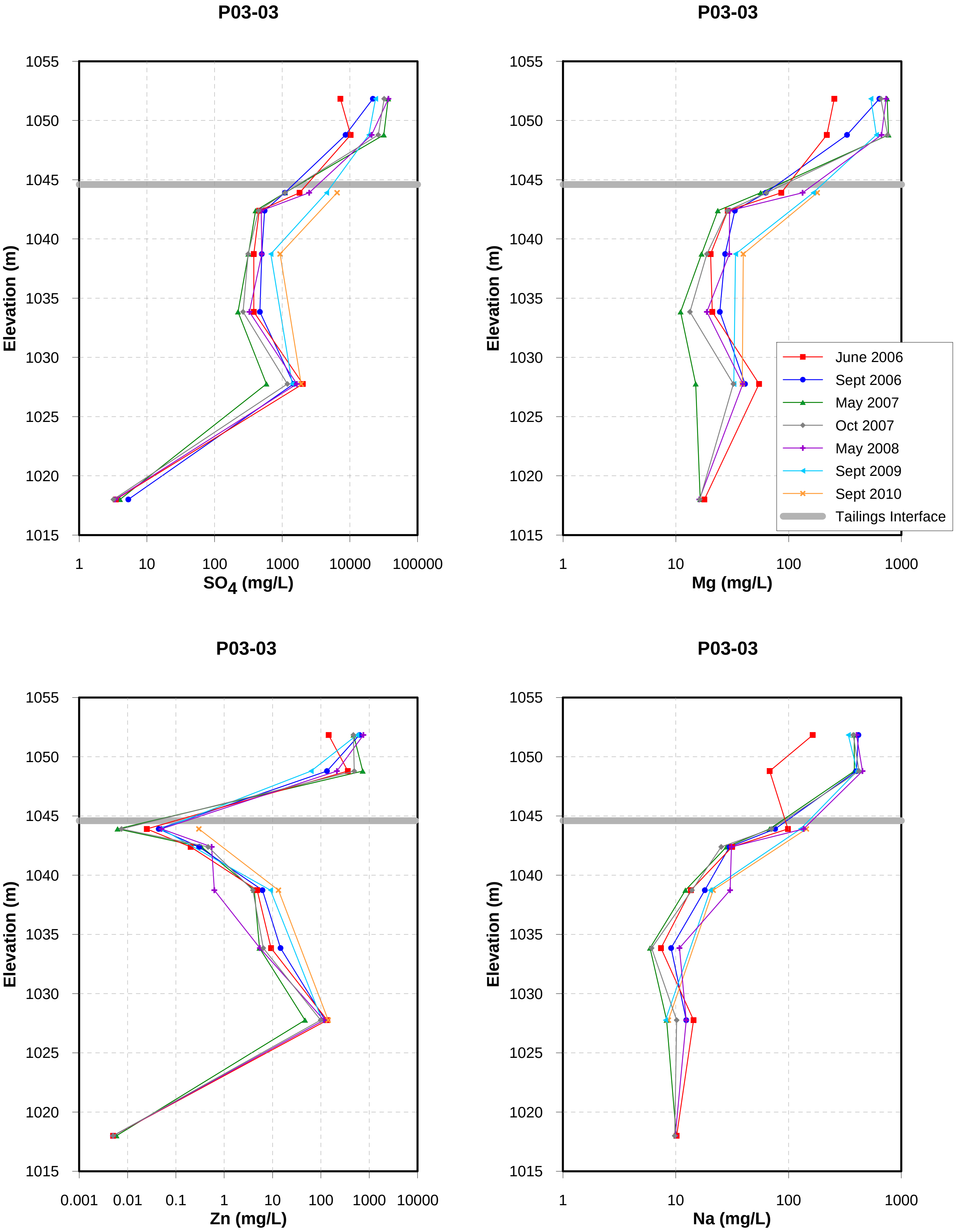


Figure 3-5a. Depth profiles for SO_4, Mg, Zn and Na in P03-03 (Second Impoundment)

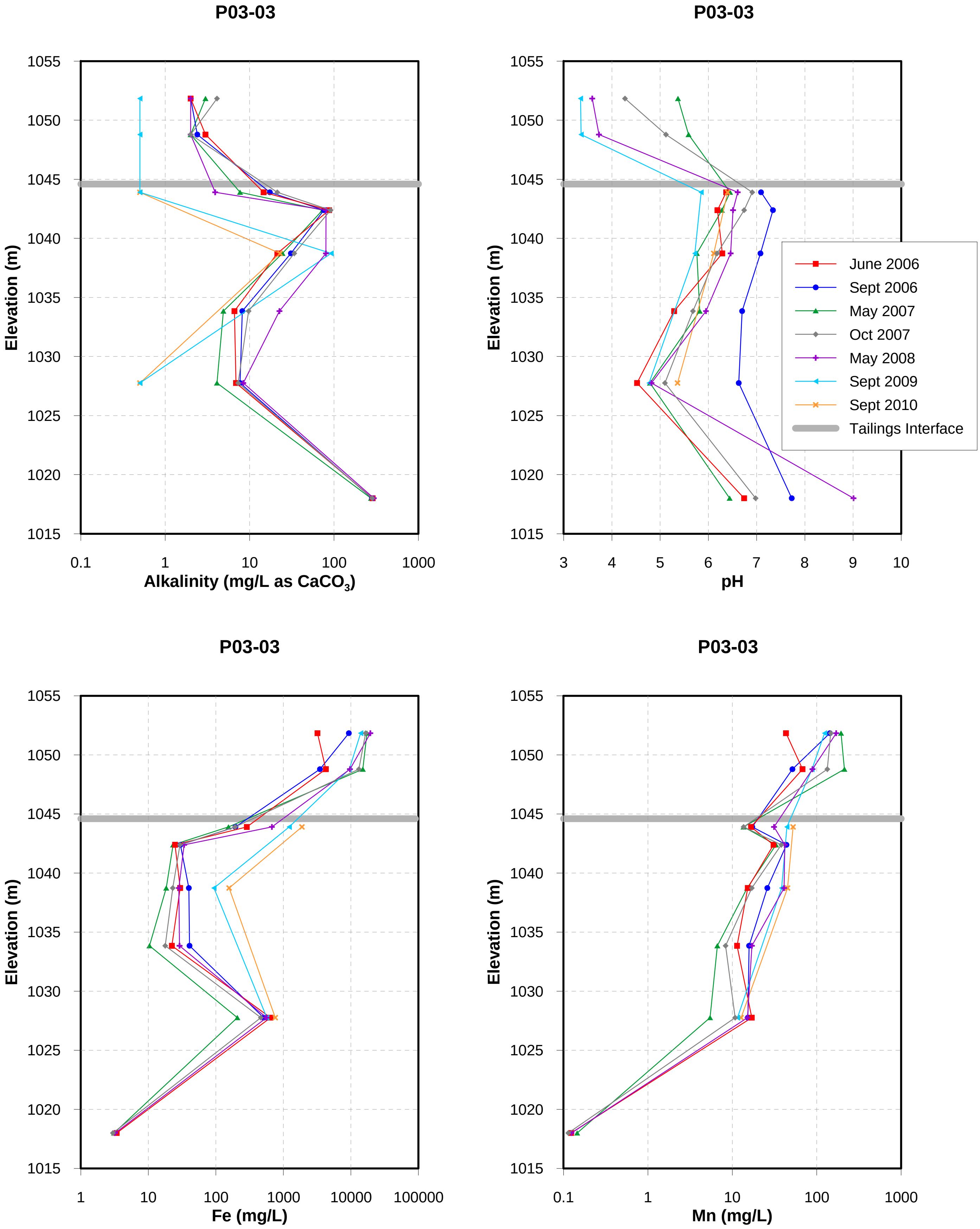


Figure 3-5b. Depth profiles for alkalinity, pH, Fe and Mn in P03-03 (Second Impoundment)

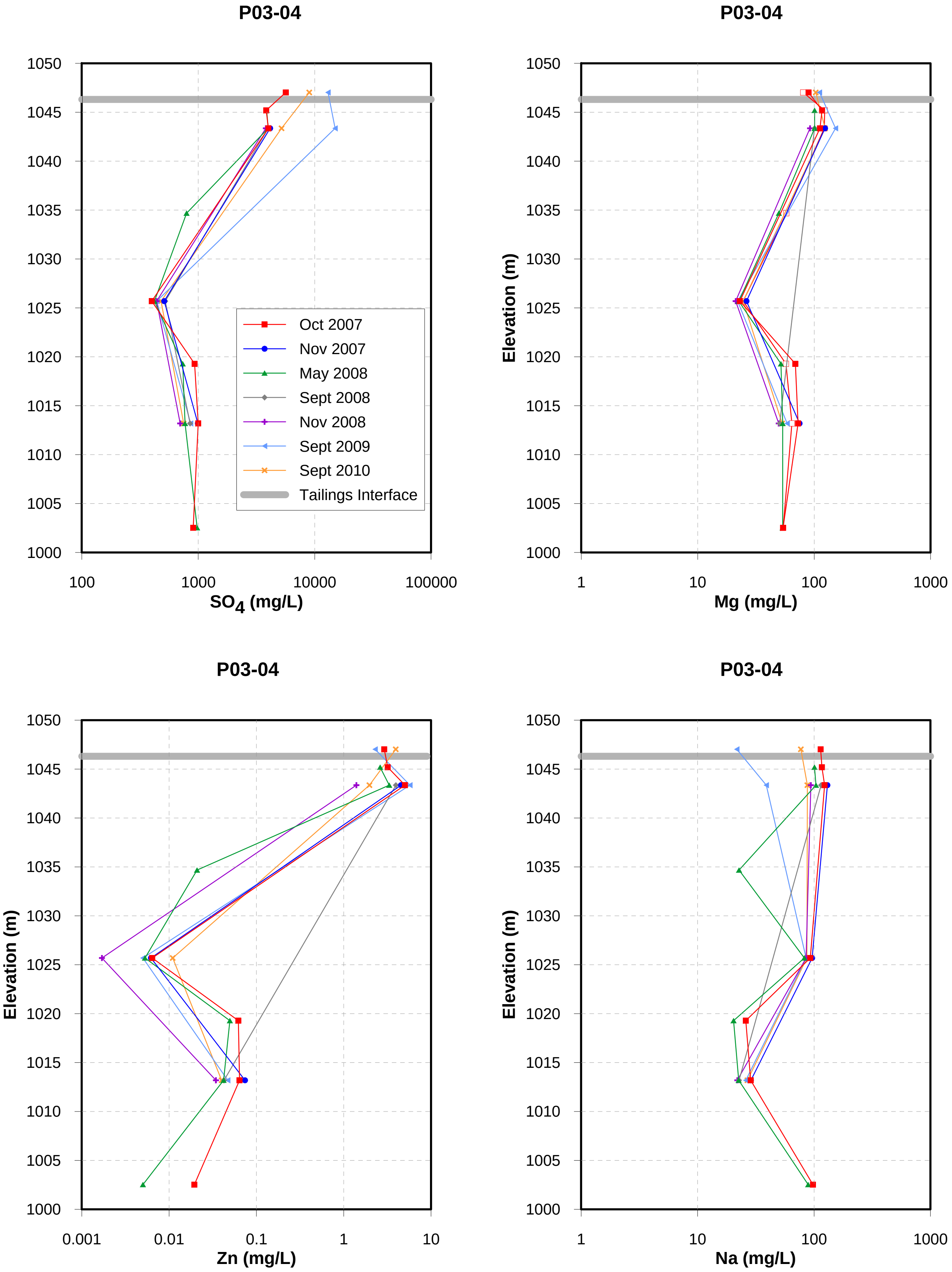


Figure 3-6a. Depth profiles for SO_4, Mg, Zn and Na in P03-04 (Second Impoundment)

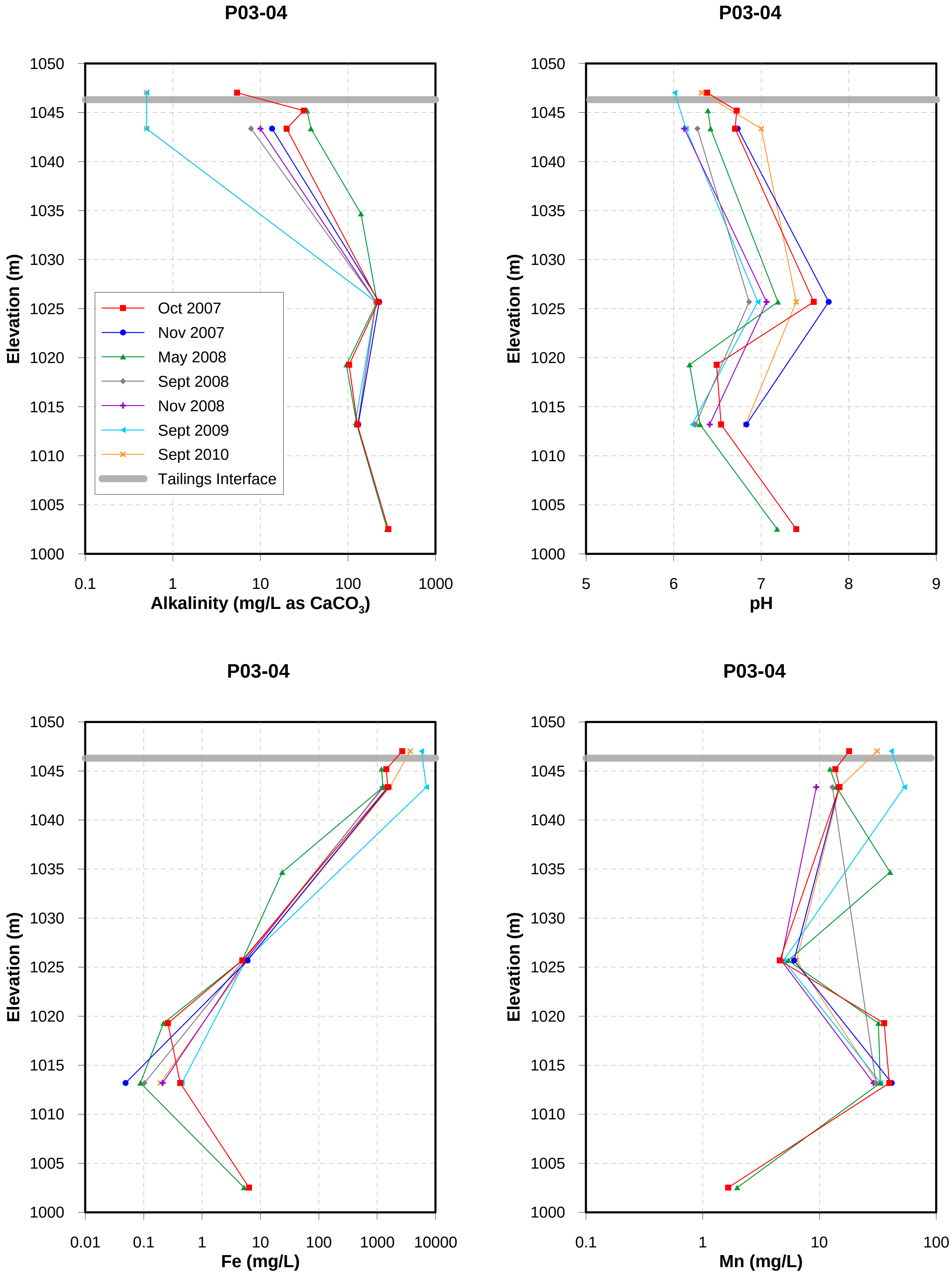


Figure 3-6b. Depth profiles for alkalinity, pH, Fe and Mn in P03-04 (Second Impoundment)

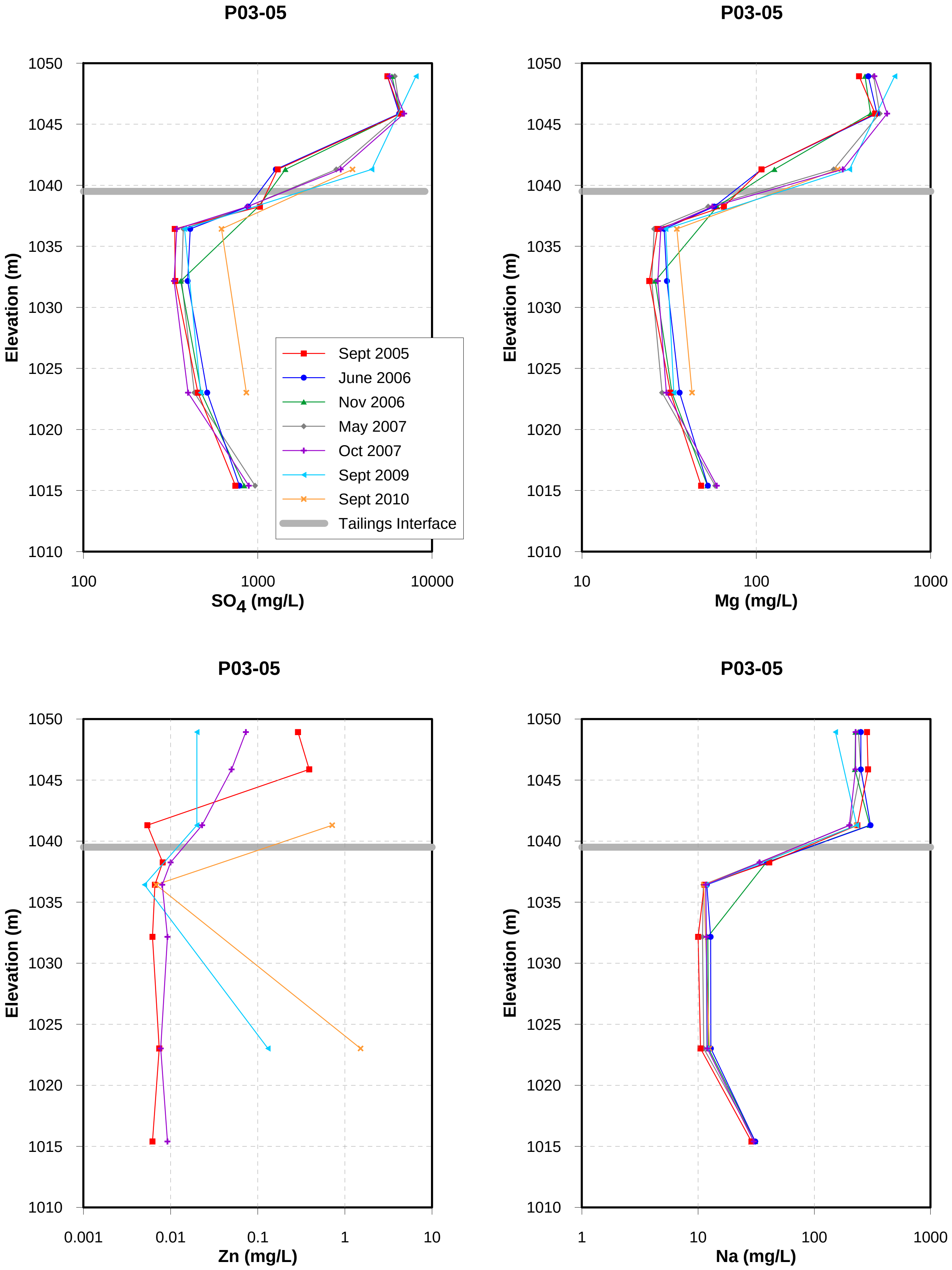


Figure 3-7a. Depth profiles for SO_4, Mg, Zn and Na in P03-05 (Second Impoundment)

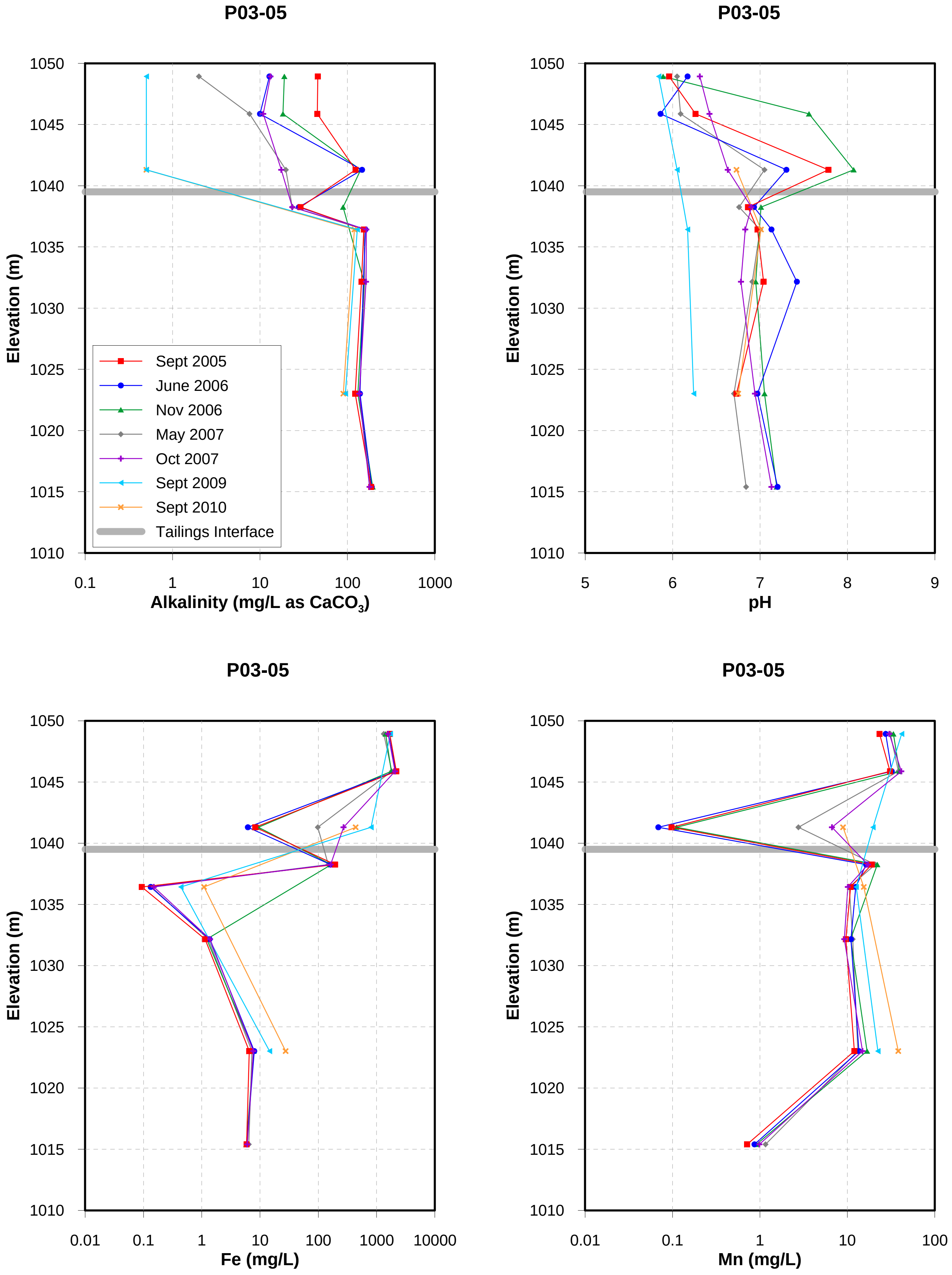


Figure 3-7b. Depth profiles for alkalinity, pH, Fe and Mn in P03-05 (Second Impoundment)

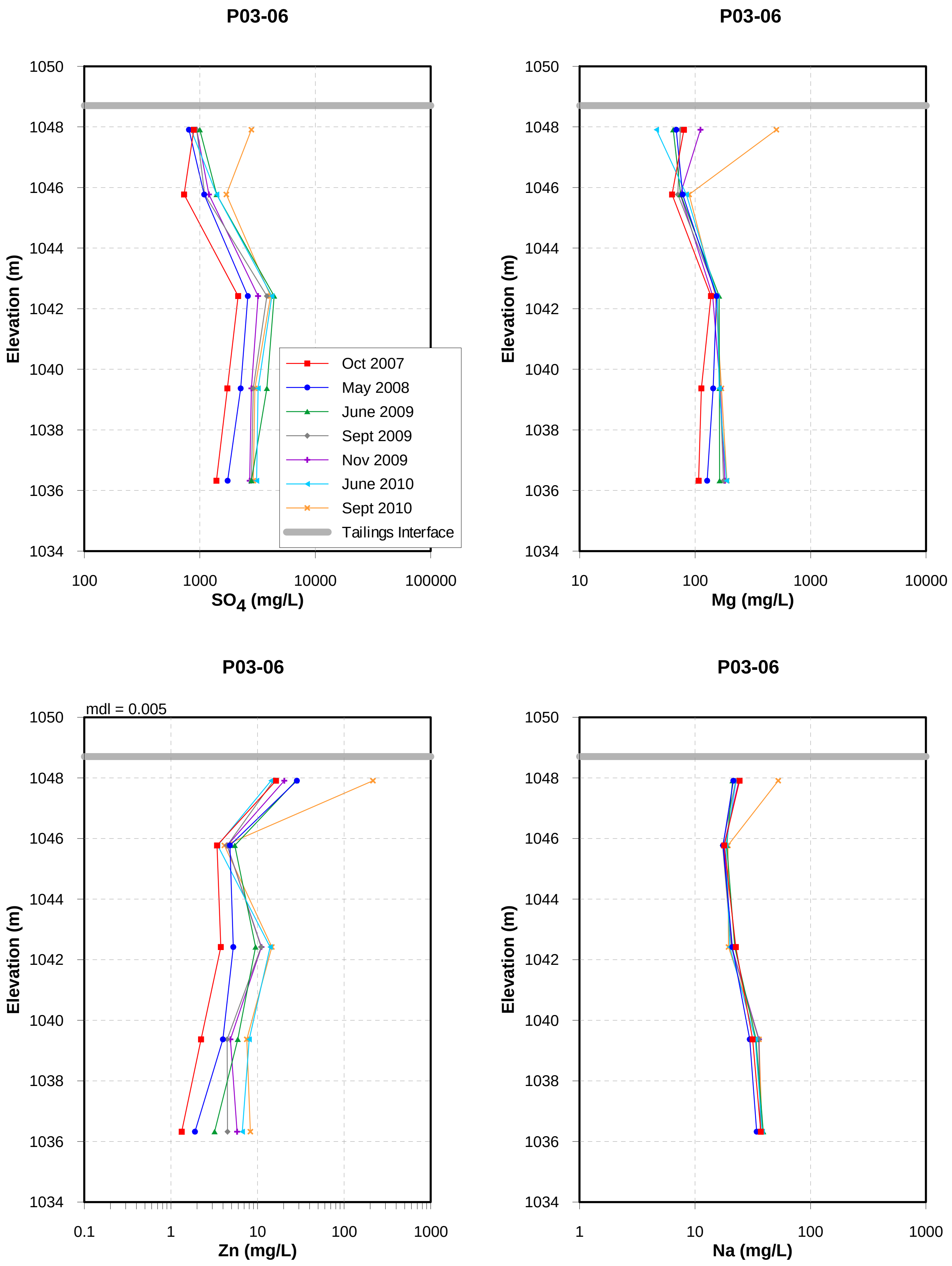


Figure 3-8a. Depth profiles for SO_4, Mg, Zn and Na in P03-06 (Second Impoundment)

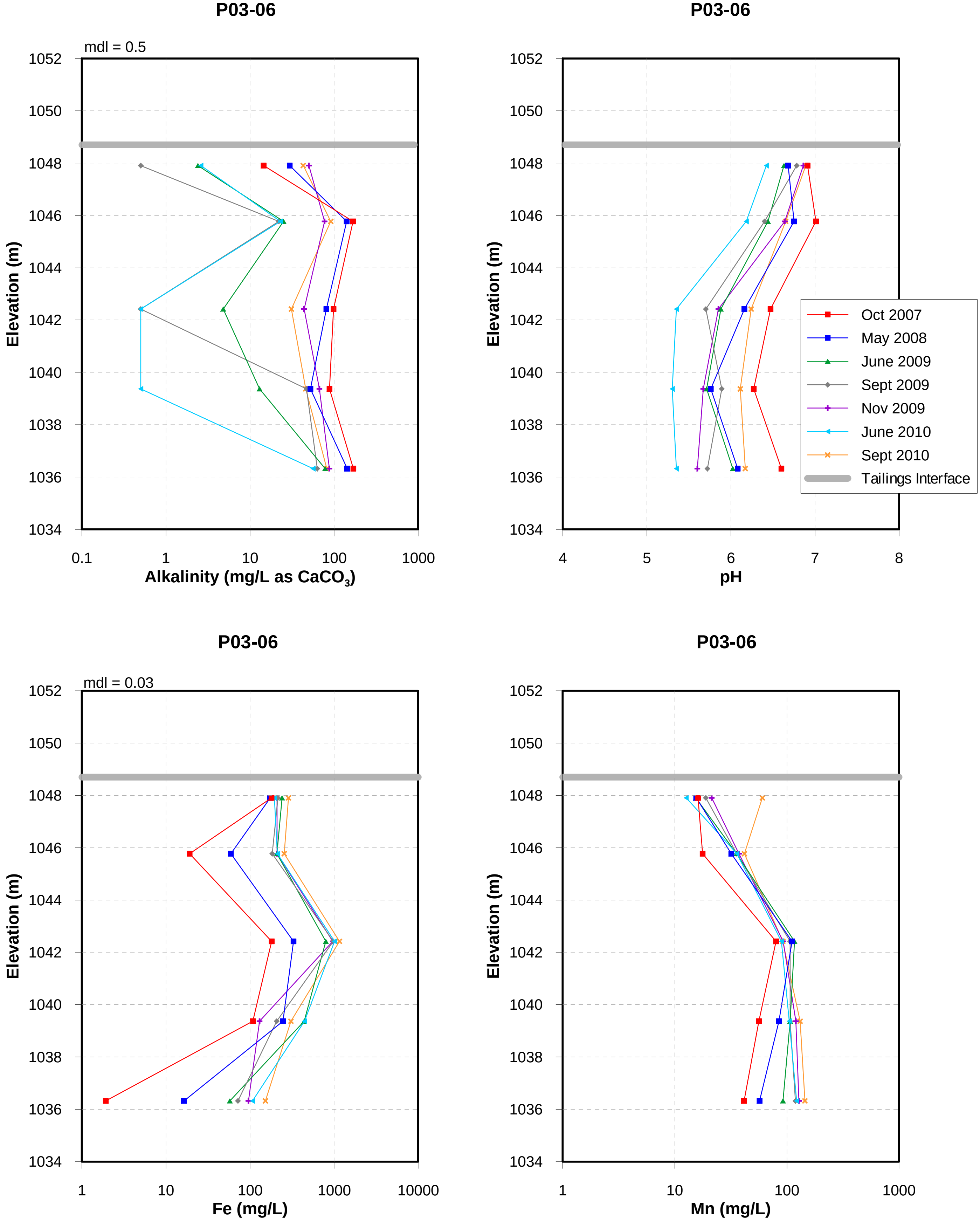


Figure 3-8b. Depth profiles for alkalinity, pH, Fe and Mn in P03-06 (Second Impoundment)

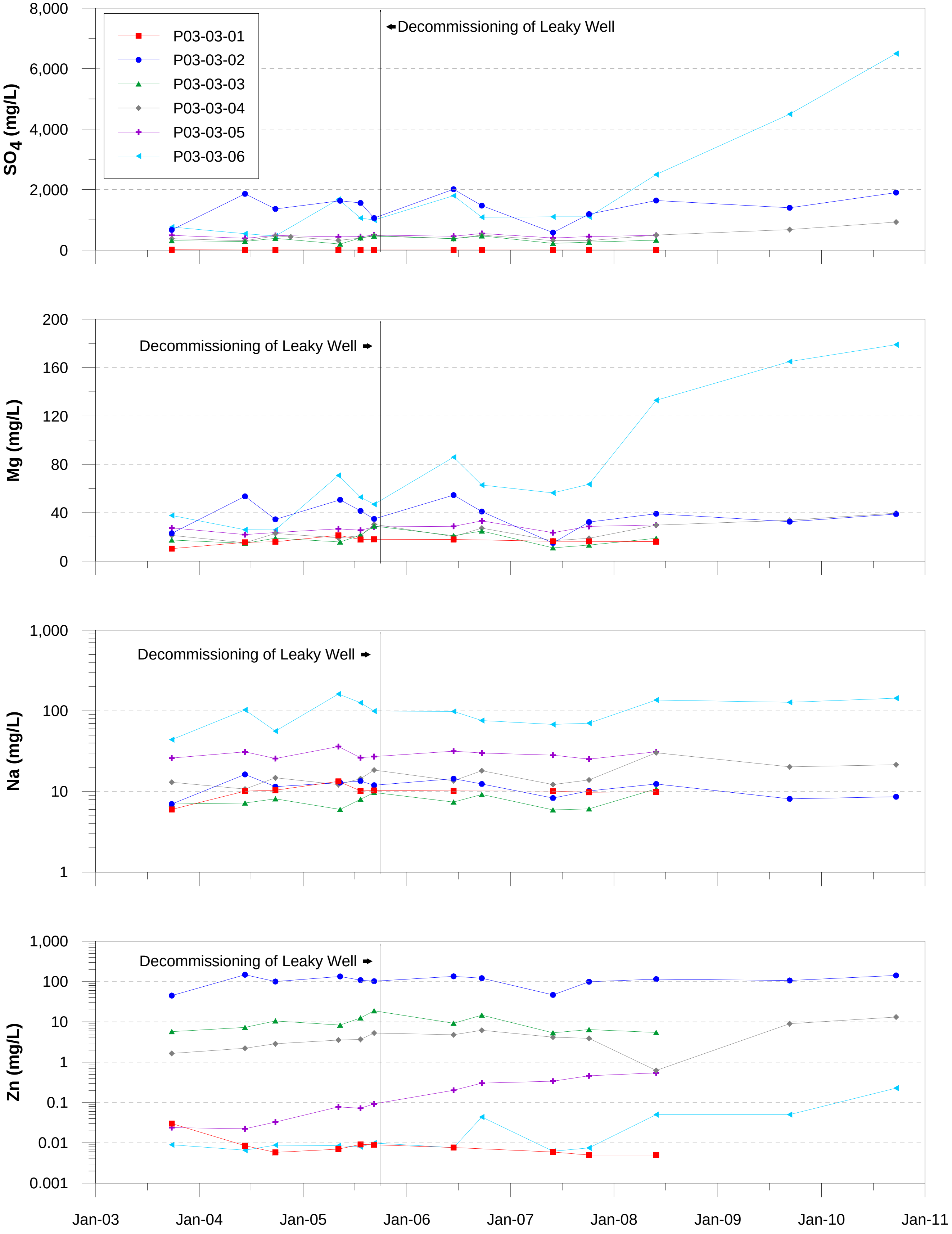


Figure 3-9a. Time trends for SO_4, Mg, Na and Zn in P03-03 (aquifer only)

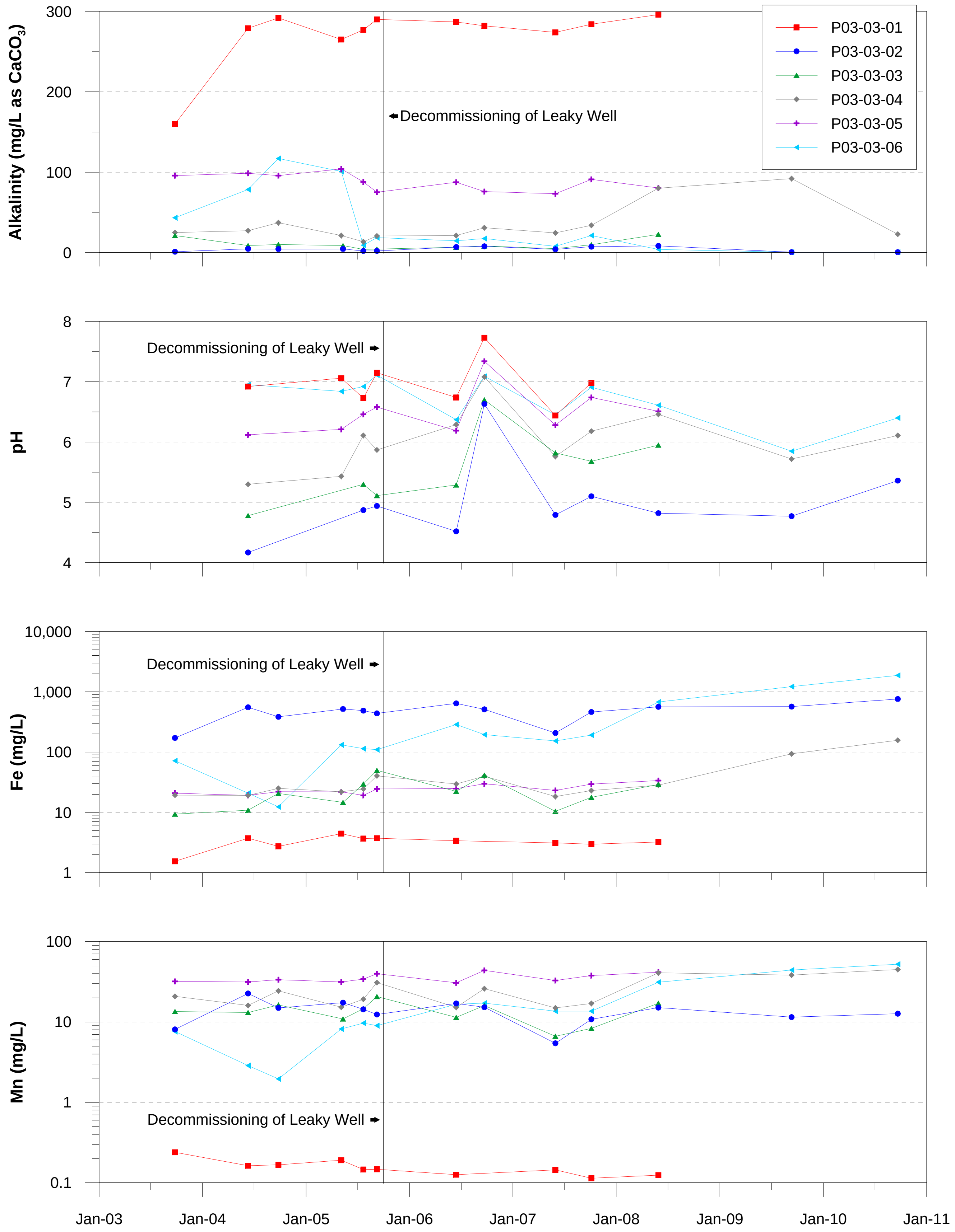


Figure 3-9b. Time trends for alkalinity, pH, Fe and Mn in P03-03 (aquifer only)

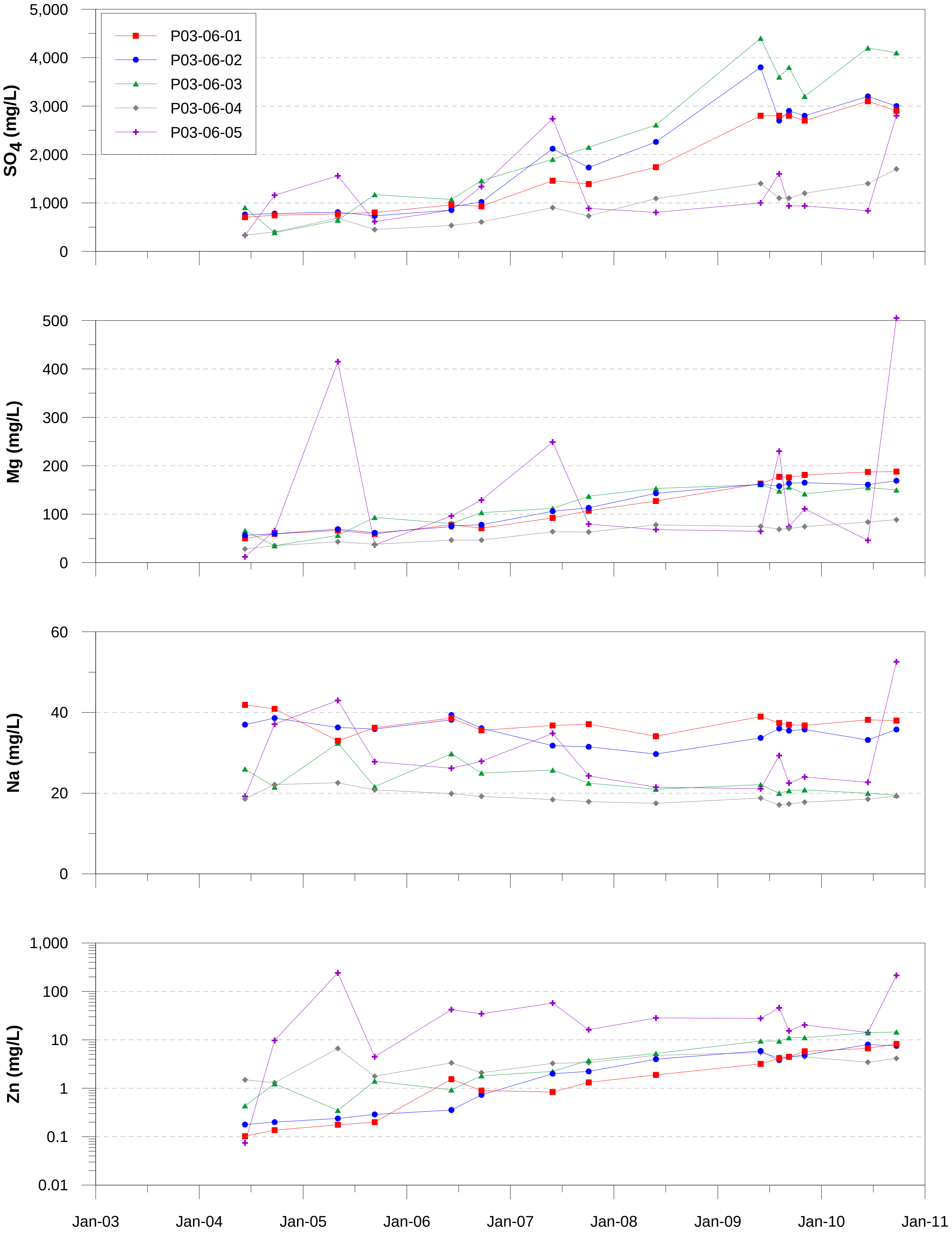


Figure 3-10a. Time trends for SO_4, Mg, Na and Zn in P03-06 (aquifer only)

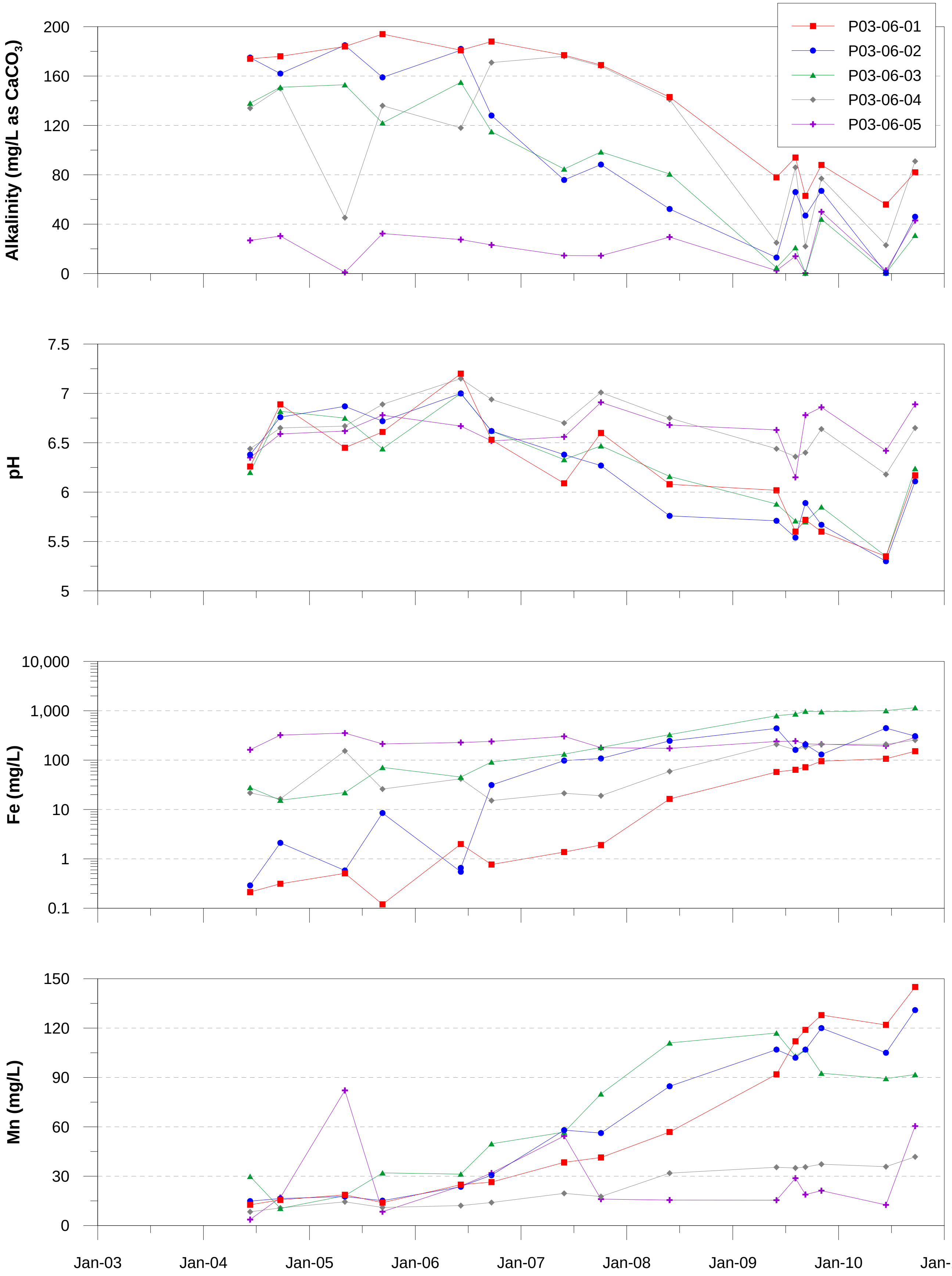


Figure 3-10b. Time trends for alkalinity, pH, Fe and Mn in P03-06 (aquifer only)

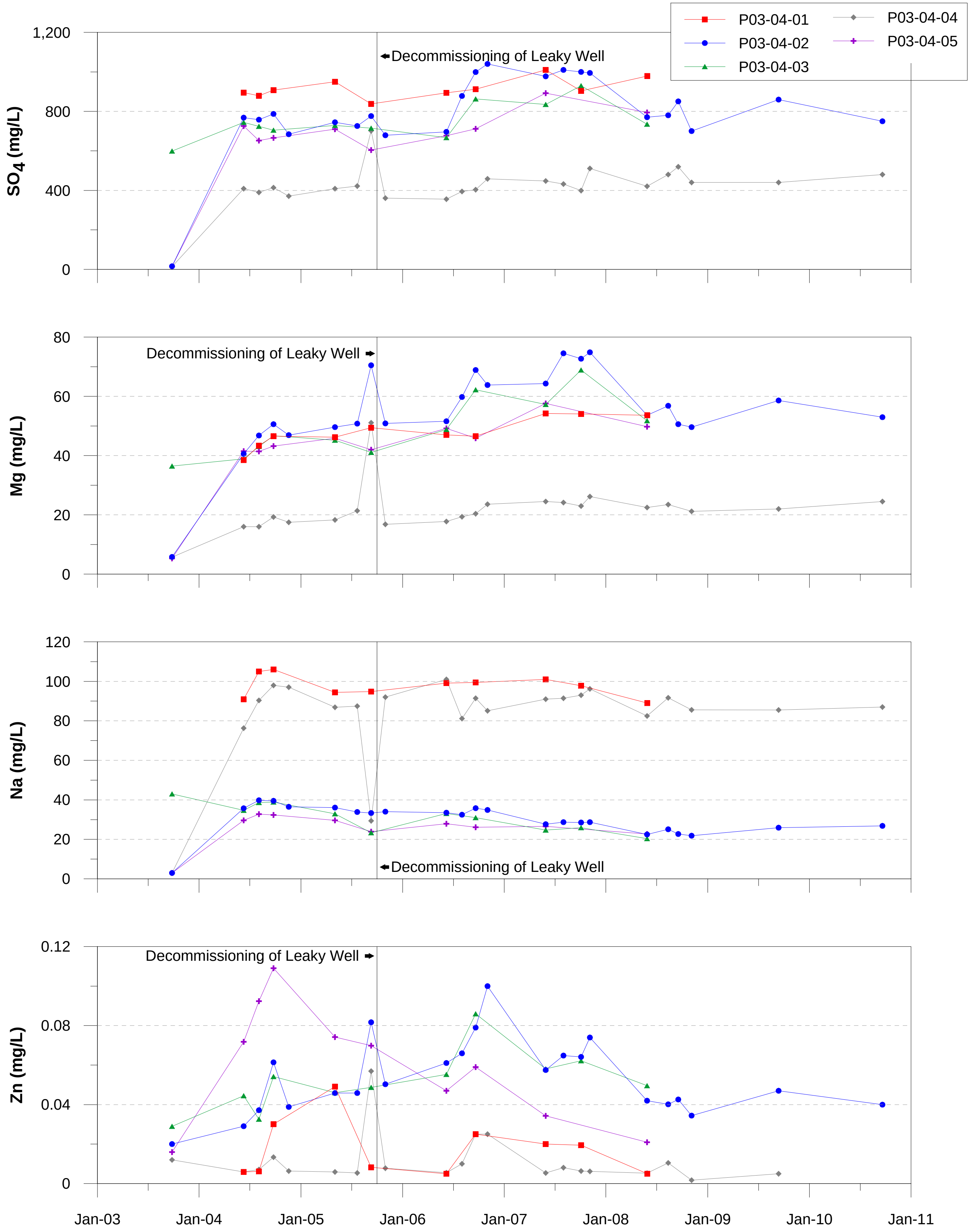


Figure 3-10c. Time trends for SO_4, Mg, Na and Zn in P03-04 (aquifer only)

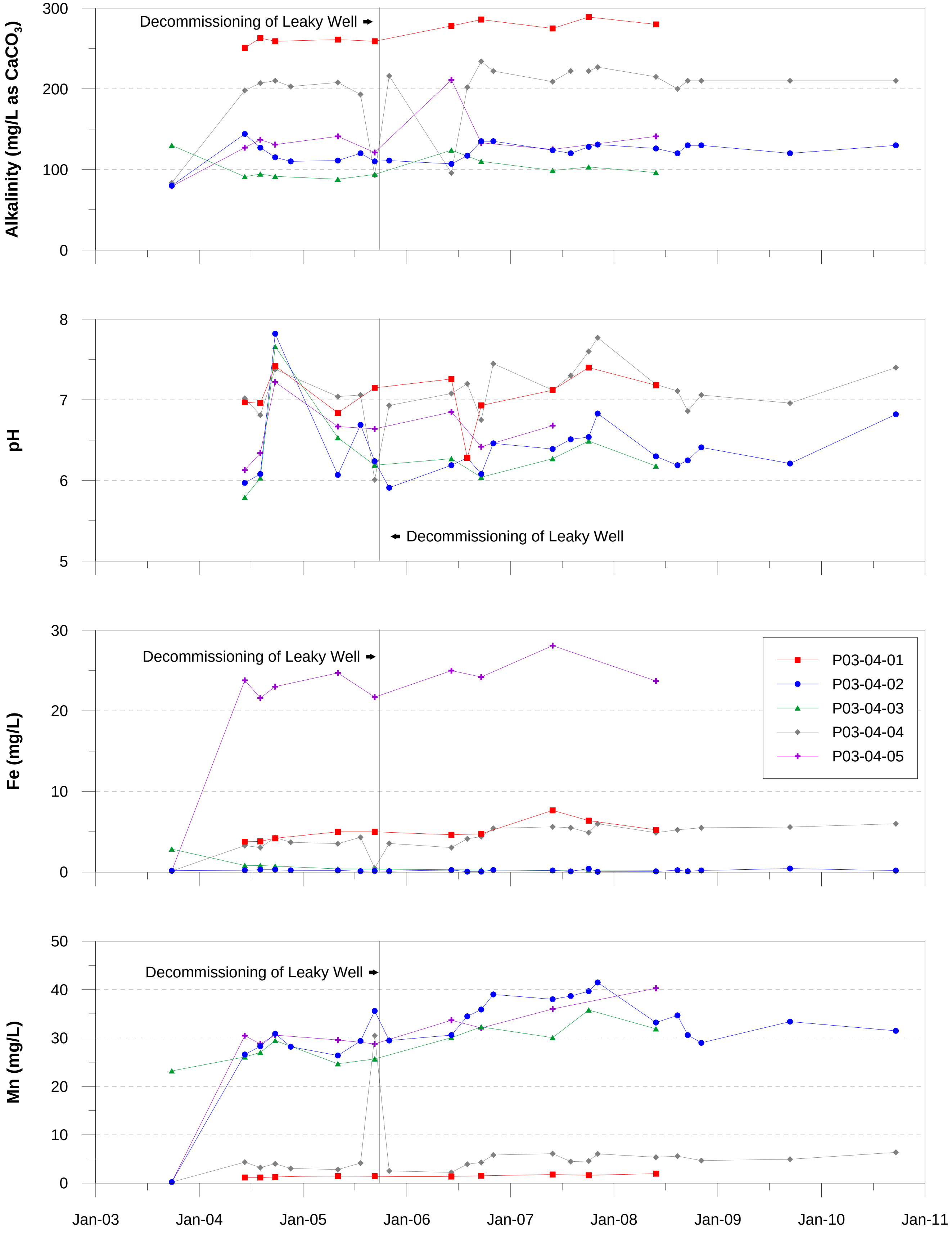


Figure 3-10d. Time trends for alkalinity, pH, Fe and Mn in P03-04 (aquifer only)

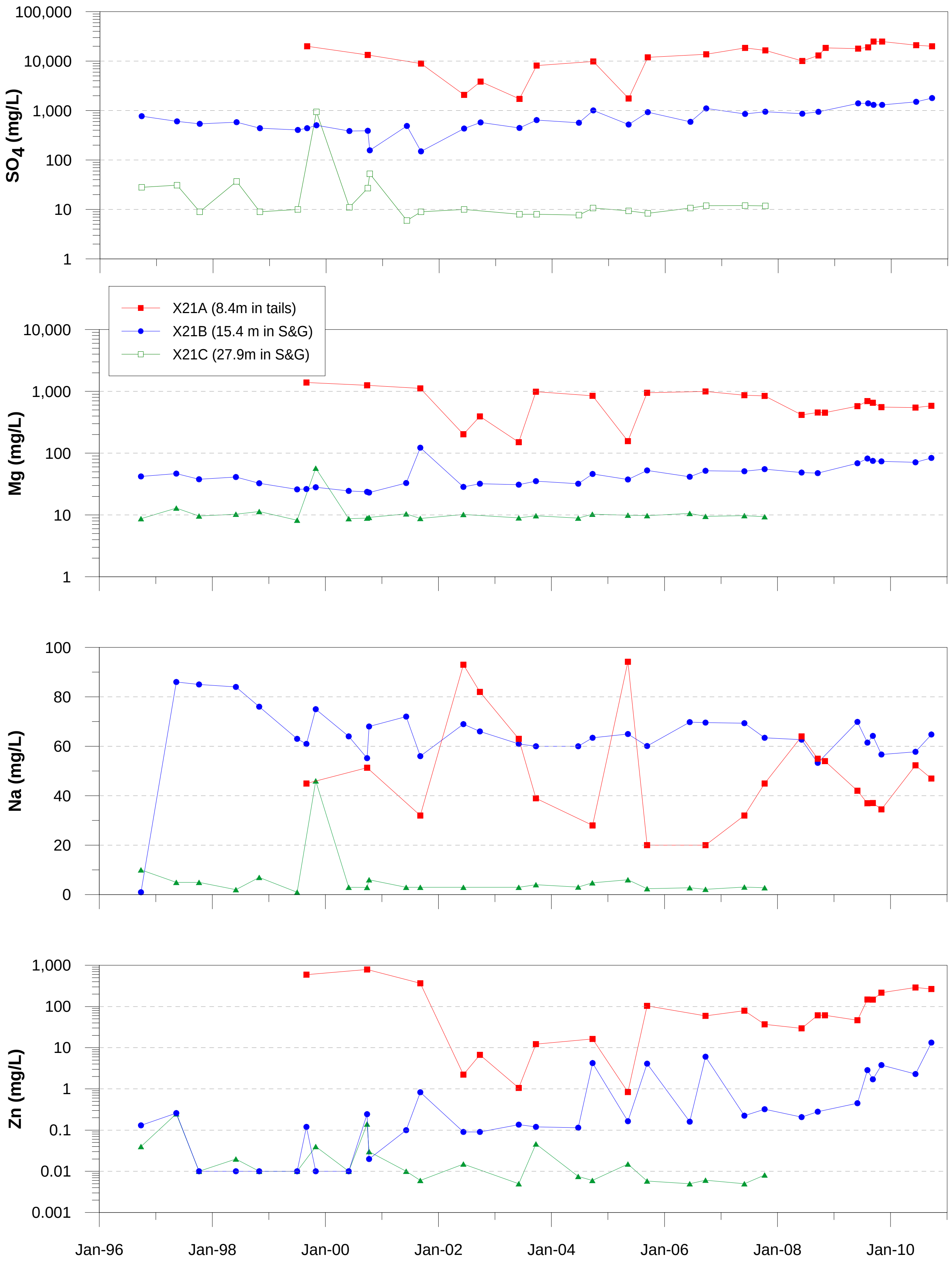


Figure 3-11a. Time trends for SO_4, Mg, Na and Zn in X21 (96), Intermediate Impoundment

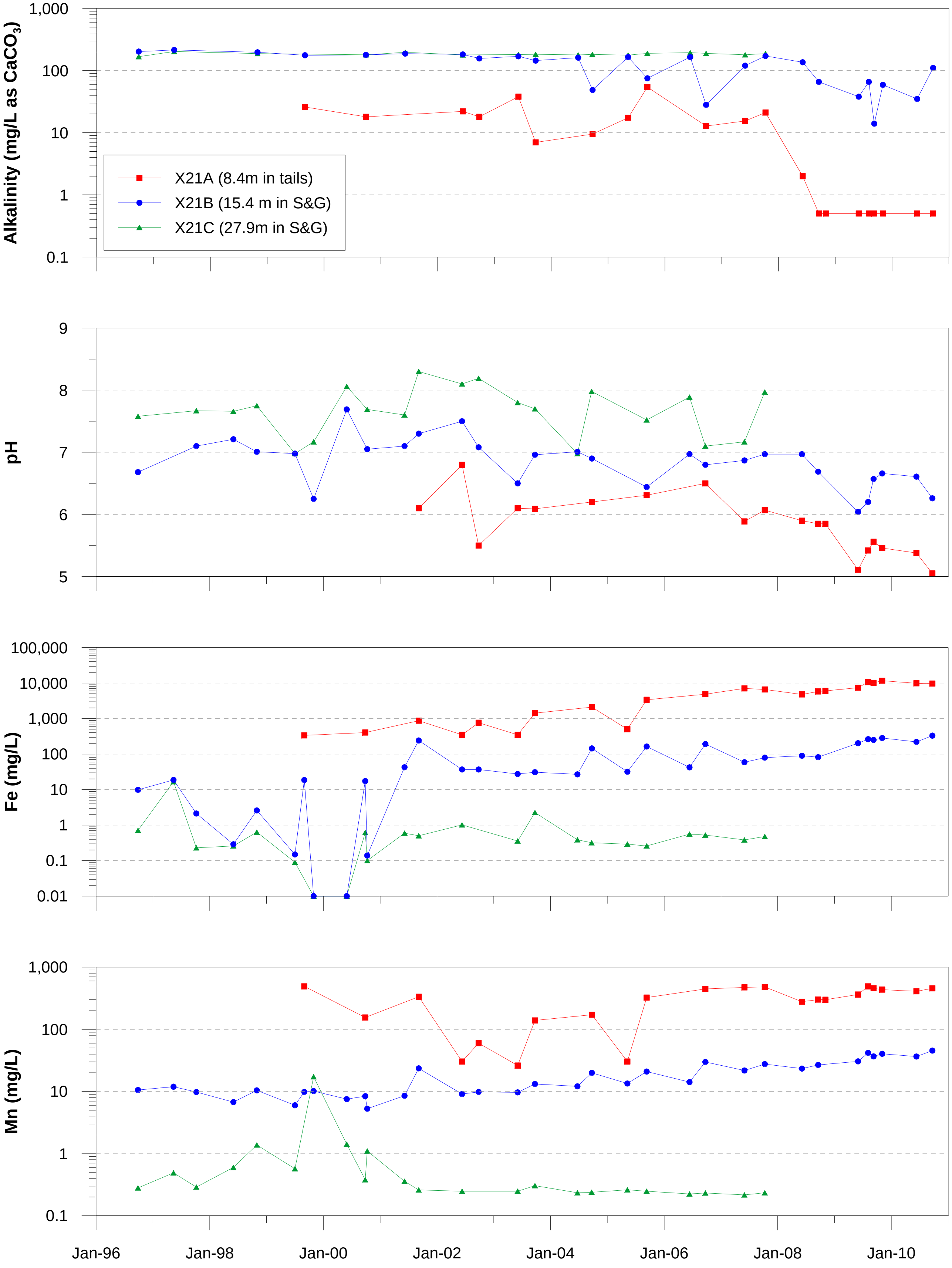


Figure 3-11b. Time trends for alkalinity, pH, Fe and Mn in X21(96), Intermediate Impoundment

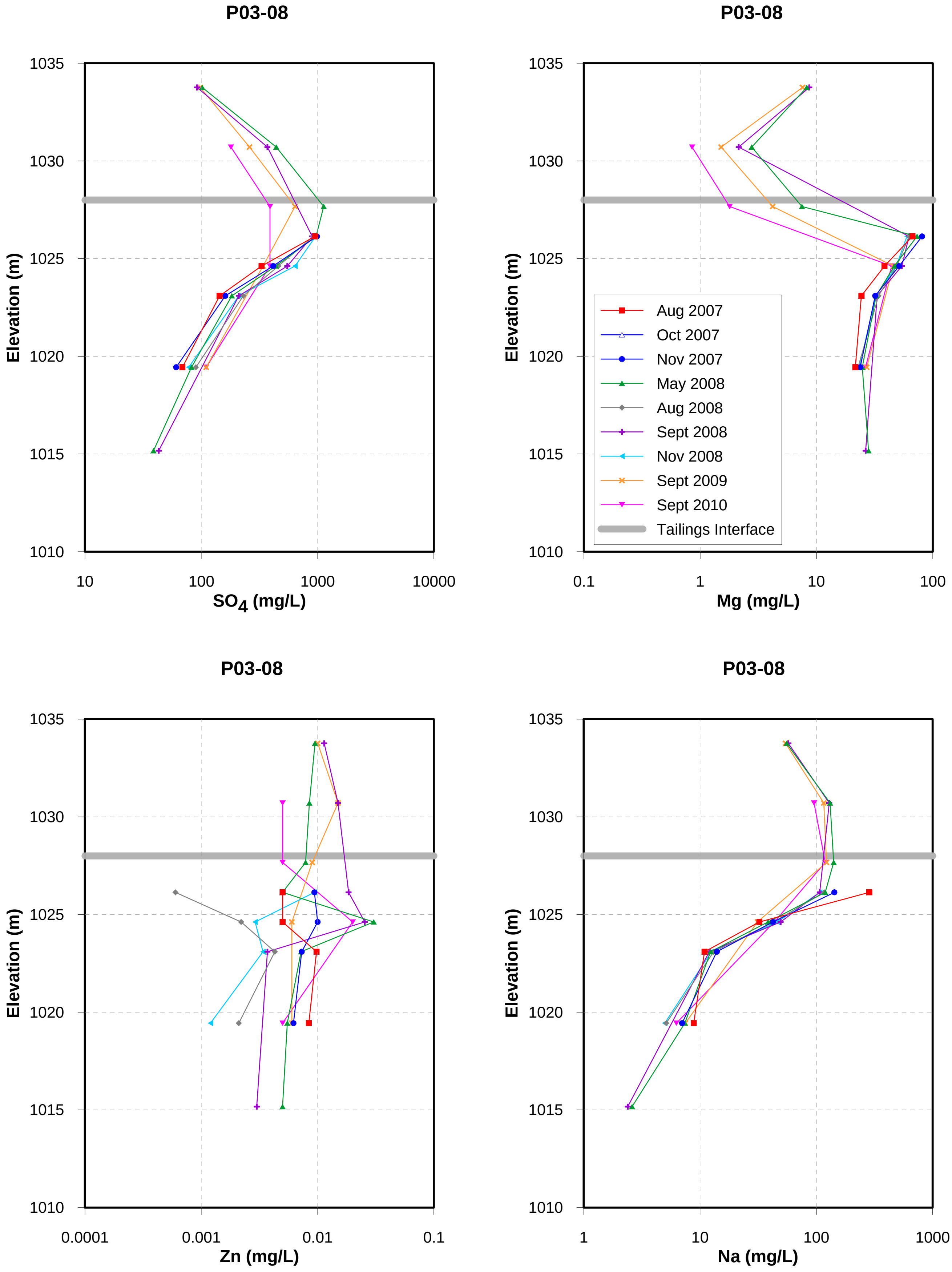


Figure 3-12a. Depth profiles for SO_4, Mg, Zn and Na in P03-08 (Intermediate Impoundment)

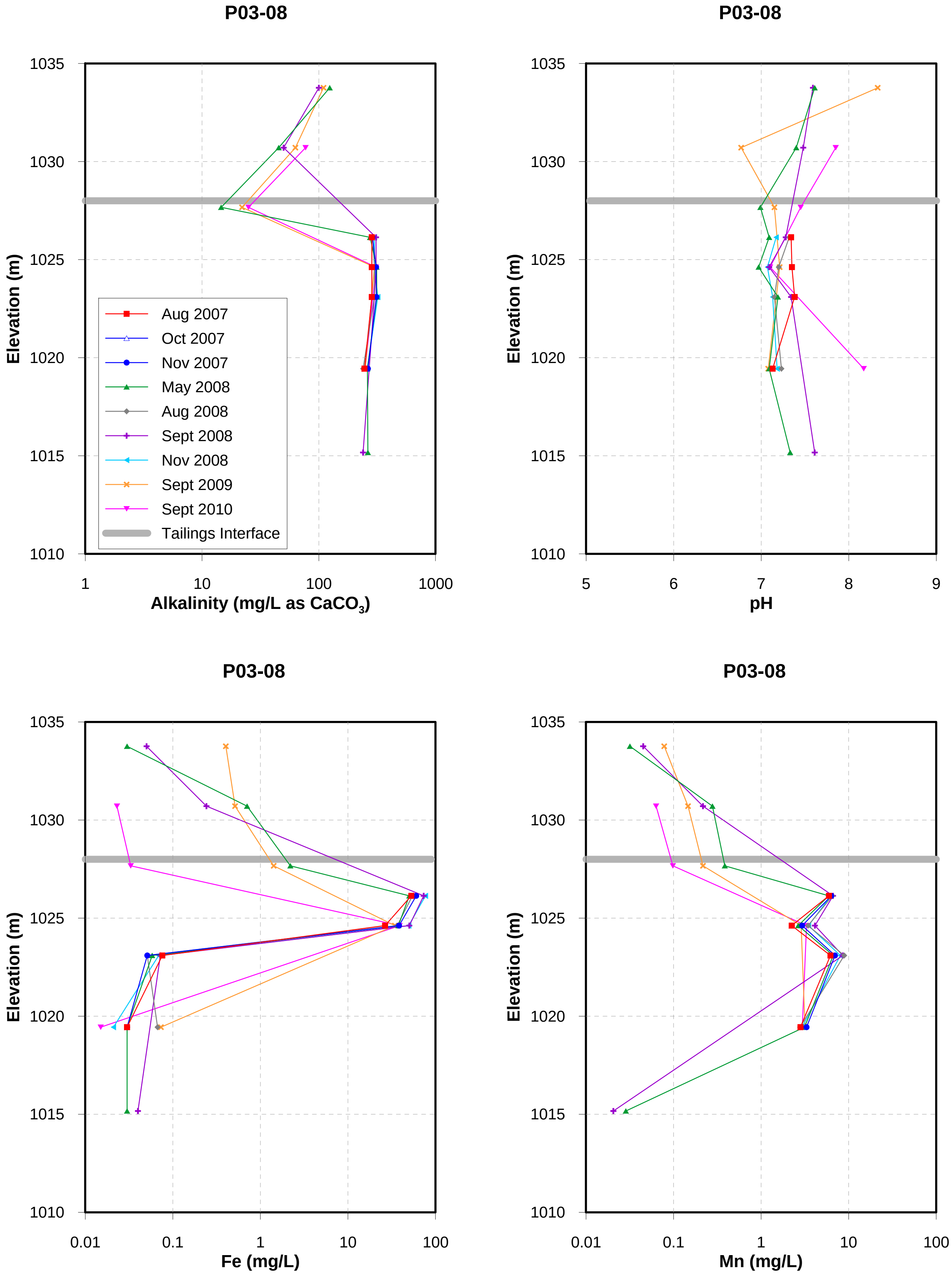


Figure 3-12b. Depth profiles for alkalinity, pH, Fe and Mn in P03-08 (Intermediate Impoundment)

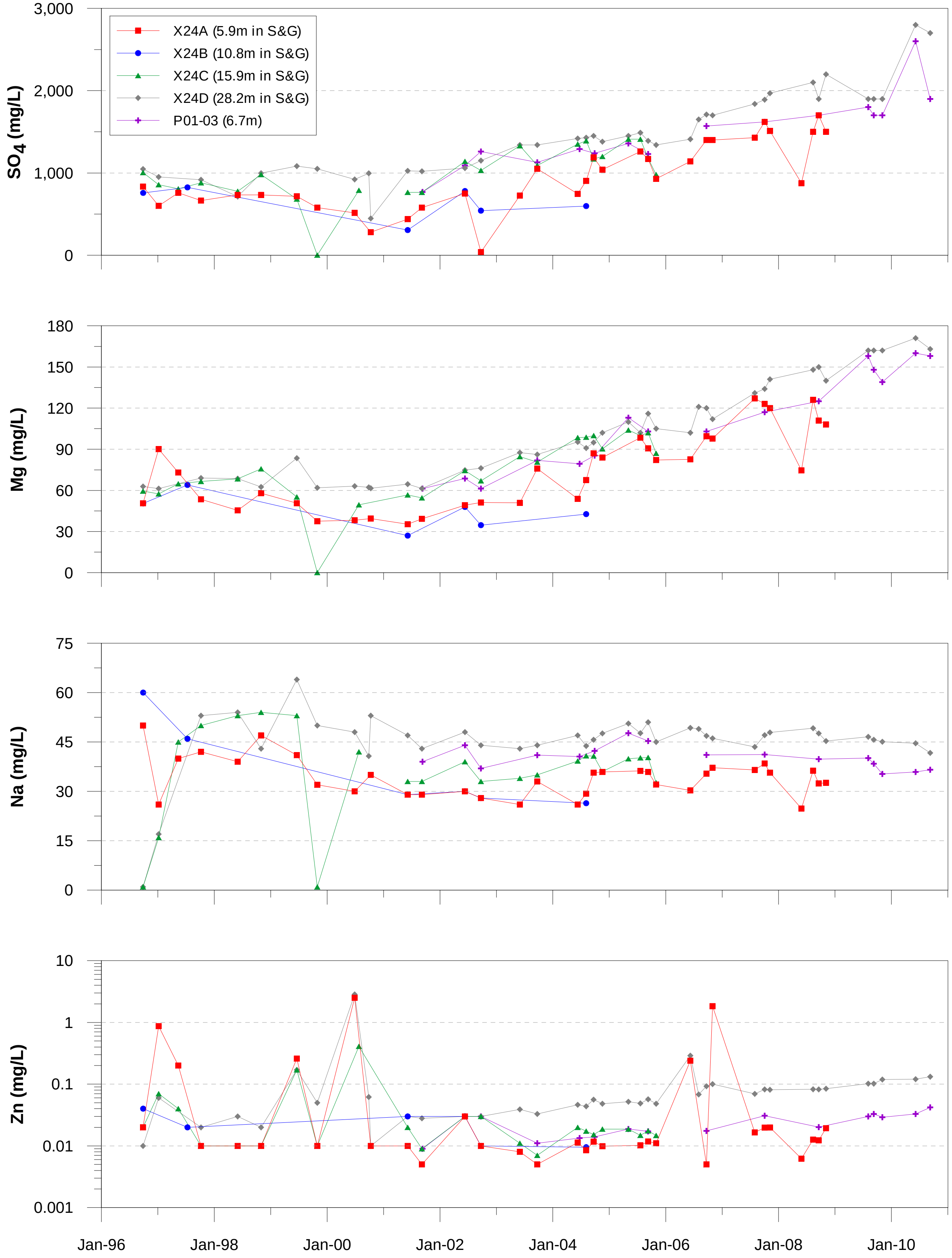


Figure 3-13a. Time trends for SO_4, Mg, Na and Zn in X24(96) and P01-03 (northern side of the Intermediate Dam)

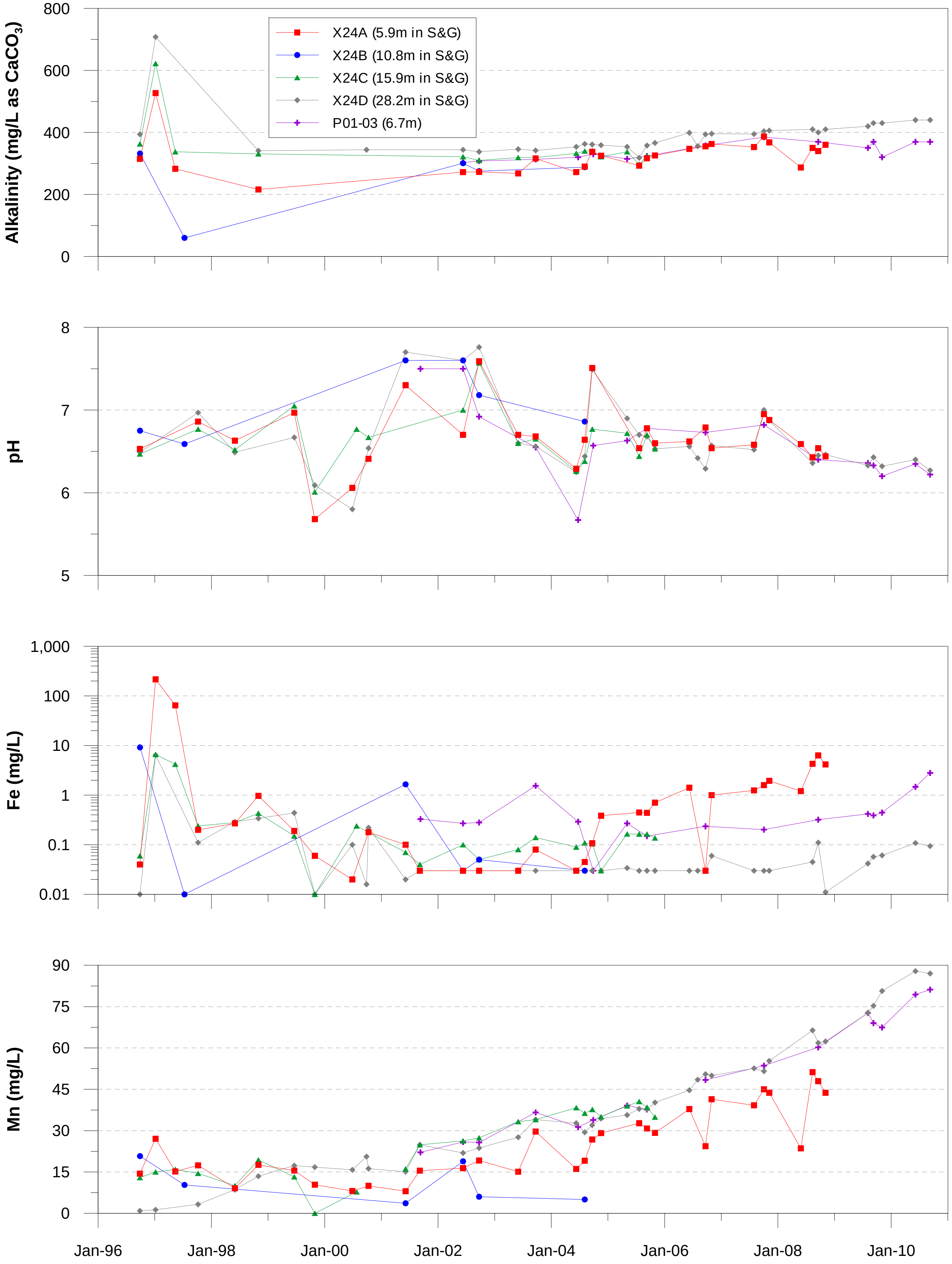


Figure 3-13b. Time trends for alkalinity, pH, Fe and Mn in X24(96) and P01-03 (northern side of the Intermediate Dam)

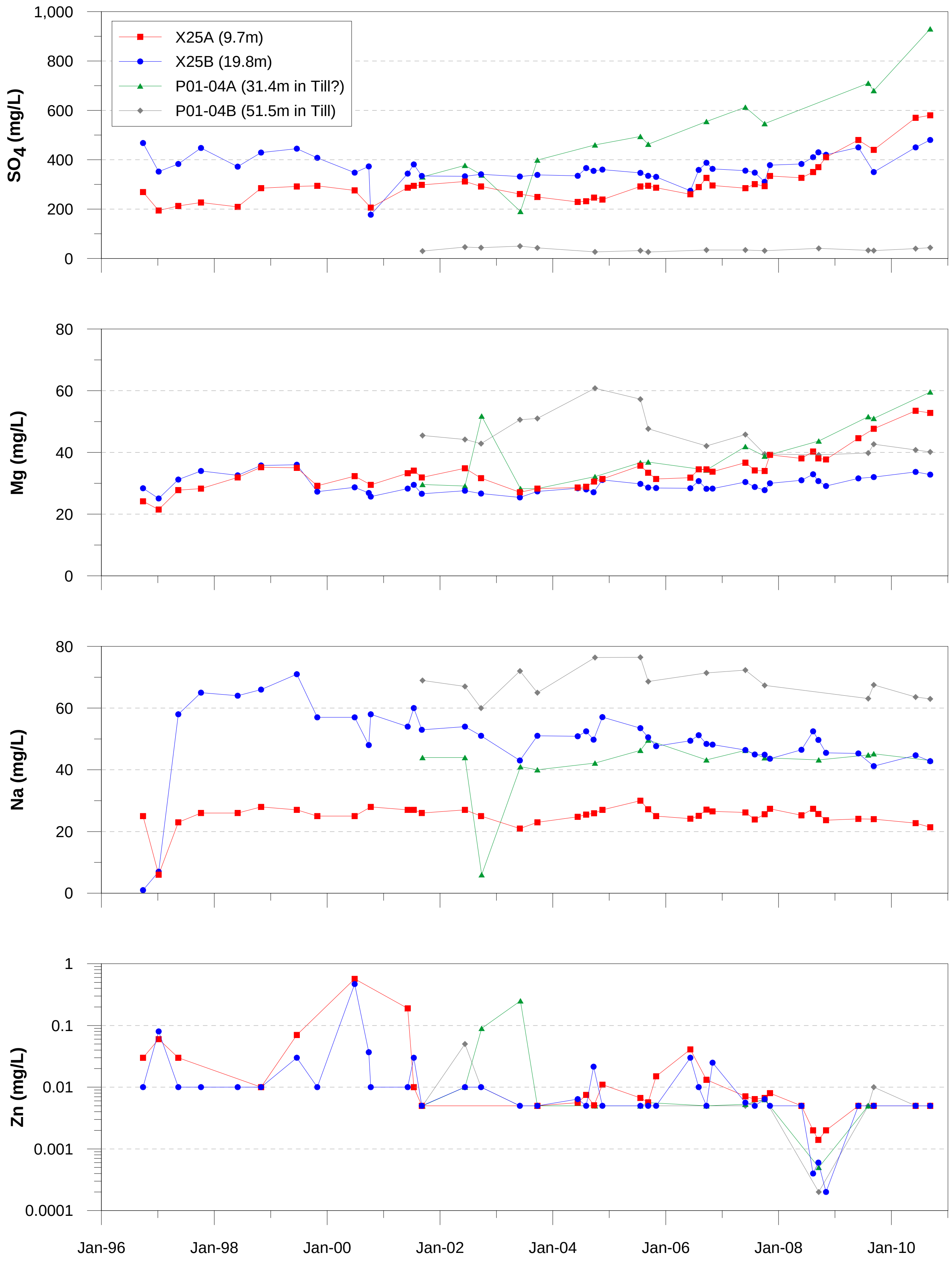


Figure 3-14a. Time trends for SO_4, Mg, Na and Zn in X25(96) and P01-04 (southern side of the Intermediate Dam)

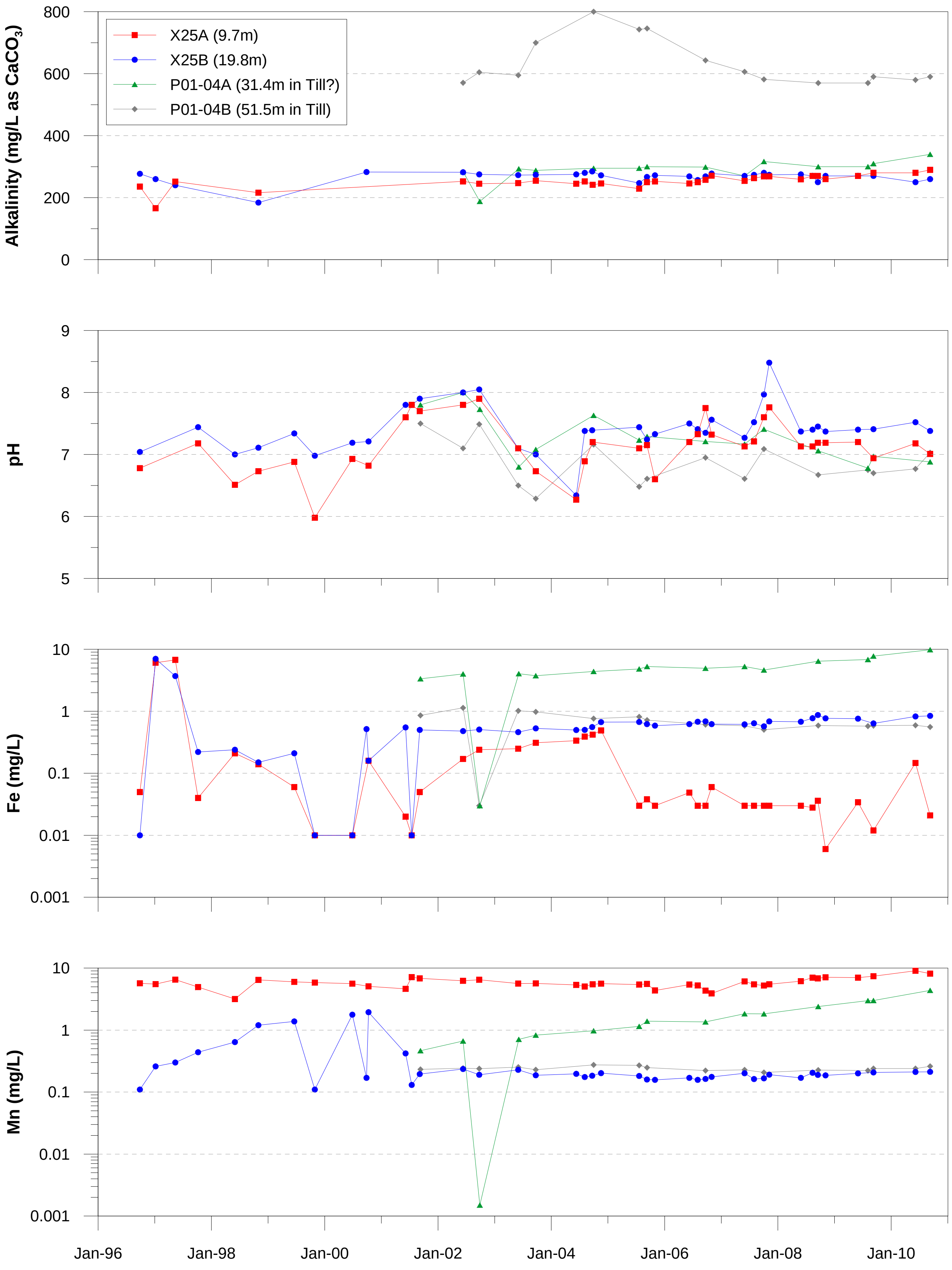


Figure 3-14b. Time trends for alkalinity, pH, Fe and Mn in X25(96) and P01-04 (southern side of the Intermediate Dam)

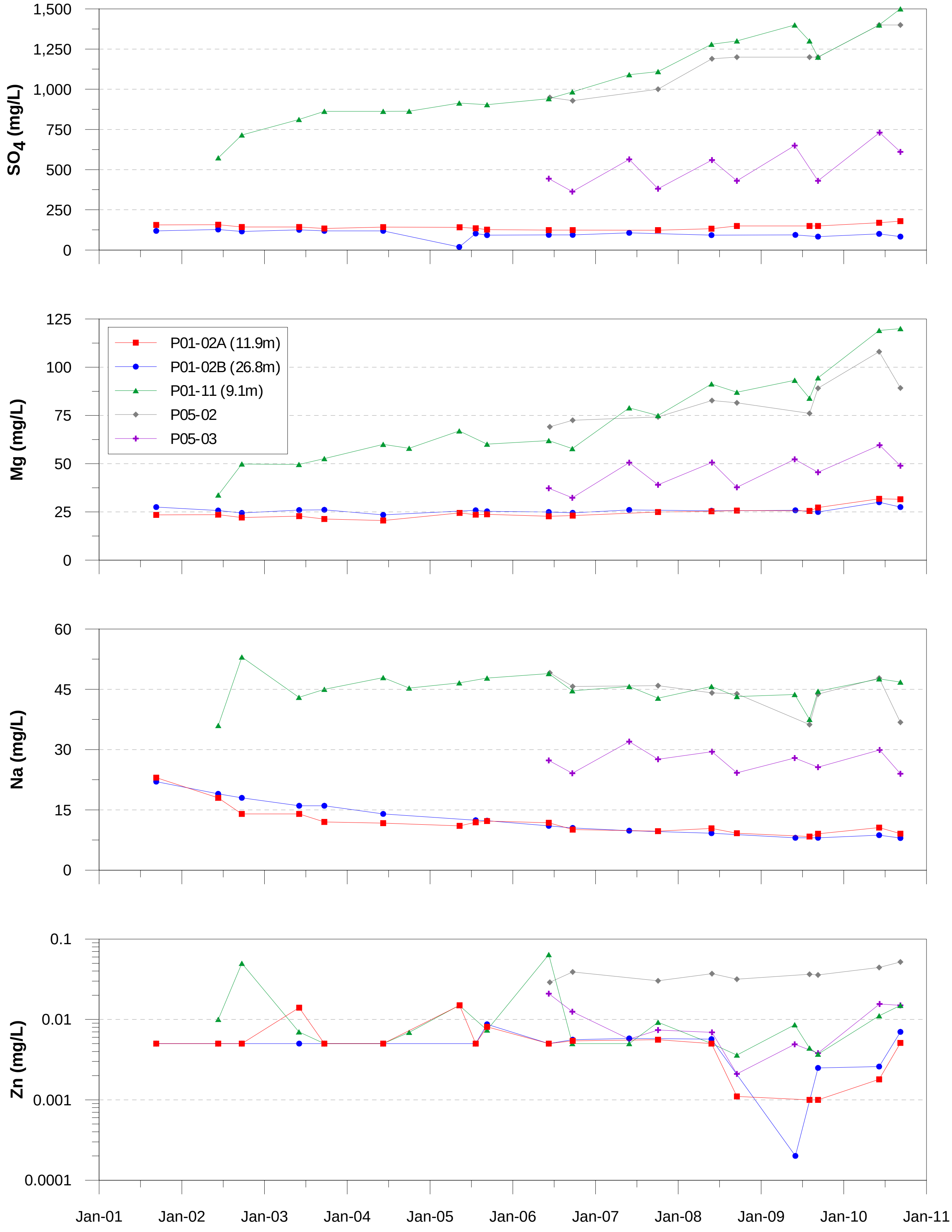


Figure 3-15a. Time trends for SO_4, Mg, Na and Zn in wells along toe of Cross Valley Dam

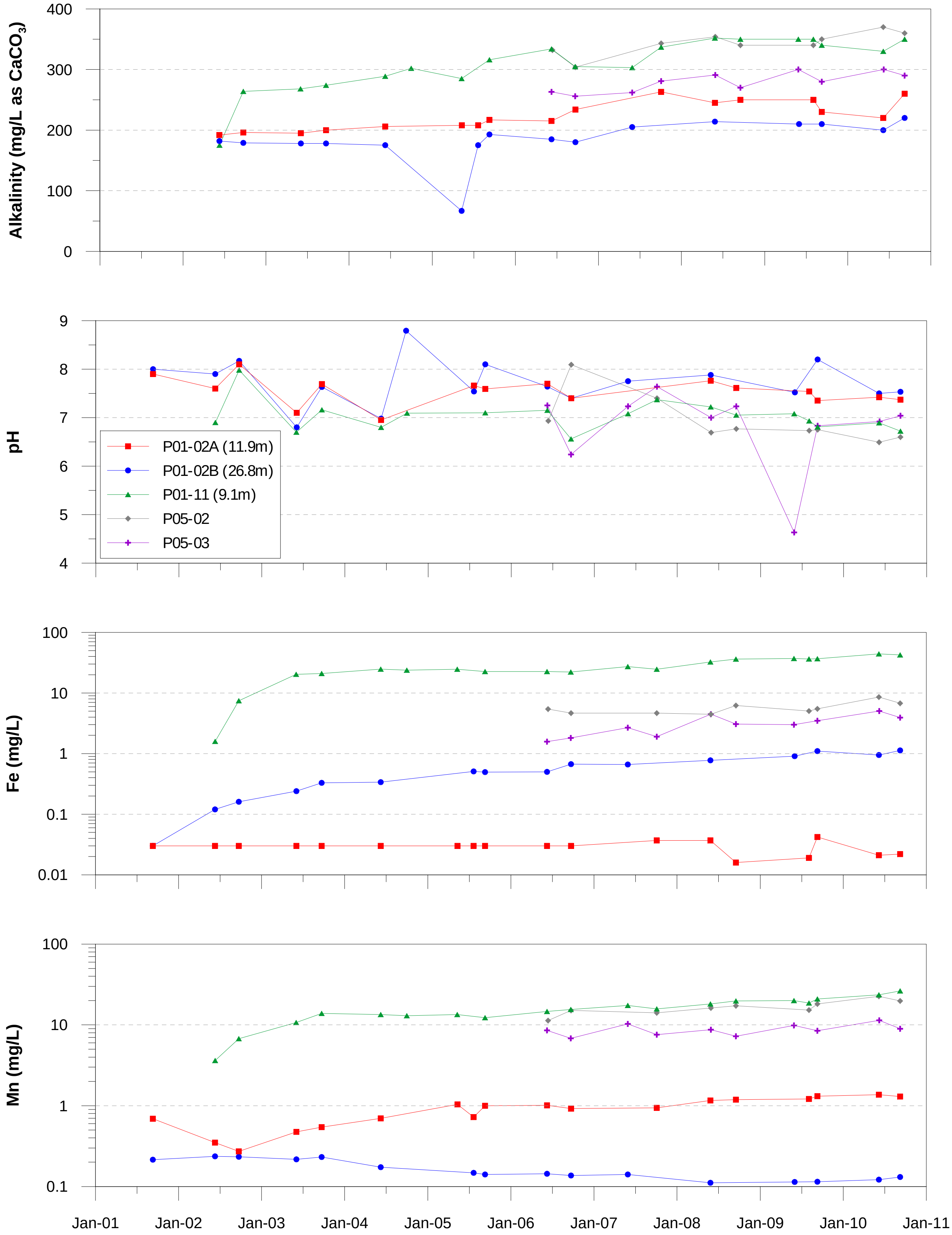


Figure 3-15b. Time trends for alkalinity, pH, Fe and Mn in wells along toe of Cross Valley Dam

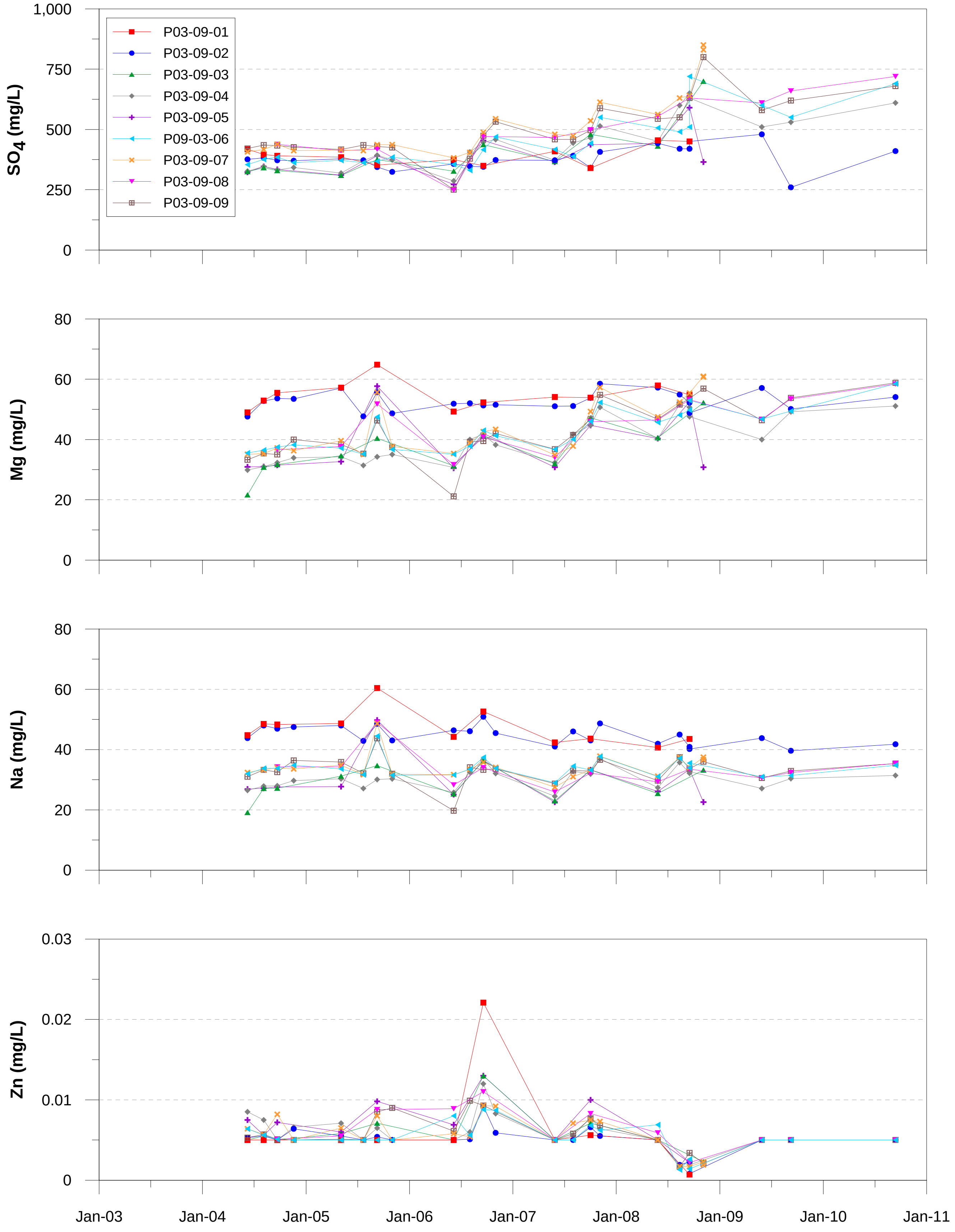


Figure 3-16a. Time trends for SO_4, Mg, Na and Zn in P03-09 (at Cross Valley Dam)

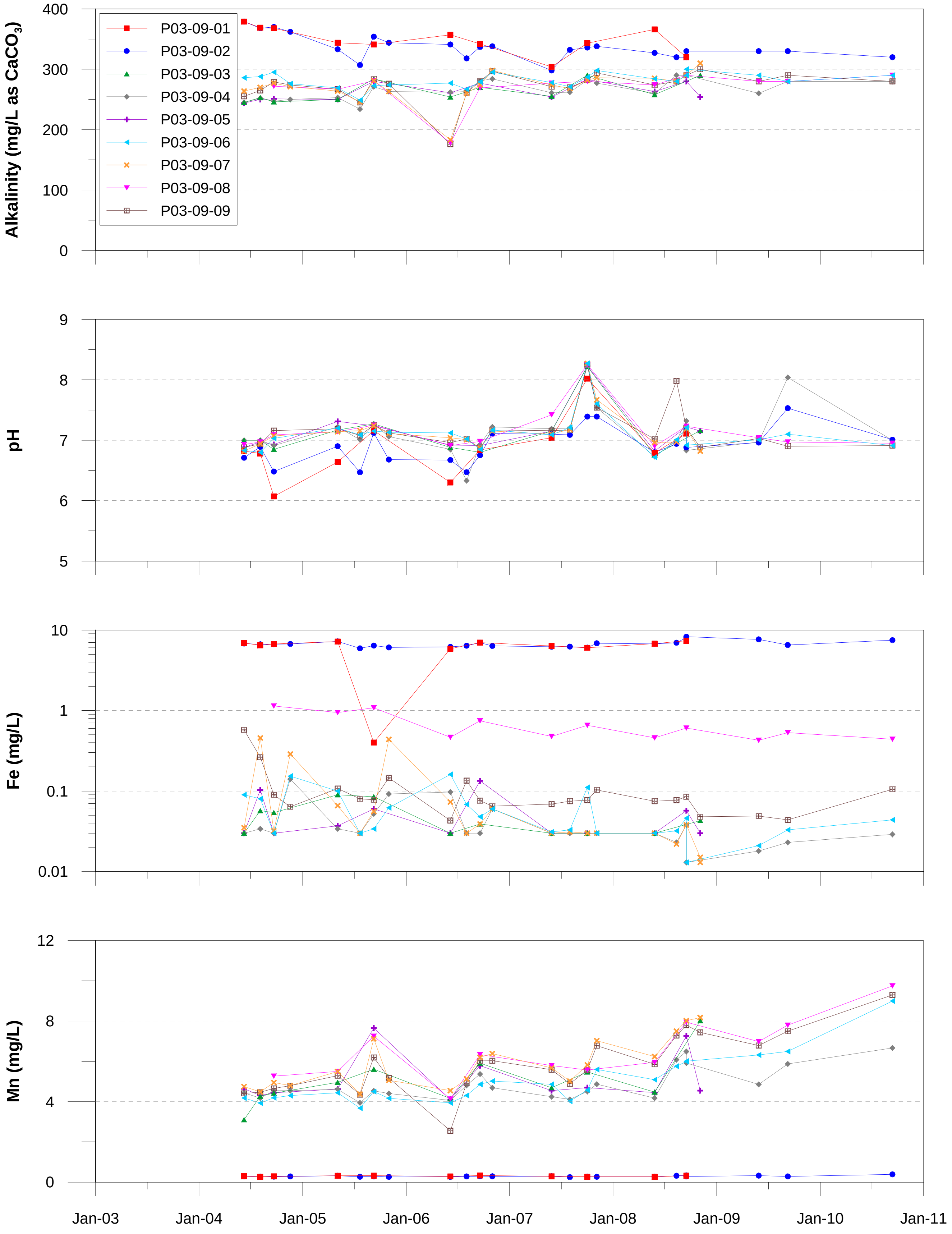


Figure 3-16b. Time trends for alkalinity, pH, Fe and Mn in P03-09 (at Cross Valley Dam)

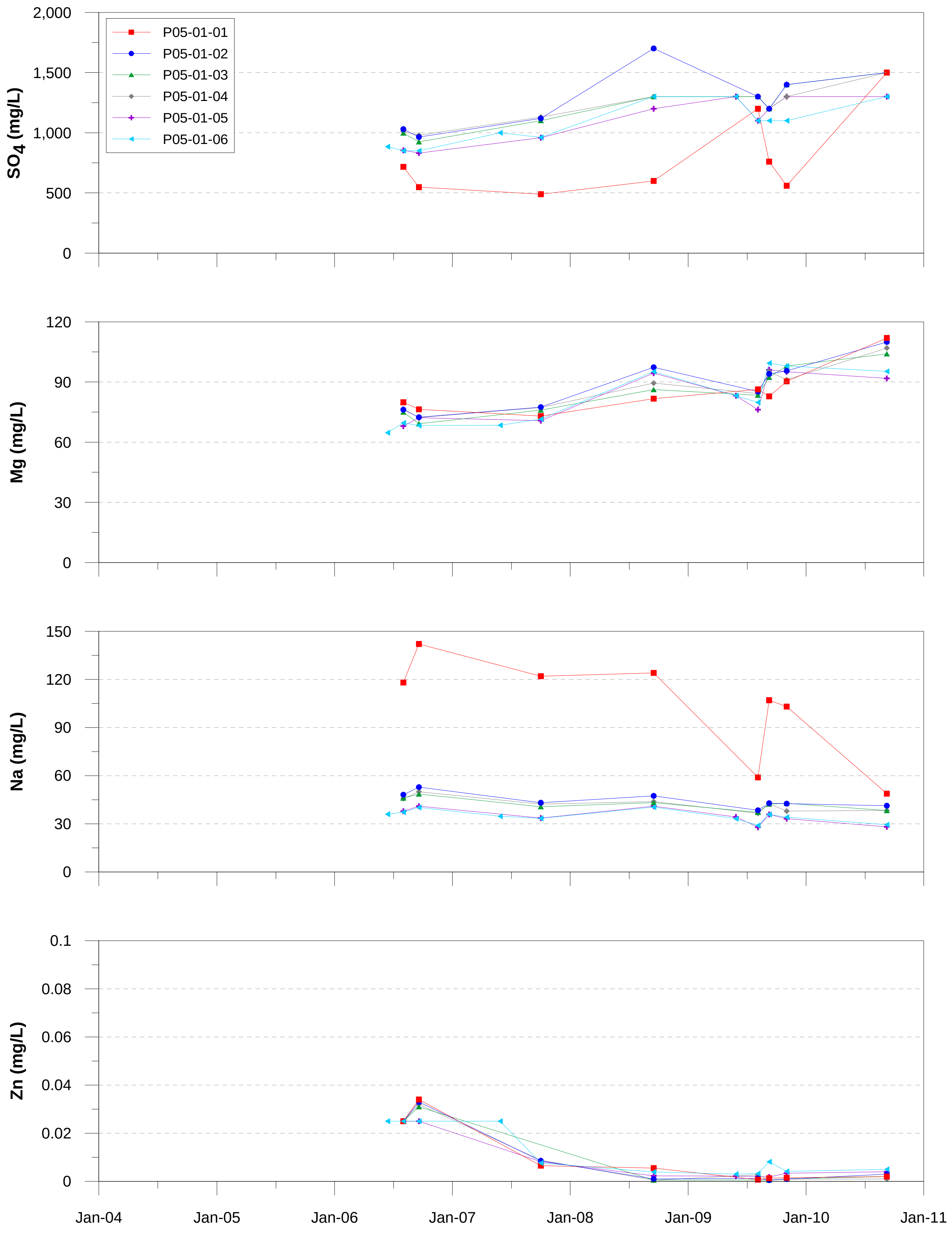


Figure 3-17a. Time trends for SO_4, Mg, Na and Zn in P05-01 (at Cross Valley Dam)

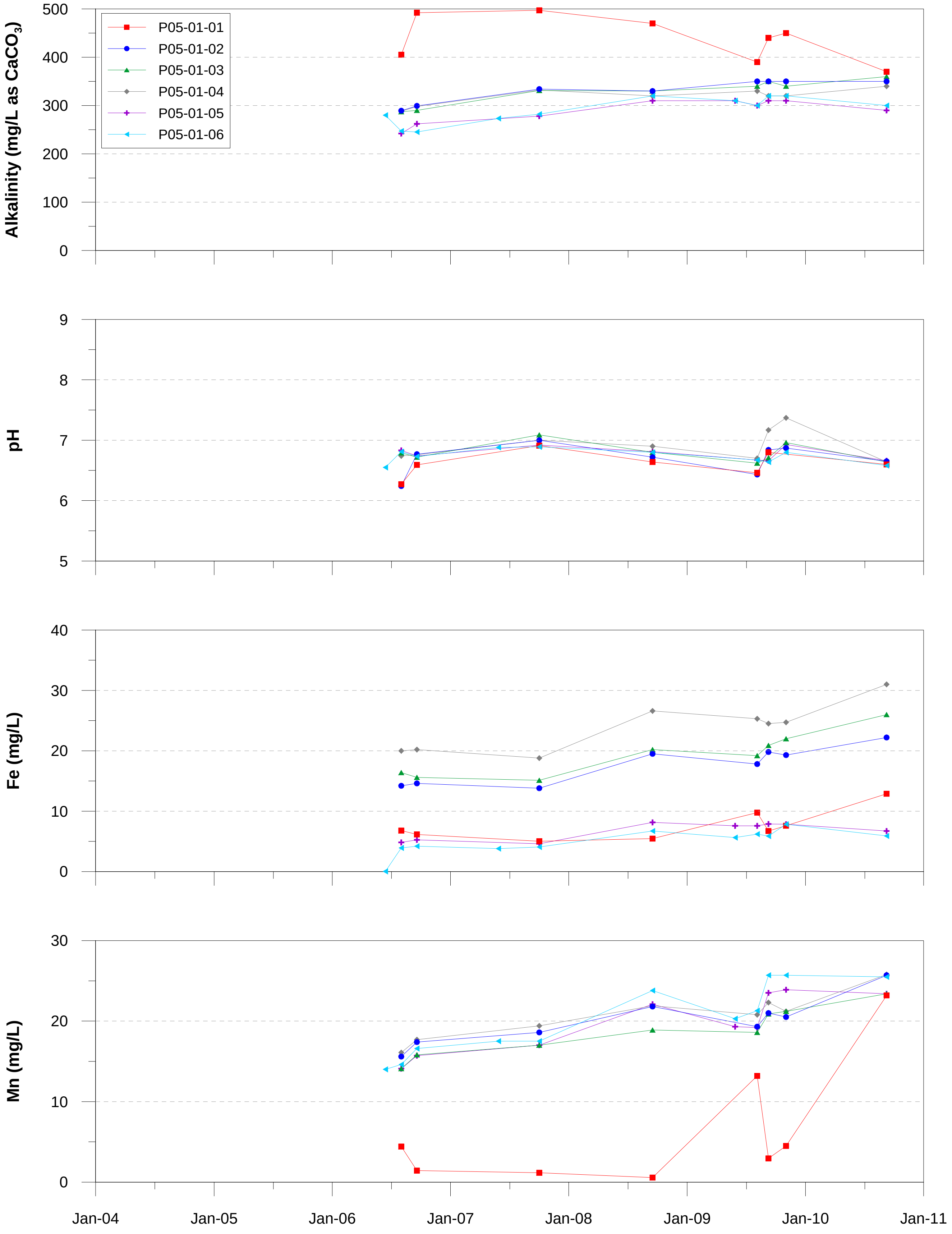


Figure 3-17b. Time trends for alkalinity, pH, Fe and Mn in P05-01 (at Cross Valley Dam)

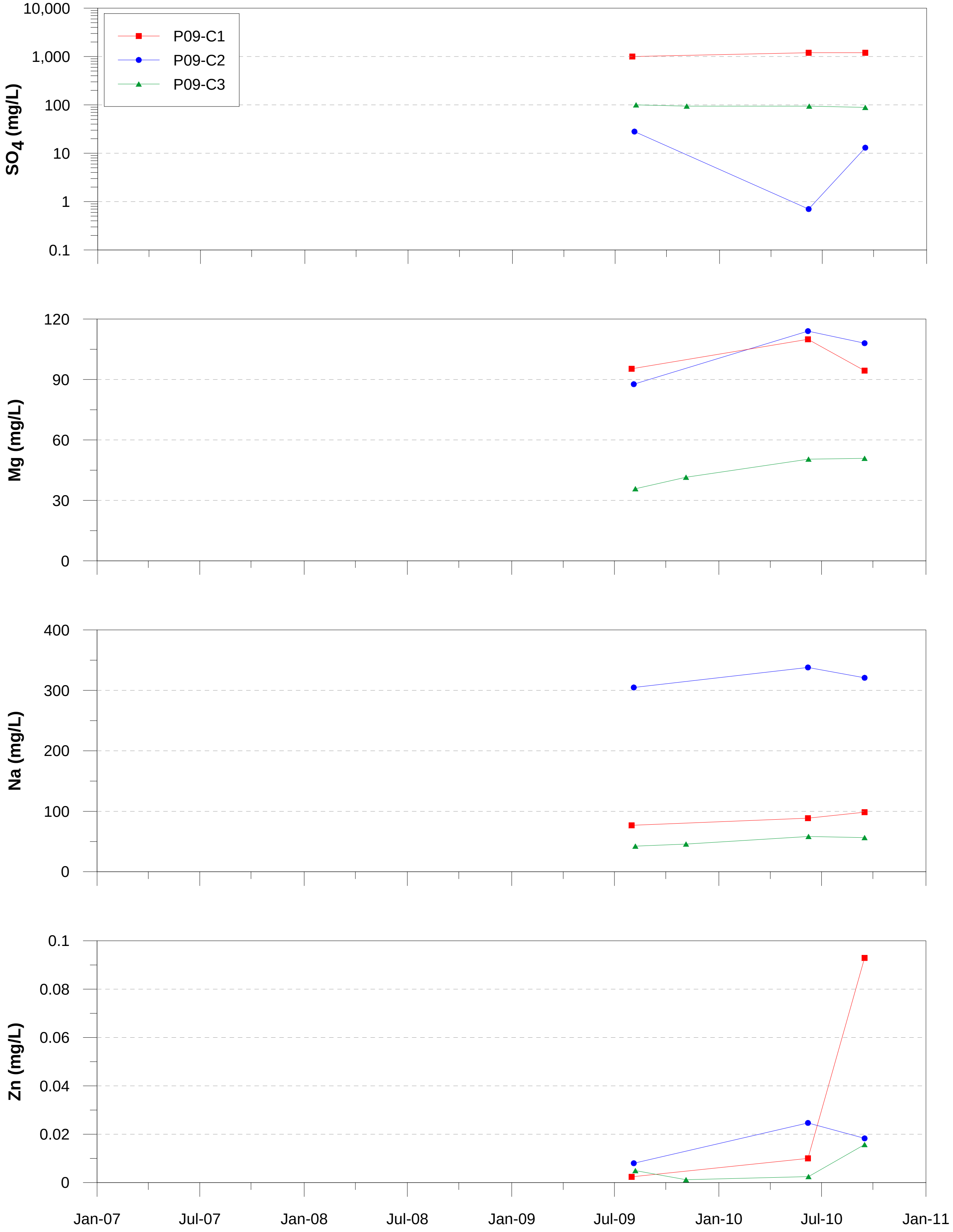


Figure 3-18a. Time trends for SO_4, Mg, Na and Zn in bedrock wells at toe of Cross Valley Dam

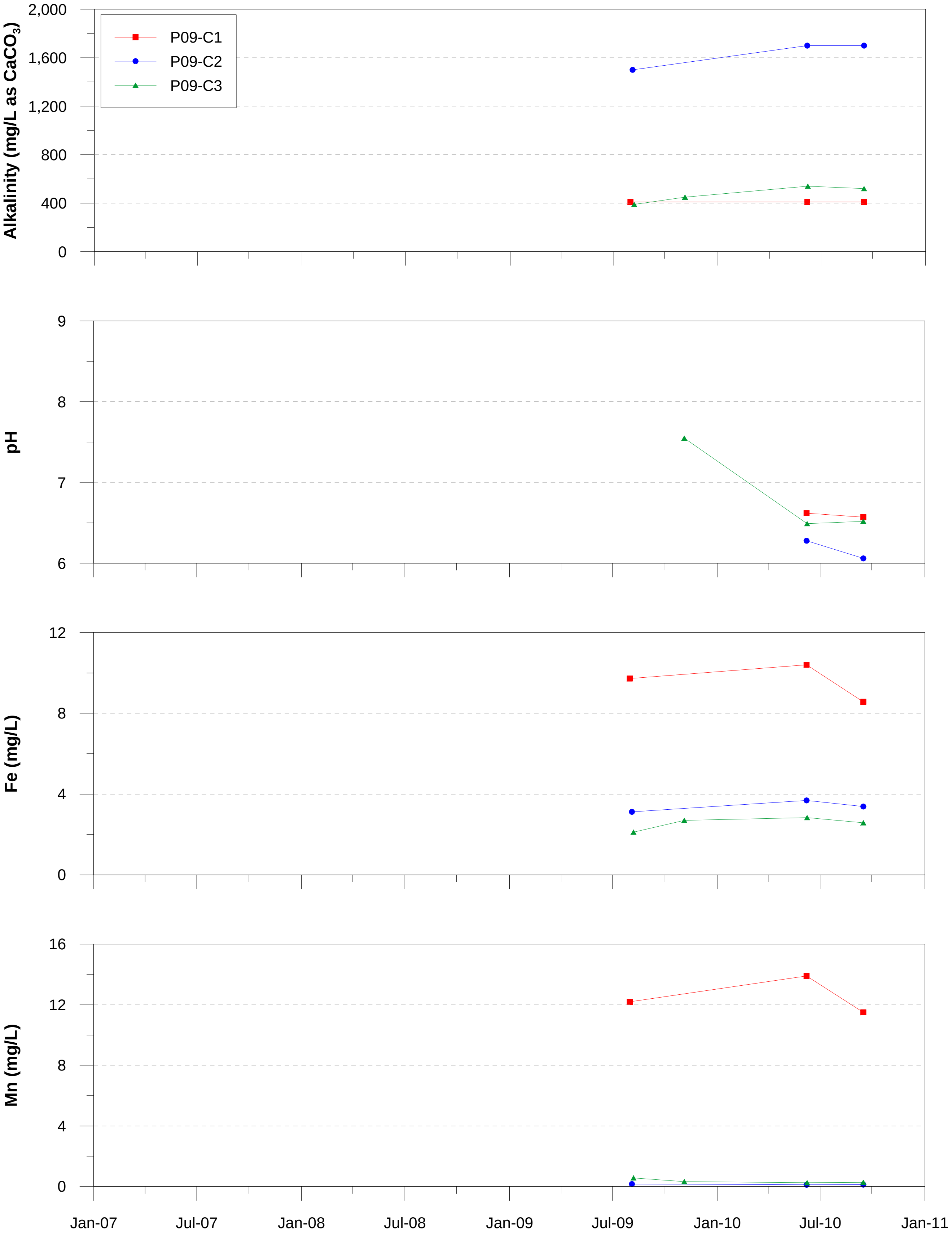


Figure 3-18b. Time trends for alkalinity, pH, Fe and Mn in bedrock wells at toe of Cross Valley Dam

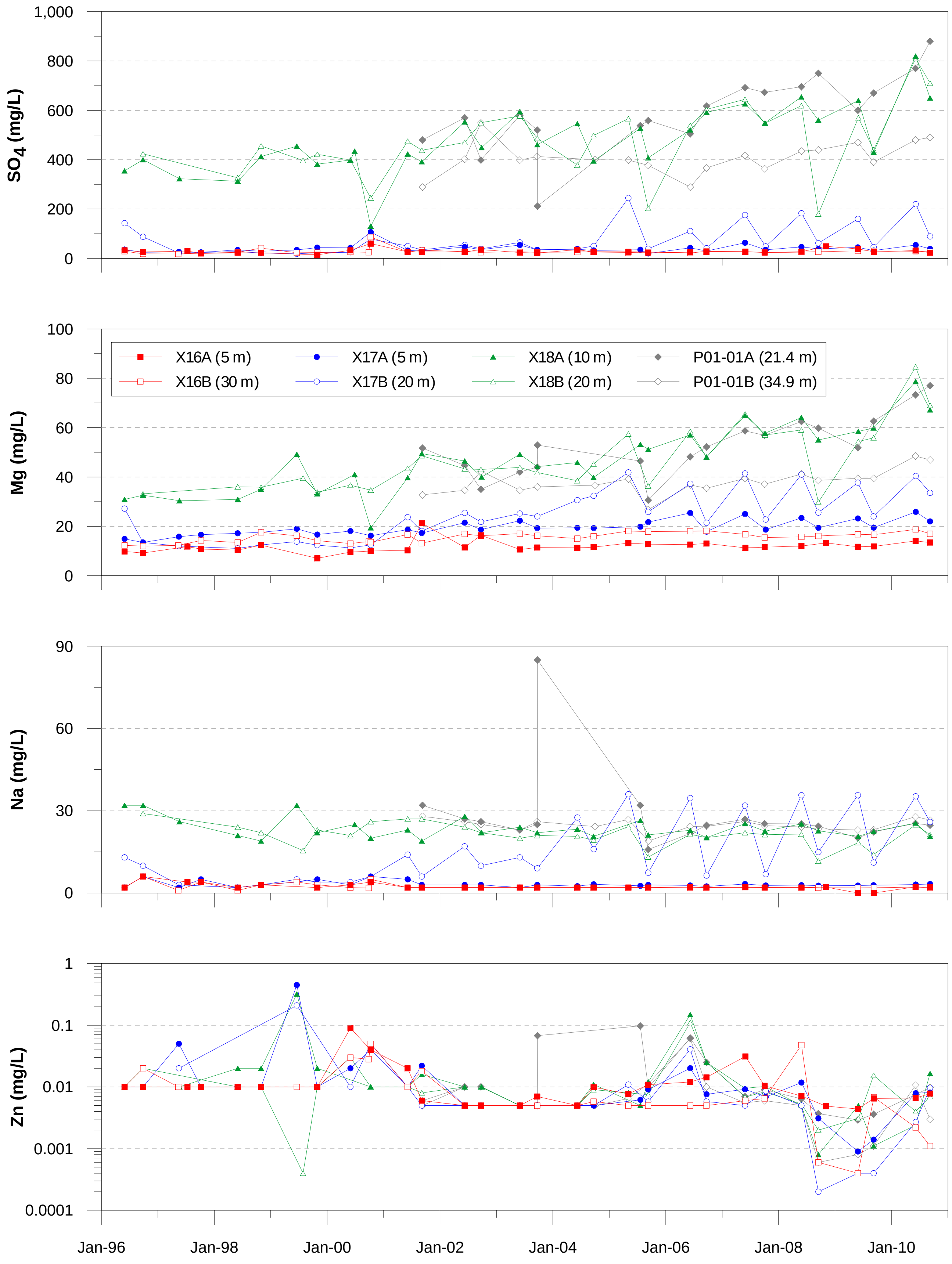


Figure 3-19a. Time trends for SO$_4$, Mg, Na and Zn in wells downgradient of Cross Valley Dam

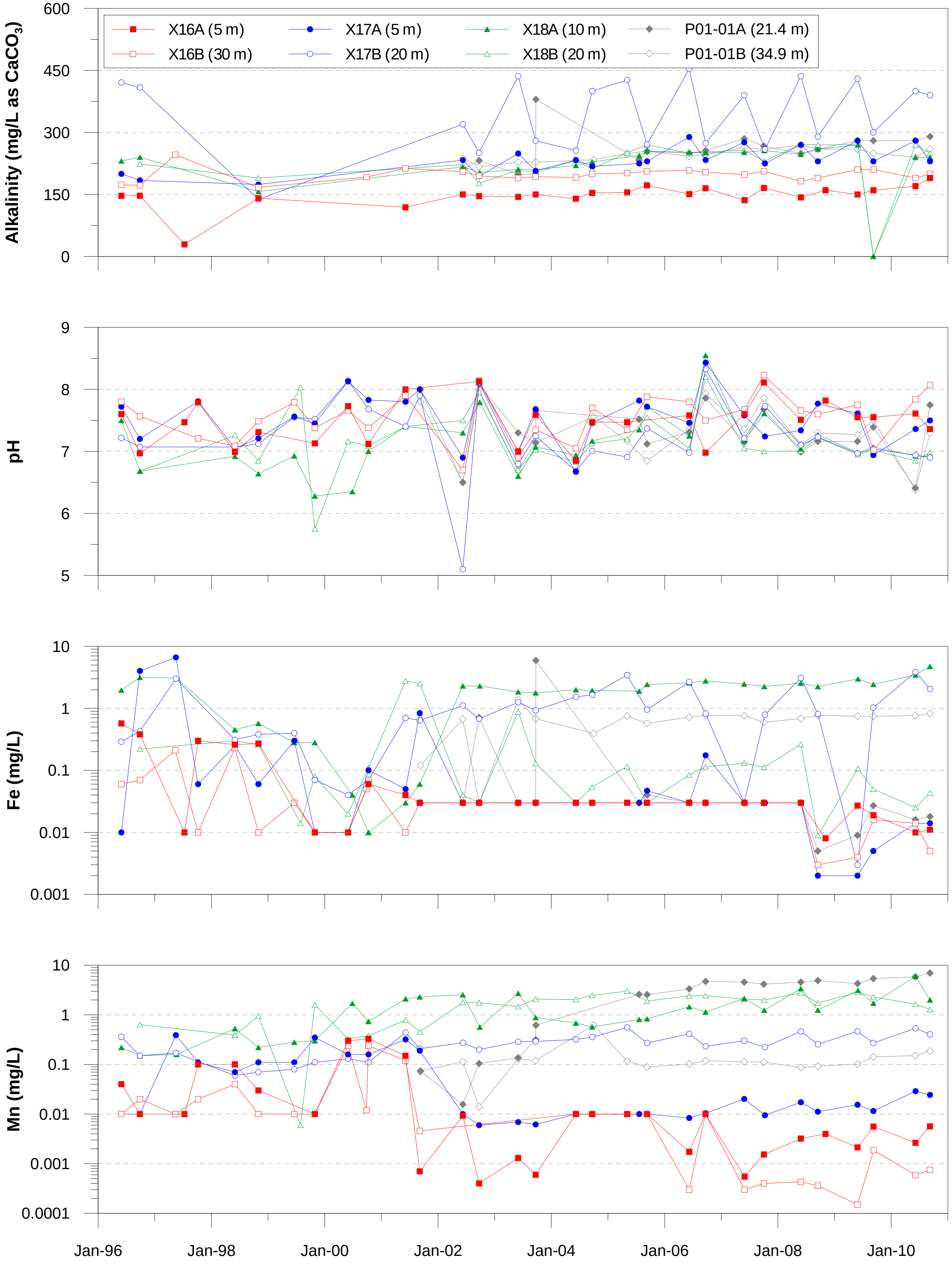
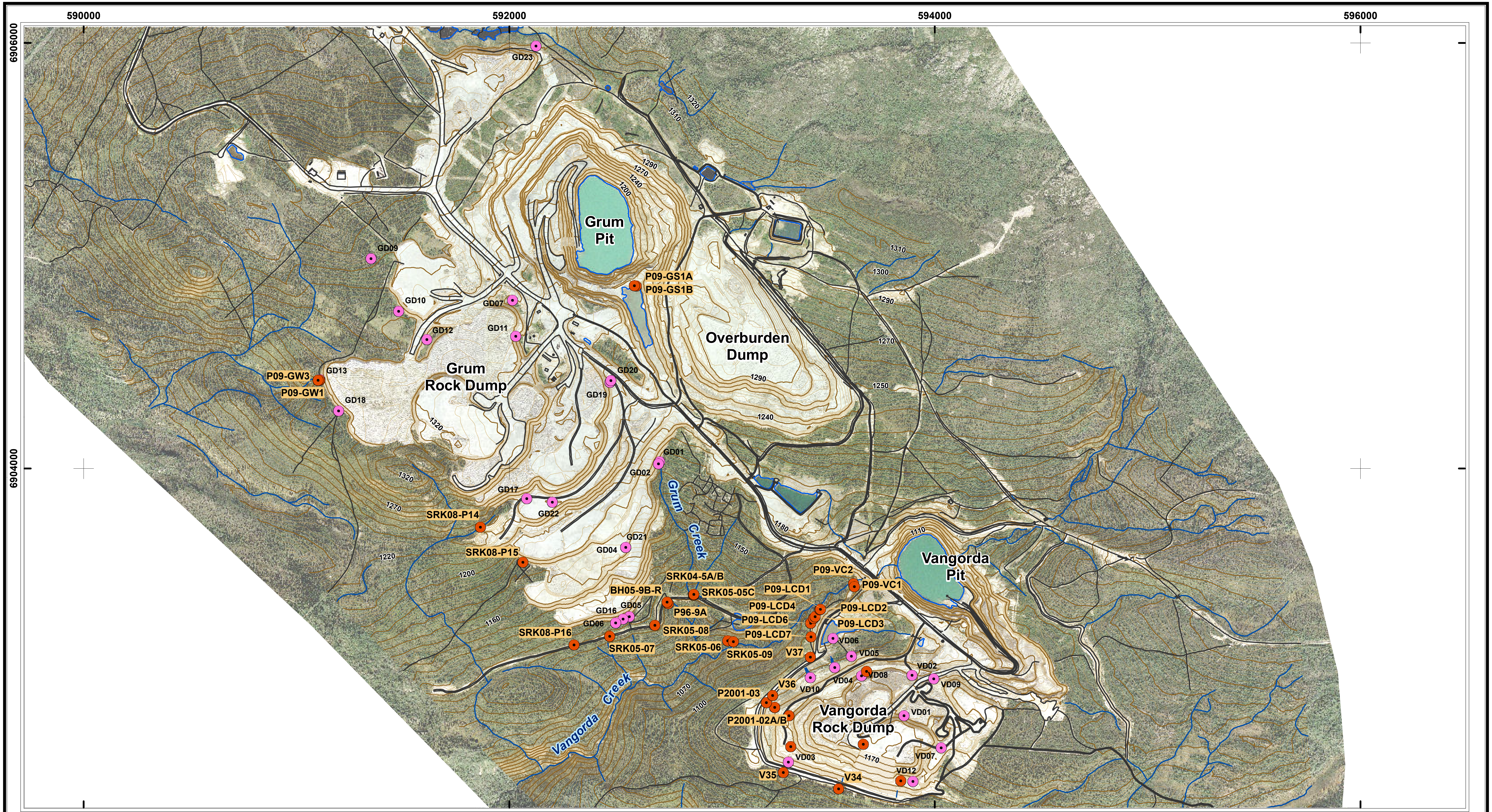


Figure 3-19b. Time trends for alkalinity, pH, Fe and Mn in wells downgradient of Cross Valley Dam



Layout of Grum & Vangorda Mine Site

Anvil Range Mining Complex

LEGEND

● Monitoring Well
● Seep Monitoring Station

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

N
W E
S

SCALE

0 300 600 900 1,200 1,500 Meters

Yukon Government

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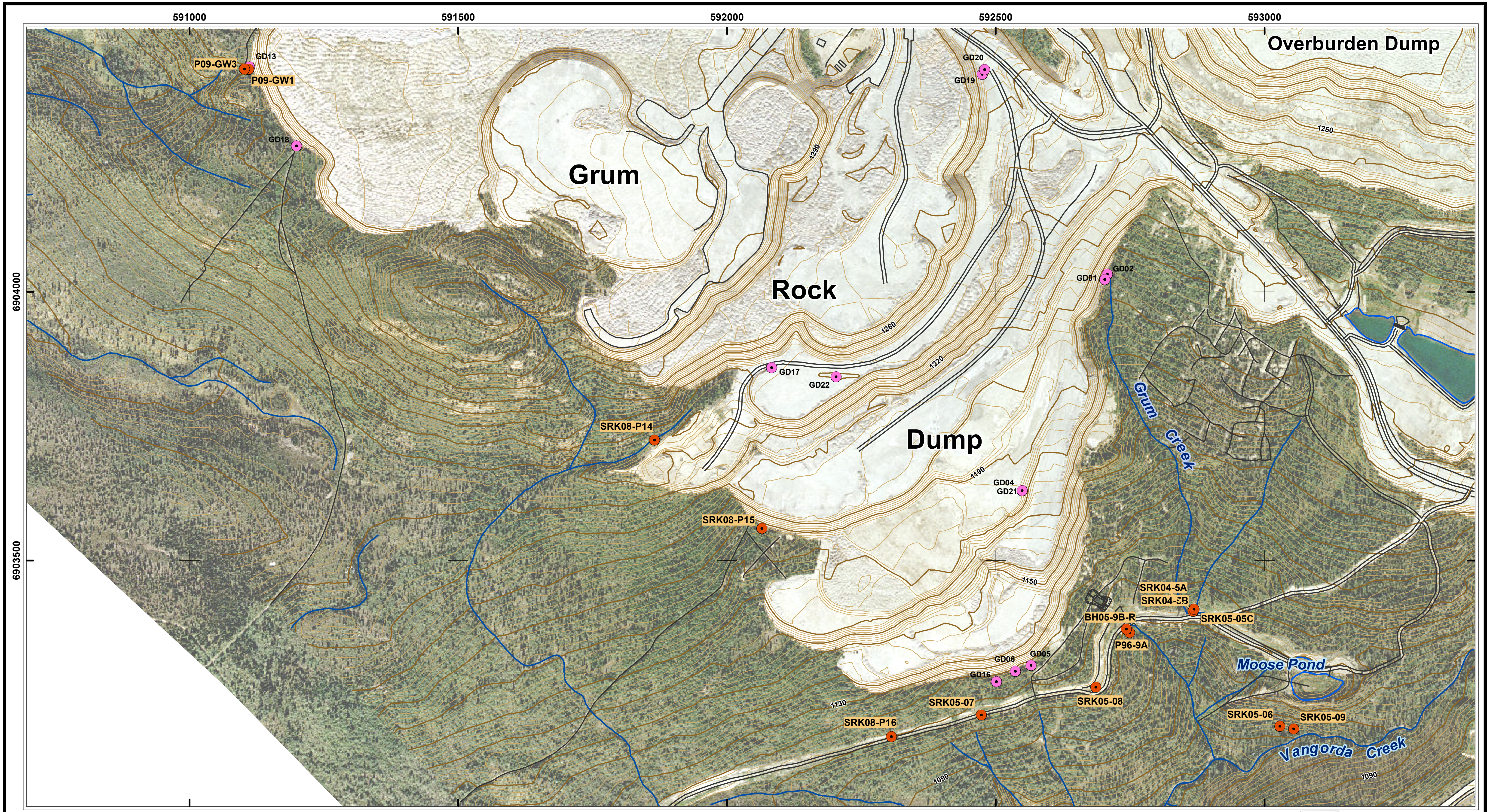
CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 4-1

DATE: 032411
DRAWN BY: OM
FILE: Faro_GrumVangorda_11.mxd



Groundwater Monitoring Wells
Grum Rock Dump Area

Grum & Vangorda Mine Site

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m

LEGEND

- ● Monitoring Well
- ● Seep Monitoring Station

N
W E
SCALE

SCALE
0 150 300 450 600
Meters

Yukon Government

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CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 4-2

DATE: 032411
DRAWN BY: OM
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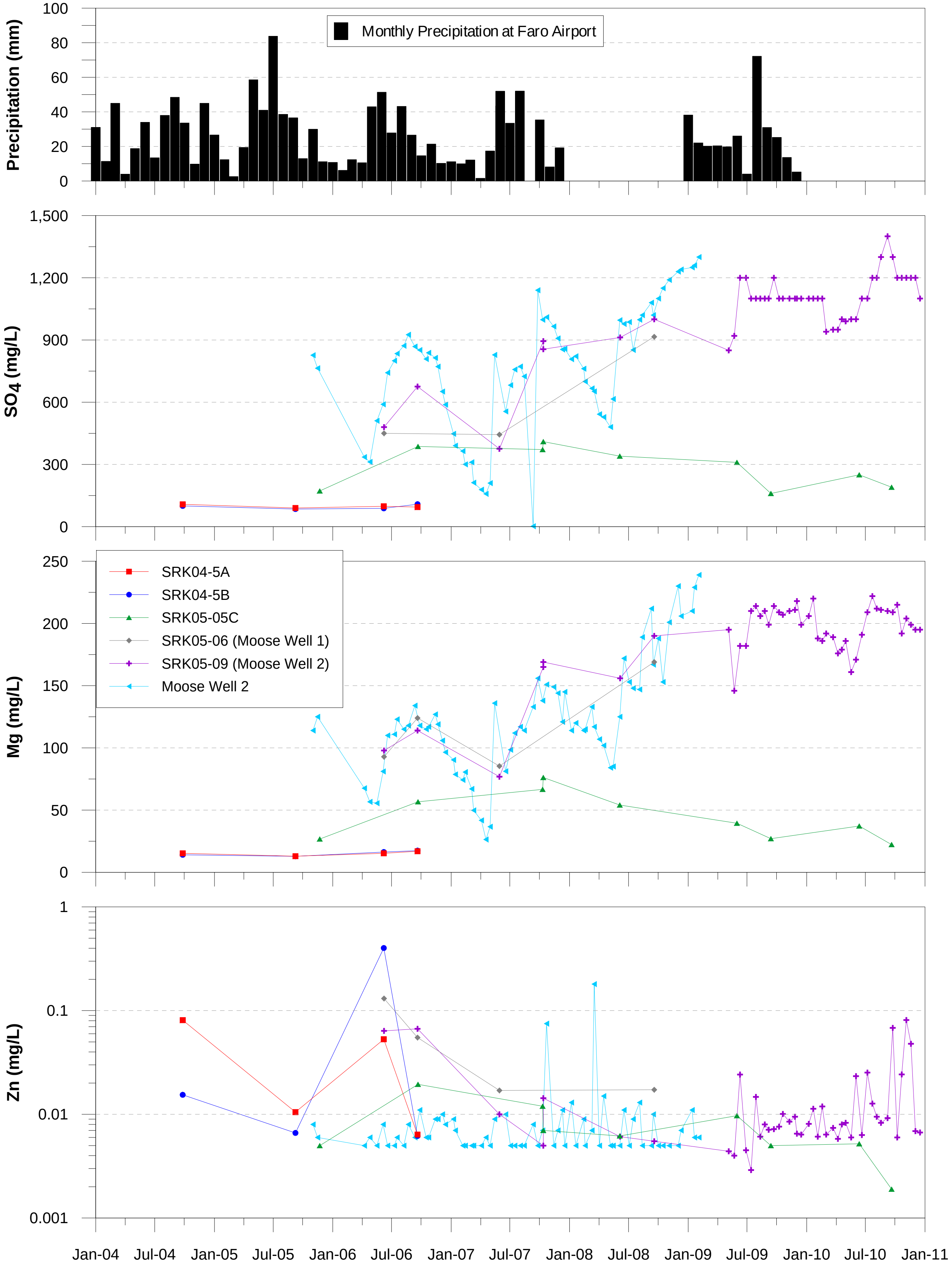


Figure 4-3a. Time trends for SO_4, Mg and Zn in wells in Grum Creek drainage

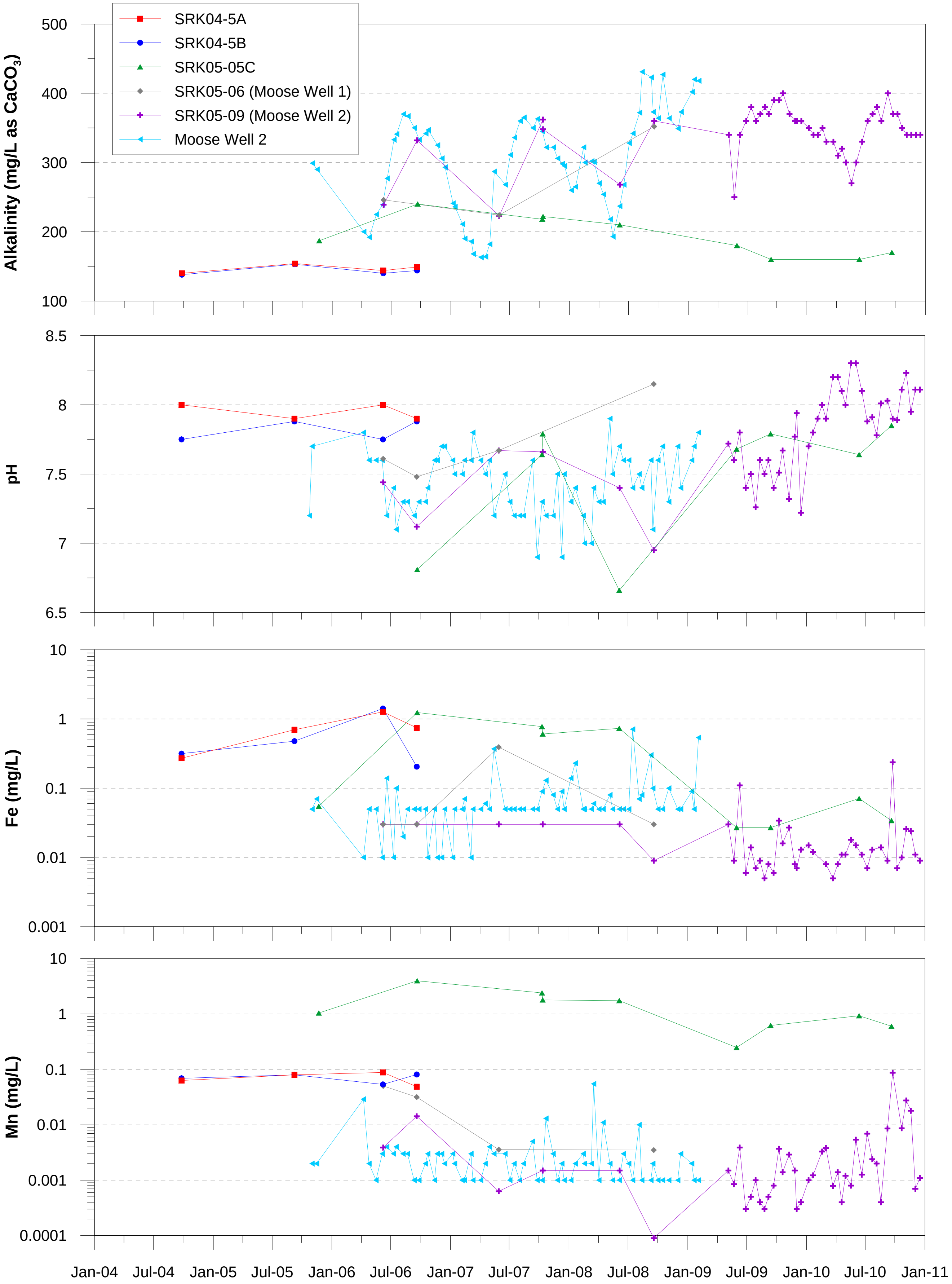


Figure 4-3b. Time trends for alkalinity, pH, Fe and Mn in wells in Grum Creek drainage

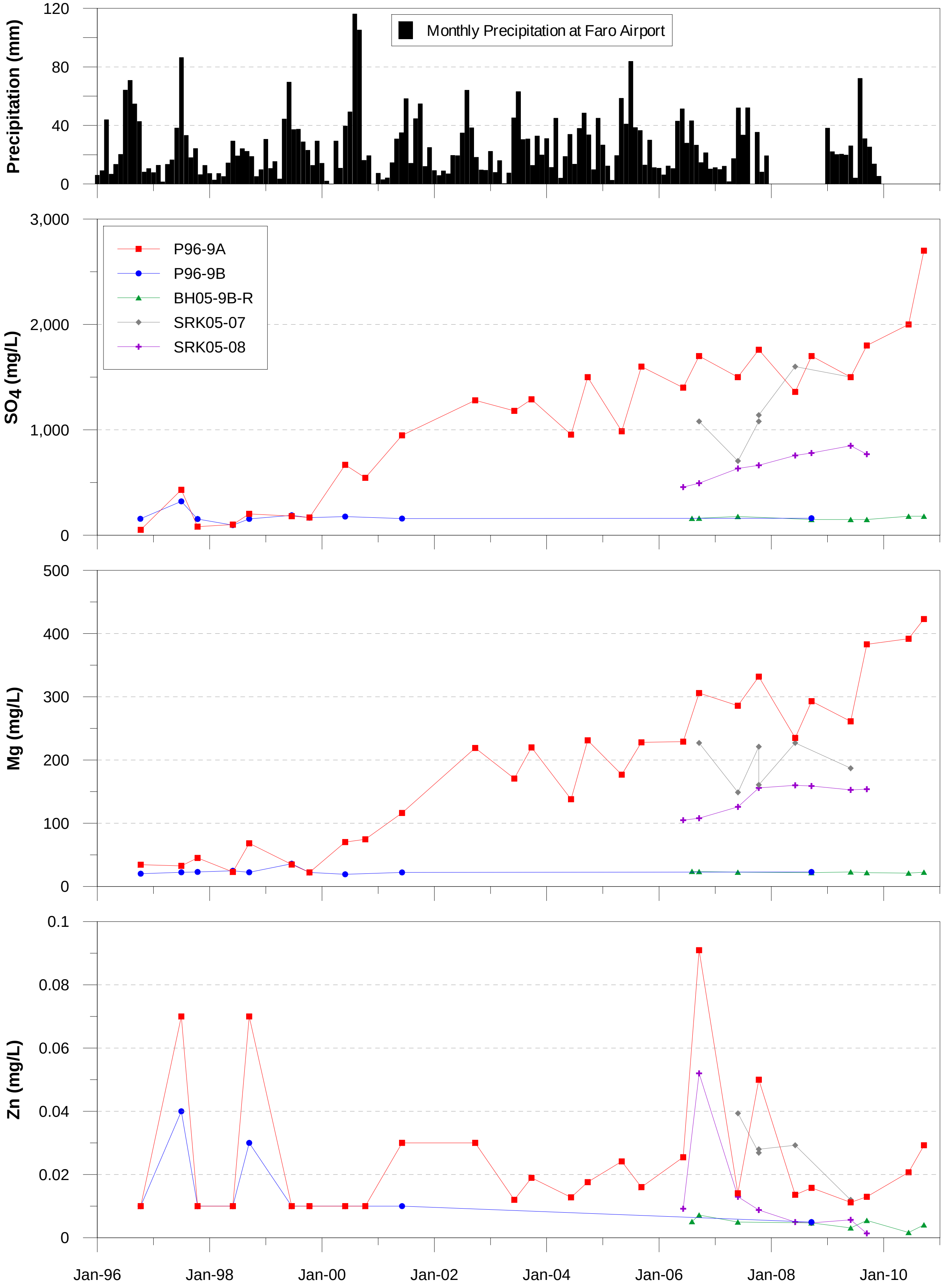


Figure 4-4a. Time trends for SO$_4$, Mg and Zn in wells located west of Grum Creek

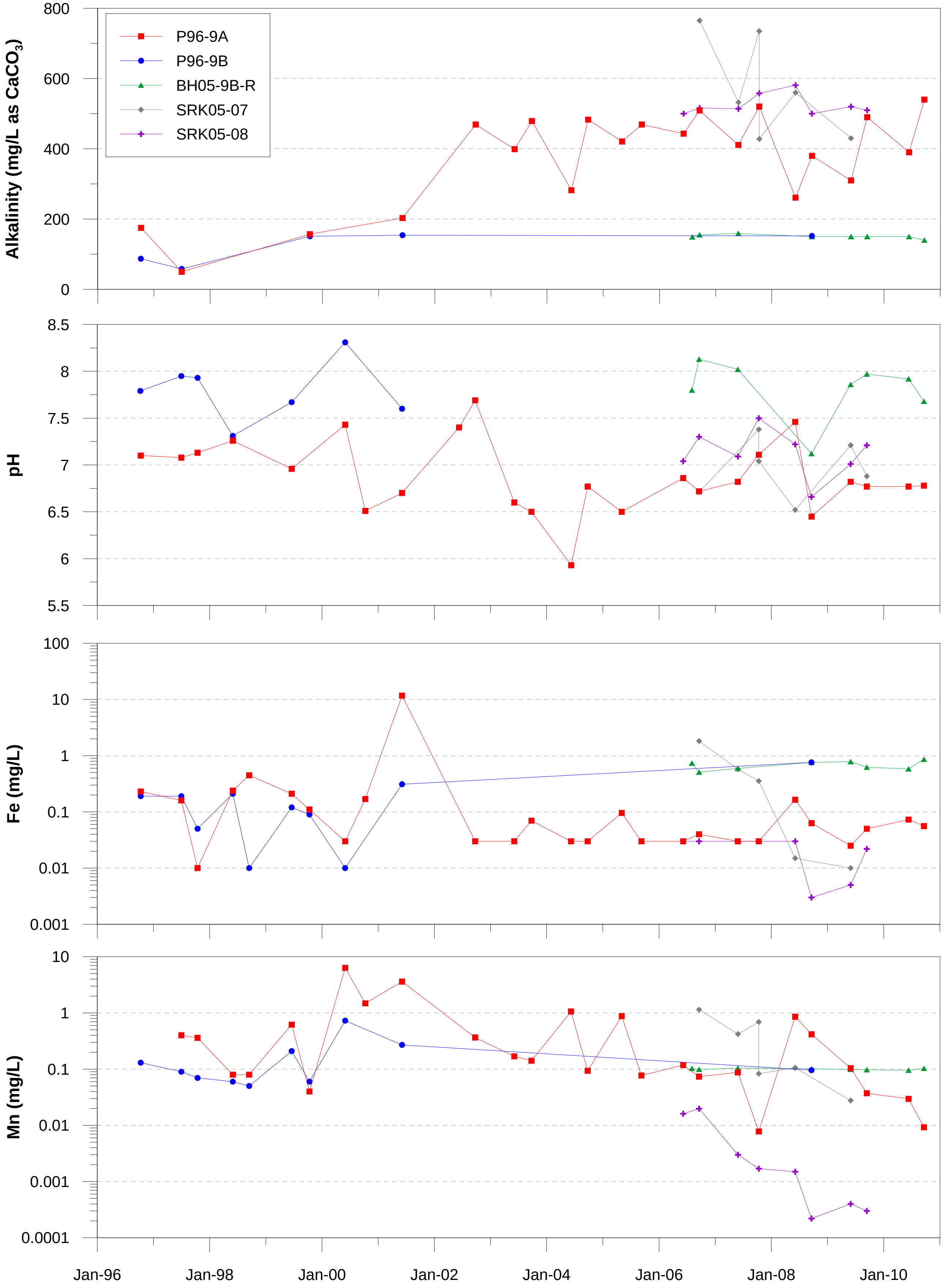


Figure 4-4b. Time trends for alkalinity, pH, Fe and Mn in wells located west of Grum Creek

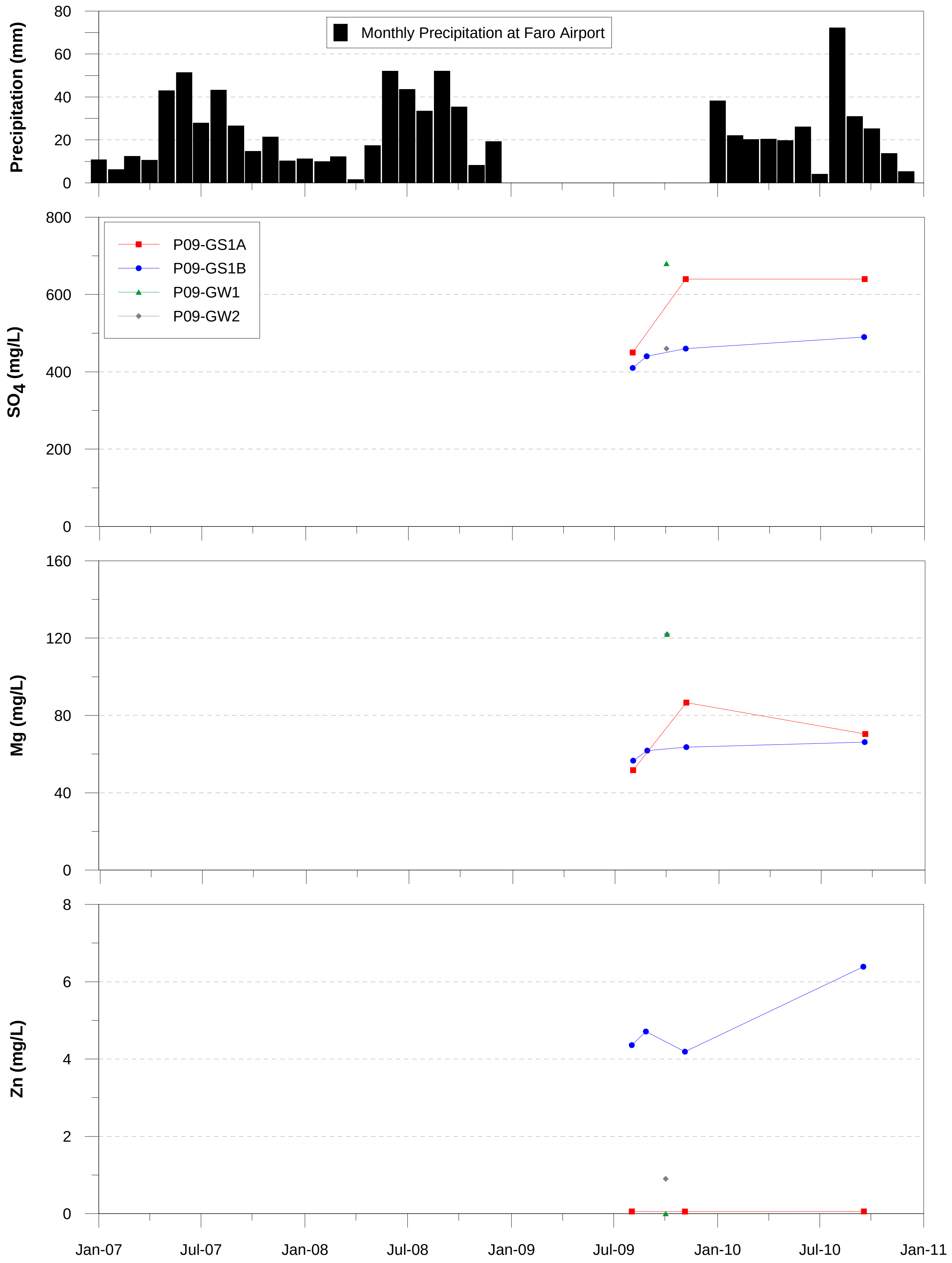


Figure 4-5a. Time trends for SO_4, Mg, Na and Zn in wells located near Grum Slot and west of Grum Dump

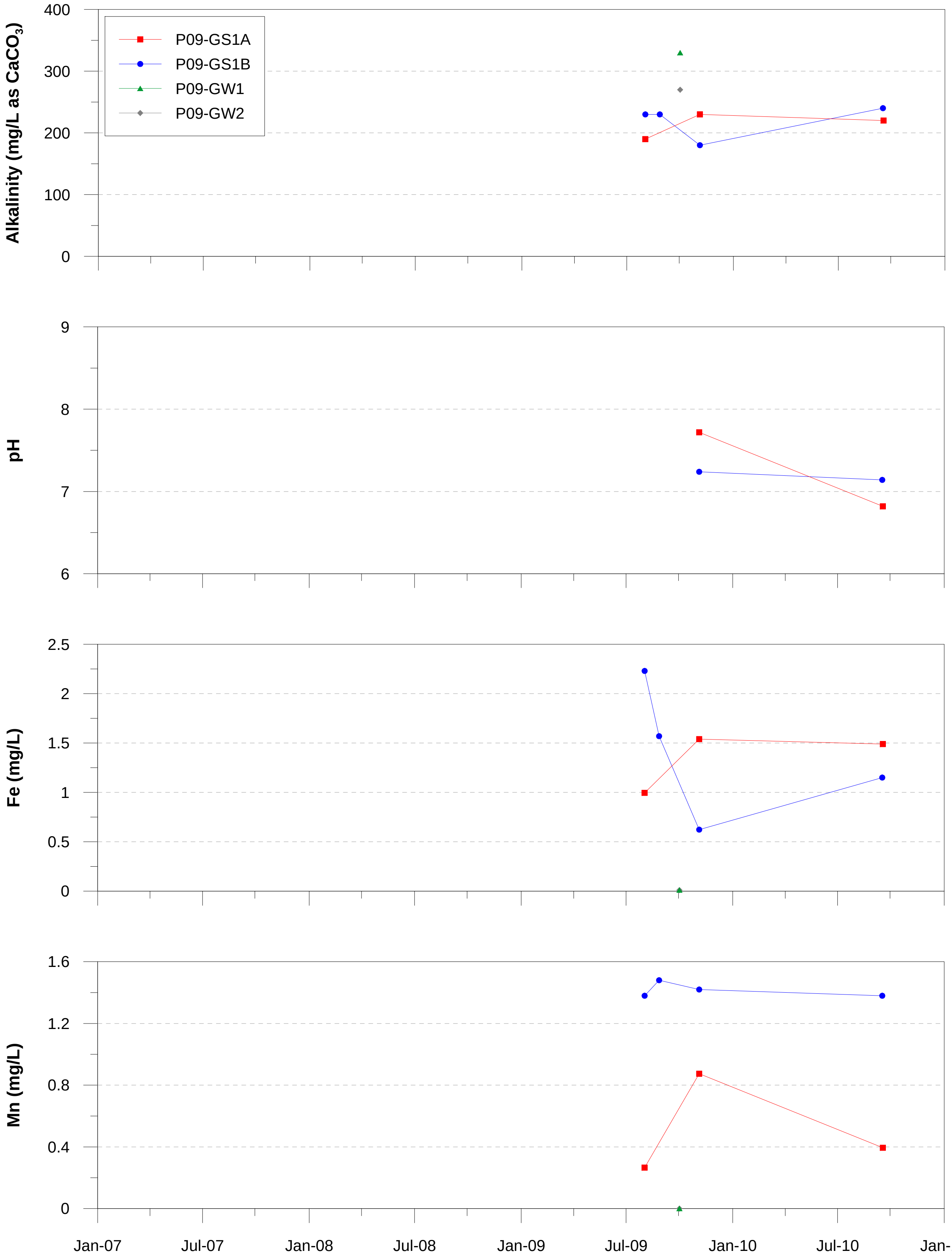


Figure 4-5b. Time trends for alkalinity, pH, Fe and Mn in wells located near Grum Slot and west of Grum Dump

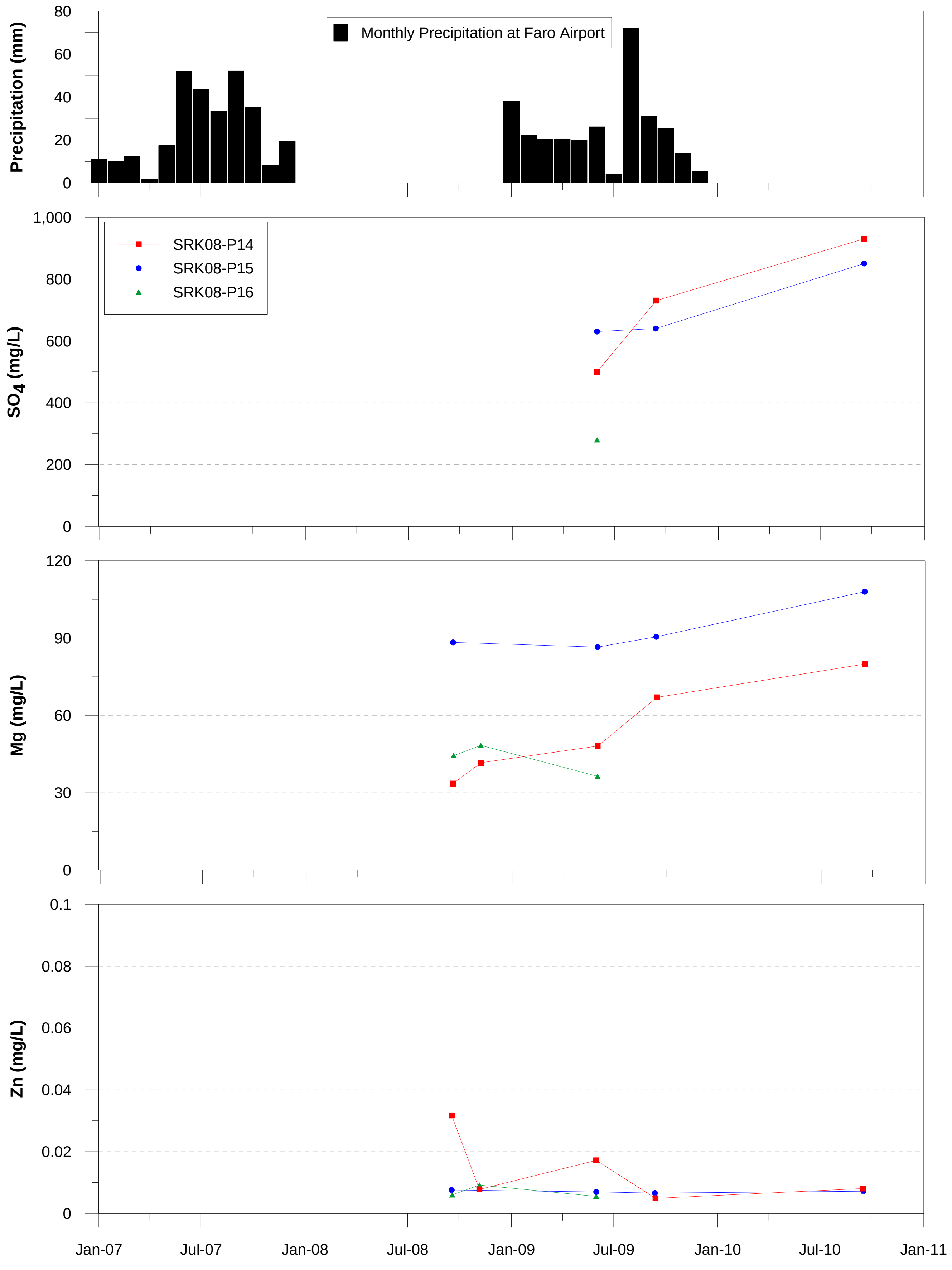


Figure 4-5c. Time trends for SO$_4$, Mg, Na and Zn in SRK08 wells located southwest of Grum Dump

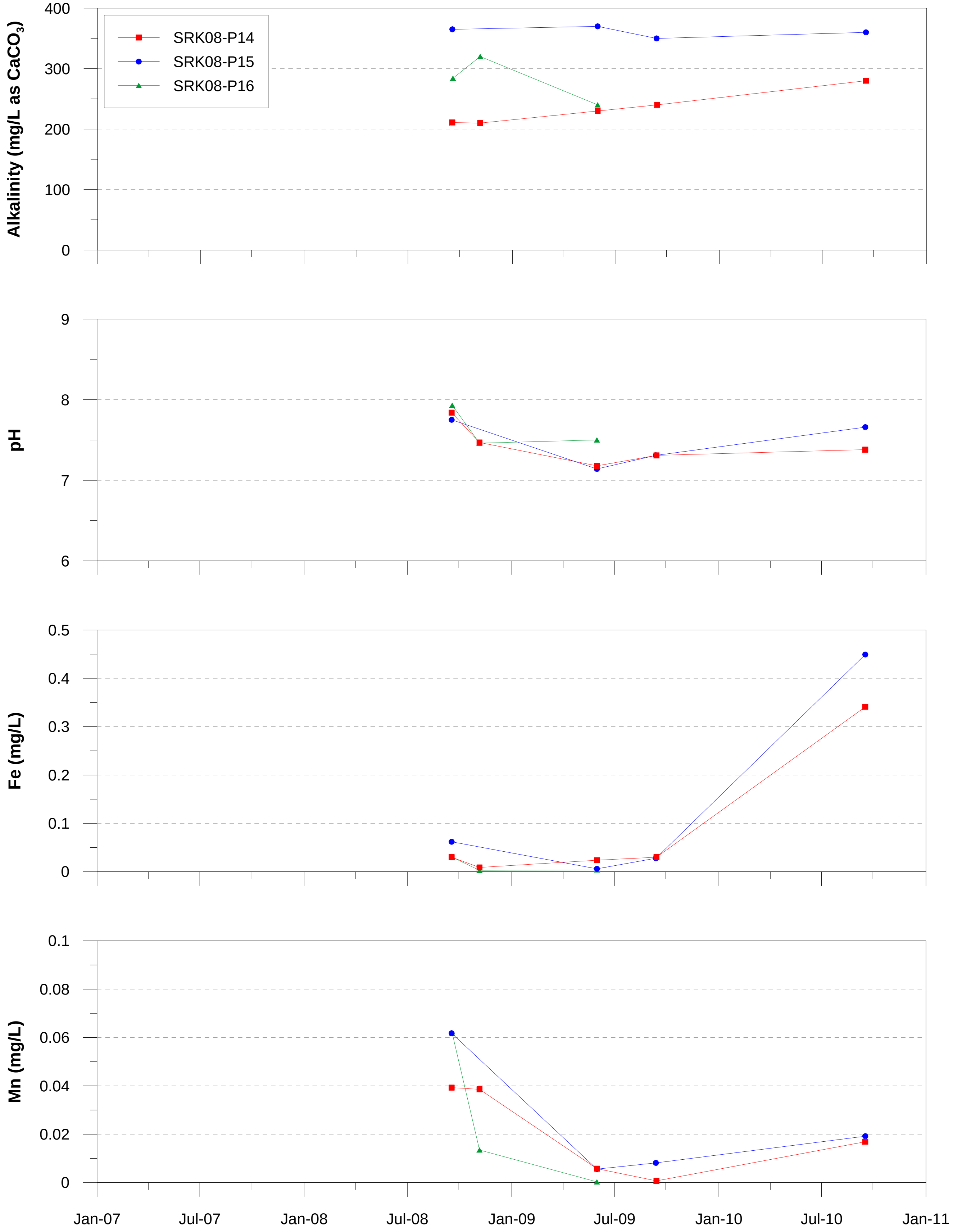
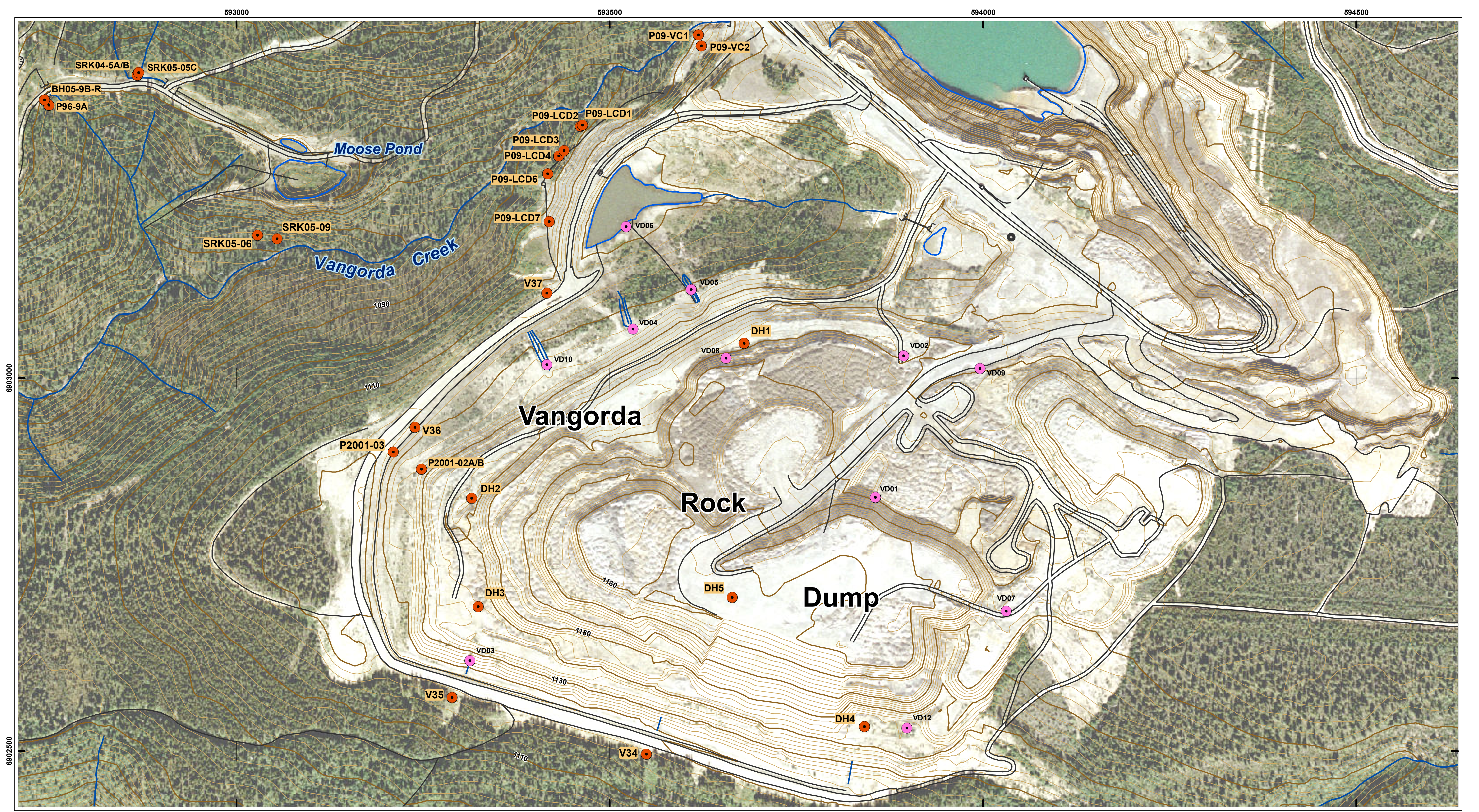


Figure 4-5d. Time trends for alkalinity, pH, Fe and Mn in SRK08 wells located southwest of Grum Dump

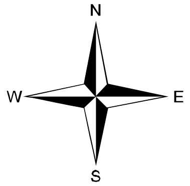


Groundwater Monitoring Wells
Vangorda Rock Dump Area

Grum & Vangorda Mine Site

PROJECTION: UTM
ZONE: 8
DATUM: NAD 83
UNITS: Meters

CONTOUR INTERVAL: 2m



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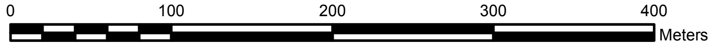

LEGEND

- ● Monitoring Well
- ● Seep Monitoring Station

Yukon Government

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CLIENT: Yukon Government
PROJECT: 2010 ARMC Groundwater Review
REPORT: RGC 118018
LOCATION: Anvil Range Mining Complex,YT, Canada

FIGURE: 4-6

DATE: 032411
DRAWN BY: OM
FILE: Faro_Vangorda11.mxd

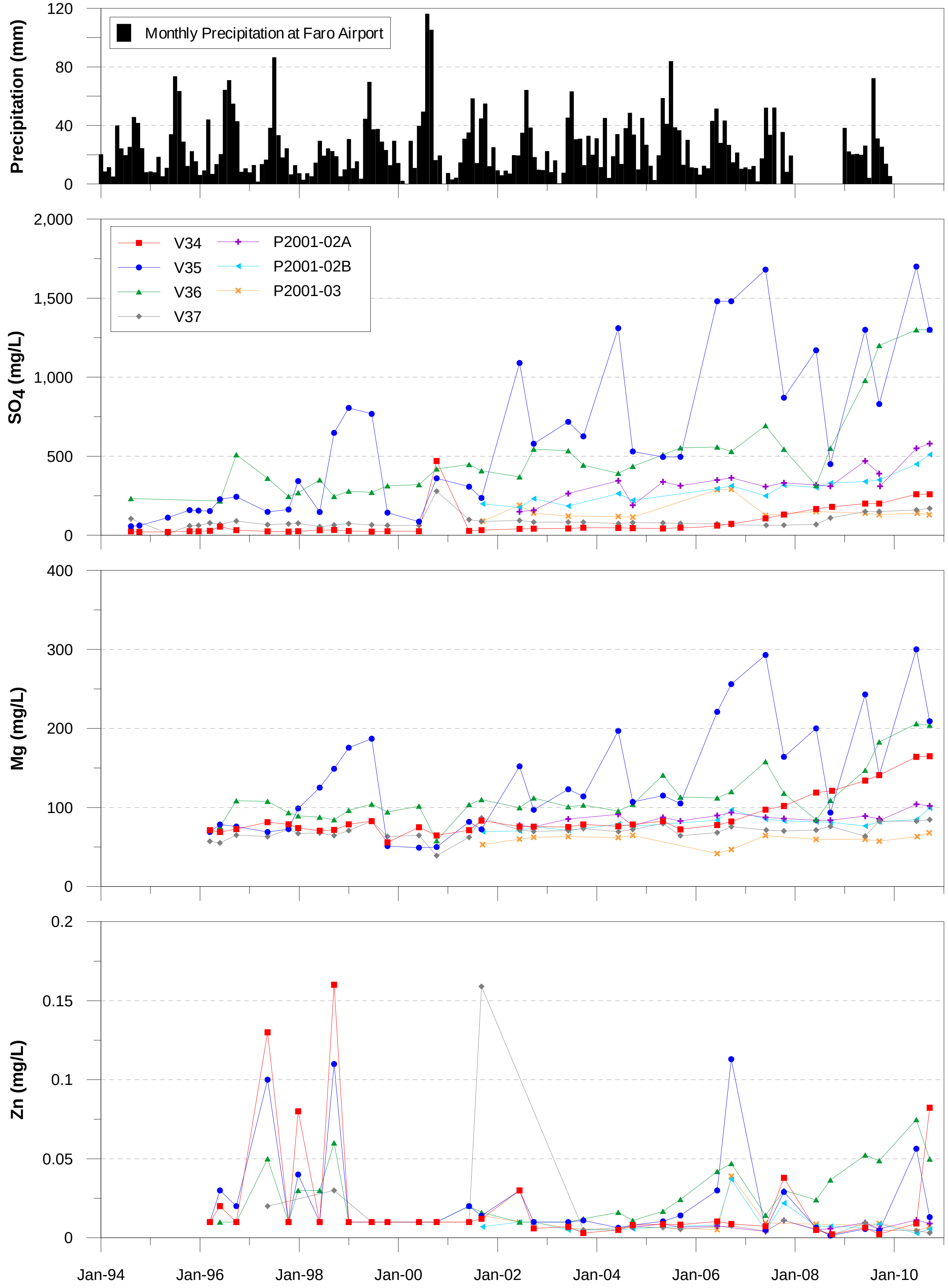

Figure 4-7a. Time trends for SO_4, Mg and Zn in wells downgradient of Vangorda Rock Dump

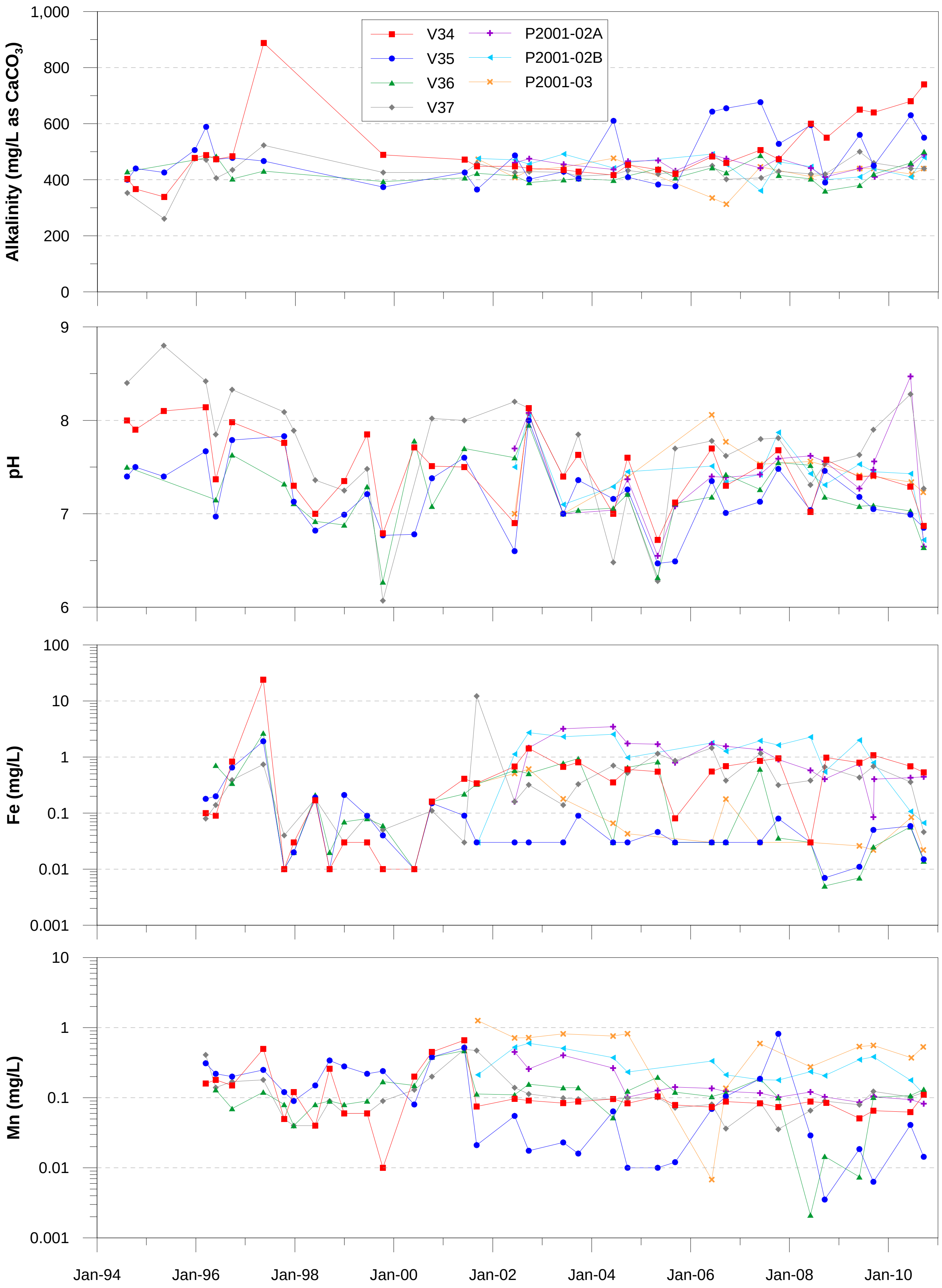

Figure 4-7b. Time trends for alkalinity, pH, Fe and Mn in wells downgradient of Vangorda Rock Dump

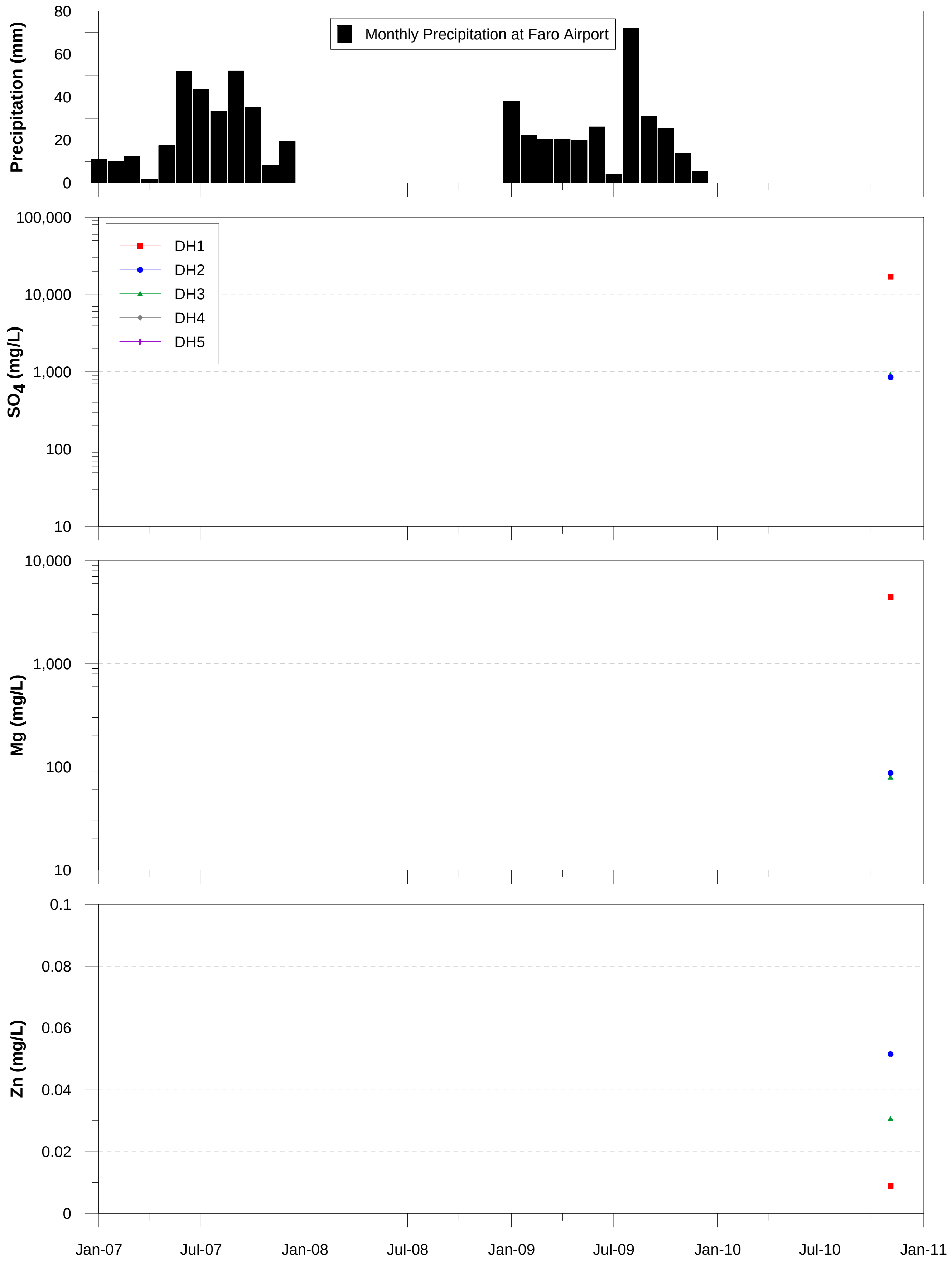

Figure 4-8a. Time trends for SO_4, Mg, Na and Zn in Vangorda Waste Rock Dump Wells

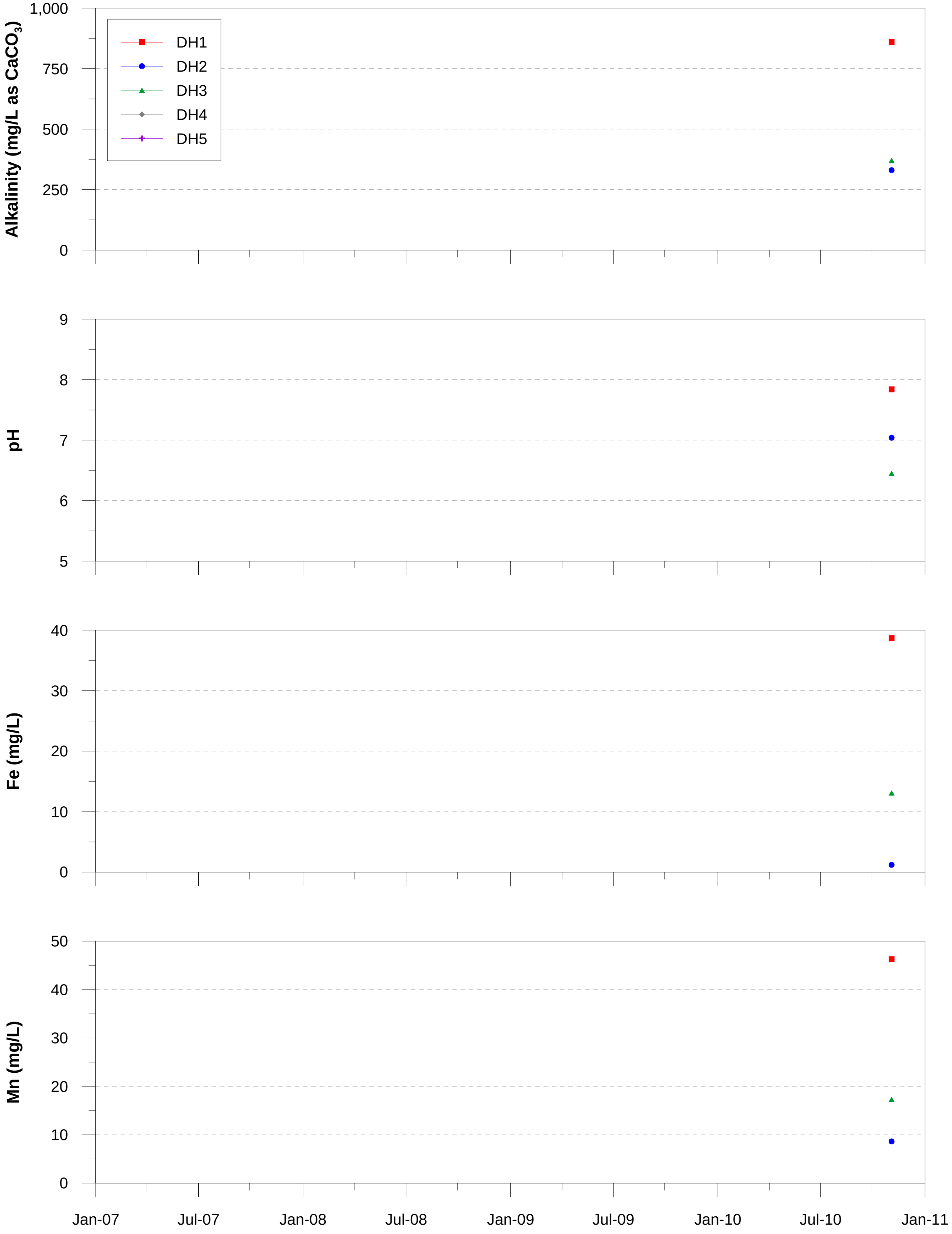

Figure 4-8b. Time trends for alkalinity, pH, Fe and Mn in Vangorda Waste Rock Dump wells

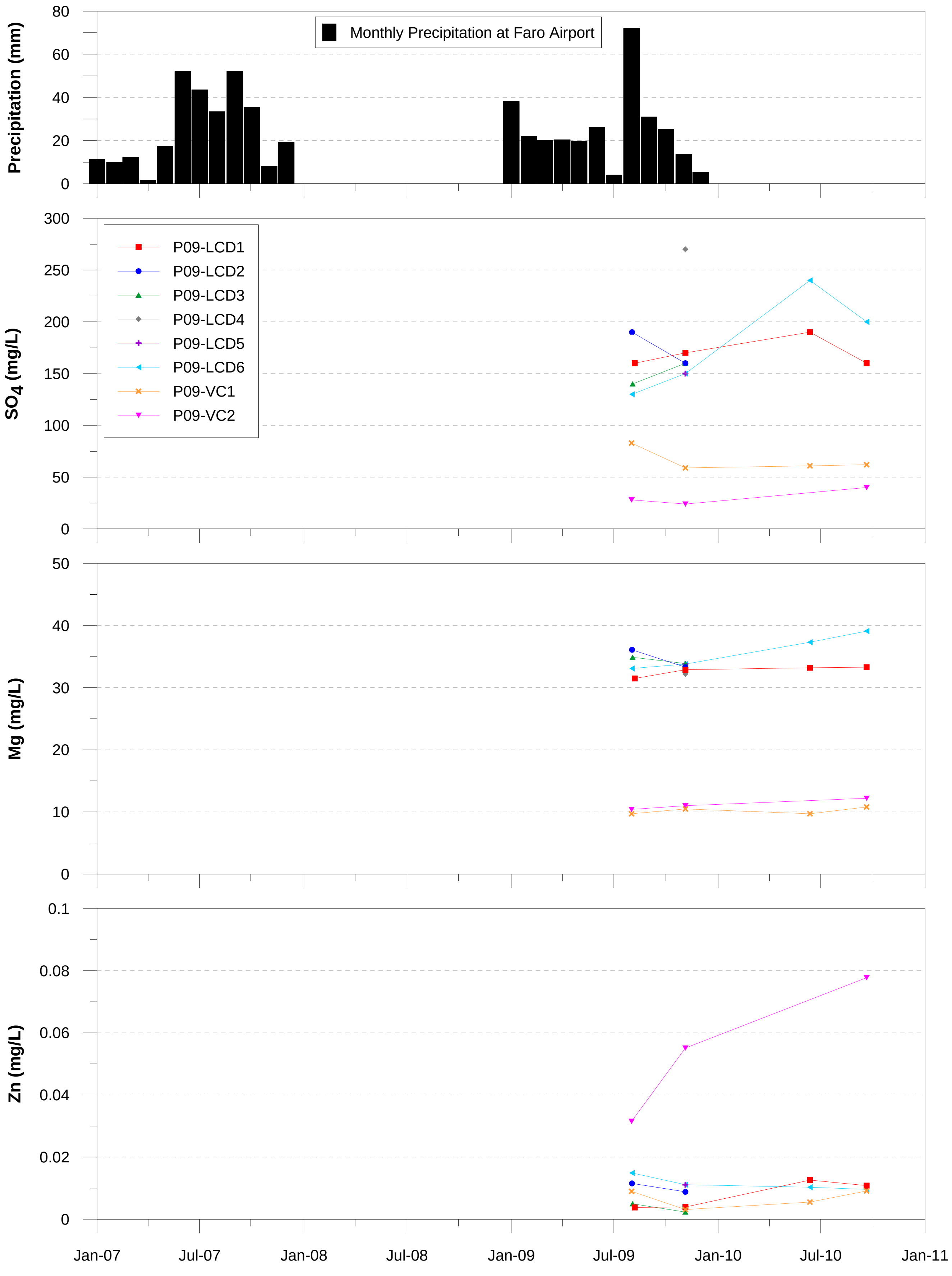

Figure 4-9a. Time trends for SO$_4$, Mg, Na and Zn in wells near Vangorda Creek and Little Creek Dam

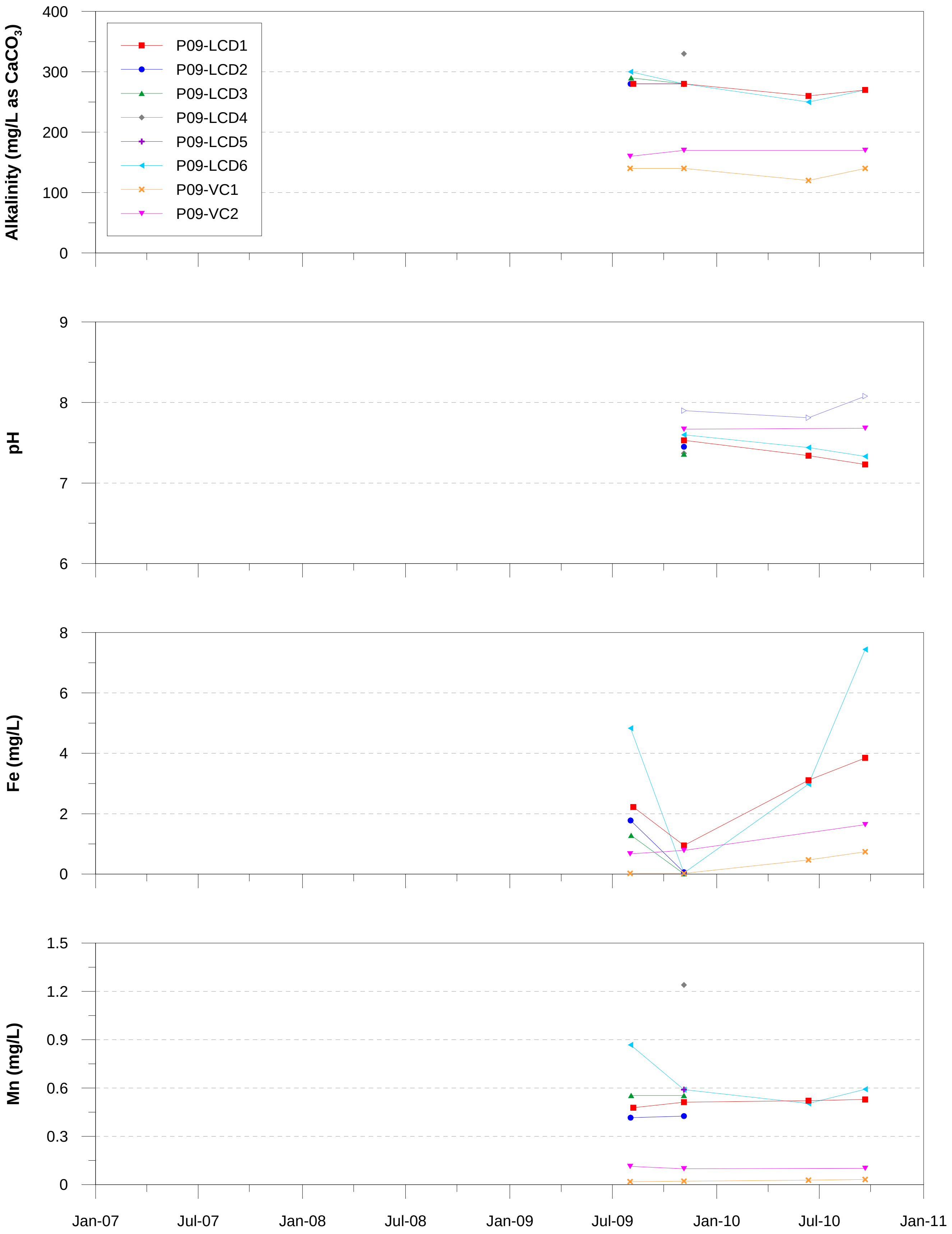

Figure 4-9b. Time trends for alkalinity, pH, Fe and Mn in wells near Vangorda Creek and Little Creek Dam